Specification for

PoweRline Intelligent Metering Evolution

Prepared by the PRIME Alliance Technical Working Group

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Abstract:

This is a complete specification for a new OFDM-based power line communication system for the provision of all kinds of Smart Grid services over electricity distribution networks. The specification also provides RF communication prescriptions based on some of the SUN FSK requirements present in the consolidated IEEE 802.15.4 standard. Both PHY and MAC layers according to IEEE conventions, plus a Convergence layer, are described in the Specification.

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1 Introduction

This document is the technical specification for the PRIME technology.

1.1 Scope

This document specifies a PHY layer, a MAC layer and a Convergence layer for complexity-effective, narrowband data transmission over electrical power lines that could be part of a Smart Grid system. Additionally, it specifies RF data transmission that extends the addressed Smart Grid scenarios.

1.2 Overview

The purpose of this document is to specify a narrowband data transmission system based on OFDM modulations scheme and a RF system based on SUN FSK (see [28] and [29]) for providing mainly core utility services.

The specification currently describes the following:

- A PHY layer capable of achieving rates of uncoded 1Mbps on the PLC medium (see chapter 3).
- A PHY layer capable of achieving SUN FSK Operating Mode 2 data rates (see [28] and [29]) on the RF medium (see chapter 3)
- A MAC layer for the power line and RF environments (see chapter 4).
- A Convergence layer for adapting several specific services (see chapter 5).
- A Management Plane (see chapter 6)

The specification is written from the transmitter perspective to ensure interoperability between devices and allow different implementations.

1.3 Normative references

The following publications contain provisions which, through reference in this text, constitute provisions of this specification. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Specification are encouraged to investigate the possibility of applying the most recent editions of the following standards:

#	Ref.	Title
[1]	EN 50065-1:2001+A1:2010	Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz - Part 1: general requirements, frequency bands and electromagnetic disturbances.
[2]	EN IEC 50065-7 Ed. 2001	Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz. Part7: Equipment impedance.
[3]	IEC 61334-4-1 Ed.1996	Distribution automation using distribution line carrier systems – Part 4: Data communication protocols – Section 1: Reference model of the communication system.
[4]	IEC 61334-4-32 Ed.1996	Distribution automation using distribution line carrier systems - Part 4: Data communication protocols - Section 32: Data link layer - Logical link control (LLC).
[5]	IEC 61334-4-511 Ed. 2000	Distribution automation using distribution line carrier systems – Part 4-511: Data communication protocols – Systems management – CIASE protocol.
[6]	IEC 61334-4-512, Ed. 1.0:2001	Distribution automation using distribution line carrier systems – Part 4-512: Data communication protocols – System management using profile 61334-5-1 – Management.
[7]	prEN/TS 52056-8-4	Electricity metering data exchange - The DLMS/COSEM suite - Part 8-4: The PLC Orthogonal Frequency Division Multiplexing (OFDM) Type 1 profile.
[8]	IEEE Std 802-2001	IEEE Standard for Local and Metropolitan Area Networks. Overview and Architecture.
[9]	IETF RFC 768	User Datagram Protocol (UDP) [online]. Edited by J. Postel. August 1980. Available from: https://www.ietf.org/rfc/rfc768.txt
[10]	IETF RFC 791	Internet Protocol (IP) [online]. Edited by Information Sciences Institute, University of Southern California. September 1981. Available from: https://www.ietf.org/rfc/rfc791.txt

#	Ref.	Title
[11]	IETF RFC 793	Transmission Control Protocol (TCP) [online]. Edited by Information Sciences Institute, University of Southern California. September 1981. Available from: https://www.ietf.org/rfc/rfc793.txt
[12]	IETF RFC 1144	Compressing TCP/IP Headers for Low-Speed Serial Links [online]. Edited by V. Jacobson. February 1990. Available from: https://www.ietf.org/rfc/rfc1144.txt.
[13]	IETF RFC 2131	Dynamic Host Configuration Protocol (DHCP) [online]. Edited by R. Droms. March 1997. Available from: https://www.ietf.org/rfc/rfc2131.txt
[14]	IETF RFC 2460	Internet Protocol, Version 6 (IPv6) Specification [online]. Edited by S. Deering, R. Hinden. December 1998. Available from: https://www.ietf.org/rfc/rfc2460.txt
[15]	IETF RFC 3022	Traditional IP Network Address Translator (Traditional NAT) [online]. Edited by P. Srisuresh, Jasmine Networks, K. Egevang. January 2001. Available from: https://www.ietf.org/rfc/rfc3022.txt
[16]	NIST FIPS-197	Specification for the ADVANCED ENCRYPTION STANDARD (AES), http://www.csrc.nist.gov/publications/fips/fips197/fips-197.pdf
[17]	NIST SP 800-57	Recommendation for Key Management. Part 1: General (Revised). Available from http://csrc.nist.gov/publications/nistpubs/800-57/sp800-57-Part1-revised2_Mar08-2007.pdf
[18]	NIST SP800-38A, Ed. 2001	Recommendation for Block Cipher Modes of Operation. Methods and Techniques. Available from http://csrc.nist.gov/publications/nistpubs/800-38a/sp800-38a.pdf.
[19]	IETF RFC 4191	IP version 6 addressing architecture. Available from http://tools.ietf.org/html/rfc4291.
[20]	IETF RFC 6282	IPv6 Datagrams on IEEE 802.15.4. Available from http://tools.ietf.org/html/rfc6282.
[21]	IETF RFC 4862	Stateless Address Configuration. Available from http://www.ietf.org/rfc/rfc4862.txt.
[22]	IETF RFC 2464	Transmission of IPv6 Packets over Ethernet Networks. Available from http://www.ietf.org/rfc/rfc4862.txt

#	Ref.	Title
[23]	NIST SP 800-108	Recommendation for Key Derivation Using Pseudorandom Functions. Available from http://csrc.nist.gov/publications/nistpubs/800-108/sp800-108.pdf
[24]	NIST SP 800-38 B	Recommendation for Block Cipher Modes of Operation: The CMAC Mode for Authentication. Available from http://csrc.nist.gov/publications/nistpubs/800-38B/SP_800-38B.pdf
[25]	NIST SP 800-38 C	Recommendation for Block Cipher Modes of Operation: the CCM Mode for Authentication and Confidentiality. Available from http://csrc.nist.gov/publications/nistpubs/800-38C/SP800-38C_updated-July20_2007.pdf
[26]	NIST SP 800-38 F	Recommendation for Block Cipher Modes of Operation: Methods for Key Wrapping. Available from http://dx.doi.org/10.6028/NIST.SP.800-38F
[27]	DRAFT NIST SP 800-90 C	Recommendation for Random Bit Generator (RBG) Constructions. Available from: http://csrc.nist.gov/publications/drafts/800-90/draft-sp800-90c.pdf
[28]	802.15.4-2015	IEEE Standard for Low-Rate Wireless Networks. Available from: https://standards.ieee.org/content/ieee-standards/en/standard/802_15_4-2015.html
[29]	802.15.4v-2017	Amendment 5: Enabling/Updating the Use of Regional Sub-GHz Bands. Available from: https://standards.ieee.org/content/ieee-standards/en/standard/802_15_4v-2017.html

1.4 Document conventions

This document is divided into chapters and annexes. The document body (all chapters) is normative (except for italics). The annexes may be normative or Informative as indicated for each annex.

Binary numbers are indicated by the prefix ‘0b’ followed by the binary digits, e.g. ‘0b0101’. Hexadecimal numbers are indicated by the prefix ‘0x’.

Mandatory requirements are indicated with ‘shall’ in the main body of this document.

Optional requirements are indicated with ‘may’ in the main body of this document. If an option is incorporated in an implementation, it shall be applied as specified in this document.

roof (.) denotes rounding to the closest higher or equal integer.

floor (.) denotes rounding to the closest lower or equal integer.

A mod B denotes the remainder (from 0, 1, …, B-1) obtained when an integer A is divided by an integer B.

1.5 Definitions

Term	Description
Band	For PLC, set of channels that may or may not be adjacent but defined for concurrent use according to channel access rules laid down in this specification. For RF, set of channels that cannot be used concurrently in a unique transmission/reception.
Band Plan	Set of bands that a device is configured to operate on.
Base Node	Master Node which controls and manages the resources of a Subnetwork.
Beacon Slot	Location of the beacon PDU within a frame.
Channel	For PLC, 46.875 kHz spectrum that may either correspond to PRIME version 1.3.6 spectrum location or any of the new extension bands defined in this version of specification. For RF, spectrum that is used in a unique transmission/reception. The spectrum width depends on the RF band the channel belongs to and on the operating mode.
Compliance Mode	A working mode of MAC protocol that supports existence of legacy 1.3.6 devices in a Subnetwork together with devices implementing this version of specification.
Destination Node	A Node that receives a frame.
Downlink	Data travelling in direction from Base Node towards Service Nodes
Hearing Domain	Area in which transmit signal from a device is received with some fidelity, without the need of intermediate amplification/repeating devices.
Level(PHY layer)	When used in physical layer (PHY) context, it implies the transmit power level.
Level (MAC layer)	When used in medium access control (MAC) context, it implies the position of the reference device in Switching hierarchy.
MAC frame	Composite unit of abstraction of time for channel usage. A MAC frame is comprised of one or more Beacons, one SCP and zero or one CFP. The transmission of the Beacon by the Base Node acts as delimiter for the MAC frame.
Neighbour Node	Node A is Neighbour Node of Node B if A can directly transmit to and receive from B.
Node	Any one element of a Subnetwork which is able to transmit to and receive from other Subnetwork elements.

Term	Description
PHY frame	The set of OFDM symbols and Preamble which constitute a single PPDU
Peer	Two devices within the hearing domain of each other and having possibility or maintaining data-connectivity with each other without need of intermediate repeater / switch devices.
Preamble	The initial part of a PHY frame, used for synchronizations purposes
Registration	Process by which a Service Node is accepted as member of Subnetwork and allocated a LNID.
Service Node	Any one Node of a Subnetwork which is not a Base Node.
Source Node	A Node that sends a frame.
Subnetwork	A set of elements that can communicate by complying with this specification and share a single Base Node.
Subnetwork address	Property that universally identifies a Subnetwork. It is its Base Node EUI-48 address.
Switching	Providing connectivity between Nodes that are not Neighbour Nodes.
Unregistration	Process by which a Service Node leaves a Subnetwork.
Uplink	Data travelling in direction from Service Node towards Base Node

1.6 Abbreviations and Acronyms

Term	Description
AC	Alternating Current
AES	Advanced Encryption Standard
AMM	Advanced Meter Management
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BPDU	Beacon PDU
BPSK	Binary Phase Shift Keying

Term	Description
CENELEC	European Committee for Electrotechnical Standardization
CFP	Contention Free Period
CID	Connection Identifier
CL	Convergence layer
CPCS	Common Part Convergence Sublayer
CRC	Cyclic Redundancy Check
CSMA-CA	Carrier Sense Multiple Access-Collision Avoidance
D8PSK	Differential Eight-Phase Shift Keying
DBPSK	Differential Binary Phase Shift Keying
DHCP	Dynamic Host Configuration Protocol
DPSK	Differential Phase Shift Keying (general)
DQPSK	Differential Quaternary Phase Shift Keying
DSK	Device Secret Key
ECB	Electronic Code Book
EMA	Exponential moving average
ENOB	Effective Number Of Bits
EUI-48	48-bit Extended Unique Identifier
EVM	Error Vector Magnitude
FCS	Frame Check Sequence
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FSK	Frequency Shift Keying
GK	Generation Key
GPDU	Generic MAC PDU
HCS	Header Check Sum

Term	Description
IEC	International Electrotechnical Committee
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IGMP	Internet Group Management Protocol
IPv4	Internet Protocol, Version 4
kbps	kilobit per second
KDIV	Key Diversifier
LCID	Local Connection Identifier
LFSR	Linear Feedback Shift Register
LLC	Logical Link Control
LNID	Local Node Identifier
LSID	Local Switch Identifier
LV	Low Voltage
LWK	Local Working Key
MAC	Medium Access Control
MK	Master Key
MLME	MAC Layer Management Entity
MPDU	MAC Protocol Data Unit
msb	Most significant bit
lsb	Least significant bit
MSPS	Million Samples Per Second
MTU	Maximum Transmission Unit
NAT	Network Address Translation
NID	Node Identifier
NSK	Network Secret Key

Term	Description
OFDM	Orthogonal Frequency Division Multiplexing
PDU	Protocol Data Unit
PHY	Physical Layer
PIB	PLC Information Base
PLC	Powerline Communications
PLME	PHY Layer Management Entity
PNPDU	Promotion Needed PDU
PPDU	PHY Protocol Data Unit
ppm	Parts per million
PSD	Power Spectral Density
PSDU	PHY Service Data Unit
QoS	Quality of Service
SAP	Service Access Point
SAR	Segmentation and Reassembly
SCP	Shared Contention Period
SCRC	Secure CRC
SDU	Service Data Unit
SEC	Security
SID	Switch Identifier
SNA	Subnetwork Address
SNK	Subnetwork Key (corresponds to either REG.SNK or SEC.SNK)
SNR	Signal to Noise Ratio
SP	Security Profile
SSCS	Service Specific Convergence Sublayer
SWK	Subnetwork Working Key

Term	Description
TCP	Transmission Control Protocol
TOS	Type Of Service
UI	Unique Identifier
USK	Unique Secret Key
VJ	Van Jacobson
WK	Working Key

2 General Description

2.1 Introduction

This document is the Specification of a communication solution to provide complexity-effective, narrowband data transmission over electrical power lines that could be part of a Smart Grid system, based on PLC using orthogonal frequency division multiplexing (OFDM) modulation scheme or RF using some of the general PHY requirements defined on clause 10 of IEEE 802.15.4-2015 [28], including as mandatory the SUN FSK PHY, defined on clause 20 of IEEE 802.15.4-2015 [28].

2.2 General description of the architecture

Figure 1 below depicts the communication layers and the scope of this specification. This specification focuses mainly on the data, control and management plane.

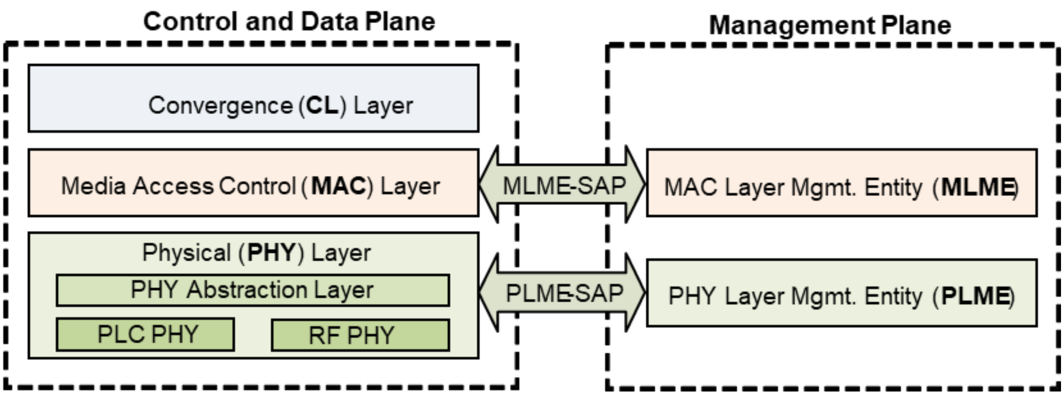

Figure 1 - Reference model of protocol layers used in the PRIME specification

The CL classifies traffic associating it with its proper MAC connection; this layer performs the mapping of any kind of traffic to be properly included in MPDUs. It may also include header compression functions. Several SSCSs are defined to accommodate different kinds of traffic into MPDUs.

The MAC layer provides core MAC functionalities of system access, bandwidth allocation, connection establishment/maintenance and topology resolution.

The PHY layer transmits and receives MPDUs between Neighbor Nodes using PLC or RF depending on the capability of devices and characteristics of the medium. On PLC, OFDM is chosen as the modulation technique because of:

- its inherent adaptability in the presence of frequency selective channels (which are common but unpredictable, due to narrowband interference or unintentional jamming);
- its robustness to impulsive noise, resulting from the extended symbol duration and use of FEC;
- its capacity for achieving high spectral efficiencies with simple transceiver implementations.

The PHY specification, described in Chapter 3, also employs a flexible coding scheme. The PHY data rates can be adapted to channel and noise conditions by the MAC.

3 Physical layer

3.1 Introduction

This chapter specifies the PHY entity employed to ensure the transmission and reception of MPDUs between Neighbor Nodes using PLC or RF depending on the capability of devices and characteristics of the medium.

The PHY Abstraction Layer provides a common interface for PLC or RF PHYs. On the transmission of of MPDUs the PHY Abstraction Layer uses PLC PHY or RF PHY depending of the selection of the MAC layer. On the reception of a MPDU the PHY Abstraction Layer reports to the MAC layer the MPDU received, the reception condition, the PHY medium, and the band (PLC) or the channel (RF) of the medium where the MPDU was received. .

The PLC PHY entity uses frequencies in the band 3 kHz up to 500 kHz. The use of these frequencies is subject to applicable local regulations, e.g. EN 50065 1:2001+A1:2010 in Europe or FCC part 15 in the US.

It is well known that frequencies below 40 kHz show several problems in typical LV power lines. For example:

- load impedance magnitude seen by transmitters is sometimes below 1Ω, especially for Base Nodes located at transformers;
- colored background noise, which is always present in power lines and caused by the summation of numerous noise sources with relatively low power, exponentially increases its amplitude towards lower frequencies;
- meter rooms pose an additional problem, as consumer behaviors are known to have a deeper impact on channel properties at low frequencies, i.e. operation of all kind of household appliances leads to significant and unpredictable time-variance of both the transfer function characteristics and the noise scenario.

Consequently, the PRIME PLC PHY specification uses the frequency band from 41.992 kHz to 471.6796875 kHz. This range is divided into eight channels, which may be used either as single independent channels or "N_{CH}" of them concurrently as a unique transmission / reception band. OFDM modulation is specified in each channel, with signal loaded on 97 equally spaced subcarriers, transmitted in symbols of 2240 microseconds, of which 192 microseconds are comprised of a short cyclic prefix. Adjacent channels are always separated by guard intervals of fifteen subcarriers (7.3 kHz). More details are provided in Annex G.

Differential modulations are used, with one of three possible constellations: DBPSK, DQPSK or D8PSK.

An additive scrambler is used to avoid the occurrence of long sequences of identical bits.

Finally, ½ rate convolutional coding and repetition code will be used along with bit interleaving. The convolutional coding, the bit interleaving and/or the repetition code can be disabled by higher layers if the channel is good enough and higher throughputs are needed.

In addition to the PLC PHY, the PHY layer can use an RF PHY to ensure the communication of the entire network, when the media conditions or the characteristics of the device require it. At each point-to-point connection, the MAC layer can select the PHY layer, and the bands or channels available in it, that are most convenient to ensure the best communication.

3.2 Overview

3.2.1 General

On the transmitter side, the PHY Layer receives a MPDU from the MAC layer and the PHY Abstraction Layer uses the PLC PHY or RF PHY to generates a PHY frame on the Physical medium according to the selection of the MAC layer.

In the case that the PHY Abstraction Layer uses the PLC PHY, the header and the PPDU is shown in Figure 2, and consists of the following steps.

A CRC is appended to the PHY header (CRC for the payload is appended by the MAC layer, so no additional CRC is inserted by the PHY). Next, CC is performed, if the optional FEC is enabled. The next step is scrambling, which is done for both PHY header and the PPDU, irrespective of whether CC is enabled. When CC is enabled, additional repetition code can be selected and, in this case, the scrambler output is repeated by a factor of four. This transmitter configuration is defined as robust mode. If CC is enabled, the scrambler output (or the repeater output in case of robust modes) is also interleaved.

The scrambled (and interleaved) bits are differentially modulated using a DBPSK, DQPSK or D8PSK scheme. The next step is OFDM, which comprises the IFFT block and the cyclic prefix generator. When header and data bits are input to the chain shown in Figure 2, the output of the cyclic prefix generation is a concatenation of OFDM symbols constituting the header and payload portions of the PPDU respectively. The header portion contains two or four OFDM symbols, while the payload portion contains M OFDM symbols. The value of M is signaled in the PHY header, as described in Section 3.3.2.3

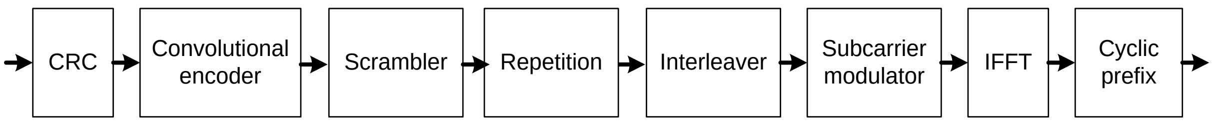

Figure 2 - Overview of PPDU processing

Two different PHY frame formats are specified, named frame of Type A and Type B. The structure of the PRIME PHY frame of Type A is shown in Figure 3. Each PHY frame of Type A starts with a preamble lasting 2.048 ms, followed by a number of OFDM symbols, each lasting 2.24 ms. The first two OFDM symbols carry the PHY frame header also referred to as the header in this specification. The header is also generated from using a process similar to the payload generation, as described in Section 3.3.2.3.1. The remaining M OFDM symbols carry payload, generated as described in Section 3.3.2.3.1. The value of M is signaled in the header and is at most equal to 63.

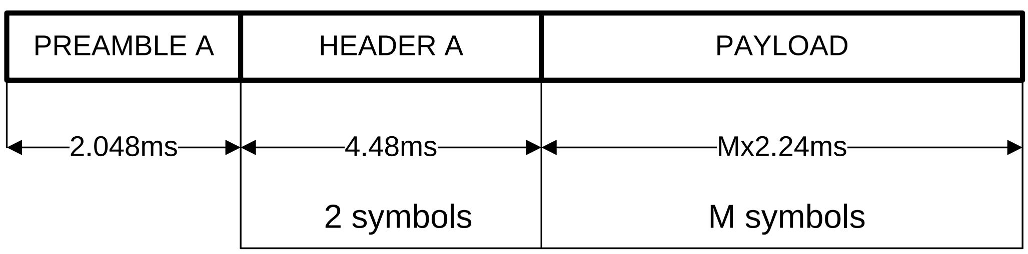

Figure 3 - PHY frame of Type A format

The structure of the PHY frame of Type B is shown in Figure 4. Each PHY frame of Type B starts with a preamble lasting 8.192 ms, followed by a number of OFDM symbols, each lasting 2.24 ms. The first four OFDM symbols carry the PHY frame header. The header is also generated from using a process similar to the payload generation, as described in Section 3.3.2.3.2. The remaining M OFDM symbols carry payload, generated as described in Section 3.3.2.3.2. The value of M is signaled in the header, and is at most equal to 252.

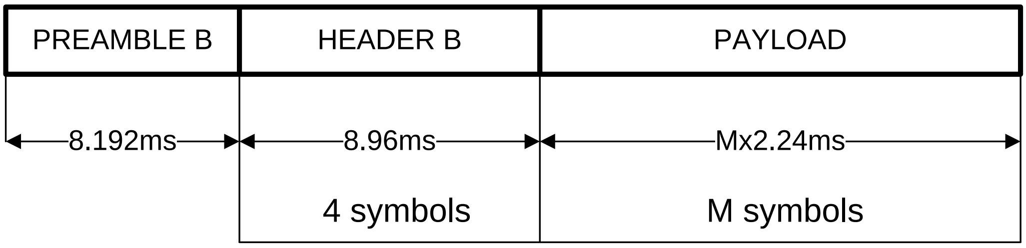

Figure 4 - PHY frame of Type B format

When the PHY Abstraction Layer uses the RF PHY, the PPDU format and processing are respectively described in clause 5.7.3 and 20.2 and 20.3 of IEEE 802.15.4 2015 [28] in the case of SUN FSK. They will be supported with the restrictions indicated throughout this specification (see in particular Section 3.4).

3.2.2 Note about backwards compatibility with PRIME v1.3.6

The current version of the PRIME specification includes new features and several modifications at PHY level. In order to ensure backwards compatibility with deployed PRIME devices, which shall be compliant with previous PRIME specification version 1.3.6, a “PHY backwards compatibility” mechanism is described in Annex J.

3.3 PLC PHY

3.3.1 PHY parameters

Table 1 lists the frequency and timing parameters used in the PRIME PHY. These parameters are common for all constellation/coding combinations.

Note: *Note that throughout this document, a sampling rate of 1 MHz and 2048-point FFT sizes are defined for specification convenience of the OFDM signals and are not intended to indicate a requirement on the implementation*

Table 1 - Frequency and Timing Parameters of the PRIME PHY

Parameter	**Values**	
Base Band clock (Hz)	1000000	
Subcarrier spacing (Hz)	488.28125	
Number of data subcarriers	N_{CH}x84 (header)	N_{CH}x96 (payload)

Parameter	**Values**	
Number of pilot subcarriers	N_{CH}x13 (header)	N_{CH}x1 (payload)
FFT interval (samples)	2048	
FFT interval (µs)	2048	
Cyclic Prefix (samples)	192	
Cyclic Prefix (µs)	192	
Symbol interval (samples)	2240	
Symbol interval (µs)	2240	
Preamble period (µs)	2048 (Type A)	8192 (Type B)

Note: *1 ≤ N_{CH} ≤ 8, where "N_{CH}" is the number of channels as defined in Section 3.1.*

Table 2 below shows the PHY data rate during payload transmission, and maximum MSDU length for various modulation and coding combinations. The robust modes, which include CC and repetition coding, only allow for DBPSK and DQPSK modulations. The effect of using more than one channel, as defined in Section 3.1, is represented by "N_{CH}" (1 ≤ N_{CH} ≤ 8).

Table 2 - PHY Payload Parameters

	DBPSK			DQPSK			D8PSK	
Convolutional Code (1/2)	On	On	Off	On	On	Off	On	Off
Repetition code	On	Off	Off	On	Off	Off	Off	Off
Information bits per subcarrier N_{BPSC}	0.5	0.5	1	1	1	2	1.5	3
Information bits per OFDM symbol N_{BPS}	N_{CH}x 48	N_{CH}x48	N_{CH}x96	N_{CH}x96	N_{CH}x96	N_{CH}x192	N_{CH}x144	N_{CH}x288
Raw data rate (kbps approx)	N_{CH}x5.4	N_{CH}x21.4	N_{CH}x42.9	N_{CH}x10.7	N_{CH}x42.9	N_{CH}x85.7	N_{CH}x64.3	N_{CH}x128.6
Maximum number of payload symbols	252	63	63	252	63	63	63	63

	DBPSK			DQPSK			D8PSK	
Maximum MPDU2 length with the maximum number of payload symbols (in bits)	N_{CH}x3016	N_{CH}x3016	N_{CH}x6048	N_{CH}x6040	N_{CH}x6040	N_{CH}x 12096	N_{CH}x9064	N_{CH}x 18144
Maximum MPDU2 length with the maximum number of payload symbols (in bytes)	N_{CH}x377	N_{CH}x377	N_{CH}x756	N_{CH}x755	N_{CH}x755	N_{CH}x1512	N_{CH}x1133	N_{CH}x2268

Table 3 shows the modulation and coding scheme and the size of the header portion of the PHY frame (see Section 3.3.2.3).

***Note:** The whole MPDU includes MPDU1 and MPDU2. The length of MPDU1 is defined in Section 3.4.3.1 for the Type A frames and Section 3.4.3.2 for Type B frames.*

Table 3 – PHY Header Parameters

	DBPSK with Header Type A	DBPSK with Header Type B
Convolutional Code (1/2)	On	On
Repetition code	Off	On
Information bits per subcarrier N_{BPSC}	0.5	0.5
Information bits per OFDM symbol N_{BPS}	N_{CH}x42	N_{CH}x42

It is strongly recommended that all frequencies used to generate the OFDM transmit signal come from one single frequency reference. The system clock shall have a maximum tolerance of ±50 ppm, including ageing.

3.3.2 Preamble, header and payload structure

3.3.2.1 Preamble

3.3.2.1.1 PRIME preamble Type A

The preamble is used at the beginning of every PPDU for synchronization purposes. In order to provide a maximum of energy, a constant envelope signal is used instead of OFDM symbols. There is also a need for the preamble to have frequency agility that will allow synchronization in the presence of frequency selective attenuation and, of course, excellent aperiodic autocorrelation properties are mandatory. A linear chirp sequence meets all the above requirements.

The preamble of Type A, named $S(t)$, is composed by N_{CH} sub-symbols where N_{CH} is the number of channels concurrently used. The set of the active channels indices is defined Ω and its i^{th} element is ω_i.

$$\Omega = \{\omega \in [1,2,\ldots,8] : \omega \text{ is an active channel}\} = \{\omega_1, \omega_2, \ldots, \omega_{N_{CH}}\}$$

The preamble sub-symbol $S_{SS}^{c}(t)$ contains a chirp signal ranging on the frequencies of channel *c* as defined in Annex G:

$$S_{SS}^{c}(t) = B \cdot window(t/T') \cdot \cos\left[2\pi\left(f_0^c t + 1/2\mu_c t^2\right)\right] \qquad 0 \le t < T'$$

where *T'* is the duration of the chirp, $\mu_c = (f_f^c - f_0^c)/T'$, f_0^c and f_f^c are the start and final frequencies of the channel *c*, respectively. The function *window(t/T')* is a shaping window of length *T'* composed by a raising roll-off region with length *ro* µs a flat region (of unitary amplitude) and a decreasing roll-off region with length *ro* µs. The definition of the roll-off region shape is left to individual implementations and should aim at reducing the out-of-band spectral emissions.

The choice of the parameter *B* determines the average preamble power that must be 4 dB higher than the average power of the header and payload OFDM symbols.

The duration *T'* of the sub-symbols, in µs, is defined as follows:

$$T' = \frac{2048 - ro}{N_{CH}} + ro$$

The preamble $S(t)$ is the concatenation of the sub-symbols $S_{SS}^{c}(t)$ with their head and tail roll-off regions overlapped:

$$S(t) = \sum_{i=0}^{N_{CH}-1} S_{SS}^{\omega_i}(t - i \cdot (T' - ro)) \qquad 0 \le t < (T - ro) \cdot N_{CH} + ro$$

To avoid rounding issues in the definition of *T'*, the length of the roll-off region depends on the number of active channels N_{CH} and its values are listed in Table 4.

Table 4 - Roll-off region length for all N_{CH} values

N_{CH}	ro [µs]	N_{CH}	ro [µs]
1	0	5	63
2	64	6	62
3	62	7	67
4	64	8	64

Note that when a single channel is used the roll-off regions are not present, T' = 2048 µs and $S(t) \equiv S_{SS}^{c}(t)$.

Figure 5 is an example of the structure of the preamble $S(t)$ when three channels are used (channel 1, channel 3 and channel 6). In this case, N_{CH} = 3, ro = 62 µs and *T'* = 724 µs.

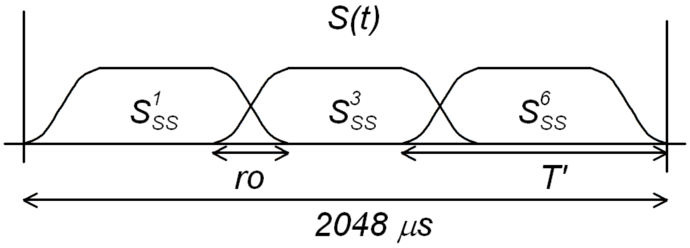

Figure 5 - Example of the preamble structure when three channels are used

3.3.2.1.2 PRIME preamble Type B

The preamble of Type B , named $S(t)$, is the concatenation of three preamble symbols $S_{PS}(t)$ and one preamble symbol with inverted sign $-S_{PS}(t)$ as shown in Figure 6.

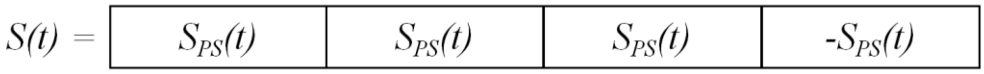

Figure 6 - Preamble Type B structure

Each preamble symbol $S_{PS}(t)$ is composed by N_{CH} sub-symbols $S_{SS}(t)$ where N_{CH} is the number of channels concurrently used. The set of the active channels indices is defined Ω and its i[th] element is ω_i.

$$\Omega = \{\omega \in [1,2,\ldots,8] : \omega \text{ is an active channel}\} = \{\omega_1, \omega_2, \ldots, \omega_{N_{CH}}\}$$

The sub-symbol $S_{SS}^c(t)$ contains a chirp signal ranging on the frequencies of channel *c* as defined in Annex G:

$$S_{SS}^c(t) = B \cdot window(t/T') \cdot \cos\left[2\pi\left(f_0^c t + 1/2 \mu_c t^2\right)\right] \qquad 0 \le t < T'$$

where *T'* is the duration of the chirp, $\mu_c = (f_f^c - f_0^c)/T'$, f_0^c and f_f^c are the final and start frequencies of the channel *c*, respectively. The function *window(t/T')* is a shaping window of length *T'* composed by a raising roll-off region with length *ro* µs a flat region (of unitary amplitude) and a decreasing roll-off region with length *ro* µs. The definition of the roll-off region shape is left to individual implementations and should aim at reducing the out-of-band spectral emissions.

The choice of the parameter *B* determines the average preamble power that must be 4 dB higher than the average power of the header and payload OFDM symbols.

The duration *T'* of the sub-symbols, in µs, is defined as follows:

$$T' = \frac{2048 - ro}{N_{CH}} + ro$$

The preamble symbol $S_{PS}(t)$ is the concatenation of the sub-symbols $S_{SS}^c(t)$ with their head and tail roll-off regions overlapped:

$$S_{PS}(t) = \sum_{i=0}^{N_{CH}-1} S_{SS}^{\omega_i}(t - i \cdot (T' - ro)) \qquad 0 \le t < (T' - ro) \cdot N_{CH} + ro$$

To avoid rounding issues in the definition of T', the length of the roll-off region depends on the number of active channels N_{CH} and its values are listed in Table 5.

Table 5 - Roll-off region length for all N_{CH} values

N_{CH}	ro [µs]	N_{CH}	ro [µs]
1	0	5	63
2	64	6	62
3	62	7	67
4	64	8	64

Note that when a single channel is used the roll-off regions are not present, T' = 2048 µs and $S_{PS}(t) \equiv S_{SS}^{c}(t)$.

Figure 7 is an example of the structure of the preamble symbol $S_{PS}(t)$ when three channels are used (channel 1, channel 3 and channel 6). In this case, N_{CH} = 3, ro = 62 µs and *T'* = 724 µs.

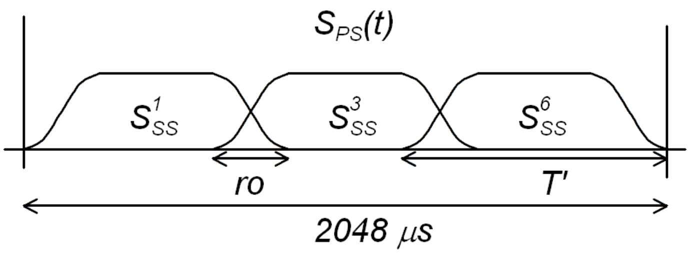

Figure 7 - Example of each of the preamble symbol structure when three channels are used

3.3.2.2 Pilot structure

The preamble is always followed by some OFDM symbols comprising the header. Each header symbol contains 13×N_{CH} pilot subcarriers, starting from the first subcarrier of each active channel and separated by 7 data subcarriers. The pilots could be used to estimate the sampling start error and the sampling frequency offset.

For subsequent OFDM symbols, one pilot subcarrier is used on the first subcarrier of each active channel to provide a phase reference for frequency domain DPSK demodulation.

In Figure 8 pilot subcarrier allocation is shown for the eight active channels case where a 2048-point FFT is used. P_i^c is the i[th] pilot subcarrier on the c[th] channel and D_i^c is the i[th] data subcarrier on the c[th] channel.

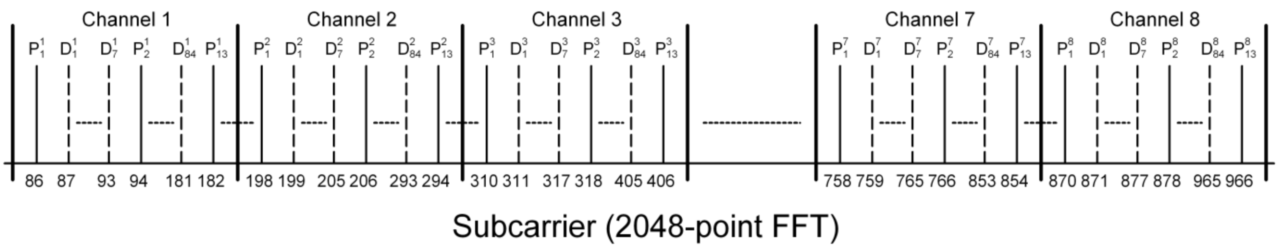

Figure 8 - Pilot and data subcarrier frequency allocation inside the header (eight active channels case)

Pilot subcarriers are BPSK modulated by a pseudo-random binary sequence (the pseudo-randomness avoids generation of spectral lines). The phase of the pilot subcarriers is controlled by the sequence pn, which is a cyclic extension of the 127-bit sequence given by:

$Pref_{0.126}$ = {0,0,0,0,1,1,1,0,1,1,1,1,0,0,1,0,1,1,0,0,1,0,0,1,0,0,0,0,0,0,1,0,0,0,1,0,0,1,1,0,0,0,1,0,1,1,1,0,1,0,1,1,
0,1,1,0,0,0,0,0,1,1,0,0,1,1,0,1,0,1,0,0,1,1,1,0,0,1,1,1,1,0,1,1,0,1,0,0,0,0,1,0,1,0,1,0,1,1,1,1,1,0,1,0,0,1,0,1,0,0
,0,1,1,0,1,1,1,0,0,0,1,1,1,1,1,1,1}

In the above, ‘1’ means 180º phase shift and ‘0’ means 0º phase shift. One bit of the sequence will be used for each pilot subcarrier, starting with the first pilot subcarrier in the first OFDM symbol, then the next pilot subcarrier, and so on. The same process is used for all the header OFDM symbols. For subsequent OFDM symbols, one element of the sequence is used for the pilot subcarrier of each active channel.

The sequence pn is generated by the scrambler defined in Figure 9 when the “all ones” initial state is used.

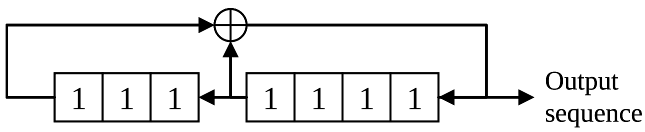

Figure 9 - LFSR for use in Pilot sequence generation

Loading of the sequence pn shall be initiated at the start of every PPDU, just after the Preamble.

3.3.2.2.1 Pilot structure for PHY frames of Type A

In the case of PHY frame of Type A, the header is composed by two OFDM symbols. The pilot and data subcarriers allocation for the eight active channels case is shown in Figure 10.

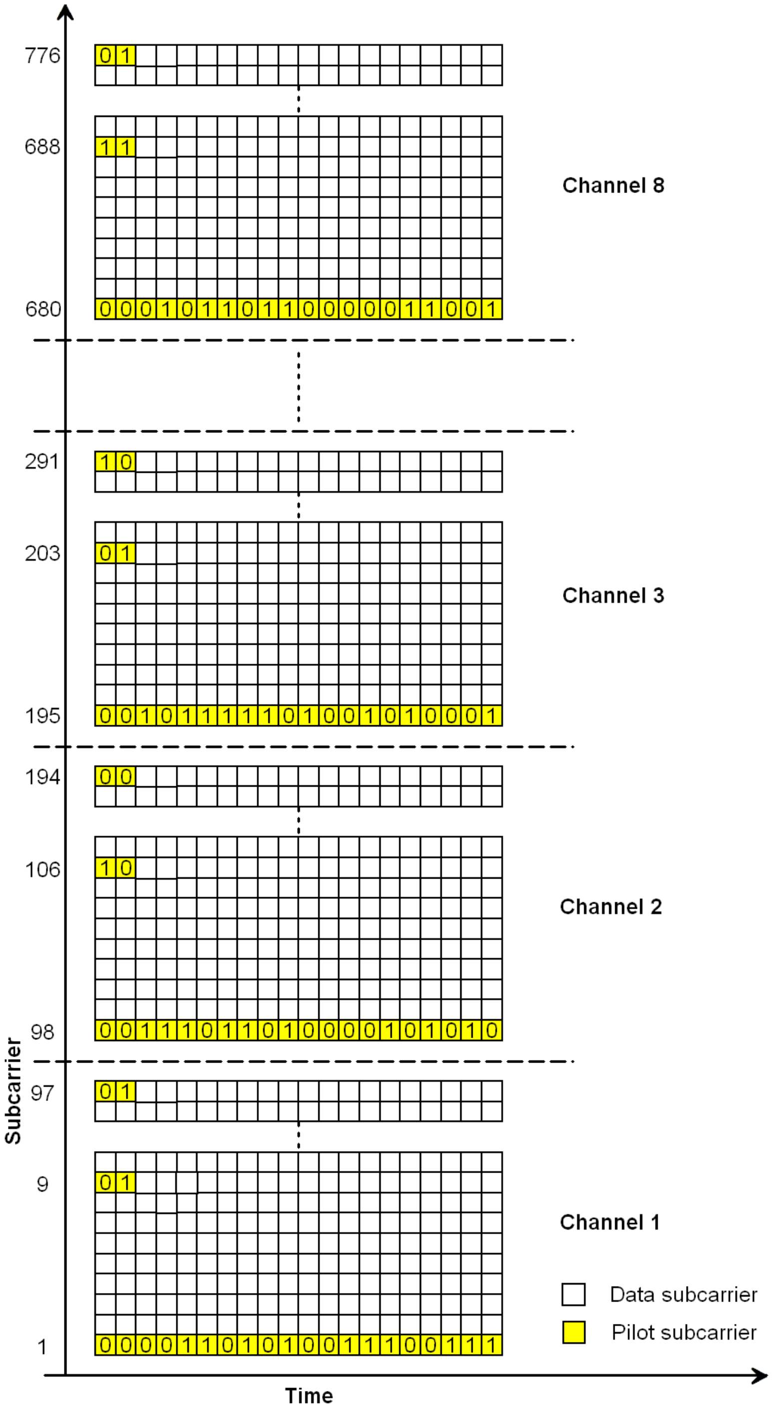

Figure 10 - PHY frame of Type A, pilot and data subcarrier allocation (eight active channels case)

3.3.2.2.2 Pilot structure for PHY frames of Type B

In the case of PHY frame of Type B, the header is composed by four OFDM symbols. The pilot and the data subcarriers allocation for the eight active channels case is shown in Figure 11.

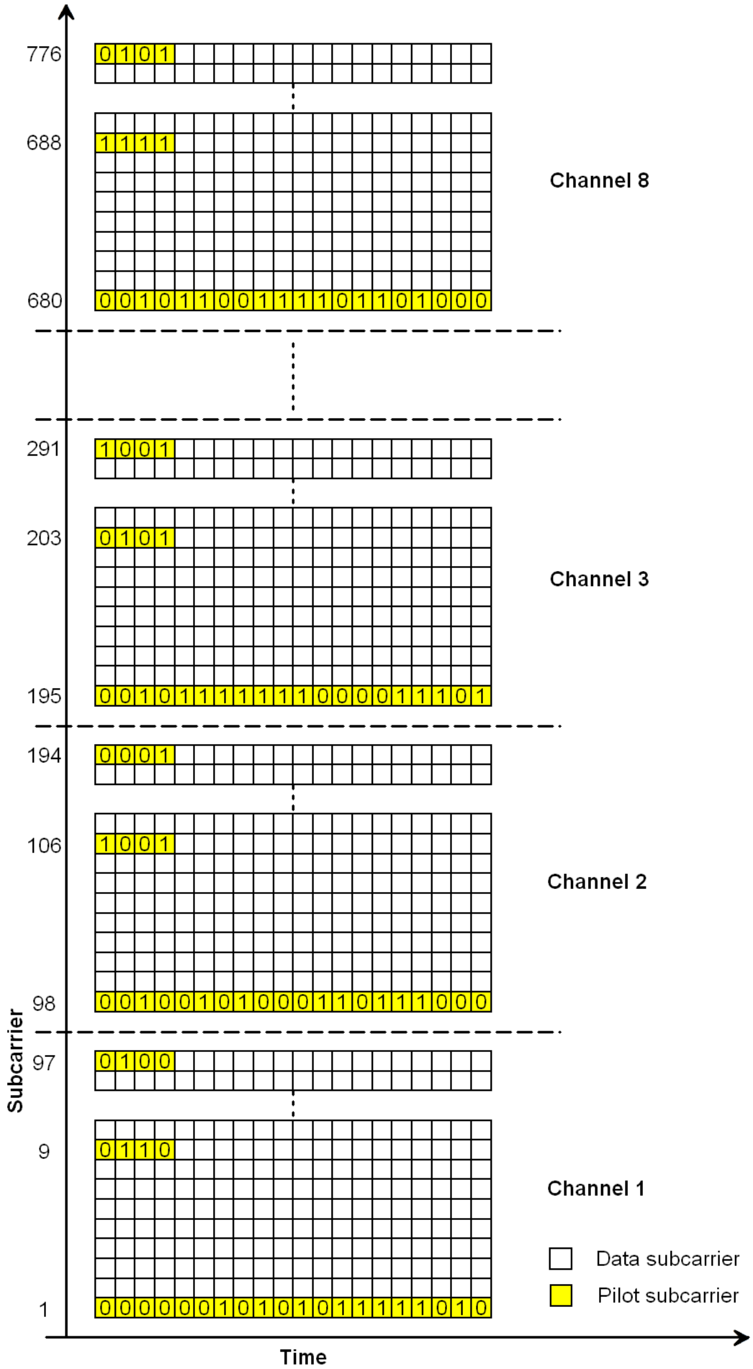

Figure 11 - PHY frame of Type B, pilot and data subcarrier allocation (eight active channels case)

3.3.2.3 Header and Payload

3.3.2.3.1 Header and payload for PHY frames of Type A

The header of Type A is composed of two OFDM symbols, which are always sent using DBPSK modulation and CC “On” (note that the repetition coding is not available for PRIME v1.3.6 devices). The payload is DBPSK, DQPSK or D8PSK modulated, depending on the configuration chosen by the MAC layer. The MAC layer may select the best modulation scheme using information from errors in previous transmissions to the same receiver(s), or by using the SNR feedback. Thus, the system will then configure itself dynamically to provide the best compromise between throughput and efficiency in the communication. This includes deciding whether or not CC is used.

Note: *The optimization metric and the target error rate for the selection of modulation and FEC scheme is left to individual implementations*

The first two OFDM symbols in the PPDU (corresponding to the header) are composed of $84 \times N_{CH}$ data subcarriers and $13 \times N_{CH}$ pilot subcarriers. After the header, each OFDM symbol in the payload carries $96 \times N_{CH}$ data subcarriers and one pilot subcarrier. Each data subcarrier carries 1, 2 or 3 bits.
The bit stream from each field must be sent msb first.

HEADER								PAYLOAD			
PROTOCOL	LEN	PAD_LEN	RESERVED	MPDU1	CRC_Ctrl	FLUSHING_H	PAD_H	MPDU2	FLUSHING_P	PAD	
4	6	6 or 9	0 or 5	54 to 630	8	6	0 or 4	8 X M	8	8 X PAD_LEN	bits

Figure 12 - PRIME PPDU of Type A: header and payload (bits transmitted before encoding)

- HEADER: The header for PRIME PPDUs of Type A comprises two OFDM symbols, containing both PHY and MAC header information. To avoid ambiguity, the MAC header is always referred to as such. The PHY header may also be referred to as just “header”. It is composed of the following fields:
  - PROTOCOL: contains the transmission scheme of the payload. Added by the PHY layer.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DBPSK	DQPSK	D8PSK	RES	DBPSK_C	DQPSK_C	D8PSK_C	RES	RES	RES	RES	RES	RS	RES	RES	RES

    Where RES means “Reserved” and the suffix “_C” means CC is “On”.
  - LEN: defines the length of the payload (after coding) in OFDM symbols. Added by the PHY layer. If LEN is equal to 0, then the PAYLOAD symbols are not present. In this case, PAD_LEN refers to the padding bytes appended to MPDU bytes to fill the MPDU1 field.
  - PAD_LEN: defines the length of the PAD field (before coding) in bytes. The length in bits of this field depends on the number of active channels: 6 for $N_{CH} = 1$ and 9 for $N_{CH} \geq 2$. Added by the PHY layer.
  - RESERVED: contains the reserved bits for future use. The length in bits of this field depends on the number of active channels: 0 for $N_{CH} = 1$ and 5 for $N_{CH} \geq 2$.
  - MPDU1: First part of the MPDU. The length in bits of this field (MPDU1Len) depends on the number of active channels:

$$MPDU1Len = \left\lfloor \frac{(N_{CH} \cdot 84 - 30) + 2}{8} \right\rfloor \cdot 8 - 2$$

    The result of the above formula is reduced by 8 (1 Byte) for $N_{CH} \geq 2$.
  - where $\lfloor x \rfloor$ denotes the nearest integer towards minus infinity of *x*.
  - CRC_Ctrl: the CRC_Ctrl(m), m = 0..7, contains the CRC checksum over PROTOCOL, LEN, PAD_LEN, RESERVED and MPDU1 field (PD_Ctrl). The polynomial form of PD_Ctrl is expressed as follows:

$$\sum_{m=0}^{69} PD_{Ctrl}(m)x^m$$

    The checksum is calculated as follows: the remainder of the division of PD_Ctrl by the polynomial $x^8 + x^2 + x + 1$ forms CRC_Ctrl(m), where CRC_Ctrl(0) is the lsb. The generator polynomial is the well-known CRC-8-ATM. Some examples are shown in Annex A. Added by the PHY layer.

- FLUSHING_H: flushing bits needed for convolutional decoding. All bits in this field are set to zero to reset the convolutional encoder. Added by the PHY layer.
- PAD_H: Padding field. In order to ensure that the number of (coded) bits generated in the header fills an integer number of OFDM symbols, pad bits may be added to the header before encoding. All pad bits shall be set to zero. The length in bits of the PAD_H field depends on the number of active channels.

  Table 6 resumes the length in bits of MPDU1 and PAD_H fields for different numbers of active channels.

Table 6 - Length in bits of MPDU1 and PAD_H fields in the PHY frame header of Type A for all possible values of N_{CH}

N_{CH}	MPDU1	PAD_H
1	54	0
2	126	4
3	214	0
4	294	4
5	382	0
6	462	4
7	550	0
8	630	4

- PAYLOAD:
  - MPDU2: Second part of the MPDU.
  - FLUSHING_P: flushing bits needed for convolutional decoding. All bits in this field are set to zero to reset the convolutional encoder. This field only exists when CC is “On”.
  - PAD: Padding field. In order to ensure that the number of (coded) bits generated in the payload fills an integer number of OFDM symbols, pad bits may be added to the payload before encoding. All pad bits shall be set to zero.

The MPDU is included in the MPDU1 and MPDU2 fields using the following logic. The first 2 bits of the MPDU are discarded for alignment purposes. The next 54 bits of the MPDU are included in the MPDU1 field. The remaining bits of the MPDU are included in the MPDU2 field. It is a work of higher layers not to use the first two bits of the MPDU as they will not be transmitted or received by the PHY layer. In reception these first non-transmitted bits will be considered as 0.

3.3.2.3.2 Header and payload for PHY frames of Type B

The header is composed of four OFDM symbols, which are always sent using DBPSK modulation, CC “On” and repetition coding “On”. However the payload is DBPSK, DQPSK or D8PSK modulated, depending on the configuration by the MAC layer. The MAC layer may select the best modulation scheme using information from errors in previous transmissions to the same receiver(s), or by using the SNR feedback. Thus, the system will then configure itself dynamically to provide the best compromise between throughput and efficiency in the communication. This includes deciding whether or not CC and repetition coding are used.

***Note**: The optimization metric and the target error rate for the selection of modulation and FEC scheme is left to individual implementations*

The first four OFDM symbols in the PPDU (corresponding to the header) are composed of $84 \times N_{CH}$ data subcarriers and $13 \times N_{CH}$ pilot subcarriers. After the header, each OFDM symbol in the payload carries $96 \times N_{CH}$ data subcarriers and N_{CH} pilot subcarriers. Each data subcarrier carries 1, 2 or 3 bits.

The bit stream from each field must be sent msb first.

HEADER								PAYLOAD			
PROTOCOL	LEN	PAD_LEN	RESERVED	CRC_Ctrl	MPDU1	FLUSHING_H	PAD_H	MPDU2	FLUSHING_P	PAD	
4	8	9	3	12	0 to 288	6	0 to 6	8 X M	8	8 X PAD_LEN	bits

Figure 13 - PRIME PPDU of Type B: header and payload (bits transmitted before encoding)

- HEADER: The PHY header is composed of the following fields:
  - PROTOCOL: contains the transmission scheme of the payload. Added by the PHY layer.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DBPSK	DQPSK	D8PSK	RES	DBPSK_C	DQPSK_C	D8PSK_C	RES	RES	RES	RES	RES	R_DBPSK	R_DQPSK	RES	RES

    Where RES means "Reserved", the suffix "_C" means CC is "On" and the prefix R_ means CC and repetition are "On".
  - LEN: defines the length of the payload (after coding) in OFDM symbols. Added by the PHY layer.
  - PAD_LEN: defines the length of the PAD field (before coding) in bytes. If LEN is equal to 0 the PAYLOAD symbols are not present, in this case PAD_LEN refers to the padding bytes appended to MPDU bytes to fill the MPDU1 field. Added by the PHY layer.
  - RESERVED: contains the reserved bits for future use.
  - CRC_Ctrl: the CRC_Ctrl(m), m = 0..11, contains the CRC checksum over PROTOCOL, LEN, PAD_LEN and RESERVED field (PD_Ctrl). The polynomial form of PD_Ctrl is expressed as follows: $\sum_{m=0}^{23} PD_{Ctrl}(m)x^m$

    The checksum is calculated as follows: the remainder of the division of PD_Ctrl by the polynomial $x^{12}+x^{11}+x^3+x^2+x+1$ forms CRC_Ctrl(m), where CRC_Ctrl(0) is the lsb. Some examples are shown in Annex A. Added by the PHY layer.
  - MPDU1: First part of the MPDU. The length in bits of this field (MPDU1Len) is a multiple of 8 and it depends on the number of active channels:

$$MPDU\,1Len = \left\lfloor \frac{(N_{CH}-1)\cdot 84 \cdot \frac{1}{2}}{8} \right\rfloor \cdot 8$$

    where $\lfloor x \rfloor$ denotes the nearest integer towards minus infinity of *x*.
  - FLUSHING_H: flushing bits needed for convolutional decoding. All bits in this field are set to zero to reset the convolutional encoder. Added by the PHY layer.
  - PAD_H: Padding field. In order to ensure that the number of (coded) bits generated in the header fills an integer number of OFDM symbols, pad bits may be added to the header before encoding. All pad bits shall be set to zero. The length in bits of PAD_H field (PAD_HLen) depends on the number of active channels:

$$PAD\_HLen = (N_{CH}-1)\cdot 84 \cdot \tfrac{1}{2} - MPDU\,1Len$$

    Table 7 resumes the length of MPDU1 and PAD_H fields for different numbers of active channels.

Table 7 - Length in bits of MPDU1 and PAD_H fields in the PHY frame header of Type B for all possible values of N_{CH}

N_{CH}	MPDU1	PAD_H
1	0	0
2	40	2
3	80	4
4	120	6
5	168	0
6	208	2
7	248	4
8	288	6

Note that on reception of a PPDU with a correct CRC_Ctrl but with PROTOCOL with reserved values, or any of the reserved bits being “1”, the receiver should consider that the payload contains LEN symbols, and should be able to discard the PDU considering the channel busy.

- PAYLOAD:
  - MPDU2: Second part of the MPDU.
  - FLUSHING_P: flushing bits needed for convolutional decoding. All bits in this field are set to zero to reset the convolutional encoder. This field only exists when CC is “On”.
  - PAD: Padding field. In order to ensure that the number of (coded) bits generated in the payload fills an integer number of OFDM symbols, pad bits may be added to the payload before encoding. All pad bits shall be set to zero.

3.3.3 Convolutional encoder

The uncoded bit stream may go through convolutional coding to form the coded bit stream. The convolutional encoder is ½ rate with constraint length K = 7 and code generator polynomials 1111001 and 1011011. At the start of every PPDU transmission, the encoder state is set to zero. As seen in Figure 12 and Figure 13, six zeros are inserted at the end of the header information bits to flush the encoder and return the state to zero. Similarly, if convolutional encoding is used for the payload, eight zeros bits are again inserted at the end of the input bit stream to ensure the encoder state returns to zero at the end of the payload. The block diagram of the encoder is shown in Figure 14.

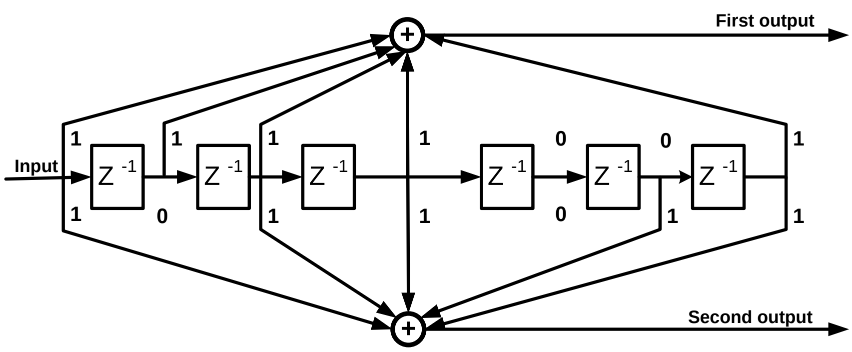

Figure 14 - Convolutional encoder

3.3.4 Scrambler

The scrambler block randomizes the bit stream, so it reduces the crest factor at the output of the IFFT when a long stream of zeros or ones occurs in the header or payload bits after coding (if any). Scrambling is always performed regardless of the modulation and coding configuration.

The scrambler block performs a xor of the input bit stream by a pseudo noise sequence pn, obtained by cyclic extension of the 127-element sequence given by:

$Pref_{0..126}$={0,0,0,0,1,1,1,0,1,1,1,1,0,0,1,0,1,1,0,0,1,0,0,1,0,0,0,0,0,0,1,0,0,0,1,0,0,1,1,0,0,0,1,0,1,1,1,0,1,0,1,1, 0,1,1,0,0,0,0,0,1,1,0,0,1,1,0,1,0,1,0,0,1,1,1,0,0,1,1,1,1,0,1,1,0,1,0,0,0,0,1,0,1,0,1,0,1,1,1,1,1,0,1,0,0,1,0,1,0,0 ,0,1,1,0,1,1,1,0,0,0,1,1,1,1,1,1,1}

Note: *The above 127-bit sequence can be generated by the LFSR defined in* Figure 15 *when the "all ones" initial state is used.*

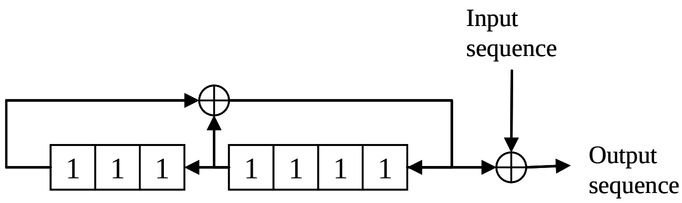

Figure 15 - LFSR for use in the scrambler block

Loading of the sequence pn shall be initiated at the start of every PPDU, just after the Preamble.

3.3.5 Repeater

The repeater block introduces both time diversity and frequency diversity to the transmitted bits repeating a bit sequence four times with the aim of increasing the communication robustness. The repeater is enabled only when robust modes are used. Figure 16 shows the behavior of the repeater.

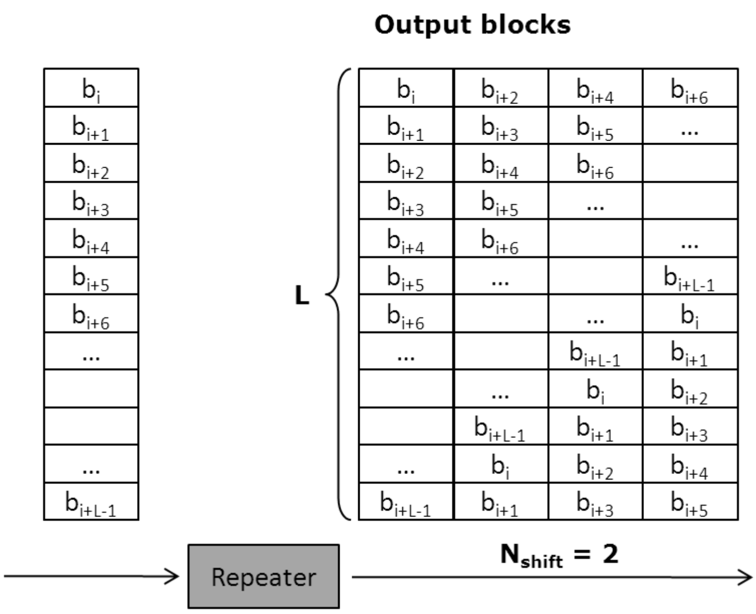

Figure 16 - Example of repeater block using a shift value = 2

The transmitted bit sequence b_i, b_{i+1}, … is divided into blocks of length L corresponding to the number of bits transmitted into one OFDM symbol according to the used transmission mode. L is equal to $84\times N_{CH}$ for the header, $96\times N_{CH}$ for the payload using robust DBPSK and $192\times N_{CH}$ for the payload using robust DQPSK, where N_{CH} is the number of channels concurrently used. Each block of L bits is repeated four times at the repeater output. Furthermore, the bits of each replicated block are obtained introducing a cyclic shift of N_{shift} to the bits of the previous block (the first output block always corresponds to the input block). N_{shift} depends on the transmission mode and its values are listed in Table 8.

Table 8 - Shift values for the Robust modes

Transmission mode	N_{shift}
Robust DBPSK (header)	2
Robust DBPSK (payload)	2
Robust DQPSK (payload)	4

3.3.6 Interleaver

Because of the frequency fading (narrowband interference) of typical power line channels, OFDM subcarriers are generally received at different amplitudes. Deep fades in the spectrum may cause groups of subcarriers to be less reliable than others, thereby causing bit errors to occur in bursts rather than be randomly scattered. If (and only if) coding is used as described in 3.4.3, interleaving is applied to randomize the occurrence of bit errors prior to decoding. At the transmitter, the coded bits are permuted in a certain way, which makes sure that adjacent bits are separated by several bits after interleaving.

Let $N_{CBPS} = 2\times N_{BPS}$ be the number of coded bits per OFDM symbol in the cases convolutional coding is used. All coded bits must be interleaved by a block interleaver with a block size corresponding to N_{CBPS}. The interleaver ensures that adjacent coded bits are mapped onto non-adjacent data subcarriers. Let v(k), with k = 0,1,…, $N_{CBPS}-1$, be the coded bits vector at the interleaver input. v(k) is transformed into an interleaved vector w(i), with i = 0,1,…, $N_{CBPS}-1$, by the block interleaver as follows:

$$w\left((N_{CBPS}/s) \times (k \bmod s) + \mathrm{floor}(k/s) \right) = v(k) \qquad k = 0,1,\ldots, N_{CBPS}-1$$

The value of s is determined by the number of coded bits per subcarrier, $N_{CBPSC} = 2\times N_{BPSC}$. N_{CBPSC} is related to N_{CBPS} such that $N_{CBPS} = 96\times N_{CBPSC}\times N_{CH}$ (payload) and $N_{CBPS} = 84\times N_{CBPSC}\times N_{CH}$ (header), where N_{CH} is the number of channels concurrently used.

$s = 8 \times (1+ \mathrm{floor}(N_{CBPSC}/2))$ for the payload and

$s = 7$ for the header.

At the receiver, the de-interleaver performs the inverse operation. Hence, if $w'(i)$, with i = 0,1,…, $N_{CBPS}-1$, is the de-interleaver vector input, the vector $w'(i)$ is transformed into a de-interleaved vector $v'(k)$, with k = 0,1,…, $N_{CBPS}-1$, by the block de-interleaver as follows:

$$v'\left(s \times i - (N_{CBPS}-1) \times \mathrm{floor}(s \times i/N_{CBPS}) \right) = w'(i) \qquad i = 0,1,\ldots, N_{CBPS}-1$$

Descriptive tables showing index permutations can be found in Annex C for reference.

Note that the interleaver parameters *k* and N_{CBPS} do not depend on the presence of the repetition encoding and their values remain the same for coded DBSPK (or coded DQPSK) and robust DBPSK (or robust DQPSK).

3.3.7 Modulation

The PPDU payload is modulated as a multicarrier differential phase shift keying signal with one pilot subcarrier and $96\times N_{CH}$ data subcarriers that comprise $96\times N_{CH}$, $192\times N_{CH}$ or $288\times N_{CH}$ bits per symbol. The header is modulated DBPSK with $13\times N_{CH}$ pilot subcarriers and $84\times N_{CH}$ data subcarriers that comprise $84\times N_{CH}$ bits per symbol.

The bit stream coming from the interleaver is divided into groups of B bits where the first bit of the group of B is the most significant bit (msb).

First of all, frequency domain differential modulation is performed. Figure 17 shows the DBPSK, DQPSK and D8PSK mapping:

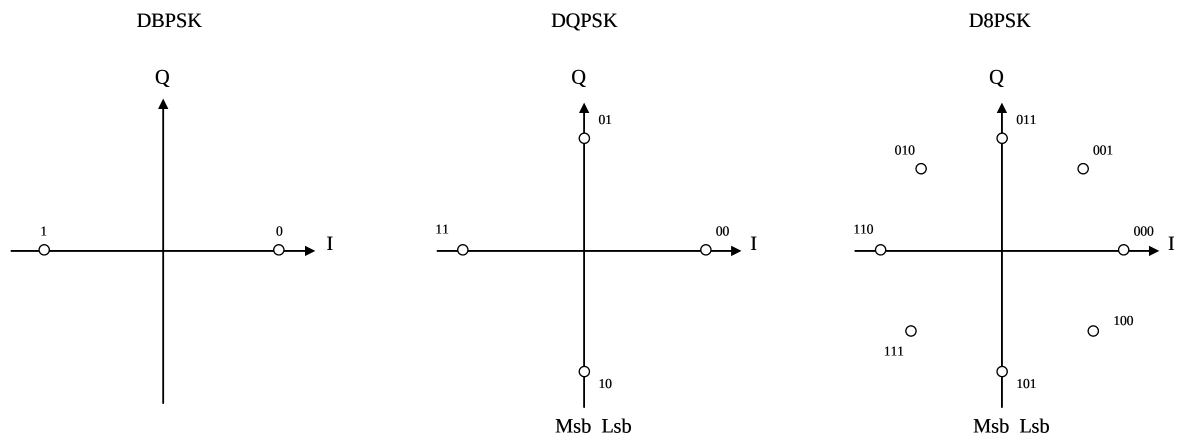

Figure 17 - DBPSK, DQPSK and D8PSK mapping

The next equation defines the P-ary DPSK constellation of P phases:

$$s_k = Ae^{j\theta_k}$$

Where:

- k is the frequency index representing the k^{th} subcarrier in an OFDM symbol. k = 1 corresponds to the phase reference pilot subcarrier.
- s_k is the modulator output (a complex number) for the k^{th} given subcarrier.
- θ_k stands for the absolute phase of the modulated signal, and is obtained as follows:
- $\theta_k = \left(\theta_{k-1} + (2\pi / P)\Delta b_k\right) \bmod 2\pi$
- This equation applies for $k > 1$ in the payload, the $k = 1$ subcarrier being the phase reference pilot. When the header is transmitted, the pilot allocated in the k^{th} subcarrier is used as a phase reference for the data allocated in the $(k+1)^{th}$ subcarrier.
- $\Delta b_k \in \{0,1,..,P-1\}$ represents the information coded in the phase increment, as supplied by the constellation encoder.
- P = 2, 4, or 8 in the case of DBPSK, DQPSK or D8PSK, respectively.
- A is a shaping parameter and represents the ring radius from the center of the constellation. The value of A determines the power in each subcarrier and hence the average power transmitted in the header and payload symbols.

If a complex 2048-point IFFT is used, the $96xN_{CH}$ subcarriers shall be mapped as shown in Figure 18. The symbol * represents complex conjugate.

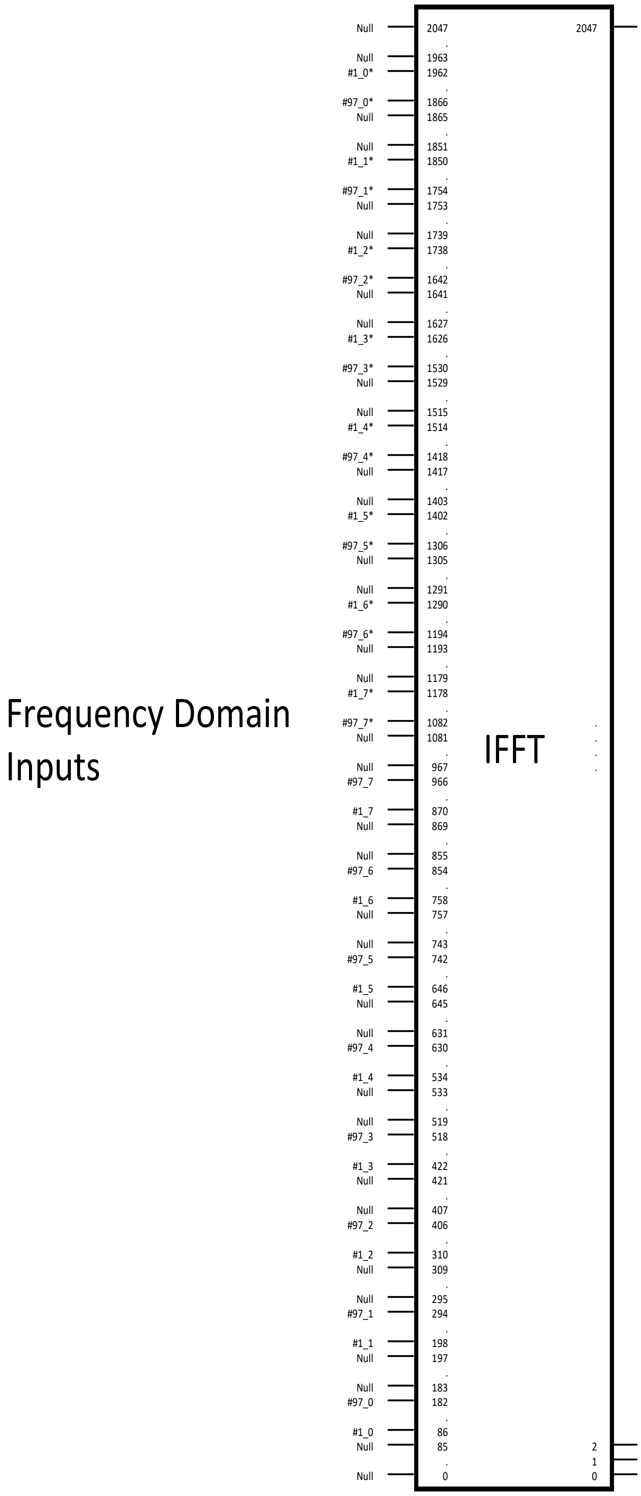

Figure 18 - Subcarrier Mapping

After the IFFT, the symbol is cyclically extended by 48 samples to create the cyclic prefix (N_{CP}).

3.3.8 Electrical specification of the transmitter

3.3.8.1 General

The following requirements establish the minimum technical transmitter requirements for interoperability, and adequate transmitter performance.

3.3.8.2 Transmit PSD

Transmitter specifications will be measured according to the following conditions and set-up.

For single-phase devices, the measurement shall be taken on either the phase or neutral connection according to Figure 19.

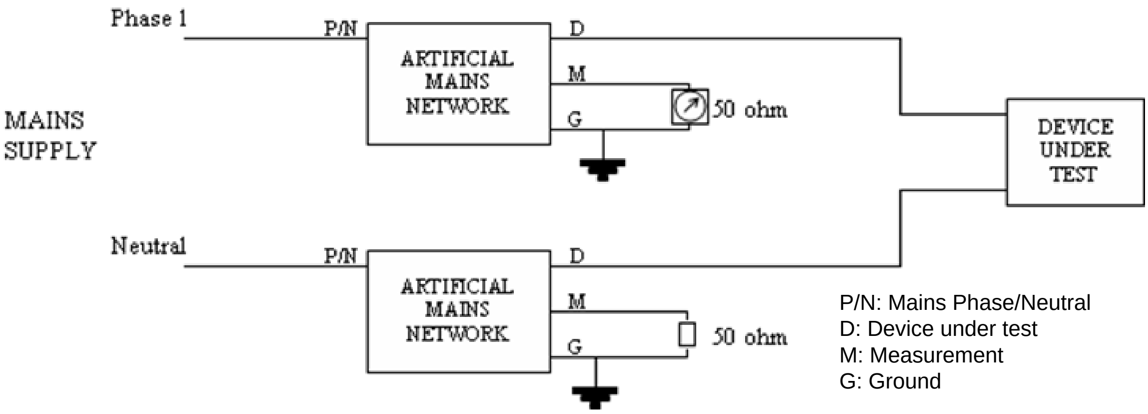

Figure 19 – Measurement set up (single-phase)

For three-phase devices which transmit on all three phases simultaneously, measurements shall be taken in all three phases as per Figure 20. No measurement is required on the neutral conductor.

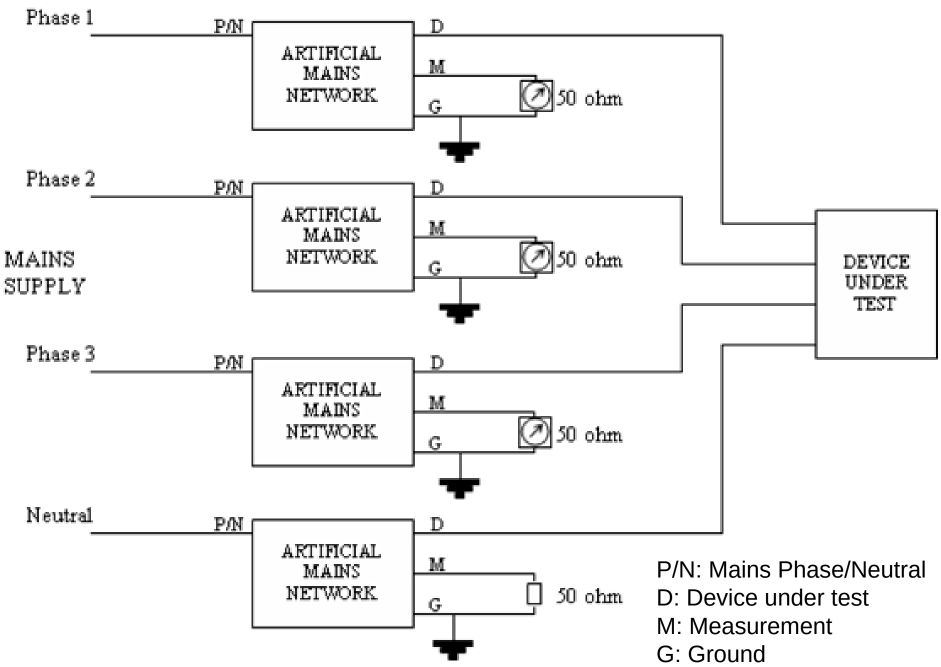

Figure 20 – Measurement set up (three-phase)

The artificial mains network in Figure 19 and Figure 20 is shown in Figure 21. It is based on EN 50065-1:2001. The 33uF capacitor and 1Ω resistor have been introduced so that the network has an impedance of 2Ω in the frequency band of interest.

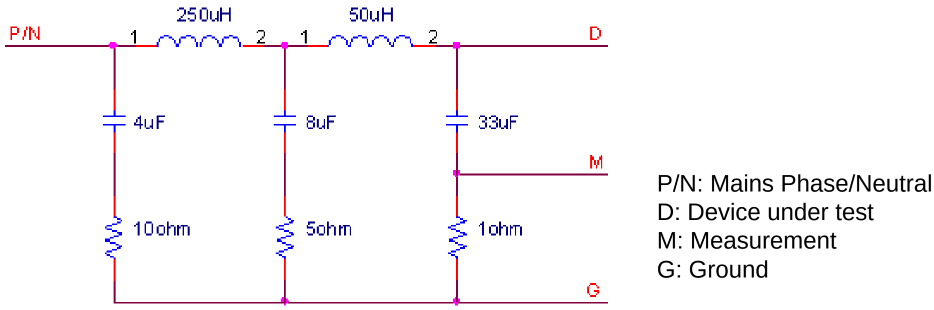

Figure 21 – Artificial mains network

All transmitter output voltages are specified as the voltage measured at the line Terminal with respect to the neutral Terminal. Accordingly, values obtained from the measuring device must be increased by 6 dB (voltage divider of ratio ½).

All devices will be tested to comply with PSD requirements over the full temperature range, which depends on the type of Node:

- Base Nodes in the range -40°C to +70°C
- Service Nodes in the range -25°C to +55°C

All tests shall be carried out under normal traffic load conditions.

In all cases, the PSD must be compliant with the regulations in force in the country where the system is used.

When driving only one phase, the power amplifier shall be capable of injecting a final signal level in the transmission Node (S1 parameter) of 120dBμVrms (1 Vrms). This could be in one of two scenarios: either the DUT is connected to a single phase as shown in Figure 19; or the DUT is connected to three phases as shown in Figure 20, but drives only one phase at a time. In both cases, connection is through the AMN of Figure 21.

For three-phase devices injecting simultaneously into all three phases, the final signal level shall be 114dBμVrms (0.5Vrms).

Note 1*: In all the above cases, note the measurement equipment has some insertion loss. Specifically, in the single-phase, configuration, the measured voltage is 6 dB below the injected signal level, and will equal 114 dBuV when the injected signal level is 120 dBuV. Similarly, when connected to three phases, the measured signal level will be 12 dB below the injected signal level. Thus, a 114 dBuV signal injected into three phases being driven simultaneously, will be measured as 102 dBuV on any of the three meters of* Figure 20.

Note 2: *Regional restrictions may apply, ex., on the reactive power drawn from a meter including a PRIME modem. These regulations could affect the powerline interface, and should be accounted for.*

3.3.8.3 Error Vector Magnitude (EVM)

The quality of the injected signal with regard to the artificial mains network impedance must be measured in order to validate the transmitter device. Accordingly, a vector analyzer that provides EVM measurements (EVM meter) shall be used, see Annex B for EVM definition. The test set-up described in Figure 19 and Figure 20 shall be used in the case of single-phase devices and three-phase devices transmitting simultaneously on all phases, respectively.

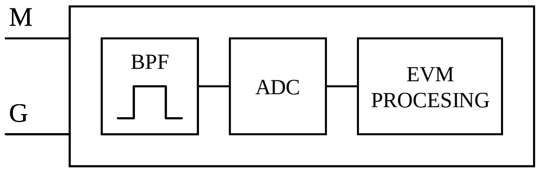

Figure 22 – EVM meter (block diagram)

The EVM meter must include a Band Pass Filter with an attenuation of 40 dB at 50 Hz that ensures anti-aliasing for the ADC. The minimum performance of the ADC is 1MSPS, 14-bit ENOB. The ripple and the group delay of the band pass filter must be accounted for in EVM calculations.

3.3.8.4 Conducted disturbance limits

Regional regulations may apply. For instance, in Europe, transmitters shall comply with the maximum emission levels and spurious emissions defined in EN50065-1:2001 for conducted emissions in AC mains in the bands 3 kHz to 9 kHz and 95 kHz to 30 MHz. European regulations also require that transmitters and receivers shall comply with impedance limits defined in EN50065-7:2001 in the range 3 kHz to 148.5 kHz.

3.4 RF PHY

The RF PHY of PRIME, will be based on some of the general PHY requirements defined on clause 10 of IEEE 802.15.4-2015 [28] and of IEEE 802.15.4v-2017 [29].

The support of PRIME profile of SUN FSK PHY, will be mandatory on PRIME devices supporting RF.

3.4.1 PRIME profile of SUN FSK PHY

The PRIME profile of SUN FSK PHY is given in clause 20 of IEEE 802.15.4-2015 [28] amended by IEEE 802.15.4v-2017 [29], together with the following statements and modifications shown in Table 9.

In this clause, the status of each requirement from the reference documents is given using the following convention:

I = ''Informative''. The statements of the reference document are provided for information only.
N = ''Normative'': The statements of the reference document shall apply without modifications or remarks.
S = ''Selection'': The statements of the reference document shall apply with the selections specified.
E = ''Extension'': The statements of the reference document shall apply with the extensions (modifications and remarks noted under the part title) specified.
N/R = ''Not Relevant'': The statements of the reference document do not apply. An explanation may be given under the part title.

References to clauses in the "Clause" column refer to the referenced document, while references to clauses/annexes in the "Title and remarks" column refer to this specification unless specifically indicated otherwise.

Table 9 - Selections from clause 20 of [28] amended by [29]

Clause	Title and remarks/modifications	Statement
20.1	Introduction	N
20.2	PPDU format for SUN FSK – The mode switch PPDU shall not be used	S
20.2.1	SHR field format	N
20.2.1.1	Preamble field – The attribute phyFskPreambleLength shall be set to eight	S
20.2.1.2	SFD – The attribute phySunFskSfd shall be set to zero	S
20.2.2	PHR field format – The Mode Switch field shall be set to zero – The FCS Type field shall be set to zero on transmission but on reception it is ignored– The Data Whitening field shall be set to one	N
20.2.3	Mode Switch PHR – Mode switch PPDUs shall not be used	N/R
20.2.4	PHY Payload field	N
20.3	Modulation and coding for SUN FSK – The 863–870 MHz frequency band shall be supported – Other frequency bands may be supported – Operating Mode #1 shall be supported – Operating Mode #2 may be supported – The operating mode shall be administratively configured	S
20.3.1	Reference modulator	N
20.3.2	Bit-to-symbol mapping	N
20.3.3	Modulation quality	N
20.3.3.1	Frequency deviation tolerance	N
20.3.3.2	Zero crossing tolerance	N
20.3.4	FEC – The FEC mode shall be administratively configured – If FEC is enabled, NRNSC shall be used	S
20.3.5	Code-symbol interleaving – NRNSC shall be supported	S
20.4	Data whitening for SUN FSK	N
20.5	Mode switch mechanism for SUN FSK – Mode switch PPDUs shall not be used	N/R
20.6	SUN FSK PHY RF requirements	N
20.6.1	Operating frequency range	N
20.6.2	Regulatory compliance	N

Table 9 - Selections from clause 20 of [28] amended by [29]

Clause	Title and remarks/modifications	Statement
20.6.3	Radio frequency tolerance – The value of T shall be computed as – $T \leq \min(T0 \times R \times h \times F0/(R0 \times h0 \times F), 20x10\text{-}6)$	N
20.6.4	Channel switch time	N
20.6.5	Transmitter symbol rate	N
20.6.6	Transmit spectral mask	N
20.6.7	Receiver sensitivity	N
20.6.8	Receiver interference rejection	N
20.6.9	TX-to-RX turnaround time	N
20.6.10	RX-to-TX turnaround time	N
20.6.11	Transmit power	N
20.6.12	Receiver maximum input level of desired signal	N
20.6.13	Receiver ED	N
20.6.14	LQI - The RF forward LQI shall be measured for each received packet and is based on the received signal power spectral density (PSD). The received signal PSD is a measurement of the received signal power at the antenna at 1 Hz bandwidth. The LQI is 1 byte value and it is mapped to the PSD as follows: • PSD < -174 dBm maps to LQI 0x00 • PSD > 80 dBm maps to LQI 0xFE • -174 dBm <= PSD <= 80 dBm is linearly interpolated between 0x00 and 0xFE (the nominal step size is 1 dB) The LQI value 0xFF represents a “not measured” LQI. Note: The PSD can be derived from the RSSI subtracting the log of the bandwidth (10 * log10(BW)). As an example, if the signal bandwidth is 100kHz, PSD = RSSI – 50.	N

3.5 PHY service specification

3.5.1 General

PHY shall have a single 20-bit free-running clock incremented in steps of 10 µs. The clock counts from 0 to 1048575 then overflows back to 0. As a result the period of this clock is 10.48576 seconds. The clock is never stopped nor restarted. Time measured by this clock is the one to be used in some PHY primitives to indicate a specific instant in time.

3.5.2 PHY Data plane primitives

3.5.2.1 General

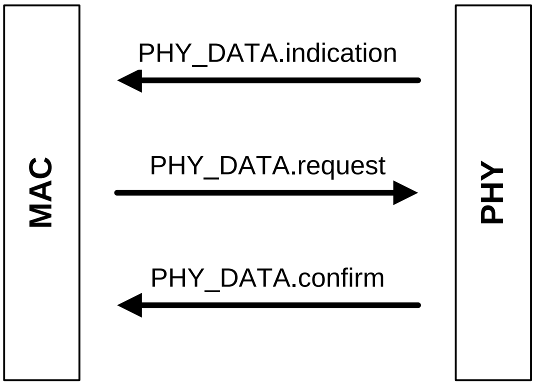

Figure 23 – Overview of PHY primitives

The PHY Abstraction Layer will provide to the MAC Layer all PHY Data plane primitives, to ensure the transmission and reception of MPDUs between Neighbor Nodes using PLC or RF.

The request primitive is passed from MAC to PHY to request the initiation of a service. On the transmission of MPDUs the PHY Abstraction Layer uses PLC PHY or RF PHY depending on the selection of the MAC layer. This selection is communicated from the MAC to the PHY Abstraction Layer using the Medium parameter.

Medium parameter will use the PCH (Physical channel characteristics) coding used also on PRO.PCH field of Table 28 of clause 4.4.2.6.5.1(Extension for Multi-PHY promotion) of this document.

The indication and confirm primitives are passed from PHY to MAC to indicate an internal PHY event that is significant to MAC. This event may be logically related to a remote service request or may be caused by an event internal to PHY.

3.5.2.2 PHY_DATA.request

3.5.2.2.1 Function

The PHY_DATA.request primitive is passed to the PHY layer entity to request the sending of a PPDU to one or more remote PHY entities using the PHY transmission procedures. It also allows setting the time at which the transmission must be started.

3.5.2.2.2 Structure

The semantics of this primitive are as follows:

PHY_DATA.request{*MPDU, Length, Level, Type, Scheme, Scheduled, Time , Medium*}.

The *MPDU* parameter specifies the MAC protocol data unit to be transmitted by the PHY layer entity. When *Medium* is a PLC PCH, it is mandatory for implementations to byte-align the MPDU across the PHY-SAP. This implies 2 extra bits (due to the non-byte-aligned nature of the MAC layer Header) to be located at the beginning of the header (Type A).

The *Length* parameter specifies the length of MPDU in bytes. Length is 2 bytes long.

The *Level* parameter specifies the output signal level according to which the PHY layer transmits MPDU. It may take one of eight values:

0: Maximal output level (MOL)

1: MOL -3 dB

2: MOL -6 dB

…

7: MOL -21 dB

The *Type* parameter specifies the PHY frame type which should be used for the transmission. When *Medium* is a PLC PCH:

0: PHY frame Type A

1: PHY frame Type B

The *Scheme* parameter specifies the transmission scheme to be used for MPDU.

When *Medium* is a PLC PCH, *Scheme* can have any of the following values:

0: DBPSK

1: DQPSK

2: D8PSK

3: Not used

4: DBPSK + Convolutional Code

5: DQPSK + Convolutional Code

6: D8PSK + Convolutional Code

7-11: Not used

12: Robust DBPSK

13: Robust DQPSK

14-15: Not used

If *Scheduled* is false, the transmissions shall start as soon as possible. If *Scheduled* is true, the Time parameter is taken into account. The *Time* parameter specifies the instant in time in which the MPDU has to be transmitted. It is expressed in 10s of µs and may take values from 0 to 2^{20}-1.

The *Medium* is the PCH (Physical channel characteristics) to be used by the PHY on the request.

Note that the Time parameter should be calculated by the MAC, taking into account the current PHY time which may be obtained by PHY_timer.get primitive. The MAC should account for the fact that no part of the PPDU can be transmitted during beacon slots and CFP periods granted to other devices in the network. If the time parameter is set such that these rules are violated, the PHY will return a fail in PHY_Data.confirm.

3.5.2.2.3 Use

The primitive is generated by the MAC layer entity whenever data is to be transmitted to a peer MAC entity or entities.

The MAC layer sends a PHY_DATA.request for each of the mediums for which it wants to send the PPDU. The PHY Abstraction Layer will send PHY_DATA.request to PLC PHY or RF PHY depending on the *Medium* requested by MAC Layer. The reception of this primitive will cause the PHY entity to perform all the PHY-specific actions and pass the properly formed PPDU to the PLC PHY of RF PHY selected on the *Medium* parameter to transfer to the peer PHY layer entity or entities. The next transmission shall start when Time = Timer.

3.5.2.3 PHY_DATA.confirm

3.5.2.3.1 Function

The PHY_DATA.confirm primitive has only local significance and provides an appropriate response to a PHY_DATA.request primitive. The PHY_DATA.confirm primitive tells the MAC layer entity whether or not the MPDU of the previous PHY_DATA.request has been successfully transmitted.

3.5.2.3.2 Structure

The semantics of this primitive are as follows:

PHY_DATA.confirm{*Result, Medium*}.

The *Result* parameter is used to pass status information back to the local requesting entity. It is used to indicate the success or failure of the previous associated PHY_DATA.request. Some results will be standard for all implementations:

0: Success.

1: Too late. Time for transmission is past.

2: Invalid *Length.*

3: Invalid *Scheme.*

4: Invalid *Level.*

5: Buffer overrun.

6: Busy channel.

7-255: Proprietary.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY on the request.

3.5.2.3.3 Use

The PHY layer sends to the MAC layer a PHY_DATA.confirm for each of the PHY_DATA.request received from MAC.

It is assumed that the MAC layer has sufficient information to associate the confirm primitive with the corresponding request primitive.

3.5.2.4 PHY_DATA.indication

3.5.2.4.1 Function

This primitive defines the transfer of data from the PHY layer entity to the MAC layer entity.

3.5.2.4.2 Structure

The semantics of this primitive are as follows:

PHY_DATA.indication{*PSDU, Length, Level, Type, Scheme, Time, Medium*}.

The *PSDU* parameter specifies the PHY service data unit as received by the local PHY layer entity. When *Medium* is a PLC PCH, it is mandatory for implementations to byte-align MPDU across the PHY-SAP. For Type A frames, this implies 2 extra bits (due to the non-byte-aligned nature of the MAC layer Header) to be located at the beginning of the header.

The *Length* parameter specifies the length of received PSDU in bytes. Length is 2 bytes long.

The *Level* parameter specifies the signal level on which the PHY layer received the PSDU.

In case *Medium* is a PLC PHY, *Level* may take one of sixteen values:

0: ≤ 70 dBuV

1: ≤ 72 dBuV

2: ≤ 74 dBuV

…

15: > 98 dBuV

In case *Medium* is SUN FSK PHY, the underlying estimator is the receiver ED defined in 20.6.13 [28] , which is a power measurement over the receiver band (signal and noise) and *Level* may take one of sixteen values:

0: ≤ - 87 dBm

1: ≤ -82 dBm

2: ≤ -77 dBm

…

15: > -17 dBm

The *Type* parameter specifies the PHY frame type with which PSDU is received. When *Medium* is a PLC PCH:

0: PHY frame Type A

1: PHY frame Type B.The *Scheme* parameter specifies the scheme with which PSDU is received.

When *Medium* is a PLC PCH, *Scheme* can have any of the following values:

0: DBPSK

1: DQPSK

2: D8PSK

3: Not used

4: DBPSK + Convolutional Code

5: DQPSK + Convolutional Code

6: D8PSK + Convolutional Code

7-11: Not used

12: Robust DBPSK

13: Robust DQPSK

14-15: Not used

The *Time* parameter is the time of receipt of the Preamble associated with the PSDU.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.2.4.3 Use

The PHY layer sends to the MAC layer a PHY_DATA.indication for each of the PSDU received from a Medium.

3.5.3 PHY Control plane primitives

3.5.3.1 General

Figure 24 shows the generate structure of PHY control plane primitives. Each primitive may have ”set”, ”get” and ”confirm” fields. Table 10 below lists the control plane primitives and the fields associated with each of them. Each row is a control plane primitive. An ”X” in a column indicates that the associated field is used in the primitive described in that row.

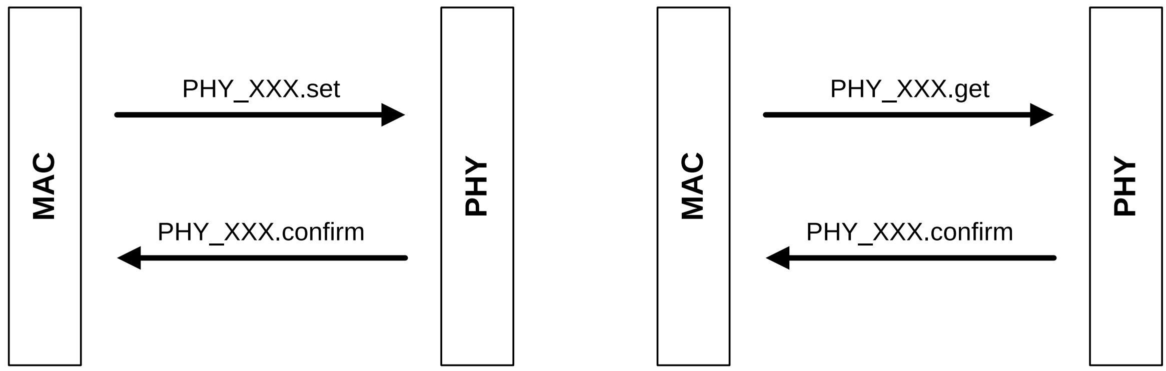

Figure 24 – Overview of PHY Control Plane Primitives

Table 10 - Fields associated with PHY Control Plane Primitives

Field	PLC PHY	RF PHY	set	get	confirm
PHY_AGC	X		X	X	X
PHY_Timer	X	X		X	X
PHY_CD	X				
PHY_CCA		X		X	X
PHY_NL	X	X		X	X
PHY_SNR	X	X		X	X
PHY_ZCT	X			X	X
PHY_CH	X	X	X	X	X

3.5.3.2 PHY_AGC.set

3.5.3.2.1 Function

The PHY_AGC.set primitive is passed to the PHY layer entity by the MAC layer entity to set the Automatic Gain Mode of the PHY layer.

3.5.3.2.2 Structure

The semantics of this primitive are as follows:

PHY_AGC.set {*Mode, Gain, Medium* }.

The *Mode* parameter specifies whether or not the PHY layer operates in automatic gain mode. It may take one of two values:

0: Auto;

1: Manual.

The *Gain* parameter specifies the initial receiving gain in auto mode. It may take one of N values:

0: *min_gain* dB;

1: *min_ gain + step* dB;

2: *min_ gain + 2*step* dB;

…

N-1: *min_ gain + (N-1)*step* dB.

where *min_ gain* and N depend on the specific implementation. *step* is also an implementation issue but it shall not be more than 6 dB. The maximum *Gain* value *min_ gain + (N-1)*step* shall be at least 21 dB.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.2.3 Use

The primitive is generated by the MAC layer when the receiving gain mode has to be changed.

3.5.3.3 PHY_AGC.get

3.5.3.3.1 Function

The PHY_AGC.get primitive is passed to the PHY layer entity by the MAC layer entity to get the Automatic Gain Mode of the PHY layer.

3.5.3.3.2 Structure

The semantics of this primitive are as follows:

PHY_AGC.get{*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.3.3 Use

The primitive is generated by the MAC layer when it needs to know the receiving gain mode that has been configured.

3.5.3.4 PHY_AGC.confirm

3.5.3.4.1 Function

The PHY_AGC.confirm primitive is passed by the PHY layer entity to the MAC layer entity in response to a PHY_AGC.set or PHY_AGC.get command.

3.5.3.4.2 Structure

The semantics of this primitive are as follows:

PHY_AGC.confirm {*Mode, Gain, Medium* }.

The *Mode* parameter specifies whether or not the PHY layer is configured to operate in automatic gain mode. It may take one of two values:

0: Auto;

1: Manual.

The *Gain* parameter specifies the current receiving gain. It may take one of N values:

0: *min_gain* dB;

1: *min_gain + step* dB;

2: *min_gain + 2*step* dB;

…

N-1: min_gain + (N-1)*step dB.

where *min_gain* and N depend on the specific implementation. *step* is also an implementation issue but it shall not be more than 6 dB. The maximum *Gain* value *min_gain + (N-1)*step* shall be at least 21 dB.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.5 PHY_Timer.get

3.5.3.5.1 Function

The PHY_Timer.get primitive is passed to the PHY layer entity by the MAC layer entity to get the current PHY time.

3.5.3.5.2 Structure

The semantics of this primitive are as follows:

PHY_Timer.get {*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.5.3 Use

The primitive is generated by the MAC layer to know the current PHY time.

3.5.3.6 PHY_Timer.confirm

3.5.3.6.1 Function

The PHY_Timer.confirm primitive is passed to the MAC layer by the PHY layer entity in response to a PHY_Timer.get command.

3.5.3.6.2 Structure

The semantics of this primitive are as follows:

PHY_Timer.confirm {*Time, Medium* }.

The *Time* parameter is specified in 10s of microseconds. It may take values of between 0 and 2^{20}-1.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.7 PHY_CD.get

3.5.3.7.1 Function

The PHY_CD.get primitive is passed to the PHY layer entity by the MAC layer entity to look for the carrier detect signal. The carrier detection algorithm shall be based on preamble detection and header recognition (see Section 3.3.2).

3.5.3.7.2 Structure

The semantics of this primitive are as follows:

PHY_CD.get {*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.7.3 Use

The primitive is generated by the MAC layer when it needs to know whether or not the physical medium is free.

3.5.3.8 PHY_CD.confirm

3.5.3.8.1 Function

The PHY_CD.confirm primitive is passed to the MAC layer entity by the PHY layer entity in response to a PHY_CD.get command.

3.5.3.8.2 Structure

The semantics of this primitive are as follows:

PHY_CD.confirm {*cd, rssi, Time, header, Medium*}.

The *cd* parameter may take one of two values:

0: no carrier detected;

1: carrier detected.

The *rssi* parameter is the Received Signal Strength Indication, not including the noise power. One of the RSSI estimator examples is shown in Annex B, but it is implementation specific. It is only relevant when *cd* equals 1. It may take one of sixteen values:

0: ≤ 70 dBuV;

1: ≤ 72 dBuV;

2: ≤ 74 dBuV;

…

15: > 98 dBuV.The T*ime* parameter indicates the instant at which the present PPDU will finish. It is only relevant when *cd* equals 1. When *cd* equals 0, *Time* parameter will take a value of 0. If *cd* equals 1 but the duration of the whole PPDU is still not known (i.e. the header has not yet been processed), *header* parameter will take a value of 1 and *time* parameter will indicate the instant at which the header will finish, specified in 10s of microseconds. In any other case the value of *Time* parameter is the instant at which the present PPDU will finish, and it is specified in 10s of microseconds. *Time* parameter refers to an absolute point in time so it is referred to the system clock.

The *header* parameter may take one of two values:

1: if a preamble has been detected but the duration of the whole PPDU is not yet known from decoding the header;

0: in any other case.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.9 PHY_NL.get

3.5.3.9.1 Function

The PHY_NL.get primitive is passed to the PHY layer entity by the MAC layer to get the noise floor level value. One of the noise estimator examples is shown in Annex B, but it is implementation specific.

3.5.3.9.2 Structure

The semantics of this primitive are as follows:

PHY_NL.get {*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.9.3 Use

The primitive is generated by the MAC layer when it needs to know the noise level present in the powerline.

3.5.3.10 PHY_NL.confirm

3.5.3.10.1 Function

The PHY_NL.confirm primitive is passed to the MAC layer entity by the PHY layer entity in response to a PHY_NL.get command.

3.5.3.10.2 Structure

The semantics of this primitive are as follows:

PHY_NL.confirm {*noise, Medium* }.

When *Medium* is a PLC PCH , the *noise* parameter may take one of sixteen values:

0: ≤ 50 dBuV;

1: ≤ 53 dBuV;

2: ≤ 56 dBuV;

…

15: > 92 dBuV.

When *Medium* is a SUN FSK PCH , the *noise* parameter may take one of sixteen values:

0: ≤ - 107 dBm

1: ≤ - 104 dBm

2: ≤ - 101 dBm

…

15: > -65 dBm

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.11 PHY_SNR.get

3.5.3.11.1 Function

The PHY_SNR.get primitive is passed to the PHY layer entity by the MAC layer entity to get the value of the Signal to Noise Ratio, defined as the ratio of measured received signal level to noise level of last received PPDU. The calculation of the SNR is described in Annex B.

3.5.3.11.2 Structure

The semantics of this primitive are as follows:

PHY_SNR.get {*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.11.3 Use

The primitive is generated by the MAC layer when it needs to know the SNR in order to analyze channel characteristics and invoke robustness management procedures, if required.

3.5.3.12 PHY_SNR.confirm

3.5.3.12.1 Function

The PHY_SNR.confirm primitive is passed to the MAC layer entity by the PHY layer entity in response to a PHY_SNR.get command.

3.5.3.12.2 Structure

The semantics of this primitive are as follows: PHY_SNR.confirm{*SNR, Medium* }.

The *SNR* parameter refers to the Signal to Noise Ratio, defined as the ratio of measured received signal level to noise level of last received PPDU. It may take one of eight values.

The mapping of the 3-bit index to the actual SNR value is given below:

0: ≤ 0 dB;

1: ≤ 3 dB;

2: ≤ 6 dB;

…

7: > 18 dB.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

When *Medium* is PLC, the SNR is calculated as specified in Annex B.

3.5.3.13 PHY_ZCT.get

3.5.3.13.1 Function

The PHY_ZCT.get primitive is passed to the PHY layer entity by the MAC layer entity to get the zero cross time of the mains and the time between the last transmission or reception and the zero cross of the mains.

3.5.3.13.2 Structure

The semantics of this primitive are as follows:

PHY_ZCT.get {*Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.13.3 Use

The primitive is generated by the MAC layer when it needs to know the zero cross time of the mains, e.g. in order to calculate the phase to which the Node is connected.

3.5.3.14 PHY_ZCT.confirm

3.5.3.14.1 Function

The PHY_ZCT.confirm primitive is passed to the MAC layer entity by the PHY layer entity in response to a PHY_ZCT.get command.

3.5.3.14.2 Structure

The semantics of this primitive are as follows:

PHY_ZCT.confirm {*Time, Medium* }.

The *Time* parameter is the instant in time at which the last zero-cross event took place.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.3.15 PHY_CCA.get

3.5.3.15.1 Function

The PHY_CCA.get primitive is passed to the PHY layer entity by the MAC layer entity for making Clear Channel assessment mode 1, as described in 10.2.7 of [28]. The PHY PIBs phyCCADuration and phyCCAThreshold control this service.

3.5.3.15.2 Structure

The semantics of this primitive are as follows:

PHY_CCA.get { }.

3.5.3.15.3 Use

The primitive is generated by the MAC layer when it needs to know whether or not the RF physical medium is free.

3.5.3.16 PHY_CCA.confirm

3.5.3.16.1 Function

The PHY_CCA.confirm primitive is passed to the MAC layer entity by the PHY layer entity in response to a PHY_CCA.get command.

3.5.3.16.2 Structure

The semantics of this primitive are as follows:

PHY_CCA.confirm {*channelState*}.

The *channelState* parameter may take one of two values:

0: channel busy

1: channel free

3.5.3.17 PHY_CH.set

3.5.3.17.1 Function

The PHY_CH.set primitive is passed to the PHY layer entity by the MAC layer entity to set the band (PLC) or the channel (RF) of the PHY medium.

3.5.3.17.2 Structure

The semantics of this primitive are as follows:

PHY_CH.set { *Medium* }.

The *Medium parameter has the format of* the PCH (Physical channel characteristics)of 4.4.2.6.5.1..

3.5.3.17.3 Use

The primitive is generated by the MAC layer in order to set the band (PLC) or the channel (RF).

3.5.3.18 PHY_CH.get

3.5.3.18.1 Function

The PHY_CH.get primitive is passed to the PHY layer entity by the MAC layer entity to get the band (PLC) or the channel (RF) of a PHY medium.

3.5.3.18.2 Structure

The semantics of this primitive are as follows:

PHY_CH.get{*Medium* }.

The *Medium parameter has the format of* the PCH (Physical channel characteristics) of 4.4.2.6.5.1 .

3.5.3.18.3 Use

The primitive is generated by the MAC layer when it needs to know the current band (PLC) or channel (RF) configured in the related physical medium..

3.5.3.19 PHY_CH.confirm

3.5.3.19.1 Function

The PHY_CH.confirm primitive is passed by the PHY layer entity to the MAC layer entity in response to a PHY_CH.set or PHY_CH.get command.

3.5.3.19.2 Structure

The semantics of this primitive are as follows:

PHY_CH.confirm {, *Medium* }.

.

The *Medium parameter has the format of* the PCH (Physical channel characteristics) of 4.4.2.6.5.1.

3.5.4 PHY Management primitives

3.5.4.1 General

PHY layer management primitives enable the conceptual PHY layer management entity to interface to upper layer management entities. Implementation of these primitives is optional. Please refer to Figure 24 to see the general structure of the PHY layer management primitives.

3.5.4.2 PLME_RESET.request

3.5.4.2.1 Function

The PLME_RESET.request primitive is invoked to request the PHY layer to reset its present functional state. As a result of this primitive, the PHY should reset all internal states and flush all buffers to clear any queued receive or transmit data. All the SET primitives are invoked by the PLME, and addressed to the PHY to set parameters in the PHY. The GET primitive is also sourced by the PLME, but is used only to read PHY parameters

3.5.4.2.2 Structure

The semantics of this primitive are as follows:

PLME_RESET.request{ *Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.2.3 Use

The upper layer management entities will invoke this primitive to tackle any system level anomalies that require aborting any queued transmissions and restart all operations from initialization state.

3.5.4.3 PLME_RESET.confirm

3.5.4.3.1 Function

The PLME_RESET.confirm is generated in response to a corresponding PLME_RESET.request primitive. It provides indication if the requested reset was performed successfully or not.

3.5.4.3.2 Structure

The semantics of this primitive are as follows:

PLME_RESET.confirm{*Result, Medium* }.

The *Result* parameter shall have one of the following values:

0: Success;

1: Failure. The requested reset failed due to internal implementation issues.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.3.3 Use

The primitive is generated in response to a PLME_RESET.request.

3.5.4.4 PLME_SLEEP.request

3.5.4.4.1 Function

The PLME_SLEEP.request primitive is invoked to request the PHY layer to suspend its present activities including all reception functions. The PHY layer should complete any pending transmission before entering into a sleep state.

3.5.4.4.2 Structure

The semantics of this primitive are as follows:

PLME_SLEEP.request{ *Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.4.3 Use

Although this specification pertains to communication over power lines, it may still be objective of some applications to optimize their power consumption. This primitive is designed to help those applications achieve this objective.

3.5.4.5 PLME_SLEEP.confirm

3.5.4.5.1 Function

The PLME_SLEEP.confirm is generated in response to a corresponding PLME_SLEEP.request primitive and provides information if the requested sleep state has been entered successfully or not.

3.5.4.5.2 Structure

The semantics of this primitive are as follows:

PLME_SLEEP.confirm{*Result, Medium* }.

The *Result* parameter shall have one of the following values:

0: Success;

1: Failure. The requested sleep failed due to internal implementation issues;

2: PHY layer is already in sleep state.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.5.3 Use

The primitive is generated in response to a PLME_SLEEP.request

3.5.4.6 PLME_RESUME.request

3.5.4.6.1 Function

The PLME_RESUME.request primitive is invoked to request the PHY layer to resume its suspended activities. As a result of this primitive, the PHY layer shall start its normal transmission and reception functions.

3.5.4.6.2 Structure

The semantics of this primitive are as follows:

PLME_RESUME.request{ *Medium* }.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.6.3 Use

This primitive is invoked by upper layer management entities to resume normal PHY layer operations, assuming that the PHY layer is presently in a suspended state as a result of previous PLME_SLEEP.request primitive.

3.5.4.7 PLME_RESUME.confirm

3.5.4.7.1 Function

The PLME_RESUME.confirm is generated in response to a corresponding PLME_RESUME.request primitive and provides information about the requested resumption status.

3.5.4.7.2 Structure

The semantics of this primitive are as follows:

PLME_RESUME.confirm{*Result, Medium* }.

The *Result* parameter shall have one of the following values:

0: Success;

1: Failure. The requested resume failed due to internal implementation issues;

2: PHY layer is already in fully functional state.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.7.3 Use

The primitive is generated in response to a PLME_RESUME.request

3.5.4.8 PLME_TESTMODE.request

3.5.4.8.1 Function

The PLME_TESTMODE.request primitive is invoked to enter the PHY layer to a test mode (specified by the mode parameter). A valid packet is transmitted and the PSDU will contain a defined reference: dummy 54-bit MAC header, message "PRIME IS A WONDERFUL TECHNOLOGY" (note the blank spaces so it represents 240 uncoded bits in ASCII format) concatenated as many times as needed to make it 256bytes. The last eight bits will be substituted for eight flushing bits set to zero. Following receipt of this primitive, the PHY layer should complete any pending transmissions in its buffer before entering the requested Test mode..

3.5.4.8.2 Structure

The semantics of this primitive are as follows:

PLME_TESTMODE.request{*enable, mode, modulation, pwr_level, Medium* }.

The *enable* parameter starts or stops the Test mode and may take one of two values:

0: stop test mode and return to normal functional state;

1: transit from present functional state to Test mode.

The *mode* parameter enumerates specific functional behavior to be exhibited while the PHY is in Test mode. It may have either of the two values.

0: continuous transmit;

1: transmit with 50% duty cycle.

The *modulation* parameter specifies which modulation scheme is used during transmissions. It may take any of the following values:

0: DBPSK;

1: DQPSK;

2: D8PSK;

3: Not used;

4: DBPSK + Convolutional Code;

5: DQPSK + Convolutional Code;

6: D8PSK + Convolutional Code;

7-11: Not used

12: Robust DBPSK

13: Robust DQPSK

14-15: Not used

The *pwr_level* parameter specifies the relative level at which the test signal is transmitted. It may take either of the following values:

0: Maximal output level (MOL);

1: MOL -3 dB;

2: MOL -6 dB;

…

7: MOL -21 dB;

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.8.3 Use

This primitive is invoked by management entity when specific tests are required to be performed.

3.5.4.9 PLME_TESTMODE.confirm

3.5.4.9.1 Function

The PLME_TESTMODE.confirm is generated in response to a corresponding PLME_TESTMODE.request primitive to indicate if transition to Testmode was successful or not.

3.5.4.9.2 Structure

The semantics of this primitive are as follows:

PLME_TESTMODE.confirm{*Result, Medium* }.

The *Result* parameter shall have one of the following values:

- 0: Success;
- 1: Failure. Transition to Testmode failed due to internal implementation issues;
- 2: PHY layer is already in Testmode.

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.9.3 Use

The primitive is generated in response to a PLME_TESTMODE.request

3.5.4.10 PLME_GET.request

3.5.4.10.1 Function

The PLME_GET.request queries information about a given PIB attribute.

3.5.4.10.2 Structure

The semantics of this primitive is as follows:

PLME_GET.request{PIBAttribute, *Medium* }

The *PIBAttribute* parameter identifies specific attribute as enumerated in *Id* fields of tables that enumerate PIB attributes (Section 6.2.2).

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.10.3 Use

This primitive is invoked by the management entity to query one of the available PIB attributes.

3.5.4.11 PLME_GET.confirm

3.5.4.11.1 Function

The PLME_GET.confirm primitive is generated in response to the corresponding PLME_GET.request primitive.

3.5.4.11.2 Structure

The semantics of this primitive is as follows:

PLME_GET.confirm{status, PIBAttribute, PIBAttributeValue, *Medium* }

The *status* parameter reports the result of requested information and may have one of the values shown in Table 11.

Table 11 - Values of the status parameter in PLME_GET.confirm primitive

Result	Description
Done = 0	Parameter read successfully
Failed =1	Parameter read failed due to internal implementation reasons.
BadAttr=2	Specified *PIBAttribute* is not supported

The *PIBAttribute* parameter identifies specific attribute as enumerated in *Id* fields of tables that enumerate PIB attributes (Section 6.2.2).

The *PIBAttributeValue* parameter specifies the value associated with given *PIBAttribute.*

The *Medium* is the PCH (Physical channel characteristics) used by the PHY to receive the PSDU.

3.5.4.11.3 Use

This primitive is generated by PHY layer in response to a PLME_GET.request primitive.

4 MAC layer

4.1 Overview

A Subnetwork can be logically seen as a tree structure with two types of Nodes: the Base Node and Service Nodes.

- **Base Node**: It is at the root of the tree structure and it acts as a master Node that provides all Subnetwork elements with connectivity. It manages the Subnetwork resources and connections. There is only one Base Node in a Subnetwork. The Base Node is initially the Subnetwork itself, and any other Node should follow a Registration process to enroll itself on the Subnetwork.
- **Service Node**: They are either leaves or branch points of the tree structure. They are initially in a Disconnected functional state and follow the Registration process in 4.6.1 to become part of the Subnetwork. Service Nodes have two functions in the Subnetwork: keeping connectivity to the Subnetwork for their Application layers, and switching other Nodes' data to propagate connectivity.

Devices elements that exhibit Base Node functionality continue to do so as long as they are not explicitly reconfigured by mechanisms that are beyond the scope of this specification. Service Nodes, on the other hand, change their behavior dynamically from "Terminal" functions to "Switch" functions and vice-versa. The changing of functional states occurs in response to certain pre-defined events on the network. Figure 25 shows the functional state transition diagram of a Service Node.

The three functional states of a Service Node are ***Disconnected***, ***Terminal*** and ***Switch***:

- **Disconnected**: This is the initial functional state for all Service Nodes. When Disconnected, a Service Node is not able to communicate data or switch other Nodes' data; its main function is to search for a Subnetwork within its reach and try to register on it.
- **Terminal**: When in this functional state a Service Node is able to establish connections and communicate data, but it is not able to switch other Nodes' data.
- **Switch**: When in this functional state a Service Node is able to perform all Terminal functions. Additionally, it is able to forward data to and from other Nodes in the same Subnetwork. It is a branch point on the tree structure.

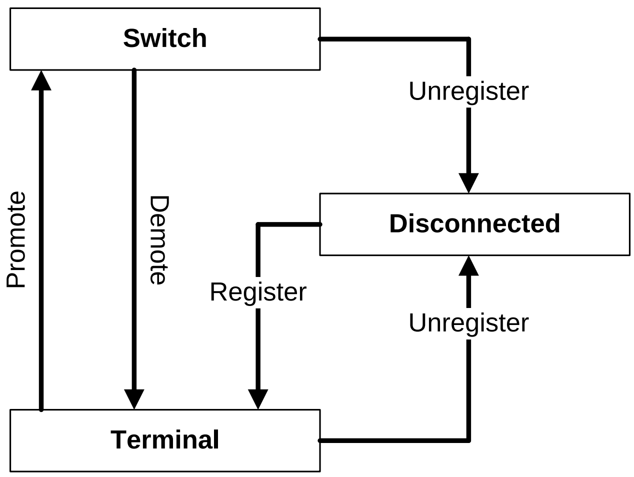

Figure 25 - Service Node states

The events and associated processes that trigger changes from one functional state to another are:

- **Registration**: the process by which a Service Node includes itself in the Base Node's list of registered Nodes. Its successful completion means that the Service Node is part of a Subnetwork. Thus, it represents the transition between Disconnected and Terminal.
- **Unregistration**: the process by which a Service Node removes itself from the Base Node's list of registered Nodes. Unregistration may be initiated by either of Service Node or Base Node. A Service Node may unregister itself to find a better point of attachment i.e. change Switch Node through which it is attached to the network. A Base Node may unregister a registered Service Node as a result of failure of any of the MAC procedures. Its successful completion means that the Service Node is Disconnected and no longer part of a Subnetwork;
- **Promotion**: the process by which a Service Node is qualified to switch (repeat, forward) data traffic from other Nodes and act as a branch point on the Subnetwork tree structure. A successful promotion represents the transition between Terminal and Switch. For nodes that support Multi-PHY promotion (see 4.6.3.3), this process may also apply to a Service Node that it is already a Switch. In this case the node which is switch on one medium becomes switch on both media. When a Service Node is Disconnected it cannot directly transition to Switch;
- **Demotion**: the process by which a Service Node ceases to be a branch point on the Subnetwork tree structure. A successful demotion represents the transition between Switch and Terminal. For nodes that support Multi-PHY promotion (see 4.6.3.3), this process may also apply to a Service Node that is Switch on two media. In this case the node which is a Switch on both media is demoted on one medium and remains Switch in the other medium (see 4.6.4).

A Subnetwork may include PLC-only Nodes, RF-only Nodes and/or PLC+RF Nodes. A PLC-only Node can be part of a Subnetwork if it has a peer communication with a PLC-only Node (Base Node or Switch) or with a PLC+RF Node (Base Node or Switch). A RF-only Node can be part of a Subnetwork if it has a peer communication with a RF-only Node (Base Node or Switch) or with a PLC+RF Node (Base Node or Switch). A PLC+RF Node can be part of a Subnetwork if it has a peer communication with the Base Node or with a Switch.

A Service Node can be registered to the Subnetwork through only one medium (PLC or RF).

A PLC-only Base Node or PLC-only Switch uses the same PLC band for beacon transmission, uplink and downlink communication. A RF-only Base Node or RF-only Switch uses the same RF channel for beacon transmission, uplink and downlink communication. A PLC+RF Base Node or Switch may use one or two medium: in a medium it uses the same PLC band or the same RF channel for beacon transmission, uplink and downlink communication.

A special use of the RF channels occurs in the case of channel hopping (see 4.6.10).

In Figure 26, a Subnetwork example is reported. BN is the Base Node. It is a PLC+RF node as well as Switch nodes B, C and J (grey nodes). Terminal Nodes A, F, G, H, K, M and Switch Nodes D and L are PLC-only nodes (white nodes). Terminal node I and Switch node E are RF-only nodes (black nodes). PLC communications (continuous lines) occur on the following bands: Channel 6 in the paths BN-A and BN-B-D-H, Channel 7 in the paths C-F and C-G and Channel 1 in the paths J-K and J-L-M. RF communications (dotted lines) occur on the following channels: Channel 1 in the path BN-J, Channel 2 in the paths B-C and B-E-I.

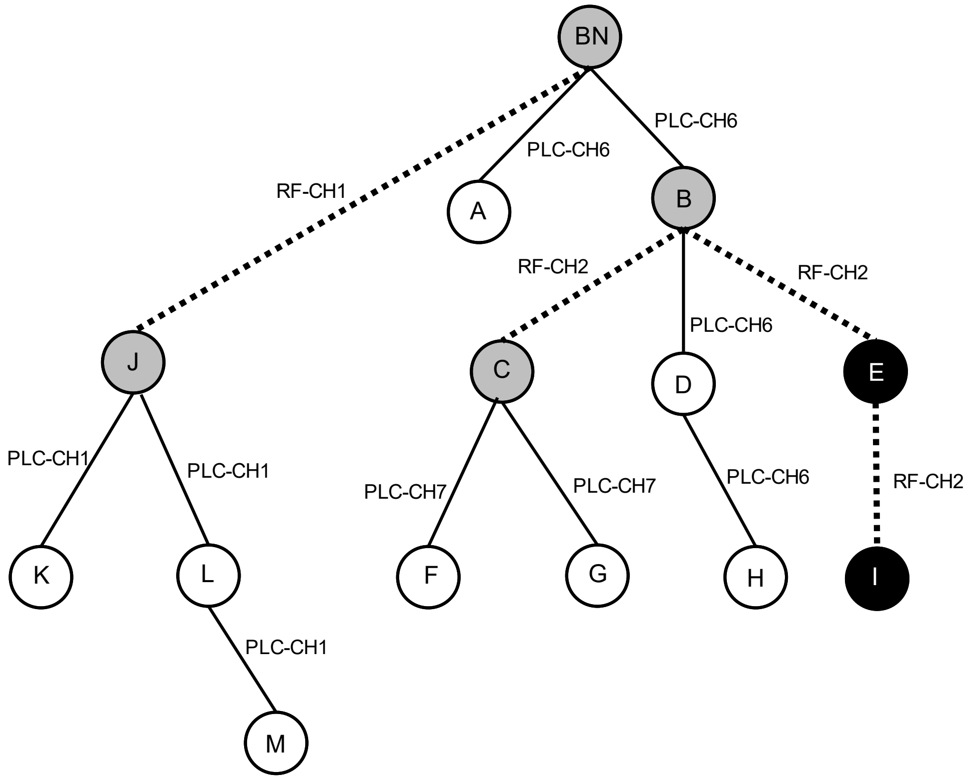

Figure 26 - Subnetwork example

4.2 Addressing

4.2.1 General

Each Node has a 48-bit universal MAC address, defined in IEEE Std 802-2001 and called EUI-48. Every EUI-48 is assigned during the manufacturing process and it is used to uniquely identify a Node during the Registration process.

The EUI-48 of the Base Node uniquely identifies its Subnetwork. This EUI-48 is called the Subnetwork Address (SNA).

The Switch Identifier (LSID) is a unique 8-bit identifier for each Switch Node inside a Subnetwork. The Subnetwork Base Node assigns an LSID during the promotion process. A Switch Node is universally identified by the SNA and LSID. LSID = 0x00 is reserved for the Base Node. LSID = 0xFF is reserved to mean “unassigned” or “invalid” in certain specific fields (see

Table 26). This special use of the 0xFF value is always made explicit when describing those fields and it shall not be used in any other field.

During its Registration process, every Service Node receives a 14-bit Local Node Identifier (LNID). The LNID identifies a single Service Node among all Service Nodes that directly depend on a given Switch. The combination of a Service Node’s LNID and SID (its immediate Switch’s LSID) forms a 22-bit Node Identifier (NID). The NID identifies a single Service Node in a given Subnetwork. LNID = 0x0000 cannot be assigned to a Terminal, as it refers to its immediate Switch. LNID = 0x3FFF is reserved for broadcast and multicast traffic (see section 4.2.3 for more information). In certain specific fields, the LNID = 0x3FFF may also be used as "unassigned" or "invalid" (see Table 12 and

Table 22). This special use of the 0x3FFF value is always made explicit when describing the said fields and it shall not be used in this way in any other field.

During connection establishment a 9-bit Local Connection Identifier (LCID) is reserved. The LCID identifies a single connection in a Node. The combination of NID and LCID forms a 31-bit Connection Identifier (CID). The CID identifies a single connection in a given Subnetwork. Any connection is universally identified by the SNA and CID. LCID values are allocated with the following rules:

- LCID=0x000 to 0x0FF, for connections requested by the Base Node. The allocation shall be made by the Base Node.
- LCID=0x100 to 0x1FF, for connections requested by a Service Node. The allocation shall be made by a Service Node.

The full addressing structure and field lengths are shown in Figure 27

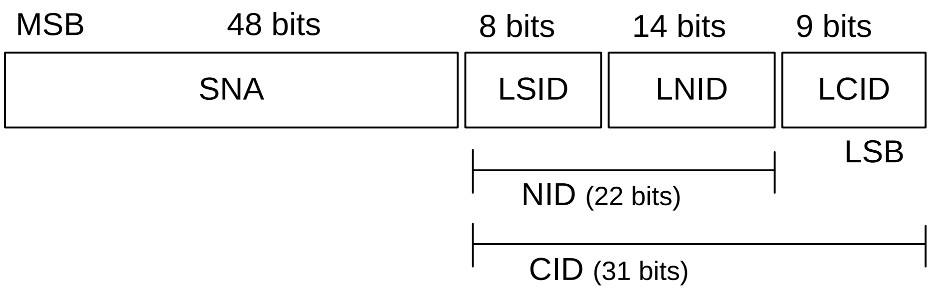

Figure 27 - Addressing Structure

When a Service Node in *Terminal* state starts promotion process, the Base Node allocates a unique switch identifier which is used by this device after transition to switch state as SID of this switch. The promoted Service Node continues to use the same NID that it used before promotion i.e. it maintains SID of its next level switch for addressing all traffic generated/destined to its local application processes. To maintain distinction between the two switch identifiers, the switch identifier allocated to a Service Node during its promotion is referred to as Local Switch Identifier (LSID). Note that the LSID of a switch device will be SID of devices that connects to the Subnetwork through it.

Each Service Node has a level in the topology tree structure. Service Nodes which are directly connected to the Base Node have level 0. The level of any Service Node not directly connected to the Base Node is the level of its immediate Switch plus one.

4.2.2 Example of address resolution

Figure 28 shows an example where Disconnected Service Nodes are trying to register on the Base Node. In this example, addressing will have the following nomenclature: (SID, LNID). Initially, the only Node with an address is Base Node A, which has an NID=(0, 0).

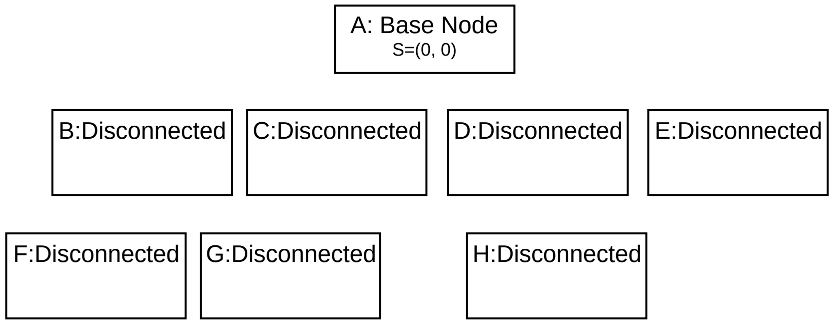

Figure 28 – Example of address resolution: phase 1

Every other Node of the Subnetwork will try to register on the Base Node. Only B, C, D and E Nodes are able to register on this Subnetwork and get their NIDs. Figure 29 shows the status of Nodes after the Registration process. Since they have registered on the Base Node, they get the SID of the Base Node and a unique LNID. The level of newly registered Nodes is 0 because they are connected directly to the Base Node.

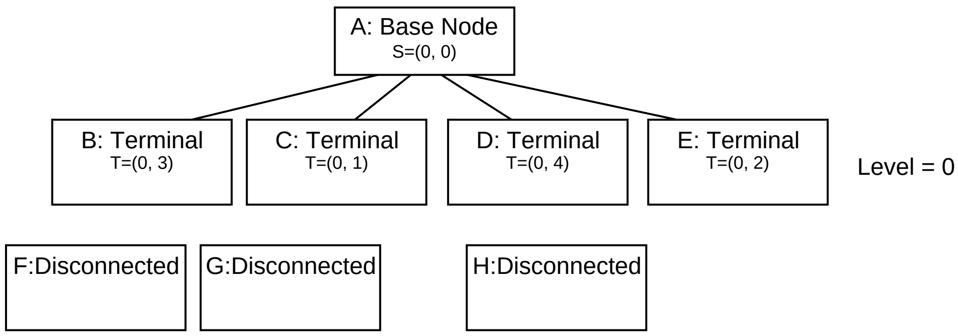

Figure 29 – Example of address resolution: phase 2

Nodes F, G and H cannot connect directly to the Base Node, which is currently the only Switch in the Subnetwork. F, G and H will send PNPDU broadcast requests, which will result in Nodes B and D requesting promotion for themselves in order to extend the Subnetwork range. During promotion, they will both be assigned unique SIDs. Figure 30 shows the new status of the network after the promotion of Nodes B and D. Each Switch Node will still use the NID that was assigned to it during the Registration process for its own communication as a Terminal Node. The new SID shall be used for all switching functions.

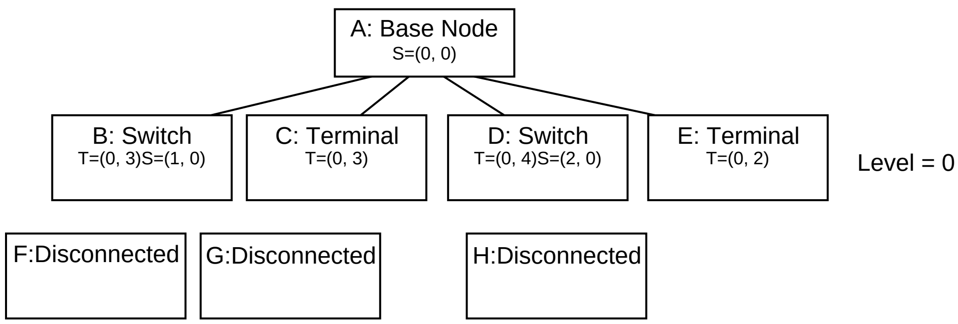

Figure 30 – Example of address resolution: phase 3

On completion of the B and D promotion process, Nodes F, G and H shall start their Registration process and have a unique LNID assigned. Every Node on the Subnetwork will then have a unique NID to communicate like a Terminal, and Switch Nodes will have unique SIDs for switching purposes. The level of newly registered Nodes is 1 because they register with level 0 Nodes. On the completion of topology resolution and address allocation, the example Subnetwork would be as shown in Figure 31.

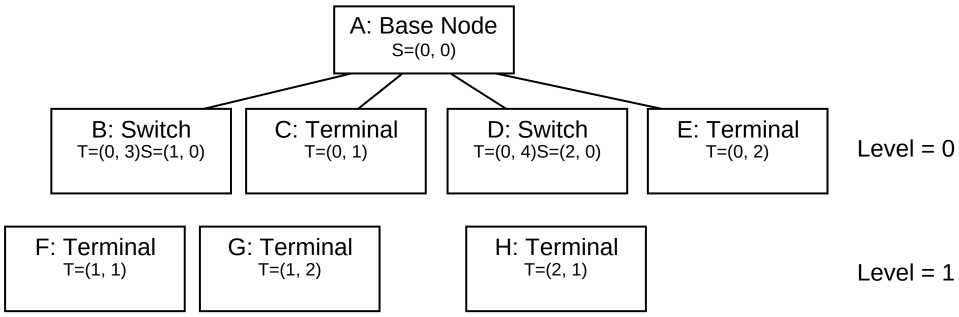

Figure 31 – Example of address resolution: phase 4

4.2.3 Broadcast and multicast addressing

Multicast and broadcast addresses are used for communicating data to multiple Nodes. There are several broadcast and multicast address types, depending on the context associated with the traffic flow. Table 12 describes different broadcast and multicast addressing types and the SID and LNID fields associated with each one.

Table 12 - Broadcast and multicast address

Type	LNID	Description
Broadcast	0x3FFF	Using this address as a destination, the packets should reach every Node of the Subnetwork.
Multicast	0x3FFE	This type of address refers to multicast groups. The multicast group is defined by the LCID.
Unicast	not 0x3FFF not 0x3FFE	The address of this type refers to the only Node of the Subnetwork whose SID and LNID match the address fields.

4.3 MAC functional description

4.3.1 Service Node start-up

At functional level, Service Node starts in Disconnected functional state in a specific initial band. If more than one band is available in Service Node and if the Band Scanning process is activated, the device will try to detect the optimal band in which an existing Subnetwork can be joined. The mechanisms adopted to select the initial band and to activate the Band Scanning process are beyond the scope of this specification.

Each Service Node shall maintain a Switch table that is updated with the reception of a beacon from any new Switch Node. Based on local implementation policies, a Service Node may select any Switch Node from the

Switch table and proceed with the Registration process with that Switch Node. The criterion for selecting a Switch Node from the Switch table is beyond the scope of this specification

On the selection of a specific Switch Node, a Service Node shall start a Registration process by transmitting the REG control packet (4.4.2.6.3) to the Base Node. The Switch Node through which the Service Node intends to carry out its communication is indicated in the REG control packet.

4.3.1.1 PNPDUs transmission

A Service Node shall listen on the initial band for at least *macMinSwitchSearchTime* before deciding that no beacon is being received. It may optionally add some random variation to *macMinSwitchSearchTime,* but this variation cannot be more than 10% of *macMinSwitchSearchTime.* If no beacons are received in this time, the Service Node shall broadcast a PNPDU.

PNPDUs are transmitted when a Service Node is not time synchronized to an existing Subnetwork, therefore there are chances that they may collide with contention-free transmissions in a nearby Subnetwork. A Service Node shall therefore necessarily transmit PNPDUs in DBPSK_CC modulation scheme before deciding to transmit them in one of the ROBUST modulation schemes (*forcing PHY BC frame format when channel 1 is used*), if such a modulation scheme is implemented in the device. The decision making's algorithm on transitioning from one modulation scheme to other when transmitting PNPDUs and scanning for Subnetworks are left to individual implementations. So as not to flood the network with PNPDUs, especially in cases where several devices are powered up at the same time, the Disconnected Nodes shall reduce the PNPDU transmission rate when they receive PNPDUs from other sources. Disconnected Nodes shall transmit at least one PNPDU per *macPromotionMaxTxPeriod* units of time and no more than one PNPDU per *macPromotionMinTxPeriod* units of time (time between PNPDUs). The algorithm used to decide the PNPDUs transmission rate is left to the implementer.

4.3.1.2 Band Scanning

The functions that may be performed in a *Disconnected* functional state during Band Scanning are: detection of any generic PRIME 1.4 messages or beacons and transmission of PNPDUs.

After the waiting time on initial band of *macMinSwitchSearchTime* (described in previous paragraph and associated to PNPDU transmission process) the Band scanning process, if activated, starts. If the Service Node does not detect traffic in the current band during *macMinBandSearchTime*, the node shall move to the next band.

If the node detects traffic in the current band the *macTrafficBandTimeout* is activated (any subsequent generic PRIME 1.4 message or beacon detection refreshes the timer), and the moving to next band is triggered only when one of the following conditions occurs:

- *macTrafficBandTimeout* expiration;

or

- *macMaxBandSearchTime* expiration.

Whenever a Service Node moves to the next band it restarts the scanning process restarting the timers associated to Band Scanning process.

While the node is in *Disconnected* functional state, the band scanning continues going through all the bands that are involved in the Band Scanning process. If a registration process is completed with success, the Service Node exits from the Band Scanning process. If the node returns in *Disconnected* functional state from *Teminal* or *Switch* functional state, the band used during prior registration is considered the new initial band and the whole process and associated timers (waiting time on initial band of *macMinSwitchSearchTime* and start of Band scanning process) restart.

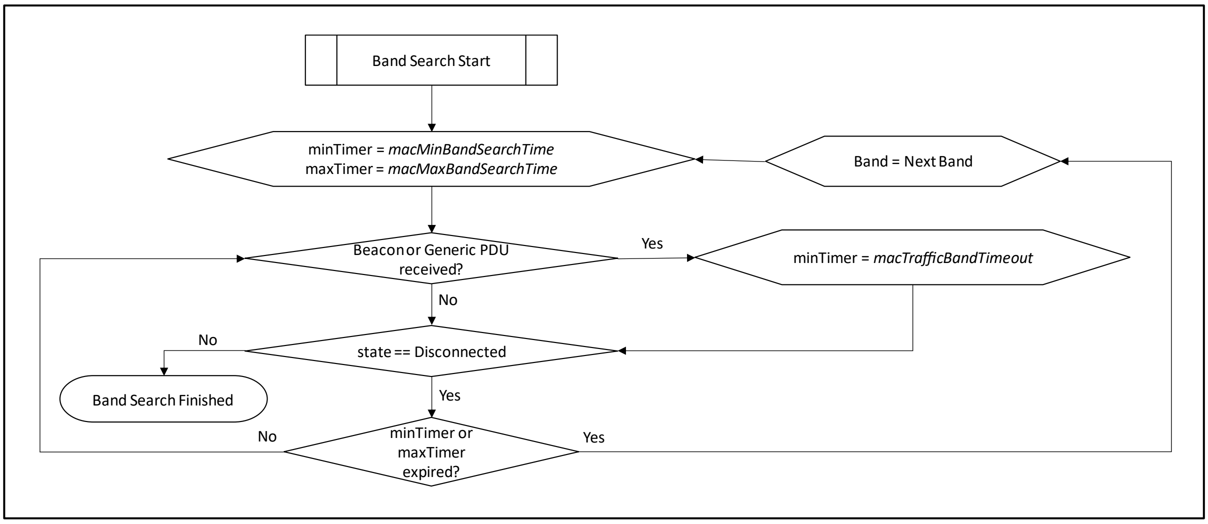

Figure 32 - Band Scanning algorithm

The optimal values of PIB attributes associated to Band Scanning process depend on several factors to be considered at system level, like the Promotion and PNPDU sending processes of other devices present in the newtwork. As general recommendations:

1) A Service Node, during Band Scanning process, should be able to transmit at least one PNPDU and wait for possible PRO_REQ_S packets consequently generated by nearby Nodes, if present in the network, before the expiration of *macMinBandSearchTime*;
2) Since the minimum frequency of a beacon is the superframe duration, the m*acTrafficBandTimeout* should be bigger than this value;
3) The *macMaxBandSearchTime* value should be configured in order to permit to Service Node, if beacons are detected in current band, to generate a reasonable number of registration requests (taking into account the MAC Control Packet retransmission settings).

4.3.2 Starting and maintaining Subnetworks

Base Nodes are primarily responsible for setting up and maintaining a Subnetwork. They would operate in a band comprising of one or more channels. Implementations claiming compliance with this specification shall support at least the mandatory bands required in the respective conformance specification. Base Nodes perform the following functions in order to setup and maintain a Subnetwork:

- **Beacon transmission**. The Base Node and all Switch Nodes in the Subnetwork shall broadcast beacons at fixed intervals of time. The Base Node shall always transmit at least one beacon per super-frame. Switch Nodes shall transmit beacons with a frequency prescribed by the Base Node at the time of their promotion, which would also be at-least one beacon per super-frame.
- **Promotion and demotion of Terminals and switches**. All promotion requests generated by Terminal Nodes upon reception of PNPDUs are directed to the Base Node. The Base Node maintains a table of all the Switch Nodes on the Subnetwork and allocates a unique SID to new incoming requests. Upon reception of multiple promotion requests, the Base Node can, at its own discretion, reject some of the requests. Likewise, the Base Node is responsible for demoting registered Switch Nodes. The demotion may either be initiated by the Base Node (based on an implementation-dependent decision process) or be requested by the Switch Node itself.
- **Registration management.** The Base Node receives Registration requests from all new Nodes trying to be part of the Subnetwork it manages. The Base Node shall process each Registration request it receives and respond with an accept or a reject message. When the Base Node accepts the registration of a Service Node, it shall allocate an unique NID to it to be used for all subsequent communication on the Subnetwork. Likewise, the Base Node is responsible for deregistering any registered Service Node. The unregistration may be initiated by the Base Node (based on an implementation-dependent decision process) or requested by the Service Node itself.
- **Connection setup and management**: The MAC layer specified in this document is connection-oriented, implying that data exchange is necessarily preceded by connection establishment. The Base Node is always required for all connections on the Subnetwork, either as an end point of the connection or as a facilitator (direct connections; Section 4.3.6) of the connection.
- **Channel access arbitration**. The usage of the channel by devices conforming to this specification may be controlled and contention-free at certain times and open and contention-based at others. The Base Node prescribes which usage mechanism shall be in force at what time and for how long. Furthermore, the Base Node shall be responsible for assigning the channel to specific devices during contention-free access periods.
- **Distribution of random sequence for deriving encryption keys.** When using Security Profile 1 (see 4.3.8.1), all control messages in this MAC specification shall be encrypted before transmission. Besides control messages, data transfers may be optionally encrypted as well. The encryption key is derived from a 128-bit random sequence. The Base Node shall periodically generate a new random sequence and distribute it to the entire Subnetwork, thus helping to maintain the Subnetwork security infrastructure.
- **Multicast group management.** The Base Node shall maintain all multicast groups on the Subnetwork. This shall require the processing of all join and leave requests from any of the Service Nodes and the creation of unsolicited join and leave messages from Base Node application requests.

4.3.3 Channel Access

4.3.3.1 MAC Frames

Time is divided into composite units of abstraction for channel usage, called MAC Frames. Composition of a MAC frame is shown in Figure 33. A frame broadly comprises of two parts:

- Contention Free Part (CFP): This is the first part of a frame. Only devices that are explicitly granted permission by Base Node are allowed to transmit in CFP. Devices allocated CFP time are also given start and end time between which they need to complete their transmission and they are not allowed to use the channel for rest of the CFP duration.
- Shared Contention Period (SCP): This is the second half of a frame following the CFP where devices are free to access the channel, provided they:
    - Comply with CSMA CA algorithm enumerated in section 4.3.3.3.2 (and 4.3.3.3.3 if PHY FSK SUN profile is supported) before transmitting their data
    - Respect SCP boundaries within a MAC Frame, together with the corresponding guard-times.

A guard-time of *macGuardTime* needs to be respected at both, beginning and end of CFP. Note that the length of CFP communicated in a beacon is inclusive of its respective guard-times.

In order to facilitate changes to SCP and CFP times in large networks where beacons may not be transmit in every frame, a notion of super-frame is defined. A super-frame is comprised of *MACSuperFrameLength* number of frames. Each frame is numbered in modulo- *MACSuperFrameLength* manner so as to propagate information of super-frame boundary to every device in the subnetwork.

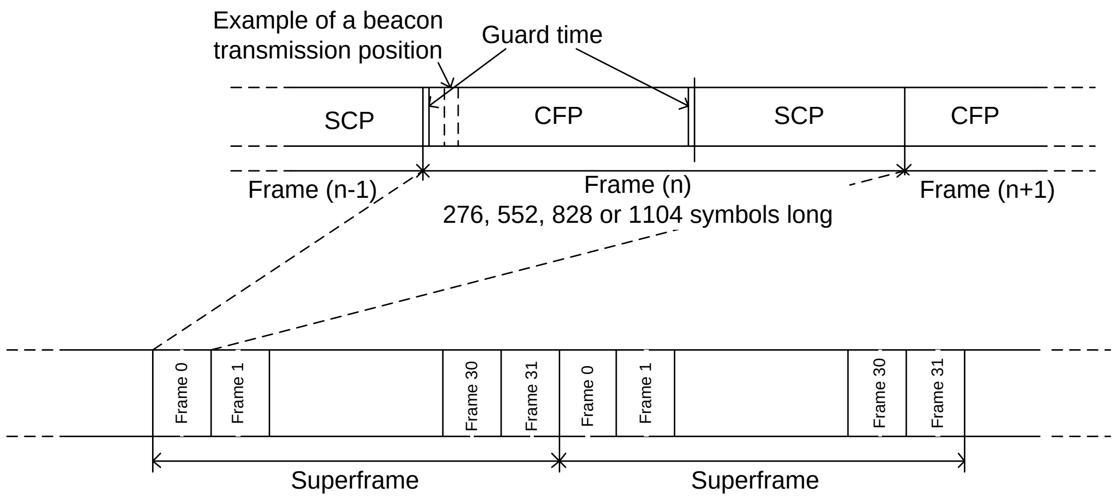

Figure 33 – Structure of a MAC Frame

The length of a frame, *macFrameLength*, together with those of SCP and of CFP are all variable and are defined by Base Node depending on factors such as channel conditions, network size etc. The following mandatory guidelines shall be followed by Base Node implementations while defining the duration of these parameters:

- Frame length can only be one of the four values specified for PIB attribute *macFrameLength*.
- CFP duration within a frame shall at all times be at least (*MACBeaconLength1* + 2 x *macGuardTime)*
- SCP duration within a frame shall at no point in time be less than *MACMinSCPLength*.

Service Nodes may continue to access the channel based on frame organization communicated by Base Node in last received BPDU. Such use of channel also applies to frames when no BPDU is received by the Service Node. Non-reception of BPDU can happen either in normal course when the corresponding Switch Node does not transmit BPDU in every frame or transient channel disturbance resulting in erroneous BPDU reception.

4.3.3.2 Contention-Free Period

Each MAC frame shall have a contention-free period whose duration, in the least, allows transmission of one BPDU.

CFP durations are allocated to Service Nodes in either of the two scenarios:

- As part of promotion procedure carried out for a Terminal node. In all such cases, the CFP allocation will be for usage as beacon-slot by the Service Node being promoted.

- As part of CFP allocation process that could be initiated either from Base Node or Service Node, for use to transport application data.

Service Nodes make channel allocation request in a CFP MAC control packet. The Base Node acts on this request and responds with a request acceptance or denial. In the case of request acceptance, the Base Node shall respond with the location of allocation time within MAC frame, the length of allocation time and number of future MAC frames from which the allocation pattern will take effect. The allocation pattern remains effective unless there is an unsolicited location change of the allocation period from the Base Node (as a result of channel allocation pattern reorganization) or the requesting Service Node sends an explicit de-allocation request using a CFP MAC control packet.

Changes resulting from action taken on a CFP MAC control message that impact overall MAC frame structure are broadcast to all devices using an FRA MAC control message.

All CFP_ALC_REQ_S requests coming from Terminal or Switch Nodes are addressed to the Base Node. Intermediate Switch Nodes along the transmission path merely act on the allocation decision by the Base Node.

Base Nodes may allocate overlapping times to multiple requesting Service Nodes. Such allocations may lead to potential interference. Thus, a Base Node should make such allocations only when devices that are allocated channel access for concurrent usage are sufficiently separated. In a multi-level Subnetwork, when a Service Node that is not directly connected to the Base Node makes a request for CFP, the Base Node shall allocate CFPs to all intermediate Switch Nodes such that the entire transit path from the source Service Node to Base Node has contention-free time-slots reserved. The Base Node shall transmit multiple CFP control packets. The first of these CFP_ALC_IND will be for the requesting Service Node. Each of the rest will be addressed to an intermediate Switch Node.

4.3.3.2.1 Beacons

4.3.3.2.1.1 General

Base Node and every other Switch Node in a Subnetwork transmit a Beacon PDU (BPDU) at least once per super-frame. A BPDU contains administrative and operational information of its respective Subnetwork. Its contents are enumerated in 4.4.4. Every Service Node in a Subnetwork is required to track beacons as explained in 4.3.4.1. In addition to using the administrative and operational information, Service Nodes also synchronize their notion of time based on time of reception of BPDUs.

Since BPDUs are important to keep a Subnetwork running, Base Node and every Switch Node transmitting a BPDU shall do so using a robust modulation scheme, which is either DBPSK_CC, DBPSK_R or DQPSK_R. Beacons in DBPSK_CC are transmitted using PHY Frame Type A. Beacons in DBPSK_R and DQPSK_R are transmitted in PHY Frame Type B. Note that the chosen modulation scheme shall be compliant with the definition of *macRobustnessManagement*. Every device, including the Base Node shall transmit BPDU with maximum output power.

4.3.3.2.1.2 Beacon-slots

Unit of time dedicated for transmission of a BPDU is called a beacon-slot. Depending on the corresponding modulation it has a length of either (*MACBeaconLength1* + *macGuardTime*), (*MACBeaconLength2* + *macGuardTime*) or (*MACBeaconLength3* + *macGuardTime*). Note that it includes not only the time required to transmit the BPDU but also the *macGuardTime* that is required to ensure minimal separation between successive transmissions.

Note that a Base Node:

- May decide to not use its beacon-slot in every frame implying that it transmits BPDU at less than once per frame frequency
- Will necessarily use its beacon-slot at least once per *MACSuperFrameLength*
- May allocate its beacon-slot location to other switches in its network for frames where it decides to not transmit its BPDU.

Every Switch Node in the Subnetwork needs to have a beacon-slot allocated in order for it to transmit its BPDU. Switch Nodes are allocated a beacon-slot at time of their promotion by the Base Node.

- Beacon-slot allocations shall necessarily be contained within the CFP duration of a frame.
- Base Node may time-multiplex beacon-slots i.e. allocate same duration of time to different switches in different frames.
- A Switch Node may request to change the duration of its beacon-slot when it decides to change the modulation scheme of its BPDU.

With the Registration of each new Switch on the Subnetwork, the Base Node may change the modulation, beacon-slot or BPDU transmission frequency (or both) of already registered Switch devices. When such a change occurs, the Base Node transmits an unsolicited PRO_REQ to each individual Switch device that is affected. The Switch device addressed in the PRO_REQ shall transmit an acknowledgement, PRO_ACK, back to the Base Node. During the reorganization of beacon-slots, if there is a change in CFP duration, the Base Node shall transmit an FRA control packet to the entire Subnetwork. The BN also sends a FRA control packet in advance of a change in length of a frame.

Switch devices that receive an FRA control packet shall relay it to their entire control domain because FRA packets are broadcast information about changes to frame structures.

This is required for the entire Subnetwork to have a common understanding of frame structure, especially in regions where the controlling Switch devices transmit BPDUs at frequencies below once per frame.

4.3.3.2.2 Additional considerations for RF PHY profile

Implementers should take care that, in all messages where CSMA-CA does not apply (for instance for transmissions inside the CFP), other MAC strategies may be needed.

4.3.3.3 Shared-contention period

4.3.3.3.1 General

Shared-contention period (SCP) is the time when any device in Subnetwork can transmit data. SCP follows the CFP duration within a frame and its duration is defined by Base Node. Collisions resulting from simultaneous attempt to access the channel are avoided by the CSMA-CA mechanism specified in this section. SCP durations are highlighted by the following key specifications:

- SCP duration within a frame shall at no point in time be less than *MACMinSCPLength*.
- Maximum possible duration of SCP shall be *(macFrameLength* - (*MACBeaconLength1* + 2 x *macGuardTime)).* This is the case of a subnetwork that does not have dedicated CFP requests from any Service Node.

4.3.3.3.2 PLC CSMA-CA algorithm

The CSMA-CA algorithm implemented in devices works as shown in Figure 34.

Implementations start with a random backoff time (*macSCPRBO*) based on the priority of data queued for transmission. *MACPriorityLevels* levels of priority need to be defined in each implementation, with a lower value indicating higher priority. In the case of data aggregation, the priority of aggregate bulk is governed by the highest priority data it contains. The *macSCPRBO* for a transmission attempt is give as below:

macSCPRBO = random (0, MIN ((2$^{(\text{Priority+txAttempts+macCSMAR1})}$ +macCSMAR2), (macSCPLength/2)))

or when Robust Modes are supported:

macSCPRBO = random (0, MIN ((2$^{(\text{Priority+txAttempts+macCSMAR1Robust})}$ +macCSMAR2Robust), (macSCPLength/2)))

macCSMAR1/macCSMAR1Robust and *macCSMAR2*/macCSMAR2Robust control the initial contention window size. *macCSMAR1*/macCSMAR1Robust helps to increase the contention window size exponentially while *macCSMAR2*/macCSMAR2Robust helps to increase the contention window linearly. A higher value of *macCSMAR1*/macCSMAR1Robust and/or *macCSMAR2*/macCSMAR2Robust is recommended for large networks. It is recommended to not decrease the default values.

Before a backoff period starts, a device should ensure that the remaining SCP time is long enough to accommodate the backoff, the number of iterations for channel-sensing (based on data priority) and the subsequent data transmission. If this is not the case, backoff should be aborted till the SCP starts in the next frame. Aborted backoffs that start in a subsequent frame should not carry *macSCPRBO* values of earlier attempts. *macSCPRBO* values should be regenerated on the resumption of the transmission attempt in the SCP time of the next frame.

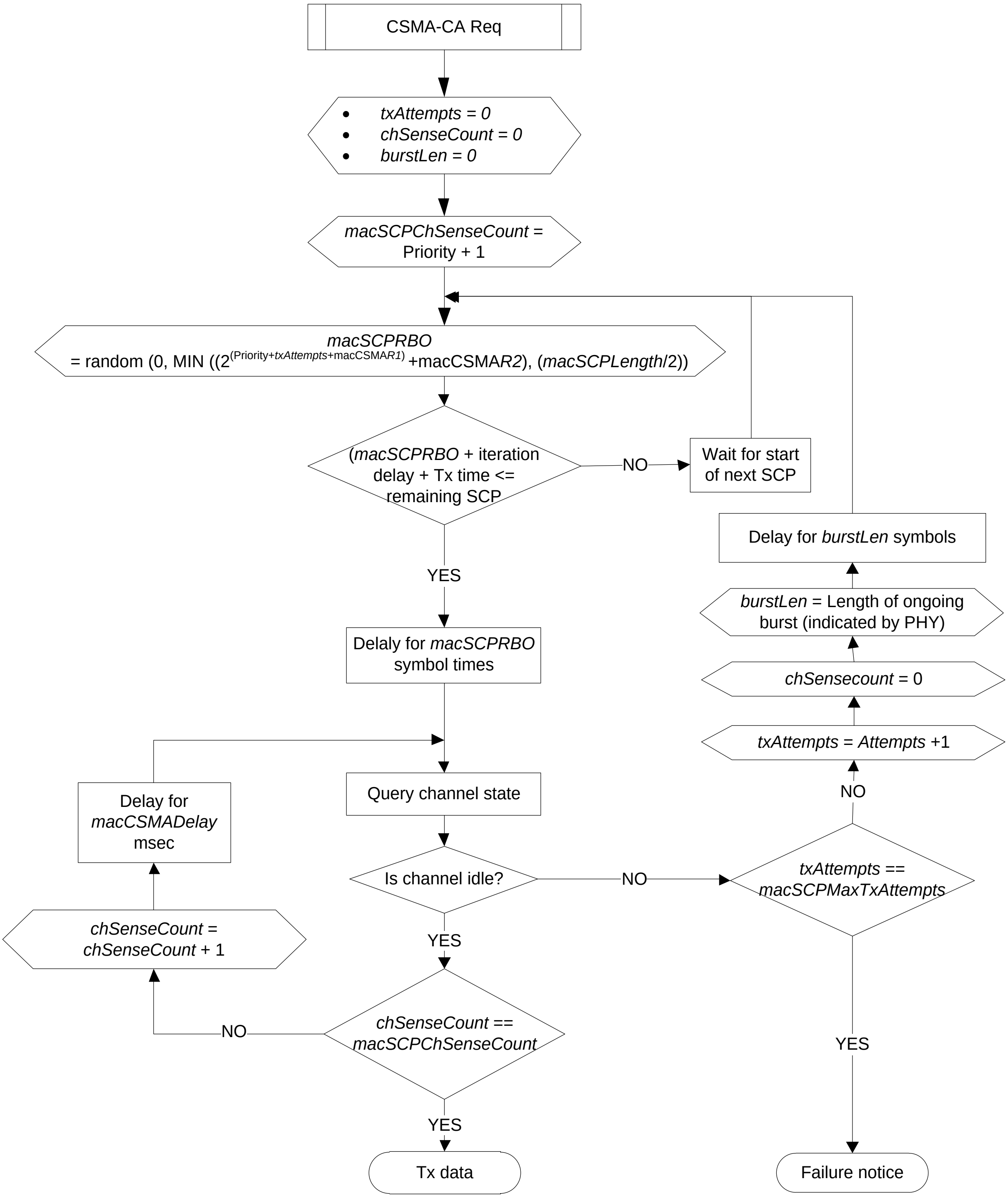

Figure 34 - Flow chart for PL CSMA-CA algorithm

On the completion of *macSCPRBO* symbol time, implementations perform channel-sensing. Channel sensing shall be performed one or more times depending on priority of data to be transmitted. The number of times for which an implementation has to perform channel-sensing (*macSCPChSenseCount*) is defined by the priority of the data to be transmitted with the following relation:

macSCPChSenseCount = Priority + 1

and each channel sense should be separated by a *macCSMADelay* ms delay.

***Note:** macSCPRBO and macCSMADelay follow a different range and different default value depending on the modulation scheme that is intended to be used for a transmission burst. If a device intends to use robust mode for some bursts, the values are conservative to account for extended PHY Frame (Type B) timings. The applicable values are listed in **6.2.3.2**. Implementations shall conform to listed range and default value corresponding to the modulation scheme used.*

When a channel is sensed to be idle on all *macSCPChSenseCount* occasions, an implementation may conclude that the channel status is idle and carry out its transmission immediately.

During any of the *macSCPChSenseCount* channel-sensing iterations, if the channel is sensed to be occupied, implementations should reset all working variables. The local counter tracking the number of times a channel is found to be busy should be incremented by one and the CSMA-CA process should restart by generating a new *macSCPRBO.* The remaining steps, starting with the backoff, should follow as above.

If the CSMA-CA algorithm restarts *macSCPMaxTxAttempts* number of times due to ongoing transmissions from other devices on the channel, the transmission shall abort by informing the upper layers of CSMA-CA failure.

4.3.3.3.3 CSMA-CA algorithm for SUN FSK PHY profile

When PRIME SUN FSK PHY profile is supported and SUN FSK PPDUs are transmitted on the SCP, the slotted version of the CSMA-CA shown in Figure 6-5 of [28] shall be used (see Figure 35). The generic description of the algorithm can be derived from section 6.2.5.1 of [28] with the following assumptions:

- SCP substitutes the concept of CAP and the start of the first backoff period of each device is aligned with the start of the SCP;
- TSCH (Timeslotted Channel Hopping) is disabled;
- CW_0 is equal to 2 as in [28];
- The Battery Life Extension is disabled;
- Writable PIBs *macMinBe*, *macMaxBe*, *macMaxCsmaBackoffs* described in Table 105 of this specification shall be implemented;
- MAC constant *aUnitBackOffPeriod* uses the definition reported in this specification in Annex D;
- the statements reported in section 6.2.5.1 of [28], which involve specific IEEE MAC concepts as PAN, Imm-Ack frames, Enh-Ack frames, Data frames, acknowledgment of a Data Request command, are ignored.

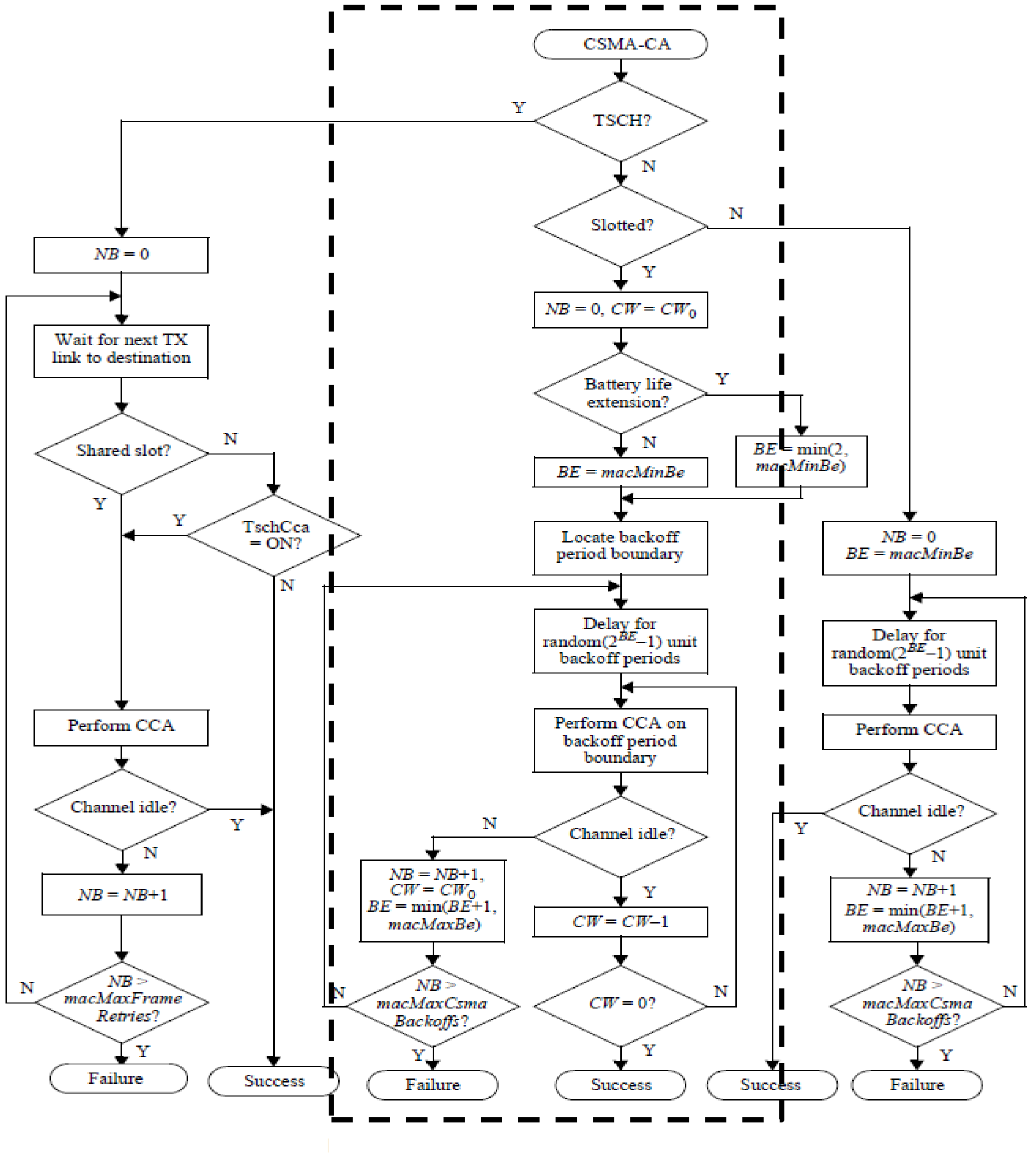

Figure 35 Flow chart for SUN FSK PHY CSMA-CA algorithm

4.3.3.3.4 MAC control packet transmission

MAC control packets (4.4.2.6) shall follow the following channel access rules:

- Always transmit in SCP
- Use priority level of *MACCtrlPktPriority*
- The MAC Control Packets shall be transmitted in a modulation scheme robust enough to reach the receiving peer but no less robust than DBPSK_CC.
- Transmitted with PHY Frame Type B for DBPSK_R and DQPSK_R. For all other modulation schemes, control packets are transmitted using PHY Frame Type A

4.3.4 Tracking switches and peers

4.3.4.1 Tracking switches

Service Nodes shall keep track of all neighboring Switch Nodes by maintaining a list of beacons received. Such tracking shall keep a Service Node updated on reception signal quality from Switch Nodes other than the one to which it is connected, thus making it possible to change connection points (Switch Node) to the Subnetwork if link quality to the existing point of connectivity degrades beyond an acceptable level.

Note that such a change of point of connectivity may be complex for Switch Nodes because of devices connected through them. However, at certain times, network dynamics may justify a complex reorganization rather than continue with existing limiting conditions.

4.3.4.2 Tracking disconnected Nodes

Terminals shall process all received PNPDUs. When a Service Node is Disconnected, it doesn't have information on current MAC frame structure so the PNPDUs may not necessarily arrive during the SCP. Thus, Terminals shall also keep track of PNPDUs during the CFP or beacon-slots.

On processing a received PNPDU, a Terminal Node may decide to ignore it and not generate any corresponding promotion request (PRO_REQ_S). Receiving multiple PNPDUs can indicate that there is no other device in the vicinity of Disconnected Nodes, implying that there will be no possibility of new devices for connecting to the Subnetwork if the Terminal Node does not request promotion itself. A Terminal Node shall ignore no more than *MACMaxPRNIgnore* PNPDUs. After this maximum number of ignored PNPDUs the Terminal Node shall start a Promotion procedure as described in 4.6.3. The time in which the procedure will start shall be randomly selected in the range of [0,*MACMaxPRNIgnore***macPromotionMinTxPeriod*] seconds.

4.3.4.3 Tracking switches under one node

Service Nodes in *Switch* functional state shall keep track of the Switches under their tree by maintaining the *macListSwitchTable*. Maintaining this information is sufficient for switching because traffic to/from Terminal Nodes will also contain the identity of their respective Switch Nodes (PKT.SID). Thus, the switching function is simplified in that maintaining an exhaustive listing of all Terminal Nodes connected through it is not necessary. After promotion Switch Nodes start with no entries in their switching table.

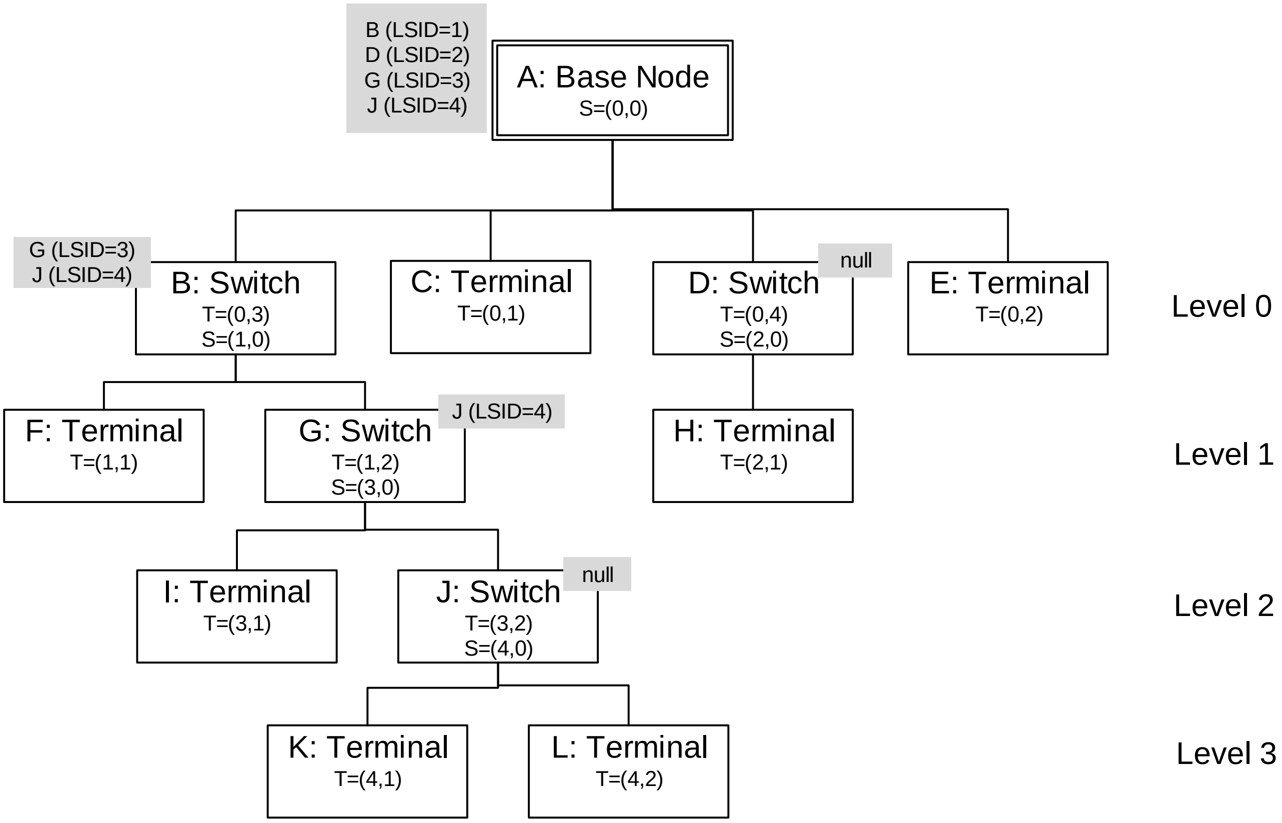

Figure 36 –Switching tables examples

One Switch Node shall include in the switching list the SID of every promoted Terminal node which is directly connected to it or to one Switch already included in the macListSwitchTable. In this case the Node shall create an entry with the stblEntryLSID value equals to the NSID field of the PRO_ACK packet, the stblEntrySID value equal to PKT.SID of the PRO.ACK Packet Header and stblEntryLNID equal to PKT.LNID of the PRO.ACK Packet Header.

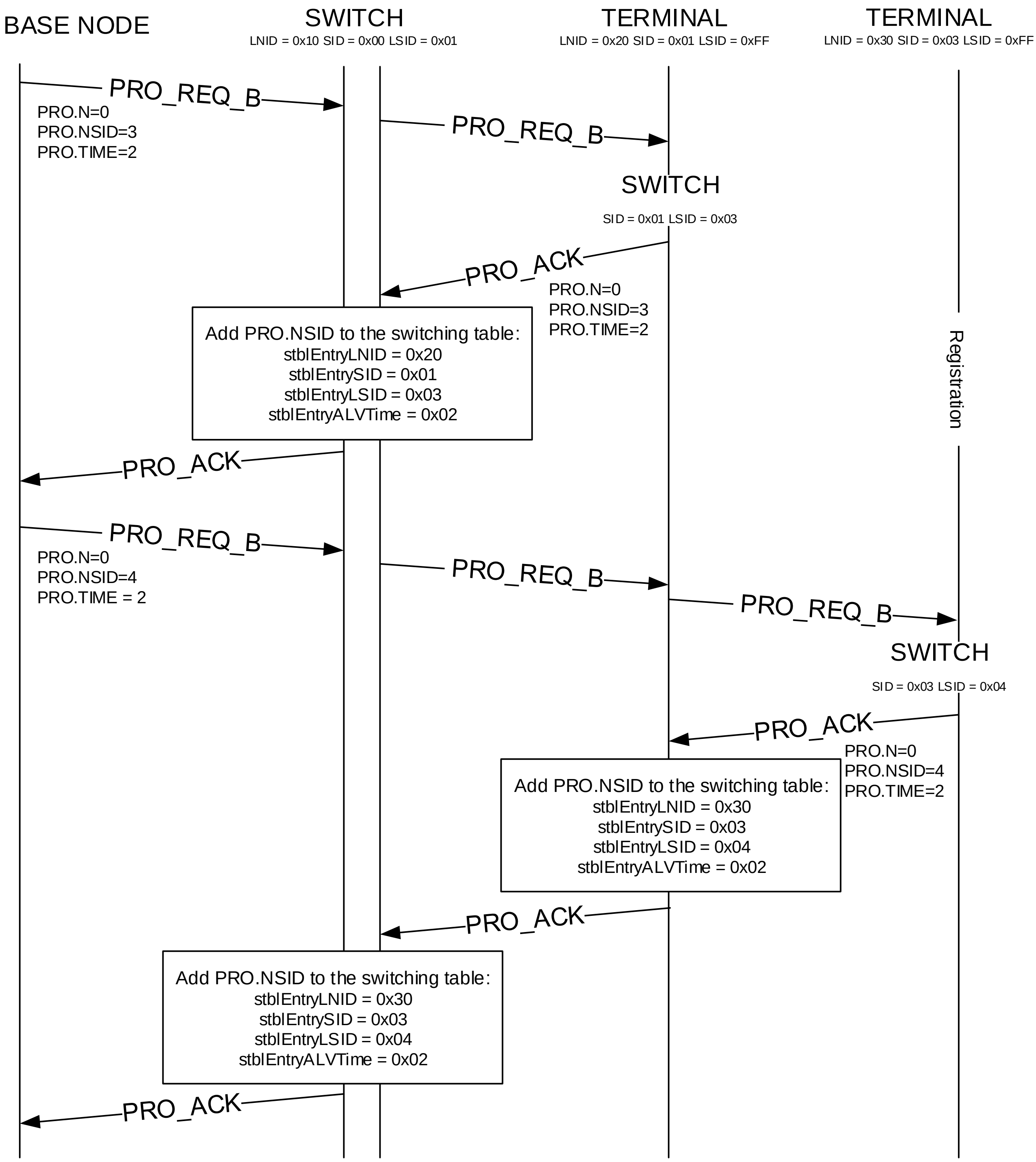

Figure 37 – Filling example for the switching table for Switch of Level 0.

Similarly the Switch Node shall mark the entry to be removed from the list the SID when a node is removed or unregistered. This is be done by listening the PRO_DEM_B, PRO_DEM_S, REG_UNR_B or REG_UNR_S packets.

Each entry of the *macListSwitchTable* also contains the information related to the Alive time related to the Switch node. The stblEntryALVTime is updated with the TIME field received during the promotion, beacon robustness change or the keep alive procedures. The Switch Node shall also maintain the $T_{keep\text{-}alive}$ timer for every Switch under its tree. The Switch Node shall refresh the timers as specified in section 4.6.5. If the $T_{keep\text{-}alive}$ timer expires the entry in the *macListSwitchTable* shall be marked to be removed.

Every time an entry is marked to be removed, the Switch Node shall check if the stblEntrySID of other entries is equal to the stblEntryLSID. In these cases all the entries shall be marked to be removed, meaning that one entire branch has left the network.

When one entry is marked to be removed the Switch Node shall wait (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds. This time ensures that all retransmit packets which use the SID have left the Subnetwork. When the timer expires the table entry shall be removed.

4.3.5 Switching

4.3.5.1 General

On a Subnetwork, the Base Node cannot communicate with every Node directly. Switch Nodes relay traffic to/from the Base Node so that every Node on the Subnetwork is effectively able to communicate with the Base Node. Switch Nodes selectively forward traffic that originates from or is destined to one of the Service Nodes in its control hierarchy. All other traffic is discarded by Switches, thus optimizing traffic flow on the network.

Different names of MAC header and packets are used in this section. Please refer to the section 4.4.2 to find their complete specification.

4.3.5.2 Switching process

Switch Nodes forward traffic to their control domain in a selective manner. The received data shall fulfill the conditions listed below for it to be switched. If the conditions are not met, the data shall be silently discarded.

Downlink packets (HDR.DO=1) shall meet any of the following conditions in order to be switched:

- Destination Node of the packet is connected to the Subnetwork through this Switch Node, i.e. PKT.SID is equal to this Switch Node's SID or its switching table contains an entry for PKT.SID.
- The packet has broadcast destination (PKT.LNID = 0x3FFF) and was sent by the Switch this Node is registered through (PKT.SID=SID of this Switch Node).
- The packet has a multicast destination (PKT.LNID=0x3FFE), it was sent by the Switch this Node is registered through (PKT.SID=SID of this Switch Node) and at least one of the Service Nodes connected to the Subnetwork through this Switch Node is a member of the said multicast group, i.e. LCID specifies a group that is requested by any downstream Node in its hierarchy.

Uplink packets (HDR.DO=0) shall meet either of the following conditions in order to be switched:

- The packet source Node is connected to the Subnetwork through this Switch Node, i.e. PKT.SID is equal to this Switch Node's SID or its switching table contains an entry for PKT.SID.
- The packet has a broadcast or multicast destination (PKT.LNID = 0x3FFF or 0x3FFE) and was transmitted by a Node connected to the Subnetwork through this Switch Node i.e. PKT.SID is equal to this Switch Node's SID or its switching table contains an entry for PKT.SID.

If a packet meets previous conditions, it shall be switched. For unicast packets, the only operation to be performed during switching is to queue it to be resent in a MAC PDU with the same HDR.DO.

In case of broadcast or multicast packets, the PKT.SID must be replaced with the Switch Node's LSID for Downlink packets. Uplink packets shall be resent unchanged.

When switching packets, the Switch Node shall ignore the length and the values of the reserved bits in the received packet. The destination Node is responsible for checking that the length and the reserved bits match the expected values.

4.3.5.3 Switching of broadcast packets

The switching of broadcast MAC frames operates in a different manner to the switching of unicast MAC frames. Broadcast MAC frames are identified by PKT.LNID=0x3FFF.

When HDR.DO=0, i.e. the packet is an uplink packet, it is unicast to the Base Node. A Switch which receives such a packet shall apply the scope rules to ensure that it comes from a lower level and, if so, Switch it upwards towards the base. The rules given in section 4.3.5.2 must be applied. The same modulation scheme and output power level as used for unicast uplink switching shall be used.

When HDR.DO=1, i.e. the packet is a Downlink packet, it is broadcast to the next level. A Switch which receives such a packet shall apply the scope rules to ensure that it comes from the higher level and, if so, switch it further to its Subnetwork. The same modulation scheme as used for beacon transmission at the maximum output power level implemented in the device shall be used so that all the devices directly connected to the Switch Node can receive the packet. The rules given in section 4.3.5.2 must be applied. The Service Node shall also pass the packet up to its MAC SAP to applications which have registered to receive broadcast packets using the MAC_JOIN service.

When the Base Node receives a broadcast packet with HDR.DO=0, it shall pass the packet up its MAC SAP to applications which have registered to receive broadcast packets. The Base Node shall also transmit the packet as a Downlink packet, i.e. HDR.DO=1, using the same modulation scheme as used for beacon transmission at the maximum output power level and following the rules given in section 4.3.5.2.

4.3.5.4 Switching of multicast packets

Switch Nodes shall maintain a multicast switching table. This table contains a list of multicast group LCIDs that have members connected to the Subnetwork through the Switch Node. The LCID of multicast traffic in both Downlink and uplink directions is checked for a matching entry in the multicast switching table. Multicast traffic is only switched if an entry corresponding to the LCID is available in the table; otherwise, the traffic is silently discarded.

A multicast switching table is established and managed by examining the multicast join messages (MUL control packet) which pass through the Switch. On a successful group join from a Service Node in its control hierarchy, a Switch Node adds a new multicast Switch entry for the group LCID, where necessary. An entry from the multicast switching table can be removed by the Base Node using the multicast leave procedure (see section 4.6.7.4.2). All entries from the multicast switching table shall be removed when a switch is demoted or unregistered. The multicast packet switching process depends on the packet direction.

When HDR.DO=0 and PKT.LNID=0x3FFE, i.e. the packet is an uplink multicast packet, it is unicast towards the Base Node. A Switch Node that receives such a packet shall apply the scope rules to ensure it comes from a lower hierarchical level and, if so, switch it upwards towards the Base Node. No LCID-based filtering is performed. All multicast packets are switched, regardless of any multicast Switch entries for the LCID. The rules given in section 4.3.5.2 must be applied. The same modulation scheme and output power level as used for unicast uplink switching shall be used.

When HDR.DO=1 and PKT.LNID=0x3FFE, i.e. the packet is a Downlink multicast packet, the multicast switching table is used. If there is an entry with the LCID corresponding to PKT.LCID in the packet, the packet is switched downwards to the part of Subnetwork controlled by this switch. The multicast traffic shall be relayed using a modulation scheme which is robust enough to ensure that all direct children which are part of the multicast group or which need to switch the multicast traffic can receive the packet. As a guideline, the same modulation scheme as used for beacon transmission at the maximum output power level can be used. The rules given in section 4.3.5.2 shall be applied. If the Service Node is also a member of the multicast group, it shall also pass the packet up its MAC SAP to applications which have registered to receive the multicast packets for that group.

When the Base Node receives a multicast packet with HDR.DO=0 and it is a member of the multicast group, it shall pass the packet up its MAC SAP to applications which have registered to receive multicast packets for that group. The Base Node shall switch the multicast packet if there is an appropriate entry in its multicast switching table for the LCID, transmitting the packet as a Downlink packet, i.e. HDR.DO=1. To transmit a downlink multicast packet by the Base Node the same rules apply as for transmitting a downlink multicast packet by a switch.

4.3.6 Direct connections

4.3.6.1 Direct connection establishment

The direct connection establishment is a little different from a normal connection although the same packets and processes are used. It is different because the initial connection request may not be acknowledged until it is already acknowledged by the target Node. It is also different because the CON_REQ_B packets shall carry information for the “direct Switch” to update the “direct switching table”.

A direct switch is not different than a general switch. It is only a logical distinction of identifying the first common switch between two service-nodes that need to communicate with each other. Note that in absence of such a common switch, the Base Node would be the direct switch.

There are two different scenarios for using directed connections. These scenarios use the network shown in Figure 38.

The first is when the source Node does not know the destination Service Node’s EUI-48 address. The Service Node initiates a connection to the Base Node and the Base Node Convergence layer redirects the connection to the correct Service Node.

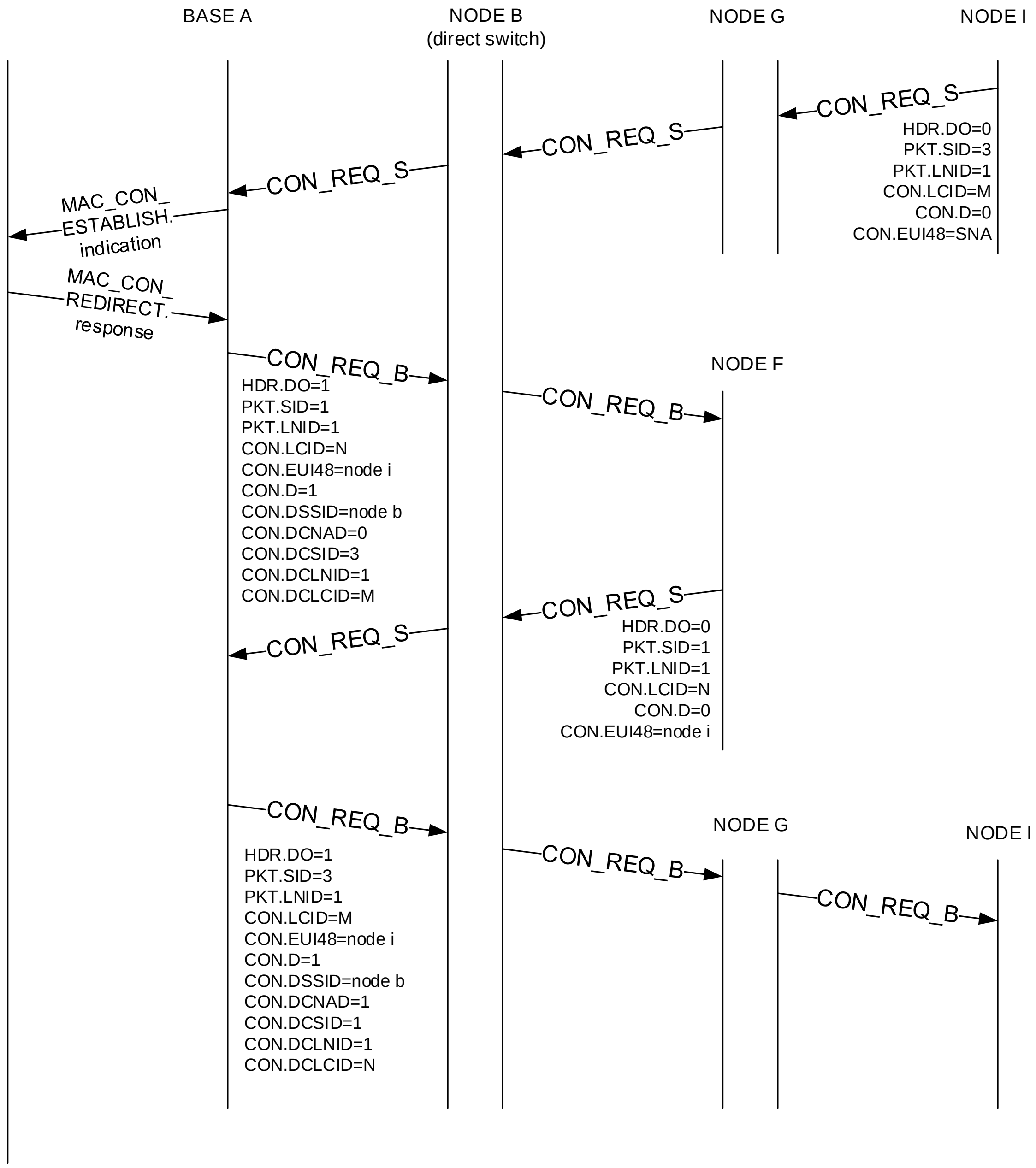

Figure 38 – Directed Connection to an unknown Service Node

The steps to establish a direct connection, as shown in Figure 38, shall be:

- When Node I tries to establish connection with Node F, it shall send a normal connection request (CON_REQ_S).
- Then, due to the fact that the Base Node knows that F is the target Service Node, it should send a connection request to F (CON_REQ_B). This packet will carry information for direct Switch B to include the connection in its direct switching table.
- F may accept the connection. (CON_REQ_S).
- Now that the connection with F is fully established, the Base Node will accept the connection with I (CON_REQ_B). This packet will carry information for the direct Switch B to include in its direct switching table.

After finishing this connection-establishment process, the direct Switch (Node B) should contain a direct switching table with the entries shown in Table 13.

Table 13 - Direct connection example: Node B's Direct switching table

Uplink			Downlink			
SID	**LNID**	**LCID**	**DSID**	**DLNID**	**DLCID**	**NAD**
1	1	N	3	1	M	0
3	1	M	1	1	N	1

The direct switching table should be updated every time a Switch receives a control packet that meets the following requirements.

- It is CON_REQ_B packet: HDR.DO=1, CON.TYPE=1 and CON.N=0;
- It contains "direct" information: CON.D=1;
- The direct information is for itself: CON.DSSID is the SID of the Switch itself.

Then, the direct switching table is updated with the information:

- Uplink (SID, LNID, LCID) = (PKT.SID, PKT.LNID, CON.LCID);
- Downlink (SID, LNID, LCID, NAD) = (CON.DCSID, CON.DCLNID, CON.DCLCID, CON.DCNAD).

The connection closing packets should be used to remove the entries.

The second scenario for using directed connections is when the initiating Service Node already knows the destination Service Node's EUI-48 address. In this case, rather than using the Base Node's address, it uses the Service Node's address. In this case, the Base Node Convergence layer is not involved. The Base Node MAC layer connects Service Node I directly to Service Node F. The resulting Switch table entries are identical to the previous example. The exchange of signals is shown in Figure 39.

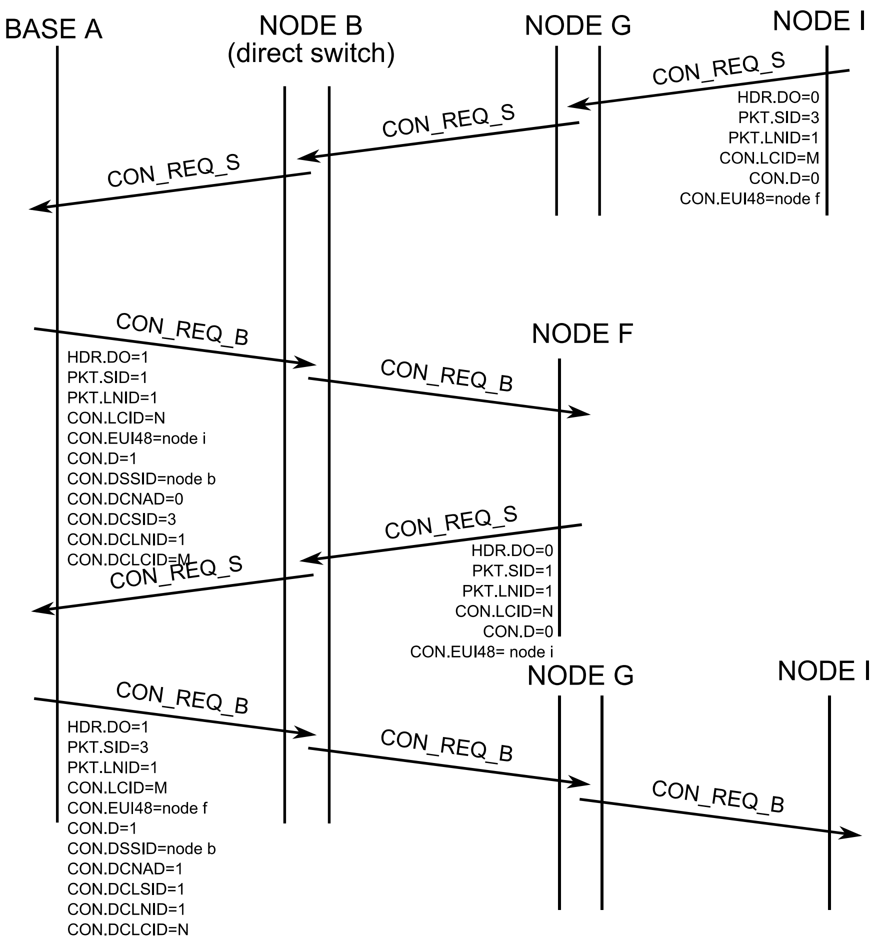

Figure 39 - Example of direct connection: connection establishment to a known Service Node

4.3.6.2 Direct connection release

The release of a direct connection is shown in Figure 40. The signaling is very similar to connection establishment for a direct connection. The D fields are used to tell the direct Switch which entries it should remove. The direct switching table should be updated every time a Switch receives a control packet that meets the following requirements.

- It is CON_CLOSE_B packet: HDR.DO=1, CON.TYPE=1 and CON.N=1;
- It contains “direct” information: CON.D=1;
- The direct information is for itself: CON.DSSID is the SID of the Switch itself.

Then, the direct switching table entry with the following information is removed:

- Uplink (SID, LNID, LCID) = (PKT.SID, PKT.LNID, CON.LCID);
- Downlink (SID, LNID, LCID, NAD) = (CON.DCSID, CON.DCLNID, CON.DCLCID, CON.DCNAD).

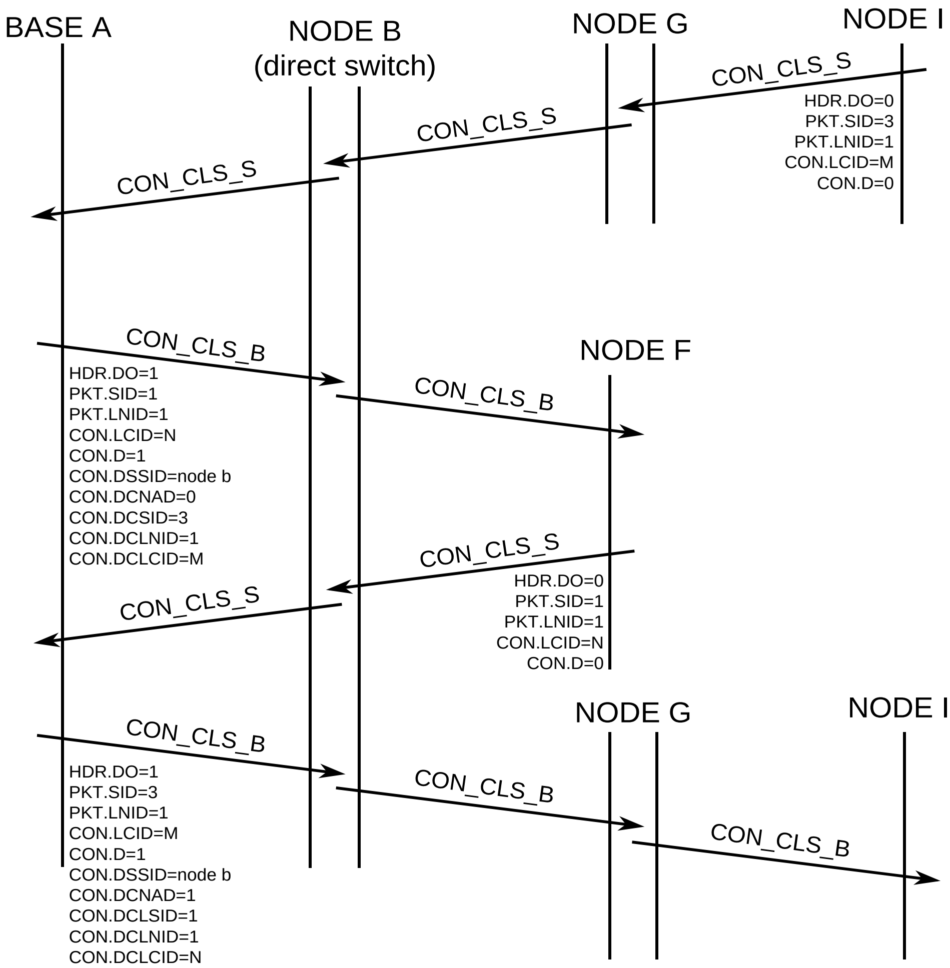

Figure 40 - Release of a direct connection

4.3.6.3 Direct connection switching

As explained in section 4.3.5.2, the normal switching mechanism is intended to be used for forwarding communication data between the Base Node and each Service Node. The “direct switching” is a mechanism to let two Nodes communicate with each other, switching the packets in a local way, i.e. without passing through the Base Node. It is not a different form of packet-switching, but rather an additional feature of the general switching process.

The first shared Switch in the paths that go from two Service Nodes to the Base Node will be called the “direct Switch” for the connections between the said Nodes. This is the Switch that will have the possibility of performing the direct switching to make the two Nodes communicate efficiently. As a special case, every Switch is the “direct Switch” between itself and any Node that is lower down in the hierarchy.

The “direct switching table” is a table every Switch should contain in order to perform the direct switching. Each entry on this table is a direct connection that must be switched directly. It is represented by the origin CID and the destination CID of the direct connection. It is not a record of every connection identifier lower down in its hierarchy, but contains only those that should be directly switched by it. The Destination Node’s ability to receive aggregated packets shall also be included in the "direct switching table" in order to fill the PKT.NAD field.

4.3.6.4 Direct switching operation

If a Switch receives an uplink (HDR.DO=0) MAC frame that is to be switched (see section 4.3.5.2 for the requirements) and its address is in the direct switching table, then the procedure is as follows:

- Change the (SID, LNID, LCID, NAD) by the Downlink part of the entry in the direct switching table.
- Queue the packet to be transmitted as a Downlink packet (HDR.DO=1).

4.3.7 Packet aggregation

4.3.7.1 General

The GPDU may contain one or more packets. The functionality of including multiple packets in a GPDU is called packet aggregation. Packet aggregation is an optional part of this specification and devices do not need to implement it for compliance with this specification. It is however suggested that devices should implement packet aggregation in order to improve MAC efficiency.

To maintain compatibility between devices that implement packet aggregation and ones that do not, there must be a guarantee that no aggregation takes place for packets whose data transit path from/to the Base Node crosses (an) intermediate Service Node(s) that do(es) not implement this function. Information about the aggregation capability of the data transit path is exchanged during the Registration process (4.6.1). A registering Service Node notifies this capability to the Base Node in the REG.CAP_PA field (1 bit, see Table 21) of its REG_REQ message. It gets feedback from the Base Node on the aggregation capability of the whole Downlink transit path in the REG.CAP_PA field of the REG_RSP message.

Based on initial information exchanged on Registration, each subsequent data packet in either direction contains aggregation information in the PKT.NAD field. In the Downlink direction, the Base Node will be responsible for filling PKT.NAD based on the value it communicated to the destination Service Node in the REG.CAP_PA field of the REG_RSP message. Likewise, for uplink data, the source Service Node will fill PKT.NAD based on the REG.CAP_PA field received in the initial REG_RSP from the Base Node. The last Switch shall use the PKT.NAD field to avoid packet aggregation when forwarding the packet to destination Service Nodes without packet aggregation capability. Intermediate Switch Nodes should have information about the aggregation capability in their switching table and shall not aggregate packets when it is known that next level Switch Node does not support this feature.

Devices that implement packet aggregation shall ensure that the size of the MSDU comprising the aggregates does not exceed the maximum capacity of the most robust transmission scheme of a PHY burst. The most robust transmission scheme refers to the most robust combination of modulation scheme, convolutional coding and repetition coding.

4.3.7.2 Packet aggregation when switching

Switch Nodes maintain information on the packet aggregation capability of all entries in their switching table, i.e. of all switches that are connected to the Subnetwork through them. This capability information is then used during traffic switching to/from the connected Switch Nodes.

The packet aggregation capability of a connecting Switch Node is registered at each transit Switch Node at the time of its promotion by sniffing relevant information in the PRO_ACK message.

- If the PKT.SID in a PRO_ACK message is the same as the switching Node, the Node being promoted is connected directly to the said Switch Node. The aggregation capability of this new Switch Node is registered as the same as indicated in PKT.NAD of the PRO_ACK packet.
- If the PKT.SID in a PRO_ACK message is different from the SID of the switching Node, it implies that the Node being promoted is indirectly connected to this Switch. The aggregation capability for this new Switch Node will thus be the same as the aggregation capability registered for its immediate Switch, i.e. PKT.SID.

Aggregation while switching packets in uplink direction is performed if the Node performing the Switch knows that its uplink path is capable of handling aggregated packets, based on capability information exchanged during Registration (REG.CAP_PA field in REG_RSP message).

Downlink packets are aggregated by analyzing the following:

- If the PKT.SID is the same as the switching Node, then it is the last switching level and the packet will arrive at its destination. In this case, the packet may be aggregated if PKT.NAD=0.
- If the PKT.SID is different, this is not the last level and another Switch will receive the packet. The information of whether or not the packet could be aggregated should be extracted from the switching table.

4.3.8 Security

4.3.8.1 General

The security functionality provides the MAC layer with confidentiality, authentication, integrity and protection against reply attacks through a secure connection method and a key management policy. All packets must use the negotiated security profile.

4.3.8.2 Security Profiles

Several security profiles are provided for managing different security needs, which can arise in different network environments. This version of the specification lists three security profiles and leaves scope for adding another security profile in future versions.

4.3.8.2.1 Security Profile 0

Communications having Security Profile 0 are based on the transmission of MAC SDUs without encryption. This profile may be used in application scenarios where either sufficient security is provided by upper communication layers or where security is not a major requirement for application use-case.

4.3.8.2.2 Security Profile 1 and 2

4.3.8.2.2.1 General

Security Profile 1 and 2 are based on several cryptographic primitives, all based upon AES-128, which provides secure functionalities for key derivation, key wrapping/unwrapping and authenticated encryption of packets. These profiles are specified with the aim of fulfilling all security requirements:"

- Confidentiality, authenticity and integrity of packets are guaranteed by the use of an authenticated encryption algorithm.
- Authentication is guaranteed by the fact that each Node has its own unique key known only by the Node itself and the Base Node.
- Replay Attacks are prevented through the use of a message counter of 4 bytes.

Note:

The scope of the Security Profile does not address any implementation specific security requirements such as protection against side channel attacks (timing attacks, power attacks, electromagnetic attacks, fault attacks, etc…). The implementer of the security profile needs to assure the cryptographic functionality is adequately protected.

- The implementer might consider counter measures depending on the environment PRIME is used. This could include the implementation of an AES algorithm with mitigation for non-invasive attacks (e.g. power analysis or electromagnetic side channel attacks). Additional tamper protection and hardening mechanisms are specified in FIPS 140-3 levels 3 and 4.

4.3.8.2.2.2 Authenticated Encryption

The cryptographic algorithms used in this specification are all based on AES, as specified in [16]. The specification describes the algorithm with three possible key sizes. PRIME uses a key length of 128 bit. A key length of 128 bit represents a good level of security for preserving privacy up to 2030 and beyond, as specified in SP800-57 [17], page 66, table 4.

AES is used in CCM mode, as specified in [25]. It is a dual-pass authenticated encryption mode. In the context of this security profile it is used accordingly to the following settings (using the same notations of [25]):

- n: the octet length of the nonce is set to 13. This allows for a maximum message size of 65535 bytes.
- q: the octet length of the binary representation of the octet length of the payload is set to 2.
- *t: the* octet length of the MAC is set to 6. Therefore *Tlen*, the MAC bit size, is set to 48.

4.3.8.2.2.2.1 Key update frequency

Security profiles set the value of the AES-CCM authentication tag (*Tlen*) to 48 bits. The maximum time limit between two re-keying events for WK and SWKis the value contained in the PIB *MACUpdateKeysTime*. This PIB's maximum allowed value shall be the one defined in Table 14 according to the available number of channels.

Table 14 - Values of *MACUpdateKeysTime* for different number of channels

Available number of channels	Life time in days
1 x 64Kb/s channel	49 days
2 x 64Kb/s channel	24 days
3 x 64Kb/s channel	16 days

4 x 64Kb/s channel	12 days
5 x 64Kb/s channel	10 days
6 x 64Kb/s channel	8 days
7 x 64Kb/s channel	7 days
8 x 64Kb/s channel	6 days

4.3.8.2.2.2.2 Nonce creation

The nonce is a value used by AES-128-CCM and is required to be unique for each different message that is processed under the same key. In order to maintain this property and to have protections against replay attacks, each Service Node needs to have a 32-bit message counter.

The 13-byte nonce, for each message, is shown in Figure 41 and is composed by the concatenation of the following entities:

- 48-bit Subnetwork Address (found in BCN.SNA)
- 8-bit SID address, identifying the Switch Node of the Service Node which generated the packet
- 2-bit set to 0 for this version of the specification. Reserved for future use.
- 14-bit LNID address, identifying the Service Node that generated the packet. The pair SID and LNID should provide a unique address within the subnetwork.
- 32-bit Message Counter, number of messages sent by the Service Node which originated the message

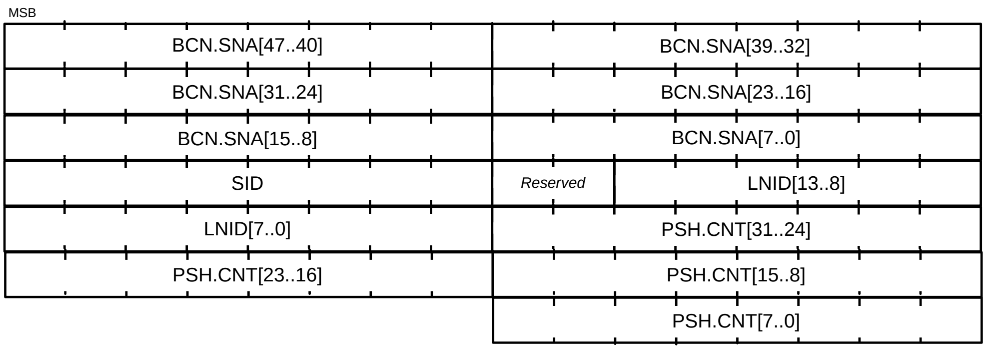

Figure 41 – Nonce structure

The nonce SID and LNID entities are derived from the senders SID and LNID as shown in Table 15.

Table 15 –Nonce SID/LNID Derivation

Packet Type / Affected Keys	Packet Direction	Nonce Entity	Nonce Entity Value
	Downlink	SID	0
		LNID	0

Packet Type / Affected Keys	Packet Direction	Nonce Entity	Nonce Entity Value
Unicast *Key: WK or SWK not re-encoded*	*Uplink*	SID	PKT.SID
		LNID	PKT.LNID
Switch Re-encoded Key: SWK *	*Downlink/ Uplink*	SID	Switch SSID
		LNID	0
Broadcast/Multicast *Key: SWK*	*Downlink*	SID	PKT.SID
		LNID	0
	Uplink	SID	PKT.SID
		LNID	PSH.LNID

* Switch re-encoded packets are all ALV messages sent by switches as well as all dowlink messages encrypted with SWK. A switch shall know the immediate switch for each SID below it to be able to derive the nonce.

4.3.8.2.2.2.2.1 Message counter (PSH: CNT)

In order to avoid repetition attacks, in case the message counter of a message is not correctly validated according to this chapter, the message shall be discarded.

In the case of messages protected with WK, each node has a message counter starting from zero, incrementing after each protected message sent. This counter shall be reset after updating to a newer key.

In the case of messages protected with SWK, the counter used for nonce creation shall act following a distributed algorithm. This counter shall also be reset after updating to a newer key.

Upon reception of downlink message, every node shall validate that the counter is bigger than the last downlink message received. If the node is an intermediate Switch Node, once validated, the message shall be re-encoded before switching it down.

Upon reception of uplink message, a Switch Node shall not perform a validation of the CNT except for the cases when the message is processed by them. These are the use cases when it shall validate the message:

- ALV messages
- Data uplink messages switched down by a Direct Switch (does not apply to the intermediate Switch Nodes, only the Direct Switch itself)

A node shall maintain a transmission counter with the next value to be used in CNT field. This value shall be used when the node encodes and re-encodes a message. After using it, the node shall increase its value by 1.

When the node receives a counter bigger than the one stored for transmission, the transmission counter shall be updated with the received counter value + 1. This applies to both downlink and uplink messages. As a guideline, note that this forces any response message to have a counter bigger than the related request message, easing validation requirement and corner cases.

In security profile 1, direct switches are allowed to ignore validation of the first uplink data message from each peer, after that first message, the switch shall perform a validation of all uplink messages. This is to simplify implementation of direct switches on both memory usage and complexity.

Base Node shall validate all the uplink counters, considering all the rules described previously. In order to perform this, it shall keep track of individual counters for each node. The algorithm to do so is left up to the manufacturer of the Base Node.

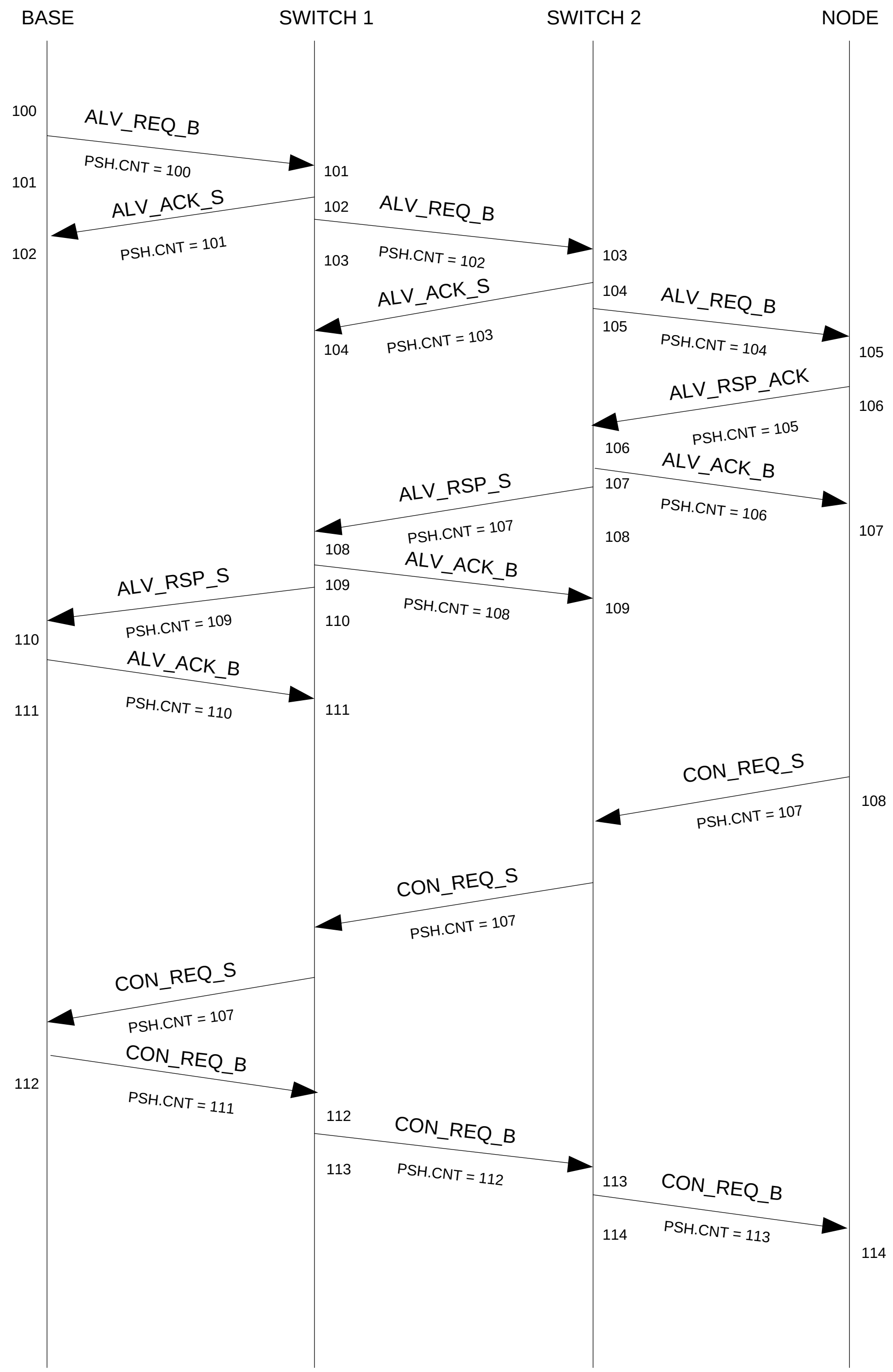

Figure 42 – Counter handling in ALV and request/response messages

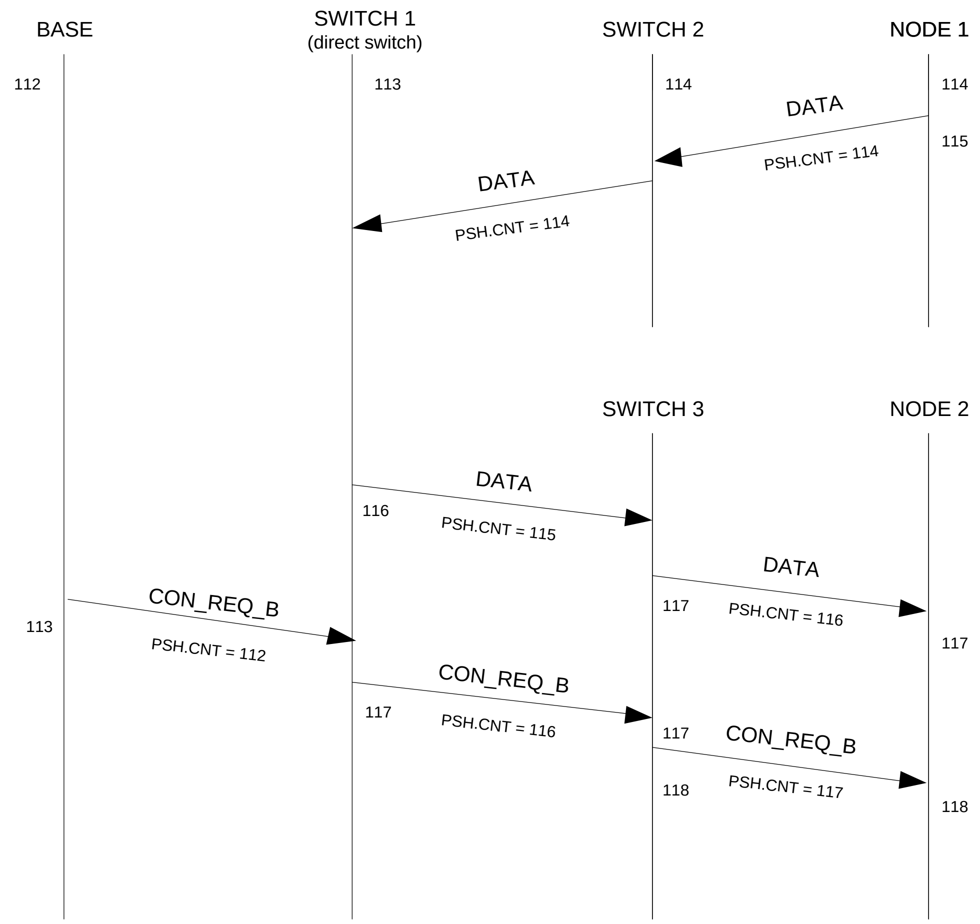

Figure 43 – Counter handling in direct connections and request messages

4.3.8.2.2.2.3 Creation of Challenge nonce for REG PDU-s

Each REG message relies on a 64 bit random number and the Subnetwork Address as a challenge. This challenge shall be used as the nonce for the authentication of the REG_REQ, REG_RSP and REG_REJ messages. The usage sequence is described in detail in 4.6.1.2.

The nonce, for each message, is shown in Figure 44, and is composed by the concatenation of the following entities:

- 40 least significant bits of the Subnetwork Address (found in BCN.SNA)
- For REG_REQ, Service Node shall generate a 64-bit random number and shall encode that value in the PSH.CNT and REG.CNT fields
- For REG_RSP and REG_REJ, REG.CNT shall be the copy of the same field coming from REG_REQ and PSH.CNT shall be PSH.CNT coming from REG_REQ incremented by 1, overflowing if necessary

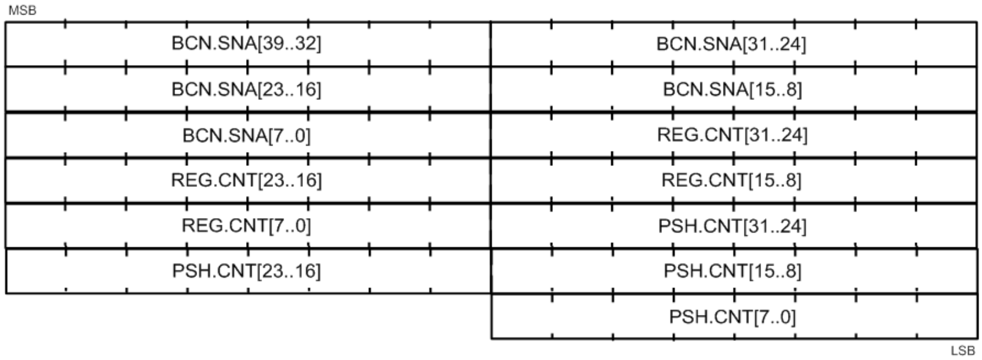

Figure 44 – REG Nonce structure

4.3.8.2.2.3 Key Derivation Algorithm

The method for key derivation is KDF in counter mode as specified in [23] using AES-CMAC [24] with key size of 128 as underlying PRF. This KDF requires 5 values as input:

- K_I which is the master key used to derive the output key K_O
- *Label* which is a string, fixed for the purpose of this security profile at “PRIME_MAC”
- *Context*, which is a string assuming different values accordingly to the purpose of the output key, which will be described in section 4.3.8.3.2
- *L* which is the size of the output key, which for the purpose of this security profile is fixed to 128.
- *r* which is an integer indicating the lengths of the binary representation of the counter and of *L*, which is fixed in this security profile to 32

4.3.8.2.2.4 Key Derivation Hierarchy

Figure 45 outlines the Key Derivation hierarchy and the process to derive the Key Wrapping Key (KWK) and the Registration Key (REGK).

The KWK is used to wrap the individual Working Key (WK) and the Subnetwork Working Key (SWK) when sent down from the Base Node to the Terminal Node, while the REGK is used for authentication in the registration process to authenticate both, BN and TN.

The random number generator used for WK and SWK should be compliant with [27].

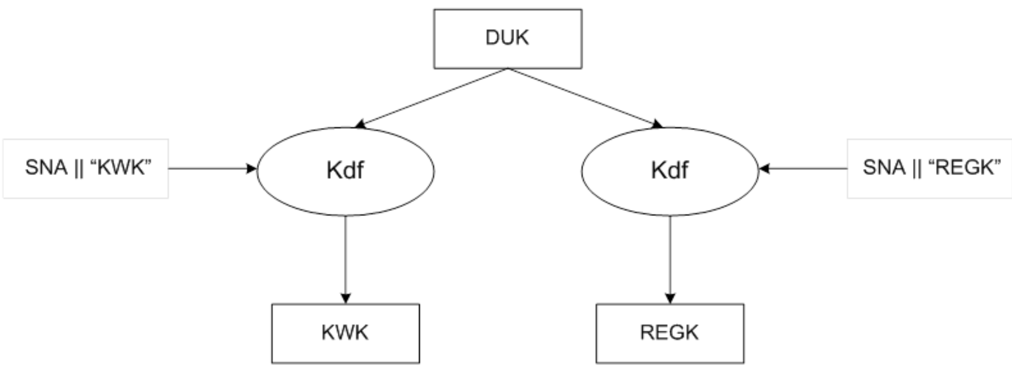

Figure 45 – Key derivation hierarchy

4.3.8.2.2.5 Key Wrapping Algorithm

The method for wrapping and unwrapping keys is referred to AES-128-KW, it is described as KW in [26], and uses AES-128 as underlying cipher. It is used to transmit keys in an encrypted form. In this security profile all keys are of 128 bit, which means that wrapped keys are 192 bits.

4.3.8.2.3 Encryption/Authentication by PDU Types

The following table shows which PDU-s are authenticated (A) and/or encrypted (E) on each of the security profiles. This table shows packet types with their names as presented in section 4.3.8.6. The packet nomination follows the following rules: if the packet is a generic name (e.g. REG), the profile will apply for all the subpacket types not listed in the table (e.g. REG_ACK).

Table 16 – Encryption/Authentication by PDU Types

PDU Type	**Profile 1**	**Profile 2**
REG_REQ, REG_RSP	REGK (A)	REGK (A)
REG_REJ	Plain	REGK (A)
Unicast DATA	WK (AE)*	WK (AE)*
SEC	WK(AE)	WK(AE)
Multicast DATA, Broadcast DATA, Direct connection DATA	SWK (AE)*	SWK (AE)*
PRO, MUL, CFP, CON, FRA, PCC, ALV, PRO_ACK, MUL_JOIN_B, MUL_LEAVE_S, PRO_DEM_S, PRO_DEM_B, REG_UNR_B, REG_UNR_S	Plain	SWK (AE)
REG_ACK	Plain	WK(A)

The rows highlighted with an asterisk (*) can be optionally sent not encrypted as described in section 4.3.8.6.

4.3.8.3 Negotiation of the Security Profile

4.3.8.3.1 General

All MAC data, including signaling PDUs (all MAC control packets defined in section 4.4.2.6) use the same security profile. This profile is negotiated during the device Registration. In the REG_REQ message the Terminal indicates a security profile it is able to support in the field REG.SPC. The Base Node may accept this security profile and so accept the Registration, sending back a REG_RSP with the same REG.SPC value. The Base Node may also accept the Registration, however it sets REG.SPC to 0, 1 or 2 indicating that security profile 0, 1 or 2 is to be used. Alternatively, the Base Node may reject the Registration if the Terminal does not provide an acceptable security profile.

It is recommended that the Terminal first attempts to register using the highest security profile it supports. In case the Base Node replies with a different value for REG.SPC, corresponding to a profile with lower security, the Terminal could refuse the registration by not sending the REG_ACK. The policy used by the Terminal to refuse a registration with a lower than expected security profile is out of the scope of this specification.

4.3.8.3.2 Key Types and Key Hierarchy

The key hierarchy of Security Profile 1 and 2 is based on three assumptions:

1. There is a 128 bit unique key on each service node called Device Unique Key (DUK). How this key is generated, provided to service nodes, is out of the scope of this specification. The DUK is managed by macSecDUK (refer to section 6.2.3.5.1.)
2. The Base Node must have knowledge of a Service Node's DUK by only knowing its EUI-48.
3. As specified by [REF TO NIST SP800-57Part1] "In general, a single key should be used for only one purpose".

The keys and their respective usage are:

Device Unique Key (DUK): DUK is used only for key derivation purposes, using the KDF described in section 4.3.8.2.2.3. It has the requirement to be unique for each device. It is used to generate KWK and REGK.

Key Wrapping Key (KWK): This key is derived from DUK using the concatenation of the Subnetwork Address (SNA) and the string "KWK" as *Context*. It is used to unwrap the keys received from the Base Node.

REG Key (REGK): This key is derived from DUK using the concatenation of the Subnetwork Address (SNA) and the string "REGK" as Context. It is used to protect, through AES-128-CCM, some of the REG control messages, specifically it is used for: REG_REQ, REG_RSP, REG_REJ only when REG.R=0. The reason is that there hasn't been any communication with the Base Node yet, so no other shared keys have been established.

Working Key (WK): This key is used to encrypt all the unicast data that is transmitted from the Base Node to a Service Node and vice versa. Each registered Service Node would have a unique WK that is known only to the Base Node and itself. The WK is randomly generated by the Base Node, wrapped through AES-128-KW and transmitted by the Base Node in REG_RSP and SEC messages.

Subnetwork Working Key (SWK): The SWK is shared by the entire Subnetwork. The SWK is randomly generated by the Base Node, wrapped through AES-128-KW and transmitted by the Base Node in REG_RSP and SEC messages.

The WK and the SWK have a limited validity time related to the random sequence generation period. The random sequence is regenerated and distributed by the Base Node at least every *MACUpdateKeysTime* seconds through the SEC control packet. If a device does not receive a new SEC message within *MACUpdateKeysTime* it shall move back from its present functional state to a *Disconnected* functional state.

The key hierarchy has been designed to ensure security of the required MAC keys, to follow NIST specifications and to be as simple as possible.

4.3.8.4 Key Distribution and Management

The Security Profile for data traffic is negotiated when a device is registered. The REG control packet contains specific fields to indicate the Security Profile for respective devices. All connections to/from the device would be required to follow the Security Profile negotiated at the time of Registration. There cannot be a difference in Security Profile across multiple connections involving the same device. The only exception to this would be the Base Node.

All keys are never transmitted in non-encrypted form over the physical channel. The SEC unicast messages transmitted by the Base Node at regular intervals contain random keys for both unicast and non-unicast traffic.

When a device initially registers on a Subnetwork, the REG response from the Base Node contains the wrapped SWK and WK. If the SN cannot unwrap the keys successfully, it shall discard the REG response and continue trying to register.

The process of updating WK is as follows:

- The SN shall start using the new WK immediately for transmission.
- The BN shall use the old WK for transmission until receiving the SEC response.
- The SN and BN shall be able to receive messages encrypted with both new and old WK until SEC exchange completes or Control packet retransmission (see 4.4.2.6.2) completes.
- If the SN cannot unwrap the new WK successfully, it shall indicate that it could not update WK and shall continue using the old WK. In such case, the BN shall retransmit the SEC message.

Upon reception of a new SWK that is successfully unwrapped, the node shall maintain the old SWK and use it to decrypt and encrypt the appropriate messages until:

1. a message is received encrypted with the new SWK.
2. the expiration of a 3-hour timer.

The timer provides a method for ensuring the old SWK will not be used indefinitely.

If the SN cannot unwrap the new SWK successfully, it shall indicate that it could not update SWK and shall continue using the old SWK. In such case, the BN shall retransmit the SEC message.

It is recommended that a Base Node register a Terminal Node with the old SWK and immediately perform a SEC procedure, with the registering Terminal Node, if the Terminal Node registers during an in progress SWK SEC procedure.

The Base Node shall maintain the old SWK for duration not to exceed 3-hours from the beginning of the SWK SEC procedure. This limit constrains the SWK SEC procedure duration to 3-hours. The Base Node can stop accepting the old SWK from any node before that duration, e.g. if it is certain that a Service Node has received a packet with the new SWK.

4.3.8.5 Encryption and Authentication

4.3.8.5.1 Security Profile 0

Not Applicable.

4.3.8.5.2 Security Profile 1 and 2

Security Profiles 1 and 2 make use of AES-CCM for packet protection but there are three different cases, accordingly to section 4.3.8.2.3:

- Plain: in the case the packet is not processed by AES-CCM and there is no Tag

Authentication Only: in this case the packet header where the PKT.RM is masked with 0, PSH, TREF (if exists) where the values are masked with 0, ARQ (if exists) and the payload should be processed by AES-CCM as associated data. This situation is depicted in Figure 46.

- Authentication and Encryption: in this case the packet header where the PKT.RM is masked with 0, PSH, TREF (if exists) where the values are masked with 0 and ARQ (if exists) should be processed as associated data, thus only being authenticated, while the payload should be processed as payload, thus authenticated and encrypted. This situation is depicted in Figure 47.

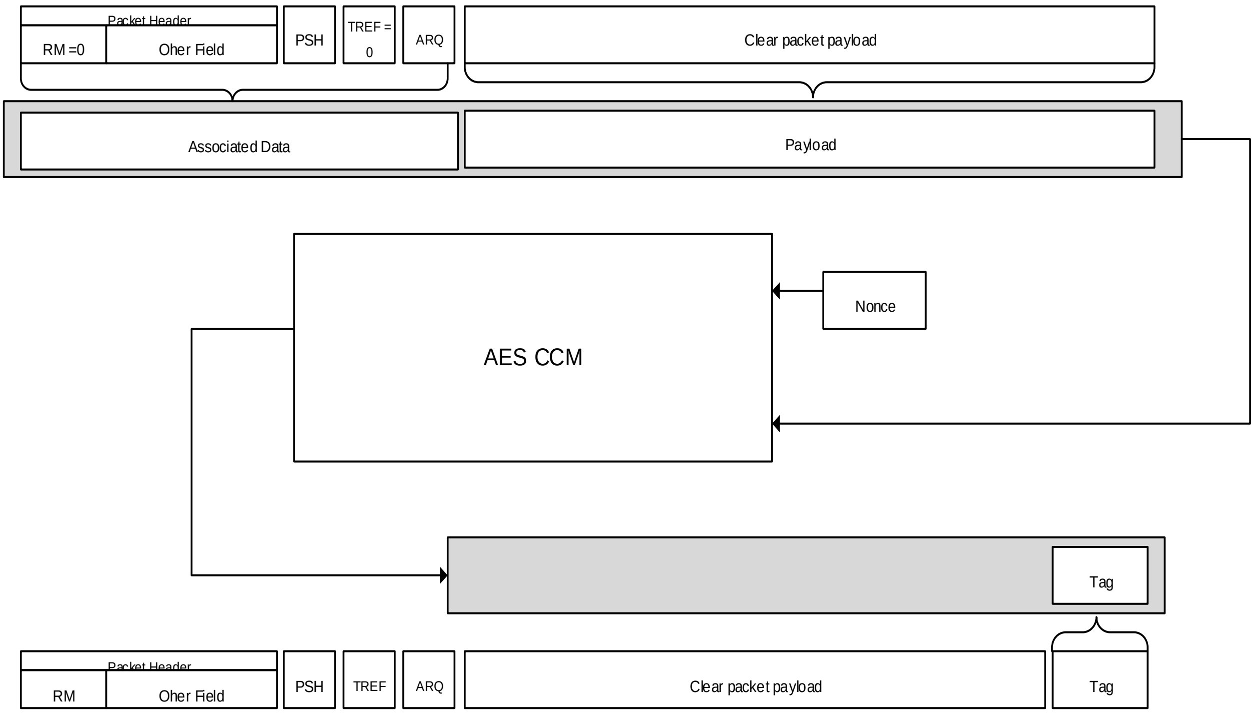

Figure 46 – Security profile 1 and 2 encryption algorithm (authentication only)

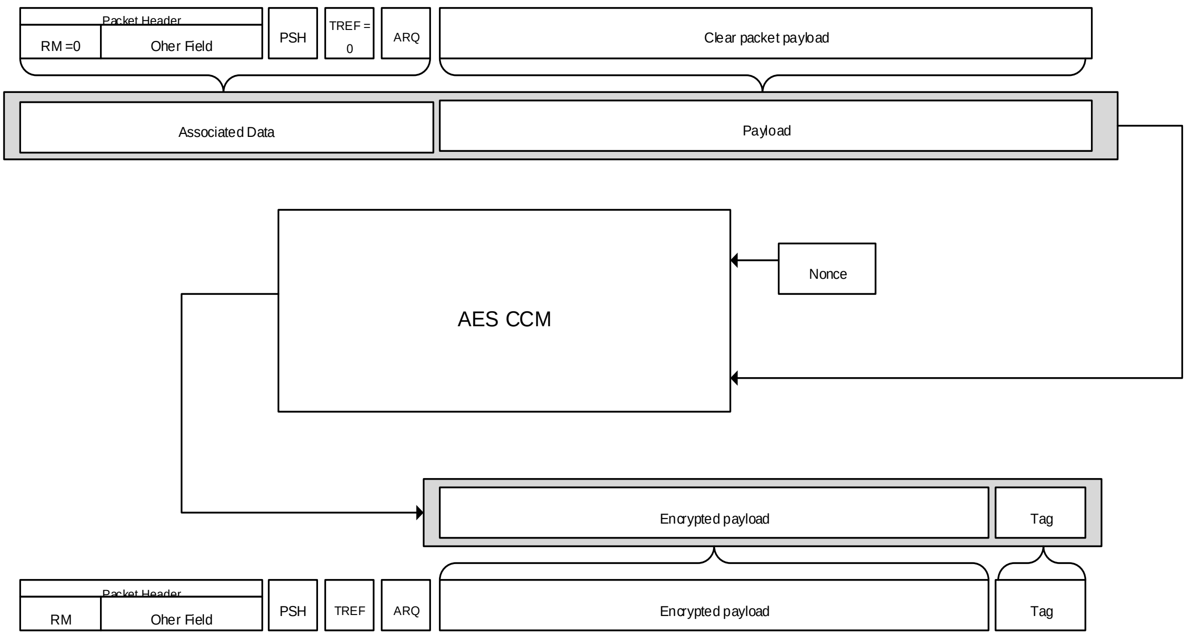

Figure 47 – Security profile 1 and 2 encryption algorithm (authentication and encryption)

4.3.8.6 Unicast and Multicast connection security negotiation

There are some use cases in which it is not desirable to authenticate and encrypt data packets. One use case of this is the firmware upgrade for images that are already signed and potentially encrypted.

For such cases both the unicast and multicast connection establishment procedures have a feature that allows a negotiation for enabling or disabling the security on DATA packets. This procedure only applies to profiles 1 and 2, because profile 0 does not allow encryption.

Each side shall indicate in the CON_REQ and MUL_JOIN packets if the DATA packets for that connection shall be authenticated and encrypted or not.

- In case both sides indicate that the DATA packets shall not be securitized, then the packets shall be sent without being authenticated or encrypted.
- If at least one of the sides indicates that the packets shall be securitized, then the packets shall be authenticated and encrypted.

Regarding broadcast connections, no negotiation takes place. Broadcast connections shall always be authenticated and encrypted.

4.3.8.7 Unicast and Multicast connection security negotiation

After initial negotiation, any multicast connection sending plain data can be upgraded to be authenticated and encrypted at any point. The usual use case is that a new node has joined the multicast group negotiating the connection to be authenticated and encrypted.

The upgrade mechanism is to start sending multicast data authenticated and encrypted, without any additional control message. Any node receiving multicast data that is authenticated and encrypted shall assume the connection has been upgraded to be authenticated and encrypted from the reception of that data.

There is no procedure for a multicast connection to be downgraded to send plain data.

4.4 MAC PDU format

4.4.1 General

There are different types of MAC PDUs for different purposes.

Note that reserved bits must always be set to 0.

To allow for PDU compatibility with previous specification versions, when it is necessary to include an additional field in an existing PDU, several options are possible:

1) If the new field fits in the reserved bits available in the PDU and the null value of the new field does not interfere with the expected behaviour of the reserved bits, it can be included using them.
2) If the new field requires more bits than the reserved bits available in the PDU, a reserved bit shall be used to indicate the presence of the new field. The new field may be added using other reserved bits

– as long as the null value does not interfere with the expected behaviour of the reserved bits – or, if that is not possible, it will be added at the end of the PDU.

3) If some fields are not used in the PDU, even if they are not reserved, a reserved bit may change their meaning.

4.4.2 Generic MAC PDU

4.4.2.1 General

Most Subnetwork traffic comprises Generic MAC PDUs (GPDU). GPDUs are used for all data traffic and most control traffic. All MAC control packets are transmitted as GPDUs.

GPDU composition is shown in Figure 48. It is composed of a Generic MAC Header followed by one or more MAC packets and 32 bit CRC appended at the end.

Figure 48 – Generic MAC PDU format

4.4.2.2 Generic MAC Header

The Generic MAC Header format is represented in Figure 46 and Table 17. The size of the Generic MAC Header is 3 bytes. Table 17 enumerates each field of a Generic MAC Header.

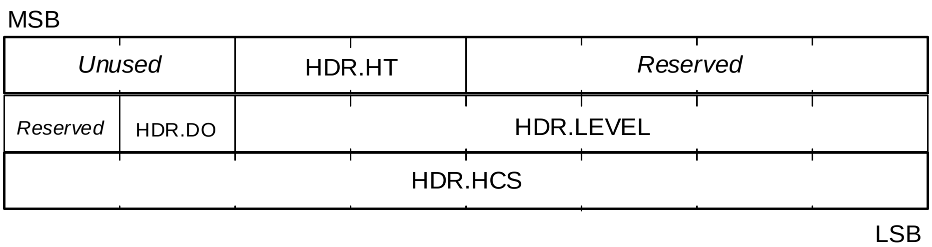

Figure 49 - Generic MAC header

Table 17 - Generic MAC header fields

Name	**Length**	**Description**
Unused	2 bits	Unused bits those are always 0; included for alignment with MAC_H field in PPDU header (Section 3.3.2.3).
HDR.HT	2 bits	Header Type. HDR.HT = 0 for GPDU
Reserved	5 bits	Always 0 for this version of the specification. Reserved for future use.
HDR.DO	1 bit	Downlink/Uplink. • HDR.DO=1 if the MAC PDU is Downlink. • HDR.DO=0 if the MAC PDU is uplink.

Name	Length	Description
HDR.LEVEL	6 bits	Level of the PDU in switching hierarchy. The packets between the level 0 and the Base Node are of HDR.LEVEL=0. The packets between levels k and k-1 are of HDR.LEVEL=k. • If HDR.DO=0, HDR.LEVEL represents the level of the transmitter of this packet. • If HDR.DO=1, HDR.LEVEL represents the level of the receiver of this packet.
HDR.HCS	8 bits	Header Check Sequence. A field for detecting errors in the header and checking that this MAC PDU is from this Subnetwork. The transmitter shall calculate the CRC of the SNA concatenated with the first 2 bytes of the header and insert the result into the HDR.HCS field (the last byte of the header). The CRC shall be calculated as the remainder of the division (Modulo 2) of the polynomial $M(x)\cdot x^8$ by the generator polynomial $g(x)=x^8+x^2+x+1$. M(x) is the input polynomial, which is formed by the bit sequence of the concatenation of the SNA and the header excluding the HDR.HCS field, and the msb of the bit sequence is the coefficient of the highest order of M(x).

4.4.2.3 Packet structure

A packet is comprised of a Packet Header and Packet Payload. Figure 50 shows the structure.

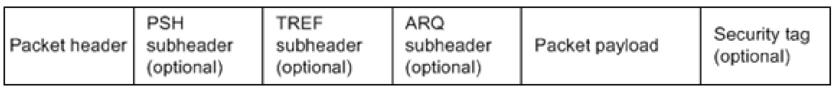

Figure 50 - Packet structure

Packet header is 7 bytes in length and its composition is shown in Figure 51. Table 18 enumerates the description of each field.

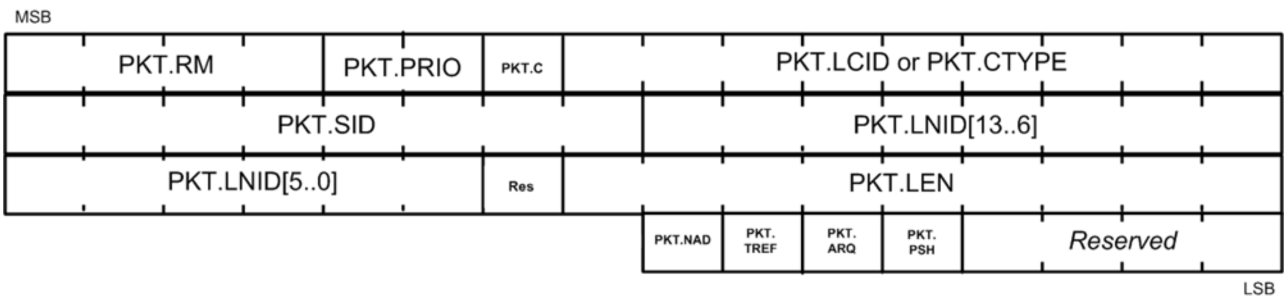

Figure 51 – Packet Header

To simplify, the text contains references to the PKT.NID fields as the composition of the PKT.SID and PKT.LNID. The field PKT.CID is also described as the composition of the PKT.NID and the PKT.LCID. The composition of these fields is described in Figure 52.

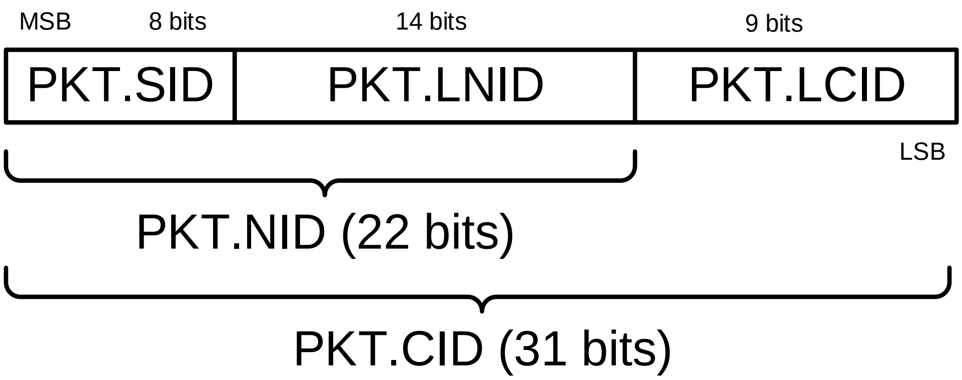

Figure 52 - PKT.CID structure

Table 18 – Packet header fields

Name	**Length**	**Description**
PKT.RM	4 bits	Weakest modulation this node can decode from the receiving peer. If the PCH is PLC • 0 – DBPSK • 1 – DQPSK • 2 – D8PSK • 3 – Not used • 4 – DBPSK + Convolutional Code • 5 – DQPSK + Convolutional Code • 6 – D8PSK + Convolutional Code • 7-11 – Not used • 12 – Robust DBPSK • 13 – Robust DQPSK • 14 – Not used • 15 – Outdated information
PKT.PRIO	2 bits	Indicates packet priority between 0 and 3.
PKT.C	1 bits	Control • If PKT.C=0 it is a data packet. • If PKT.C=1 it is a control packet.
PKT.LCID / PKT.CTYPE	9 bits	Local Connection Identifier or Control Type • If PKT.C=0, PKT.LCID represents the Local Connection Identifier of data packet. • If PKT.C=1, PKT.CTYPE represents the type of the control packet.

Name	Length	Description
PKT.SID	8 bits	Switch identifier • If HDR.DO=0, PKT.SID represents the SID of the packet source. • If HDR.DO=1, PKT.SID represents the SID of the packet destination.
PKT.LNID	14 bits	Local Node identifier. • If HDR.DO=0, PKT.LNID represents the LNID of the packet source • If HDR.DO=1, PKT.LNID represents the LNID of the packet destination.
Reserved	1bit	Always 0 for this version of the specification. Reserved for future use.
PKT.LEN	9 bits	Length of the packet excluding the packet header and the authentication tag (if present). It is the sum of the lengths of the payload and the subheaders (if any).
PKT.NAD	1 bit	No Aggregation at Destination • If PKT.NAD=0 the packet may be aggregated with other packets at destination. • If PKT.NAD=1 the packet may not be aggregated with other packets at destination.
PKT.TREF	1 bit	TREF subheader presence: • If PKT.TREF=0 the packet doesn’t include a TREF subheader. • If PKT.TREF=1 the packet includes a TREF subheader.
PKT.ARQ	1 bit	ARQ subheader presence: • If PKT.ARQ=0 the packet doesn’t include an ARQ subheader. • If PKT.ARQ=1 the packet includes an ARQ subheader.
PKT.PSH	1 bit	Packet security subheader presence: • If PKT.PSH=0 the packet doesn’t include a security subheader. • If PKT.PSH=1 the packet includes a security subheader.
Reserved	4 bits	Always 0 for this version of the specification. Reserved for future use.

The “ARQ subheader”, “TREF subheader” and “security subheader” are optional. Their presence depends on the PKT.ARQ, PKT.TREF and PKT.PSH flags. The description of the ARQ subheader will be done in the section 4.7.3.2 and the description of the TREF subheader will be done in section 4.8. MAC Control packets shall not include a TREF or ARQ subheader.

4.4.2.4 CRC

The CRC is the last field of the GPDU. It is 32 bits long. It is used to detect transmission errors. The CRC shall cover the concatenation of the SNA with the GPDU except for the CRC field itself.

The input polynomial M(x) is formed as a polynomial whose coefficients are bits of the data being checked (the first bit to check is the highest order coefficient and the last bit to check is the coefficient of order zero).

The Generator polynomial for the CRC is $G(x)=x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1$. The remainder R(x) is calculated as the remainder from the division of $M(x)\cdot x^{32}$ by G(x). The coefficients of the remainder shall then be the resulting CRC.

4.4.2.5 Security header

For the security profiles 1 and 2, the security subheader contains the needed information to authenticate and/or encrypt the packet.

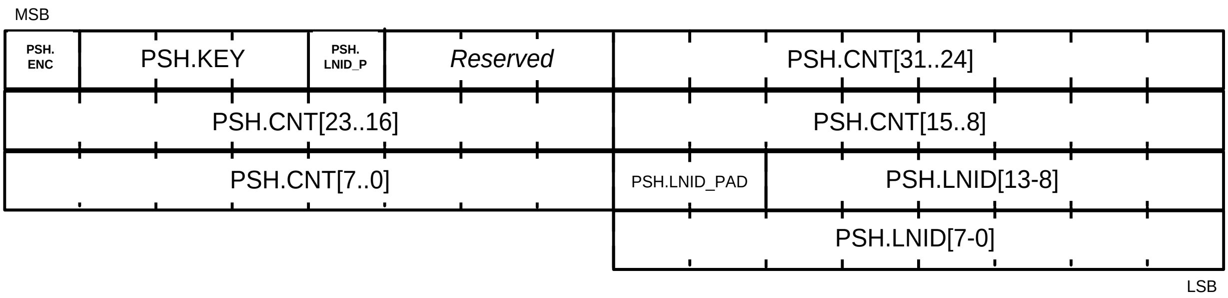

Figure 53 – Security subheader

The description of the fields is described in the following table.

Table 19 – Security subheader fields

Name	Length	Description
PSH.ENC	1 bit	Flag to determine if the packet is encrypted: 0 – The packet is Authenticated 1 – The packet is Authenticated and Encrypted
PSH.KEY	3 bits	Key used for the encoding of this packet: 0 – WK 1 – SWK 2 – REG 3-8 – Reserved for future used.
PSH.LNID_P	1 bit	Flag to determine if the PSH.LNID is present (counting the reserved bits leading it). 0 – If PSH.LNID is not present 1 – If PSH.LNID is present
Reserved	3 bits	Always 0 for this version of the specification. Reserved for future use.
PSH.CNT	32 bits	Counter to be used in the nonce composition. *** For replay protection, receiving node needs to discard packets that do not follow the rules described in 0.**
PSH.LNID_PAD	2 bits	Always 0 for this version of the specification. Reserved for future use. Only present if PSH.LNID_P field set to one.

Name	Length	Description
PSH.LNID	14 bits	Transmitter LNID field to create the nonce when it cannot be derived from the packet. The exception being REG packets. Only present if PSH.LNID_P field set to one.

When the security header is present, a 48-bit authentication tag is appended to the packet. The authentication tag is the output of the AES-CCM operation (see Figure 47).

4.4.2.6 MAC control packets

4.4.2.6.1 General

MAC control packets enable a Service Node to communicate control information with their Switch Node, Base Node and vice versa. A control packet is transmitted as a GPDU and is identified with PKT.C bit set to 1 (See section 4.4.2 for more information about the fields of the packets).

There are several types of control messages. Each control message type is identified by the field PKT.CTYPE. Table 20 lists the types of control messages. The packet payload (see section 4.4.2.3) shall contain the information carried by the control packets. This information differs depending on the packet type.

Table 20 - MAC control packet types

Type (PKT.CTYPE)	Packet name	Packet description
1	REG	Registration management
2	CON	Connection management
3	PRO	Promotion management
5	FRA	Frame structure change
6	CFP	Contention-Free Period request
7	ALV	Keep-Alive
8	MUL	Multicast Management
10	SEC	Security information
11	PCC	Programmed configuration change

4.4.2.6.2 Control packet retransmission

For recovery from lost control messages, a retransmit scheme is defined. MAC control transactions comprising of exchange of more than one control packet may follow the retransmission mechanism described in this section.

The retransmission scheme shall be applied to the following packets when they require a response:

- CON_REQ_S, CON_REQ_B;

- CON_CLS_S, CON_CLS_B;
- REG_RSP;
- PRO_REQ_B;
- MUL_JOIN_S, MUL_JOIN_B;
- MUL_LEAVE_S, MUL_LEAVE_B;
- MUL_SW_LEAVE_B
- SEC_REQ

Devices involved in a MAC control transaction using retransmission mechanism shall maintain a retransmit timer and a message fail timer.

At the requester of a control message transaction:

- When the one of the above messages in a transaction is transmitted, the retransmit timer is started with value greater or equal to macMinCtlReTxTimer and the control message fail timer is started with value macCtrlMsgFailTime.

If a response message is received the retransmit timer and control message fail timer are stopped and the transaction is considered complete. Note that it is possible to receive further response messages. These would be messages that encountered network delays.

- If the retransmit timer expires the control message is retransmitted and the retransmit timer is re-started with value greater or equal to macMinCtlReTxTimer (value can be different from the previous one).
- If the control message fail timer expires, failure result corresponding to respective MAC-SAP should be returned to the calling entity. Implementations may also choose to inform their local management entity of such failure. If the retransmission is done by the Service Node, the device shall return to the *Disconnected* functional state

At the responder of a control message transaction:

- The receiver of a message must determine itself if this message is a retransmit. If so, no local action is needed other than sending a reply to the response.

If the received message is not a retransmit, the message shall be processed and a response returned to the sender.

- For transactions which use three messages in the transaction, e.g. promotion as shown in 4.6.3, the responder shall perform retransmits in exactly the same way as the requester. This ensures that if the third message in the transaction is lost, the message shall be retried and the transaction completed.

The following message sequence charts show some examples of retransmission. Figure 54 shows two successful transactions without requiring retransmits.

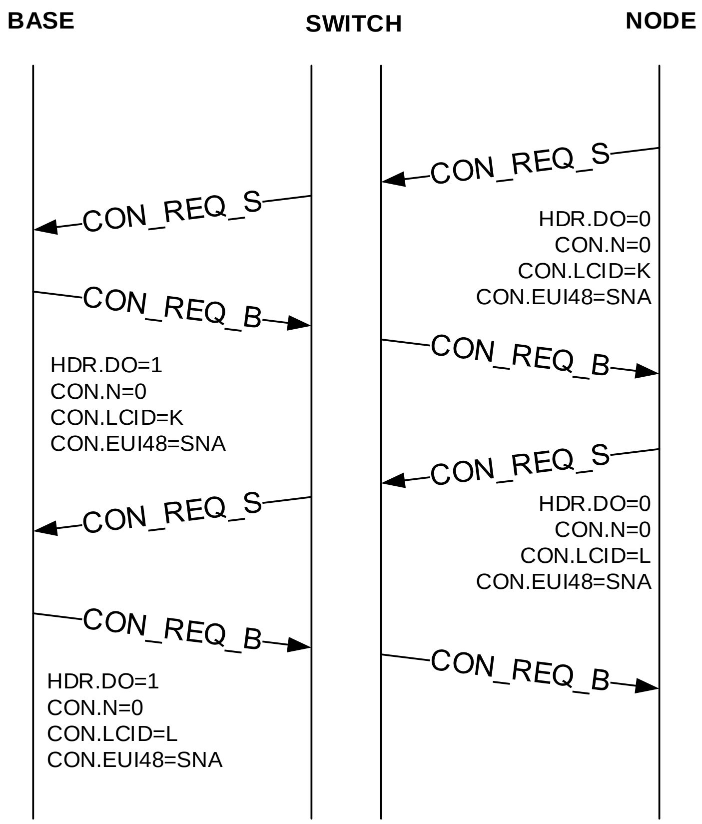

Figure 54 – Two transactions without requiring retransmits

Figure 55 shows a more complex example, where messages are lost in both directions causing multiple retransmits before the transaction completes.

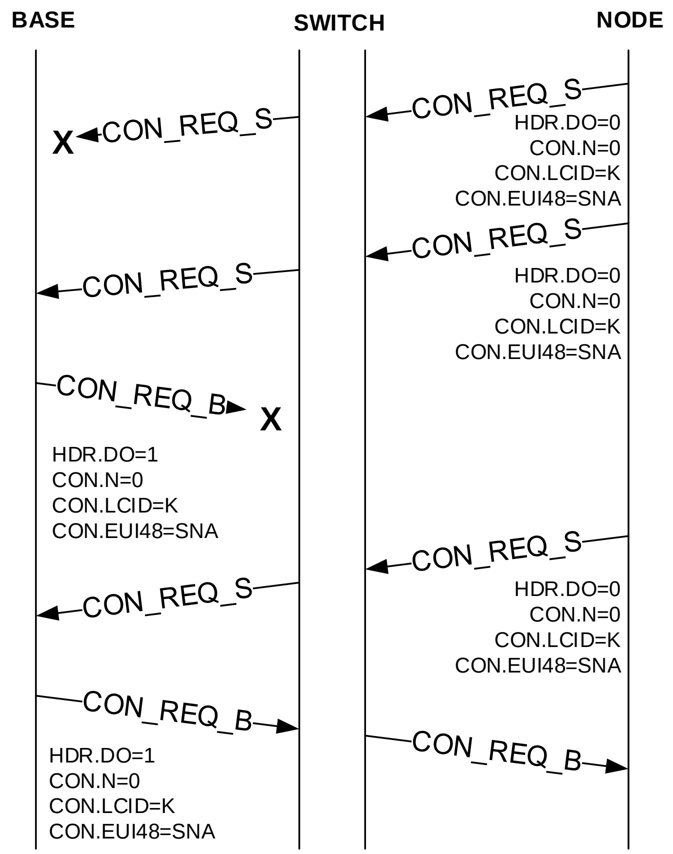

Figure 55 - Transaction with packet loss requiring retransmits

Figure 56 shows the case of a delayed response causing duplication at the initiator of the control transaction.

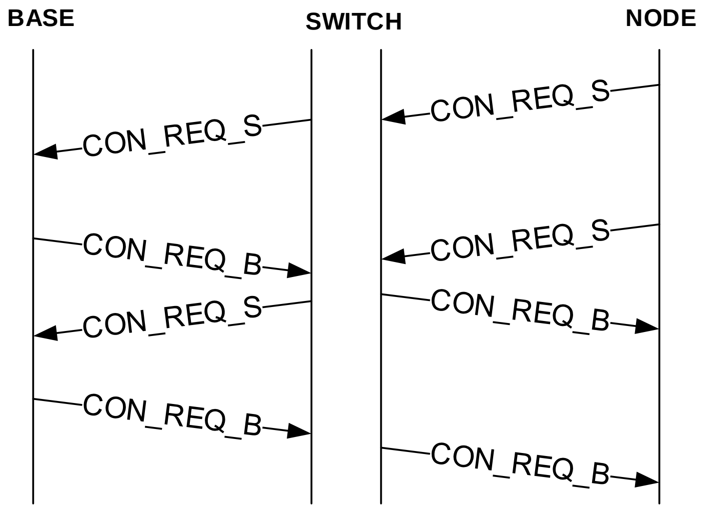

Figure 56 – Duplicate packet detection and elimination

4.4.2.6.3 REG control packet (PKT.CTYPE=1)

This control packet is used to negotiate the Registration process. The description of data fields of this control packet is described in Table 21 and Figure 57. The meaning of the packets differs depending on the direction of the packet. This packet interpretation is explained in Table 21. These packets are used during the registration and unregistration processes, as explained in 4.6.1 and 4.6.2.

2247 **Table 21 - REG control packet fields**

Name	Length	Description
REG.N	1 bit	Negative **REG.N=1 for the negative register;** **REG.N=0 for the positive register.** (see Table 20)
REG.R	1 bit	Roaming REG.R=1 if Node already registered and wants to perform roaming to another Switch; REG.R=0 if Node not yet registered and wants to perform a clear registration process. It shall be set by SN in REG_REQ.
REG.SPC	2 bits	Security Profile Capability for Data PDUs: REG.SPC=0 No encryption capability; REG.SPC=1 Security profile 1 capable device; REG.SPC=2 Security profile 2 capable device; REG.SPC=3 Security profile 3 capable device (not yet specified).
REG.CAP_R	1 bit	Robust mode Capable 1 if the device is able to transmit/receive robust mode frames 0 if the device is not It shall be set by SN in REG_REQ
REG.CAP_BC	1 bit	Backwards Compatible with 1.3.6 1 if the device can operate in backwards compatible mode with 1.3.6 PRIME 0 if the device is not It shall be set by SN in REG_REQ and by BN in REG_RSP.

Name	Length	Description
REG.CAP_SW	1 bit	Switch Capable 1 if the device is able to behave as a Switch Node; 0 if the device is not. It shall be set by SN in REG_REQ.
REG.CAP_PA	1 bit	Packet Aggregation Capability 1 if the SN device has packet aggregation capability; if the BN device has packet aggregation capability together with all the switches along the downlink path to the registration requesting SN and the requesting SN itself; 0 otherwise. It shall be set by SN in REG_REQ and by BN in REG_RSP.
REG.CAP_CFP	1 bit	Contention Free Period Capability 1 if the device is able to perform the negotiation of the CFP; 0 if the device cannot use the Contention Free Period in a negotiated way. It shall be set by SN in REG_REQ and by BN in REG_RSP.
REG.CAP_DC	1 bit	Direct Connection Capability 1 if the device is able to perform direct connections; 0 if the device is not able to perform direct connections. It shall be set by SN in REG_REQ.
REG.ALV_F	1 bit	Bit to indicate which ALV mechanism is required to be used by the new Service Node while it is part of this Subnetwork. 1 ALV procedure of v1.4 shall be used 0 ALV procedure of v1.3.6 (section K.2.5) shall be used. It shall be set by BN in REG_RSP. **Note:** Base Node shall not selectively use different values of this bit between different Service Nodes in its Subnetwork. In case ALV procedure of v1.3.6 is used, all Service Nodes shall be instructed with REG.ALV_F bit set to 0.

Name	Length	Description
REG.CAP_MP	1 bit	Multi-PHY Capability REG_REQ 1 if the device is able to generate multi-PHY promotion message 0 if not REG_RSP 1 if the base node is able to process multi-PHY promotion message 0 if not
REG.CAP_ARQ	1 bit	ARQ Capable 1 if the device is able to establish ARQ connections; 0 if the device is not able to establish ARQ connections. It shall be set by SN in REG_REQ and by BN in REG_RSP.
REG.TIME	3 bits	Time to wait for an ALV procedure before assuming the Service Node has been unregistered by the Base Node. ALV.TIME = 0 => 128 seconds ~ 2.1 minutes; ALV.TIME = 1 => 256 seconds ~ 4.2 minutes; ALV.TIME = 2 => 512 seconds ~ 8.5 minutes; ALV.TIME = 3 => 2048 seconds ~ 34.1 minutes; ALV.TIME = 4 => 4096 seconds ~ 68.3 minutes; ALV.TIME = 5 => 8192 seconds ~ 136.5 minutes; ALV.TIME = 6 => 16384 seconds ~ 273.1 minutes; ALV.TIME = 7 => 32768 seconds ~ 546.1 minutes; It shall be set by BN in REG_RSP.
REG.EUI-48	48 bit	EUI-48 of the Node EUI-48 of the Node requesting the Registration.

Name	Length	Description
REG.RM_F	2 bits	Forces an encoding for the given node disabling robustness-management for its transmission, it can be disabled. Only used in REG_RSP. In all other message variants, this shall be 0. 0 - Disable, automatic robustness-management by the service nodes 1 - DBPSK_CC, device shall transmit always in DBPSK_CC 2 - DQPSK_R , device shall transmit always in DQPSK_R 3 - DBPSK_R , device shall transmit always in DBPSK_R
REG.SAR_SIZE	3 bits	Maximum SAR segment size the service node shall use. Only used in REG_RSP. In all other message variants, this shall be 0.0: Not mandated by BN (SAR operates normally) 1: SAR = 16 bytes 2: SAR =32 bytes 3: SAR = 48 bytes 4: SAR =64 bytes 5: SAR =128 bytes 6: SAR =192 bytes 7: SAR =255 bytes
Reserved	3 bits	Always 0 for this version of the specification. Reserved for future use.
REG.CNT	32 bits	A counter to be used as the nonce for the registration PDU-s authentication/encryption.
REG.SWK	192 bits	Subnetwork key wrapped with KWK that shall be used to derive the Subnetwork working key
REG.WK	192 bits	Encrypted authentication key wrapped with KWK. This is a random sequence meant to act as authentication mechanism.

The PKT.SID field is used in this control packet as the Switch where the Service Node is registering. The PKT.LNID field is used in this control packet as the Local Node Identifier being assigned to the Service Node during the registration process negotiation.

The REG.CAP_PA field is used to indicate the packet aggregation capability as discussed in Section 4.3.7. In the uplink direction, this field is an indication from the registering Terminal Node about its own capabilities. For the Downlink response, the Base Node evaluates whether or not all the devices in the cascaded chain from itself to this Terminal Node have packet-aggregation capability. If they do, the Base Node shall set REG.CAP_PA=1; otherwise REG.CAP_PA=0.

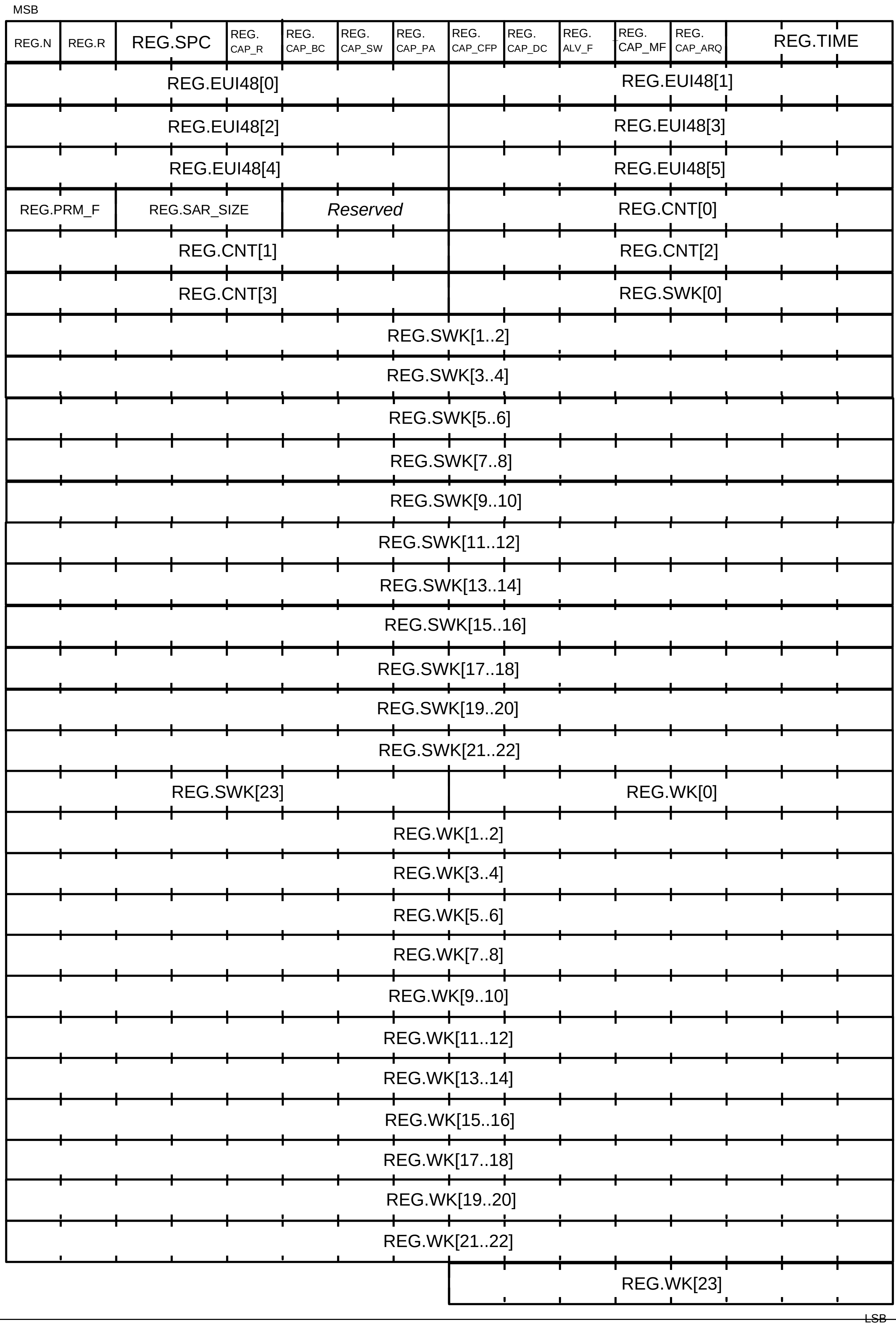
MSB
REG.N
REG.R
REG.SPC
REG. CAP_R
REG. CAP_BC
REG. CAP_SW
REG. CAP_PA
REG. CAP_CFP
REG. CAP_DC
REG. ALV_F
REG. CAP_MF
REG. CAP_ARQ
REG.TIME
REG.EUI48[0]
REG.EUI48[1]
REG.EUI48[2]
REG.EUI48[3]
REG.EUI48[4]
REG.EUI48[5]
REG.PRM_F
REG.SAR_SIZE
Reserved
REG.CNT[0]
REG.CNT[1]
REG.CNT[2]
REG.CNT[3]
REG.SWK[0]
REG.SWK[1..2]
REG.SWK[3..4]
REG.SWK[5..6]
REG.SWK[7..8]
REG.SWK[9..10]
REG.SWK[11..12]
REG.SWK[13..14]
REG.SWK[15..16]
REG.SWK[17..18]
REG.SWK[19..20]
REG.SWK[21..22]
REG.SWK[23]
REG.WK[0]
REG.WK[1..2]
REG.WK[3..4]
REG.WK[5..6]
REG.WK[7..8]
REG.WK[9..10]
REG.WK[11..12]
REG.WK[13..14]
REG.WK[15..16]
REG.WK[17..18]
REG.WK[19..20]
REG.WK[21..22]
REG.WK[23]
LSB

Figure 57 - REG control packet structure

Table 22 - REG control packet types

Name	HDR.DO	PKT.LNID	REG.N	REG.R	Description
REG_REQ	0	0x3FFF	0	R	Registration request • If R=0 any previous connection from this Node shall be lost; • If R=1 any previous connection from this Node shall be maintained.
REG_RSP	1	< 0x3FFF	0	R	Registration response. This packet assigns the PCK.LNID to the Service Node.
REG_ACK	0	< 0x3FFF	0	R	Registration acknowledged by the Service Node.
REG_REJ	1	0x3FFF	1	0	Registration rejected by the Base Node.
REG_UNR_S	0	< 0x3FFF	1	0	• After a REG_UNR_B: Unregistration acknowledge; • Alone: Unregistration request initiated by the Node.
REG_UNR_B	1	< 0x3FFF	1	0	• After a REG_UNR_S: Unregistration acknowledge; • Alone: Unregistration request initiated by the Base Node

Fields REG.SWK and REG.WK are of significance only for REG_RSP messages with Security Profiles 1 and 2 (REG.SCP=1 and REG.SCP=2). For all other message-exchange variants using the REG control packet, these fields shall not be present reducing the length of payload.

In REG_RSP message, the REG.SWK and REG.WK shall always be inserted wrapped with KWK.

Field REG.CNT is of significance only for REG_REQ, REG_RSP and REG_REJ messages with Security Profiles 1 and 2 (REG.SCP=1 and REG.SCP=2). For all other message-exchange variants using the REG control packet, these fields shall not be present reducing the length of payload.

4.4.2.6.4 CON control packet (PKT.CTYPE = 2)

This control packet is used for negotiating the connections. The description of the fields of this packet is given in Table 23 and Figure 58 The meaning of the packet differs depending on the direction of the packet and on the values of the different types.

Table 24 shows the different interpretation of the packets. The packets are used during the connection establishment and closing.

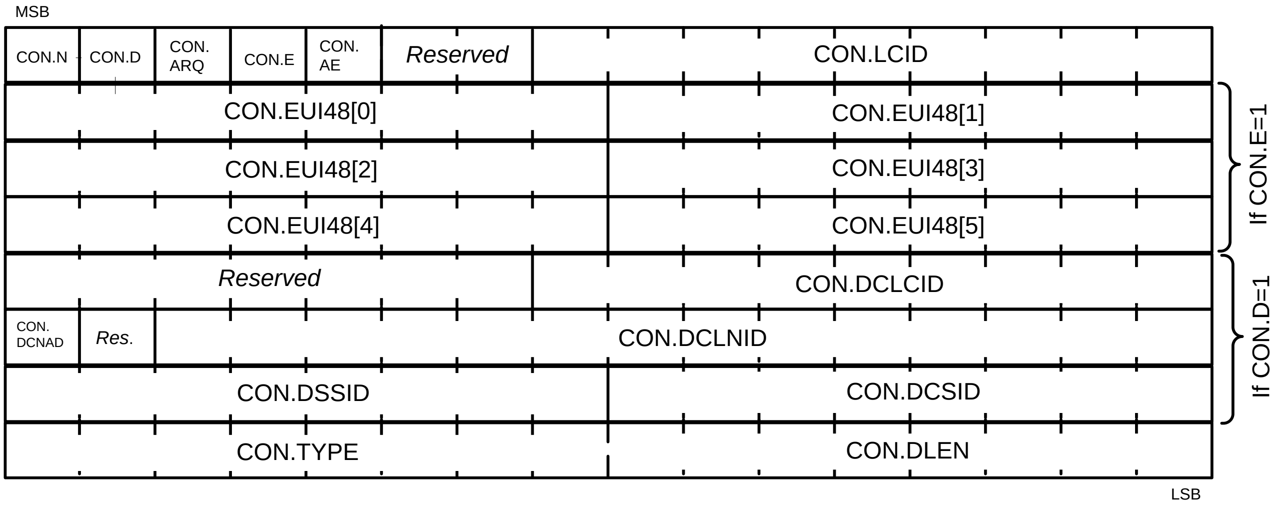

Figure 58 - CON control packet structure

Note that Figure 58 shows the complete message with all optional parts. When CON.D is 0, CON.DCNAD, CON.DSSID, CON.DCLNID, CON.DCLID, CON.DCSID and the reserved field between CON.DCNAD and CON.DSSID shall not be present in the message. Thus, the message shall be 6 octets smaller. Similarly, when CON.E is zero, the field CON.EUI-48 shall not be present, making the message 6 octets smaller.

Table 23 - CON control packet fields

Name	Length	Description
CON.N	1 bit	Negative • CON.N=1 for the negative connection; • CON.N=0 for the positive connection.
CON.D	1 bit	Direct connection • CON.D=1 if information about direct connection is carried by this packet; • CON.D=0 if information about direct connection is not carried by this packet.
CON.ARQ	1 bit	ARQ mechanism enable • CON.ARQ=1 if ARQ mechanism is enabled for this connection; • CON.ARQ=0 if ARQ mechanism is not enabled for this connection.
CON.E	1 bit	EUI-48 presence • CON.E = 1 to have a CON.EUI-48; • CON.E = 0 to not have a CON.EUI-48 so that this connection establishment is for reaching the Base Node CL.

Name	Length	Description
CON.AE	1 bit	Use authentication and encryption on the data sent using this connection. • CON.AE = 1 to encrypt and authenticate the data packets. • CON.AE = 0 to send the plain data without any authentication and encryption. This flag is valid in both directions; each side shall set it to the desired value. The highest security will be applied in case the values do not match. So if any side sets this flag to 1 the data shall be authenticated and encrypted. NOTE: This flag only can be 1 on security profiles 1 and 2.
Reserved	2 bits	Reserved for future version of the protocol. This shall be 0 for this version of the protocol.
CON.LCID	9 bits	Local Connection Identifier. The LCID is reserved in the connection request. LCIDs from 0 to 255 are assigned by the connection requests initiated by the Base Node. LCIDs from 256 to 511 are assigned by the connection requests initiated by the local Node. This is the identifier of the connection being managed with this packet. This is not the same as the PKT.LCID of the generic header, which does not exist for control packets.
CON.EUI-48	48 bits (Present if CON.E=1)	EUI-48 of destination/source Service Node/Base Node for connection request. When not performing a directed connection, this field shall not be included. When performing a directed connection, it may contain the SNA, indicating that the Base Node Convergence layer shall determine the EUI-48. • CON.D = 0, Destination EUI-48; • CON.D = 1, Source EUI-48.
Reserved	7 bits (Present if CON.D=1)	Reserved for future version of the protocol. This shall be 0 for this version of the protocol.
CON.DCLCID	9 bits (Present if CON.D=1)	Direct Connection LCID This field represents the LCID of the connection identifier to which the one being established shall be directly switched.

Name	Length	Description
CON.DCNAD	1 bit (Present if CON.D=1)	Reserved for future version of the protocol. Direct Connection Not Aggregated at Destination This field represents the content of the PKT.NAD field after a direct connection Switch operation.
Reserved	1 bits (Present if CON.D=1)	Reserved for future version of the protocol. This shall be 0 for this version of the protocol.
CON.DCLNID	14 bits (Present if CON.D=1)	Direct Connection LNID This field represents the LNID part of the connection identifier to which the one being established shall be directly switched.
CON.DSSID	8 bits (Present if CON.D=1)	Direct Switch SID This field represents the SID of the Switch that shall learn this direct connection and perform direct switching.
CON.DCSID	8 bits (Present if CON.D=1)	Direct Connection SID This field represents the SID part of the connection identifier to which the one being established shall be directly switched.
CON.TYPE	8 bits	Connection type. The connection type (see Annex E) specifies the Convergence layer to be used for this connection. They are treated transparently through the MAC common part sublayer, and are used only to identify which Convergence layer may be used.
CON.DLEN	8 bits	Length of CON.DATA field in bytes
CON.DATA	*(variable)* (Present if CON.DLEN>0)	Connection specific parameters. These connections specific parameters are Convergence layer specific. They shall be defined in each Convergence layer to define the parameters that are specific to the connection. These parameters are handled in a transparent way by the common part sublayer.

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2284 **Table 24 - CON control packet types**

Name	HDR.DO	CON.N	Description
CON_REQ_S	0	0	Connection establishment request initiated by the Service Node.

Name	HDR.DO	CON.N	Description
CON_REQ_B	1	0	The Base Node shall consider that the connection is established with the identifier CON.LCID. • After a CON_REQ_S: Connection accepted; • Alone: Connection establishment request.
CON_CLS_S	0	1	The Service Node considers this connection closed: • After a CON_REQ_B: Connection rejected by the Node; • After a CON_CLS_B: Connection closing acknowledge; • Alone: Connection closing request.
CON_CLS_B	1	1	The Base Node shall consider that the connection is no longer established. • After a CON_REQ_S: Connection establishment rejected by the Base Node; • After a CON_CLS_S: Connection closing acknowledge; • Alone: Connection closing request.

4.4.2.6.5 PRO control packet (PKT.CTYPE = 3)

This control packet is used to promote a Service Node from Terminal function to Switch function. This control packet is also used to exchange information that is further used by the Switch Node to transmit its beacon. The description of the fields of this packet is given in Table 25, and Figure 60. The meaning of the packet differs depending on the direction of the packet and on the values of the different types.

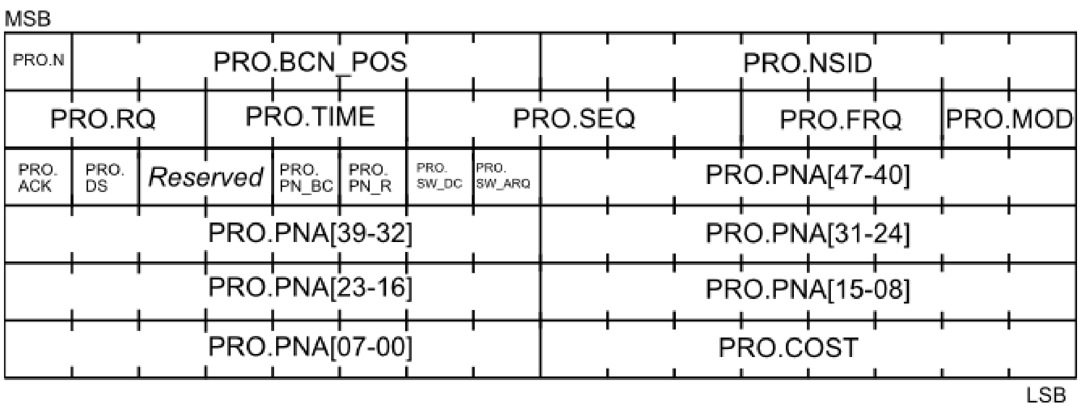

Figure 59 - PRO_REQ_S control packet structure

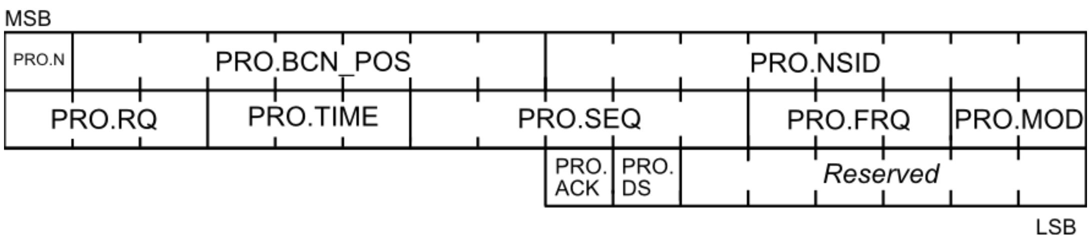

Figure 60 - PRO control packet structure

Note that Figure 59 includes all fields as used by a PRO_REQ_S message. All other messages are much smaller, containing only fields shown in Figure 60.

Table 25 - PRO control packet fields

Name	Length	Description
PRO.N	1 bit	Negative PRO.N=1 for the negative promotion PRO.N=0 for the positive promotion
PRO.BCN_POS	7 bits	Position of this beacon in symbols from the beginning of the frame.
PRO.NSID	8 bits	New Switch Identifier. This is the assigned Switch identifier of the Node whose promotion is being managed with this packet. This is not the same as the PKT.SID of the packet header, which must be the SID of the Switch this Node is connected to, as a Terminal Node.
PRO.RQ	3 bits	Receive quality of the PNPDU message received from the Service Node requesting the Terminal to promote.
PRO.TIME	3 bits	The ALV.TIME that is being used by the terminal that shall become a switch. On a reception of this time in a PRO_REQ_B the Service Node shall reset the Keep-Alive timer in the same way as receiving an ALV_REQ_B.
PRO.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.
PRO.FRQ	3 bits	Transmission frequency of Beacon, encoded as: FRQ = 0 => 1 beacon every frame FRQ = 1 => 1 beacon every 2 frames FRQ = 2 => 1 beacon every 4 frames FRQ = 3 => 1 beacon every 8 frames FRQ = 4 => 1 beacon every 16 frames FRQ = 5 => 1 beacon every 32 frames FRQ = 6 => *Reserved* FRQ = 7 => *Reserved*
PRO.MOD	2 bits	For PLC, the modulation of the transmitted Beacons, is encoded as: ENC = 0 => DBPSK + Convolutional Code ENC = 1 => Robust DQPSK ENC = 2 => Robust DBPSK ENC = 3 => Reserved For RF, this field is reserved for future use.
PRO.ACK	1 bit	Flag to differentiate the PRO_REQ_S from the PRO_ACK
PRO.DS	1 bit	Double switch flag. Used for switches that have to send a second beacon. This field is described in more detail in section 4.6.3.

Reserved	2 bits	Reserved for future versions of the protocol. Shall be set to 0 for this version of the protocol.
PRO.PN_BC	1 bit	Backwards Compatibility mode of the node represented by PRO.PNA. 1 if the device is backwards compatible with 1.3.6 PRIME 0 if it is not
PRO.PN_R	1 bit	Robust mode compatibility of the node represented by PRO.PNA. 1 if the device supports robust mode 0 if it is not
PRO.SWC_DC	1 bit	Direct Connection Switching Capability 1 if the device is able to behave as Direct Switch in direct connections. 0 otherwise
PRO.SWC_ARQ	1 bit	ARQ Buffering Switching Capability 1 if the device is able to perform buffering for ARQ connections while switching. 0 if the device is not able to perform buffering for ARQ connections while switching.
PRO.PNA	0 or 48 bits	Promotion Need Address, contains the EUI-48 of the Terminal requesting the Service Node promotes to become a Switch. This field is only included in the PRO_REQ_S message.
PRO. COST	0 or 8 bits	Total cost from the Terminal Node to the Base Node. This value is calculated in the same way a Switch Node calculates the value it places into its own Beacon PDU. This field is only included in the PRO_REQ_S message.

2297

2298 **Table 26 - PRO control packet types**

Name	HDR. DO	PRO. N	PRO. ACK	PRO. NSID	Description
PRO_REQ_S	0	0	0	-	Used by terminal nodes to request a promotion to switch nodes. This is not part of any procedure, just an information message, so there shall not be any PRO_ACK/PRO_NACK in response. Used by switch nodes to request a beacon modulation change. In this case it is a procedure, so the base node shall respond with a PRO_ACK/PRO_NACK.

Name	HDR. DO	PRO. N	PRO. ACK	PRO. NSID	Description
PRO_REQ_B	1	0	0	< 0xFF	The Base Node shall consider that the Service Node has promoted with the identifier PRO.NSID. • To a terminal node: Promotion acceptance with allocating LSID or Promotion request initiated by the Base Node. • To a switch node: Beacon information change initiated by the Base Node.
PRO_ACK	-	0	1	< 0xFF	Acknowledge. Used by both the Base Node and the Service Node to acknowledge with a positive answer the procedure. Procedures this message applies to are: PRO_REQ_S for beacon change modulation or PRO_REQ_B.
PRO_NACK	-	1	1	< 0xFF	Negative Acknowledge. Used by both the Base Node and the Service Node to acknowledge with a negative answer the procedure. Procedures this message applies to be: beacon change modulation.
PRO_DEM_S	0	1	0	< 0xFF	Used by Service Nodes to request a demotion, to reject a promotion or to positively acknowledge a demotion.
PRO_DEM_B	1	1	0	-	Used by the Base Node to request a demotion, to reject a promotion or to positively acknowledge a demotion.

Table 26 shows the different interpretation of the packets. The promotion process is explained in more detail in 4.6.3.

4.4.2.6.5.1 Extension for Multi-PHY promotion

To support the extension to handle Multiple PHY layers, the reserved bytes of the PRO_REQ_S and PRO_REQ_B messages are used to create new versions of the messages named PRO_REQ_S_MultiPHY (Figure 61) and PRO_REQ_B_MultiPHY (Figure 62), where some not used fields have been also redefined.

The new messages and their use are defined in Table 27 and the new fields in Table 28

Table 27 - Extension for Multi PHY Promotion

Name	HDR.DO	PRO.N	PRO.ACK	Reserved	Description
PRO_REQ_S_MultiPHY	0	0	0	01b	Used by service nodes to request a promotion in a different physical medium from the one where the node is connected to the network. This physical medium could be either RF or PLC
PRO_REQ_B_MultiPHY	1	0	0	100xxxb	Used by the Base Node to accept a PRO_REQ_S_MultiPHY promotion request from a service node or to request a promotion in a different physical medium from the one where the node is connected to the network.

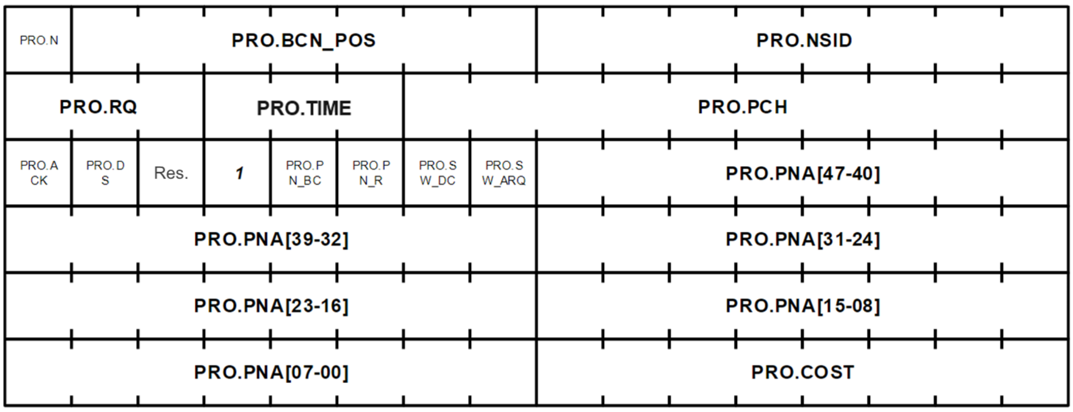

Figure 61 - PRO_REQ_S Multi PHY control packet structure

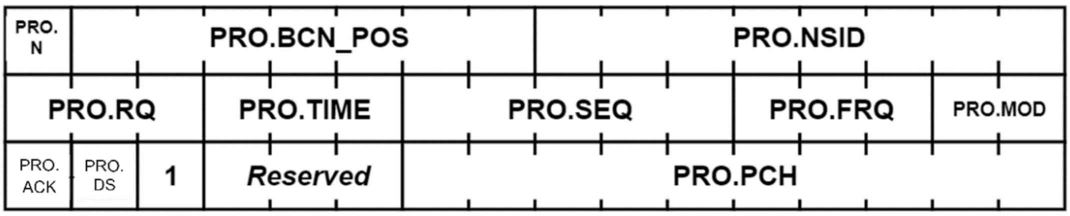

Figure 62- PRO_REQ_B Multi PHY control packet structure

Table 28 – New fields defined in the MultiPHY PRO messages

Name	Length	Description
PRO.PCH	10 bits	Codification of the Physical layer to where a new switch is requested. – PRO.PCH[09]=0b for the PLC PHY – PRO.PCH[09]=1b for the SUN FSK PHY, based on clause 20 of [28,29] If PRO.PCH[9]=0 for the PLC PHY – PRO.PCH[08]=0b reserved – PRO.PCH[07-00] PLC channels used. As examples; – PRO.PCH[07-00]=01H if Channel 1 only is used . – PRO.PCH[07-00]=80H if Channel 8 only is used . – PRO.PCH[07-00]=FCH if Channel 3 to 8 are used. If PRO.PCH[9]=1 for the RF PHY – PRO.PCH[08-00] RF channels used, *NumChan*, according to channel numbering defined on [28,29] (10.1.2.8) from 0 to TotalNumChan-1

4.4.2.6.6 FRA control packet (PKT.CTYPE = 5)

This control packet is broadcast from the Base Node and relayed by all Switch Nodes to the entire Subnetwork. It is used to circulate information on the change of Frame structure at a specific time in future. The description of fields of this packet is given inTable 29 and Figure 63.

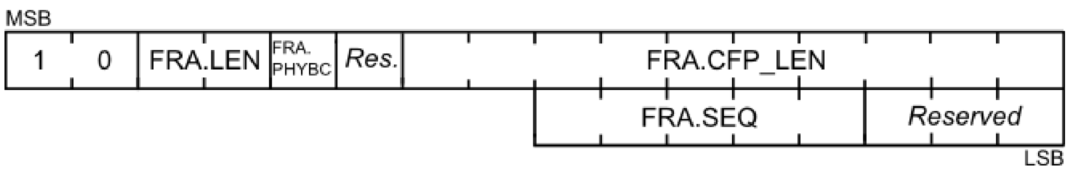

Figure 63 - FRA control packet structure

Table 29 - FRA control packet fields

Name	Length	Description
Reserved	2 bits	Reserved bits. Shall be set to 0b10 for this version of this specification
FRA.LEN	2 bits	Length of the frame to be applied in the next superframe. This shall be the *macFrameLength,* encoded with same semantics as the PIB attribute. •

Name	Length	Description
FRA.PHYBC	1 bit	The network is working on PHY backwards compatibility mode, all the nodes that need to send Type B PHY Frames shall use PHY backwards compatible frames. • 0 if the subnet is not working in PHY backwards compatibility mode. • 1 if the subnet is working in PHY backwards compatibility mode.
Reserved	1 bit	Reserved for future version of this protocol. In this version, this field shall be initialized to 0.
FRA.CFP_LEN	10 bits	Length of CFP.
FRA.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.
Reserved	3 bits	Reserved for future version of this protocol. In this version this field shall be set to 0.

4.4.2.6.7 CFP control packet (PKT.CTYPE = 6)

This control packet is used for dedicated contention-free channel access time allocation to individual Terminal or Switch Nodes. The description of the fields of this packet is given in

Table 30 and Figure 64. The meaning of the packet differs depending on the direction of the packet and on the values of the different types.

Table 31 represents the different interpretation of the packets.

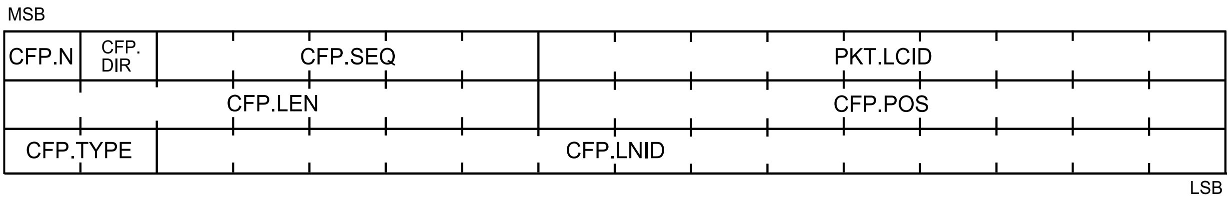

Figure 64 - CFP control packet structure

Table 30 - CFP control message fields

Name	Length	Description
CFP.N	1 bit	0: denial of allocation/deallocation request; 1: acceptance of allocation/deallocation request.
CFP.DIR	1 bit	Indicate direction of allocation. 0: allocation is applicable to uplink (towards Base Node) direction; 1: allocation is applicable to Downlink (towards Service Node) direction.
CFP.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.
CFP.LCID	9 bits	LCID of requesting connection.

Name	Length	Description
CFP.LEN	7 bits	Length (in symbols) of requested/allocated channel time per frame.
CFP.POS	9 bits	Offset (in symbols) of allocated time from beginning of frame.
CFP.TYPE	2 bits	0: Channel allocation packet; 1: Channel de-allocation packet; 2: Channel change packet.
CFP.LNID	14 bits	LNID of Service Node that is the intended user of the allocation.

Table 31 - CFP control packet types

Name	CFP.TYP	HDR.DO	Description
CFP_ALC_REQ_S	0	0	Service Node makes channel allocation request
CFP_ALC_IND	0	1	• After a CFP_ALC_REQ_S: Requested channel is allocated • Alone: Unsolicited channel allocation by Base Node
CFP_ALC_REJ	0	1	Requested channel allocation is denied
CFP_DALC_REQ	1	0	Service Node makes channel de-allocation request
CFP_DALC_RSP	1	1	Base Node confirms de-allocation
CFP_CHG_IND	2	1	Change of location of allocated channel within the CFP.

4.4.2.6.8 ALV control packet (PKT.CTYPE = 7)

The ALV control message is used for Keep-Alive signaling between a Service Node, the Service Nodes above it and the Base Node. It is also used to test every hop in the path of that particular node performing robustness-management. Structures of these messages are shown in Figure 65, Figure 66 and Figure 67 and individual fields are enumerated in

Table 32. The different Keep-Alive message types are shown in ALV.VALU(*) to zero.

Table 33. These messages are sent periodically, as described in section 4.6.5.

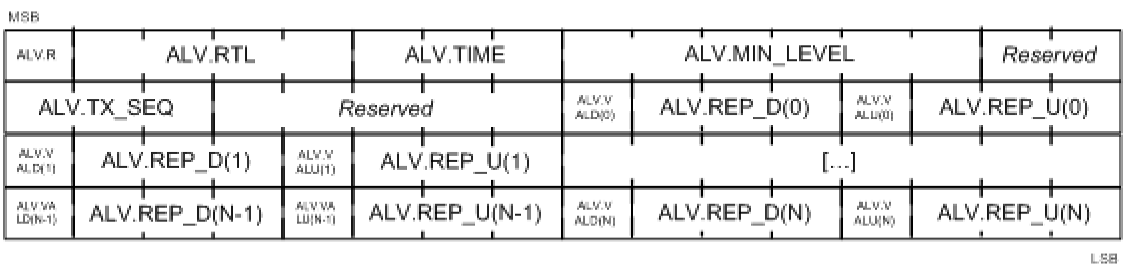

Figure 65 - ALV_RSP_S / ALV_REQ_B Control packet structure

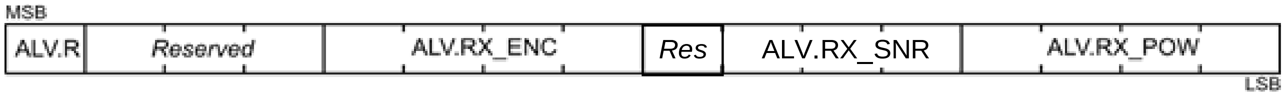

Figure 66 - ALV_ACK_B/ALV_ACK_S control packet structure

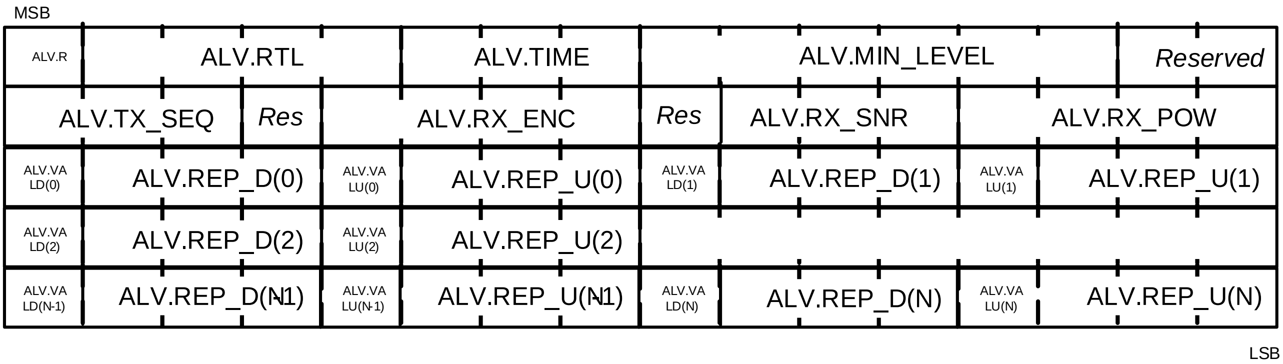

Figure 67 - ALV_RSP_ACK Control packet structure

Table 32 - ALV control message fields

Name	Length	Description
ALV.R	1 bit	Request/Response field. • 1 in the requests/response • 0 in the acknowledges
ALV.RTL	4 bits	Total number of repetitions left across the entire path.
ALV.TIME	3 bits	Time to wait for an ALV procedure before assuming the Service Node has been unregistered by the Base Node. ALV.TIME = 0 => 128 seconds ~ 2.1 minutes; ALV.TIME = 1 => 256 seconds ~ 4.2 minutes; ALV.TIME = 2 => 512 seconds ~ 8.5 minutes; ALV.TIME = 3 => 2048 seconds ~ 34.1 minutes; ALV.TIME = 4 => 4096 seconds ~ 68.3 minutes; ALV.TIME = 5 => 8192 seconds ~ 136.5 minutes; ALV.TIME = 6 => 16384 seconds ~ 273.1 minutes; ALV.TIME = 7 => 32768 seconds ~ 546.1 minutes
ALV.MIN_LEVEL	6 bits	Minimum level of the node to add independent records to the REP_D/REP_U table. For downlink case, if the switch's level+1 is equal or lower than ALV.MIN_LEVEL it shall sum its repetitions to the first record (record number 0: ALV.REP_U(0)). For uplink case, if the switch's (or terminal's) level is equal or lower than ALV.MIN_LEVEL it shall sum its repetitions to the first record.
Reserved	2 bit	Reserved for future use. Shall be 0 for this version of the specification.
ALV.TX_SEQ	3 bits	Sequence of number of transmissions, to keep track if the loss in the ALV process is due to the REQ/RSP process or the ACK. This is to avoid an incorrect evaluation of downlink/uplink because of ACK loses. All the ALV operations shall start with sequence number 0, every time a node starts a hop level operation it shall set this field to 0, and each repetition it shall increase it until ACK is received.
ALV.VALD(*)	1 bit	Flag to indicate that the REP_D record contains valid information. • 1 information contained in REP_D records is valid • 0 information in REP_D shall be discarded
ALV.REP_D(*)	3 bits	Number of repetitions for the given downlink hop. Valid values: • 0-5 : Number of repetitions • 6 : 6 or more repetitions (for record as a sum of various levels) • 7 : All the retries finished for this hop
ALV.VALU(*)	1 bit	Flag to indicate that the REP_U record contains valid information. • 1 information contained in REP_D records is valid • 0 information in REP_D shall be discarded

ALV.REP_U(*)	3 bits	Number of repetitions for the given uplink hop. In the ALV_REQ_B the base node shall fill these fields with the repetitions of each hop for the last ALV procedure of that hop. In the ALV_RSP_S the service node shall fill the field with the uplink repetitions. Valid values: • 0-5 : Number of repetitions • 6 : 6 or more repetitions (for record as a sum of various levels) • 7 : All the retries finished for this hop
ALV.RX_SNR	3 bits	Signal to Noise Ratio at which the ALV_REQ_B/ALV_RSP_S was received. It corresponds to the SNR parameter defined in 3.5.3.12.2 (values from 0 to 7).
ALV.RX_POW	4 bits	Power at which the ALV_REQ_B/ALV_RSP_S was received. It corresponds to the Level parameter defined in 3.5.2.4.2.
ALV.RX_ENC	4 bits	Encoding at which the ALV_REQ_B/ALV_RSP_S was received. • 0 – DBPSK • 1 – DQPSK • 2 – D8PSK • 3 – Not used • 4 – DBPSK + Convolutional Code • 5 – DQPSK + Convolutional Code • 6 – D8PSK + Convolutional Code • 7-11 – Not used • 12 – Robust DBPSK • 13 – Robust DQPSK • 14 – Not used • 15 – Outdated information

The * symbol means that there are a variable number of records for the same field, each record shall be fulfilled by a Service Node in the path to the Terminal Node that shall receive the ALV, Position N shall be the hop of the Service Node target of the ALV procedure, N-1 shall be the parent Switch Node of that node, and so on. For the switches with level below or equal than ALV.MIN_LEVEL shall add their repetitions information to the record ALV.REP_U(0)/ALV.REP_D(0). The Base Node shall make sure that the number of records is correct for the given ALV.MIN_LEVEL value.

The base node shall fill the ALV.REP_U(*) registries with the last ALV operation's uplink retries for each hop, if it does not have that information it shall reset the appropriate ALV.VALU(*) to zero.

Table 33 – Keep-Alive control packet types

Name	HDR.DO	ALV.R	Description
ALV_REQ_B	1	1	Keep-Alive request message.
ALV_ACK_B	1	0	Keep-Alive acknowledge to a response.
ALV_RSP_S	0	1	Keep-Alive response message in case the node is not the target node (PKT.SID != receiver SSID)
ALV_RSP_ACK	0	1	Keep-Alive response acknowledge message in case the node is the target node (PKT.SID == receiver SSID)
ALV_ACK_S	0	0	Keep-Alive acknowledge to a request.

4.4.2.6.9 MUL control packet (PKT.CTYPE = 8)

The MUL message is used to control multicast group membership. The structure of this message and the meanings of the fields are described in Table 34 and Figure 68. The message can be used in different ways as described in

Table 35.

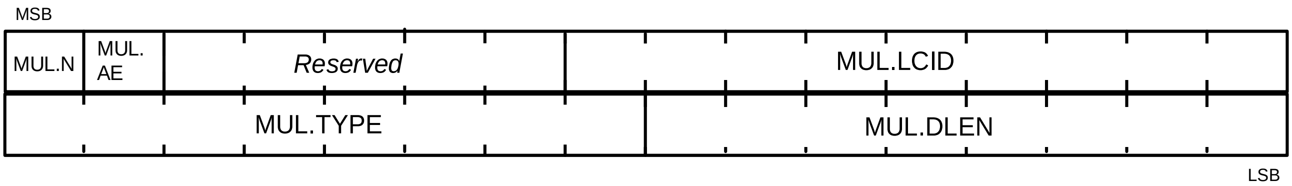

Figure 68 - MUL control packet structure

Table 34 - MUL control message fields

Name	Length	Description
MUL.N	1 bit	Negative • MUL.N = 1 for the negative multicast connection, i.e. multicast group leave. • MUL.N = 0 for the positive multicast connection, i.e. multicast group join.

Name	Length	Description
MUL.AE	1 bit	Use authentication and encryption on the data sent using this multicast connection. • MUL.AE = 1 to encrypt and authenticate the data packets. • MUL.AE = 0 to send the plain data without any authentication and encryption. This flag is valid in both directions; each side shall set it to the desired value. The highest security will be applied in case the values do not match. So if any side sets this flag to 1 the data shall be authenticated and encrypted. ***NOTE:*** *This flag only can be 1 on security profiles 1 and 2.*
Reserved	5 bits	Reserved for future version of the protocol. This shall be 0 for this version of the protocol.
MUL.LCID	9 bits	Local Connection Identifier. The LCID indicates which multicast distribution group is being managed with this message.
MUL.TYPE	8 bits	Connection type. The connection type specifies the Convergence layer to be used for this connection. They are treated transparently through the MAC common part sublayer, and are used only to identify which Convergence layer may be used. See Annex E.
MUL.DLEN	8 bits	Length of data in bytes in the MUL.DATA field
MUL.DATA	*(variable)*(Present if MUL.DLEN >0)	Connection specific parameters. These connections specific parameters are Convergence layer specific. They shall be defined in each Convergence layer to define the parameters that are specific to the connection. These parameters are handled in a transparent way by the common part sublayer.

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2375 **Table 35 – MUL control message types**

Name	HDR.DO	MUL.N	PKT.LNID	Description
MUL_JOIN_S	0	0	>0	Multicast group join request initiated by the Service Node, or an acknowledgement when sent in response to a MUL_JOIN_B.
MUL_JOIN_B	1	0	>0	The Base Node shall consider that the group has been joined with the identifier MUL.LCID. • After a MUL_JOIN_S: join accepted; • Alone: group join request.

Name	HDR.DO	MUL.N	PKT.LNID	Description
MUL_LEAVE_S	0	1	>0	The Service Node leaves the multicast group: • After a MUL_JOIN_B: Join rejected by the Node; • After a MUL_LEAVE_B: group leave acknowledge; • Alone: group leave request.
MUL_LEAVE_B	1	1	>0	The Base Node shall consider that the Service Node is no longer a member of the multicast group. • After a MUL_JOIN_S: Group join rejected by the Base Node; • After a MUL_LEAVE_S: Group leave acknowledge; • Alone: Group leave request.
MUL_SW_LEAVE_B	1	1	0	The switch node shall stop switching multicast data for the multicast group. This message is always initiated by the base node. The addressing shall be with the switch's SSID and LNID == 0 to distinguish this message from MUL_LEAVE_B.
MUL_SW_LEAVE_S	0	1	0	The switch node is no longer switching multicast data for the multicast group. This message is sent as a response to MUL_SW_LEAVE_B. The addressing shall be with the switch's SSID and LNID == 0 to distinguish this message from MUL_LEAVE_S.

4.4.2.6.10 SEC control packet (PKT.CTYPE = 10)

The SEC control message is a unicast message transmitted authenticated and encrypted (WK) by the Base Node to every node in the Subnetwork to update the WK and SWK. The random sequence used by devices in a Subnetwork is dynamic and changes from time to time to ensure a robust security framework. The structure of this message is shown in Table 36 and Figure 69. Further details of security mechanisms are given in Section 4.3.8.

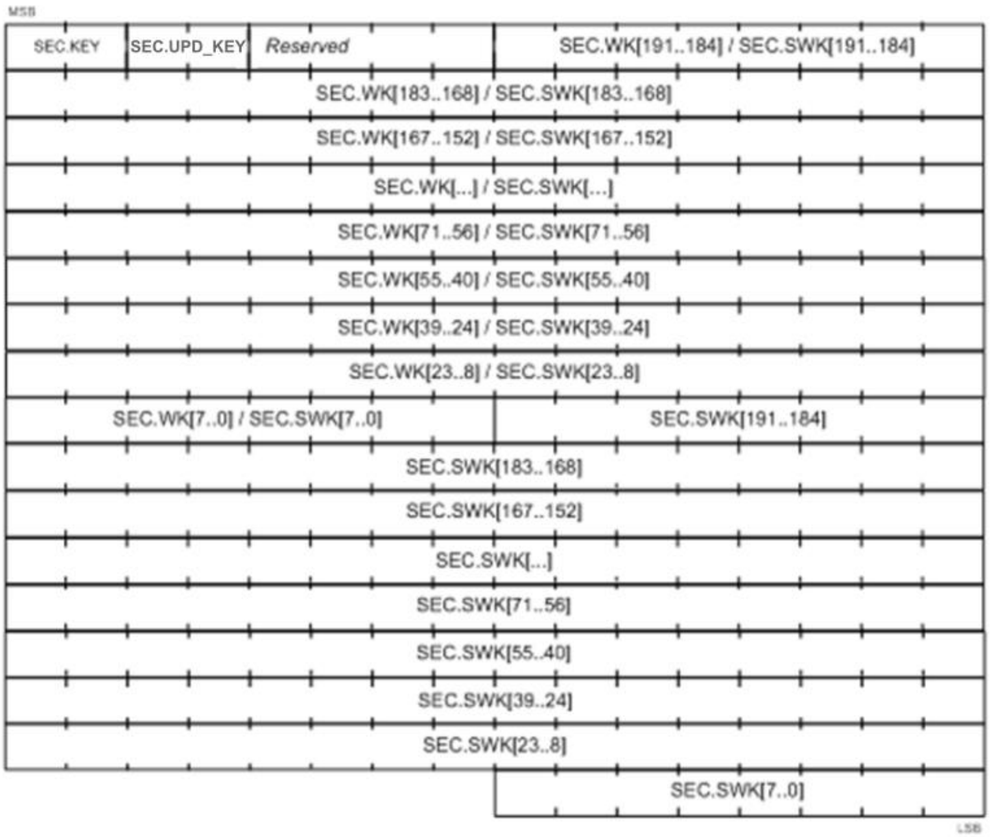


Figure 69 – SEC control packet structure

Table 36 – SEC control message fields

Name	Length	Description
SEC.KEY	2 bits	In the SEC_REQ it indicates which key is present In the SEC_RSP it indicates which key was to be updated 0 - reserved 1 – only SEC.WK is present / only SEC.WK to be updated 2 – only SEC.SWK is present / only SEC.SWK to be updated 3 – SEC.WK and SEC.SWK are present / SEC.WK and SEC.SWK to be updated
SEC.UPDATED_KEY	2 bits	In the SEC_RSP it indicates which key has being updated 0 - reserved 1 – only SEC.WK was updated 2 – only SEC.SWK was updated 3 – SEC.WK and SEC.SWK were updated Only used in SEC_RSP. In all other message variants, this shall be 0.
Reserved	4 bits	Shall always be encoded as 0 in this version of the specification.
SEC.WK	192 bits	(optional in SEC_REQ, not present in SEC_RSP) Working Key wrapped by KWK.

SEC.SWK	192 bits	(optional in SEC_REQ, not present in SEC_RSP) Subnetwork Working Key wrapped by KWK.

Table 37 - SEC control packet types

Name	HDR.DO	Description
SEC_REQ	1	Security key update request message.
SEC_RSP	0	Security key update acknowledge to a request.

4.4.2.6.11 PCC control packet (PKT.CTYPE = 11)

This control packet is broadcast from the Base Node and relayed by all Switch Nodes to the entire Subnetwork. It is used to circulate information on a Programmed Configuration Change event, like a change of Physical layer channel/band that will be used by the Base Node at a specific time in future. The description of fields of this packet is given in Table 38, Table 39 and Figure 70. Further details are given in 4.6.10.

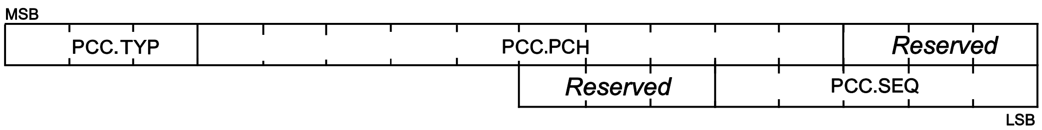


Figure 70 – PCC control packet structure

Table 38 - PCC control packet fields

Name	Length	Description
PCC.TYP	3 bits	The Programmed Configuration Change Type, encoded as: 0 => Change in Physical layer channel/band on a specific medium 1-7 => Reserved for future uses

Name	Length	Description
PCC.PCH	10 bits	Codification of the new Physical layer channel/band that will be used by the Base Node on a specific medium. – PCC.PCH[09]=0b for the PLC channels – PCC.PCH[09]=1b for the SUN FSK PHY, based on clause 20 of [28,29] If PCC.PCH[9]=0b for the PLC channels - PCC.PCH[08]=0b reserved - PCC.PCH[07-00] PLC channels used. As examples; - PCC.PCH[07-00]=01H if Channel 1 only is used. - PCC.PCH[07-00]=80H if Channel 8 only is used. - PCC.PCH[07-00]=FCH if Channel 3 to 8 are used. If PCC.PCH[9]=1b for the RF channels - PCC.PCH[08-00] RF channels used, NumChan, according channel numbering defined on [28,29] (10.1.2.8) from 0 to TotalNumChan This field is only included in the PCC_PHY_CH message
Reserved	6 bits	Reserved for future version of this protocol. In this version this field shall be set to 0. This field is only included in the PCC_PHY_CH message
PCC.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.

Table 39 - PCC control message types

Name	PCC.TYP	Description
PCC_PHY_CH	000	Physical Configuration Change

4.4.3 Promotion Needed PDU

If a Node is Disconnected and it does not have connectivity with any existing Switch Node, it shall send notifications to its neighbors to indicate the need for the promotion of any available Terminal

Node. Figure 71 represents the Promotion Needed MAC PDU (PNPDU) that must be sent on an irregular basis in this situation.

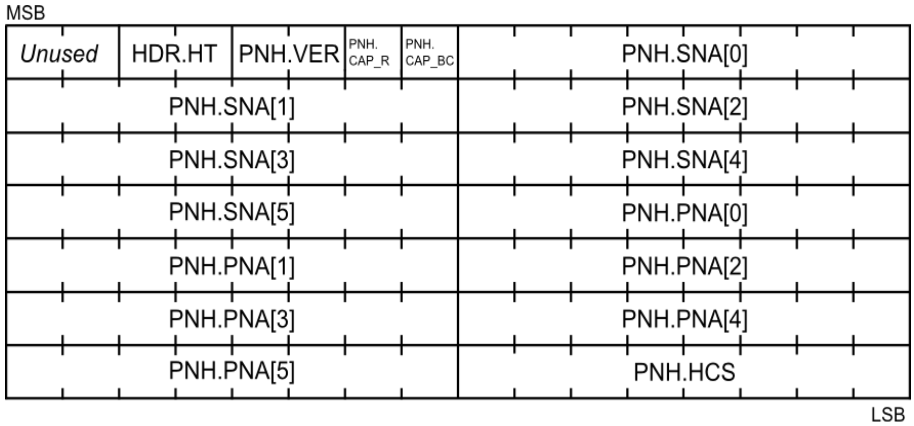


Figure 71 - Promotion Need MAC PDU

Table 40 shows the promotion need MAC PDU fields.

Table 40 - Promotion Need MAC PDU fields

Name	Length	Description
Unused	2 bits	Unused bits which are always 0; included for alignment with MAC_H field in PPDU header (Section 3.3.3).
HDR.HT	2 bits	Header Type HDR.HT = 1 for the Promotion Need MAC PDU
PNH.VER	2 bits	Version of PRIME Specification: • 0 – 1.3.6 PRIME • 1 – 1.4 PRIME • 2,3 – Reserved for future use
PNH.CAP_R	1 bit	Flag to define if the node supports Robust mode • 0 – If the node does not support Robust mode • 1 – if the node does support Robust mode
PNH.CAP_BC	1 bit	Flag to define if the node supports Backwards Compatibility with 1.3.6 version of the specification • 0 – The node does not support Backwards Compatibility with 1.3.6 • 1 – The node supports Backwards Compatibility with 1.3.6

Name	Length	Description
PNH.SNA	48 bits	Subnetwork Address. The EUI-48 of the Base Node of the Subnetwork the Service Node is trying to connect to. FF:FF:FF:FF:FF:FF to ask for the promotion in any available Subnetwork. SNA[0] is the most significant byte of the OUI/IAB and SNA[5] is the least significant byte of the extension identifier, as defined in: http://standards.ieee.org/regauth/oui/tutorials/EUI-48.html. The above notation is applicable to all EUI-48 fields in the specification.
PNH.PNA	48 bits	Promotion Need Address. The EUI-48 of the Node that needs the promotion. It is the EUI-48 of the transmitter.
PNH.HCS	8 bits	Header Check Sequence. A field for detecting errors in the header. The transmitter shall calculate the PNH.HCS of the first 13 bytes of the header and insert the result into the PNH.HCS field (the last byte of the header). It shall be calculated as the remainder of the division (Modulo 2) of the polynomial $M(x)\cdot x^8$ by the generator polynomial $g(x)=x^8+x^2+x+1$. M(x) is the input polynomial, which is formed by the bit sequence of the header excluding the PNH.HCS field, and the msb of the bit sequence is the coefficient of the highest order of M(x).

As it is always transmitted by unsynchronized Nodes and, therefore, prone to creating collisions, it is a special reduced size header.

4.4.4 Beacon PDU

Beacon PDU (BPDU) is transmitted by every Switch device on the Subnetwork, including the Base Node. The purpose of this PDU is to circulate information on MAC frame structure and therefore channel access to all devices that are part of this Subnetwork. The BPDU is transmitted at definite fixed intervals of time and is also used as a synchronization mechanism by Service Nodes. Figure 72 below shows contents of a beacon transmitted by the Base Node and each Switch Device. It is important to remark that the BCN.HOP_POS field may be only transmitted on the RF medium, so the beacon format may be different on the two media.

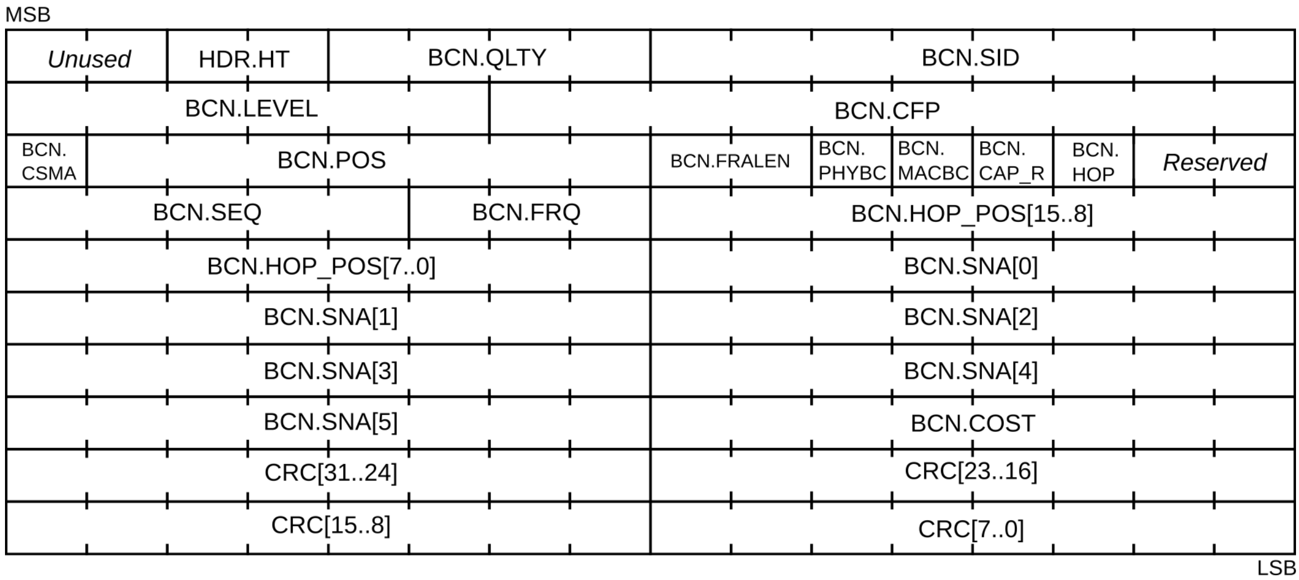


Figure 72 – Beacon PDU structure

Table 41 shows the beacon PDU fields.

Table 41 - Beacon PDU fields

Name	Length	Description
Unused	2 bits	Unused bits which are always 0; included for alignment with MAC_H field in PPDU header (Fig 7, Section 3.3.3).
HDR.HT	2 bits	Header Type HDR.HT = 2 for Beacon PDU

Name	Length	Description
BCN.QLTY	4 bits	Quality of round-trip connectivity from this Switch Node to the Base Node. ,with the following meaning: BCN.QLTY = 0 if 1/2 < rtdp <= 1 BCN.QLTY = 1 if 3/8 < rtdp <= 1/2 BCN.QLTY = 2 if 1/4 < rtdp <= 3/8 BCN.QLTY = 3 if 3/16 < rtdp <= 1/4 BCN.QLTY = 4 if 1/8 < rtdp <= 3/16 BCN.QLTY = 5 if 3/32 < rtdp <= 1/8 BCN.QLTY = 6 if 1/16 < rtdp <= 3/32 BCN.QLTY = 7 if 3/64 < rtdp <= 1/16 BCN.QLTY = 8 if 1/32 < rtdp <= 3/64 BCN.QLTY = 9 if 3/128 < rtdp <= 1/32 BCN.QLTY = 10 if 1/64 < rtdp <= 3/128 BCN.QLTY = 11 if 3/256 < rtdp <= 1/64 BCN.QLTY = 12 if 1/128 < rtdp <= 3/256 BCN.QLTY = 13 if 3/512 < rtdp <= 1/128 BCN.QLTY = 14 if 1/256 < rtdp <= 3/512 BCN.QLTY = 15 if rtdp <= 1/256 where: rtdp = Rount Trip Drop Probability. Probability for a packet to be dropped when it is supposed to go downlink and be answered uplink (or the other way around) between the Base Node and the Switch Node. It is up to the manufacturer how to detect it, and It doesn't have to be very accurate, just an estimation. As a guideline, ALV packets can be used to calculate this field.
BCN.SID	8 bits	Switch identifier of transmitting Switch
BCN.LEVEL	6 bits	Hierarchy of transmitting Switch in Subnetwork
BCN.CFP	10 bits	CFP length in symbols.
BCN.CSMA	1 bit	PLC CSMA/CA Algorithm used in the Subnetwork. • 0 – CSMA/CA Algorithm 1 (i.e. v1.4) • 1 – CSMA/CA Algorithm 2 (i.e. v1.3.6, as in backward compatibility mode)
BCN.POS	7 bits	Position of this beacon in symbols from the beginning of the frame.
BCN.FRA_LEN	2 bits	Length of the frame. • 0 - 276 symbols • 1 - 552 symbols • 2 - 828 symbols • 3 - 1104 symbols

Name	Length	Description
BCN.PHYBC	1 bit	PHY backwards compatibility mode: 0 – The network is working in normal mode. 1 - The network is working on PHY backwards compatibility mode, all the nodes that need to send Type B PHY Frames shall use PHY backwards compatible frames.
BCN.MACBC	1 bit	MAC backward compatibility mode: 0 – The network is working in 1.4 mode. 1 – The network is working in MAC backward compatibility mode, see section 4.9 for details.
BCN.CAP_R	1 bit	Robust Mode Capable 1 – The device is able to transmit/receive robust mode frames. 0 – The device is not able to transmit/receive robust mode frames.
BCN.HOP	1 bit	Indicates the presence of the BCN.HOP_POS field needed for channel hopping synchronization: 0 – The BCN.HOP_POS field is not present. 1 – The BCN.HOP_POS field is present.
Reserved	2 bits	Always 0 for this version of the specification. Reserved for future use.
BCN.SEQ	5 bits	Sequence number of this BPDU in super frame. Incremented for every beacon the Base Node sends and is propagated by Switch through its BPDU such that entire Subnetwork has the same notion of sequence number at a given time.
BCN.FRQ	3 bits	Transmission frequency of this BPDU. Values are interpreted as follows: 0 = 1 beacon every frame 1 = 1 beacon every 2 frames 2 = 1 beacon every 4 frames 3 = 1 beacon every 8 frames 4 = 1 beacon every 16 frames 5 = 1 beacon every 32 frames 6 = Reserved 7 = Reserved
BCN.HOP_POS	16 bits	This field indicates the current macHoppingSequencePosition required for channel hopping synchronization. This field is optional and only present when indicated by the BCN.HOP field.
BCN.SNA	48 bits	Subnetwork identifier in which the Switch transmitting this BPDU is located

Name	Length	Description
BCN.COST	8 bits	Total cost from the transmitting Switch Node to the Base Node. The cost of a single hop is calculated based on modulation scheme used on that hop in both downlink and uplink direction. Values are derived as follows: 8PSK = 0 QPSK = 0 BPSK = 0 8PSK_F = 0 QPSK_F = 1 BPSK_F = 2 QPSK_R = 4 BPSK_R = 8 The Base Node shall transmit in its beacon a BCN.COST of 0. A Switch Node shall transmit in its beacon the value of BCN.COST received from its upstream Switch Node, plus the cost of the upstream hop to its upstream Switch, calculated as the addition of both uplink and downlink costs. When this value is larger than what can be held in BCN.UPCOST the maximum value of BCN.COST shall be used.
CRC	32 bits	The CRC shall be calculated with the same algorithm as the one defined for the CRC field of the MAC PDU (see section 0 for details). For CRC calculation the field CRC is set to the constant 0x00010400. The CRC shall be calculated over the whole BPDU, including constant CRC field

The BPDU is also used to detect when the uplink Switch is no longer available either by a change in the characteristics of the medium or because of failure etc. If a Service Node fails to receive all the expected beacons during Nmiss-beacon superframes it shall declare the link to its Switch as unusable. The Service Node shall stop sending beacons itself if it is acting as a Switch. It shall close all existing MAC connections. The Service Node then enters the initial Disconnected state and searches for a Subnetwork join. This mechanism complements the Keep-Alive mechanism which is used by a Base Node and its switches to determine when a Service Node is lost.

4.5 MAC Service Access Point

4.5.1 General

The MAC service access point provides several primitives to allow the Convergence layer to interact with the MAC layer. This section aims to explain how the MAC may be used. An implementation of the MAC may not use all the primitives listed here; it may use other primitives; or it may have a function-call based interface rather than message-passing, etc. These are all implementation issues which are beyond the scope of this specification.

The .request primitives are passed from the CL to the MAC to request the initiation of a service. The .indication and .confirm primitives are passed from the MAC to the CL to indicate an internal MAC event that is significant to the CL. This event may be logically related to a remote service request or may be caused by an event internal to the local MAC. The .response primitive is passed from the CL to the MAC to provide a response to a .indication primitive. Thus, the four primitives are used in pairs, the pair .request and .confirm and the pair .indication and .response. This is shown in Figure 73, Figure 74, Figure 75 and Figure 76.

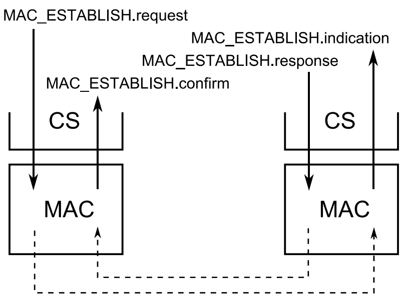


Figure 73 – Establishment of a Connection

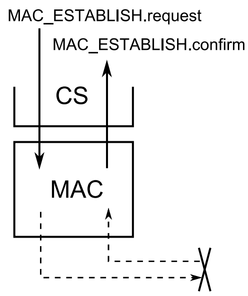


Figure 74 – Failed establishment of a Connection

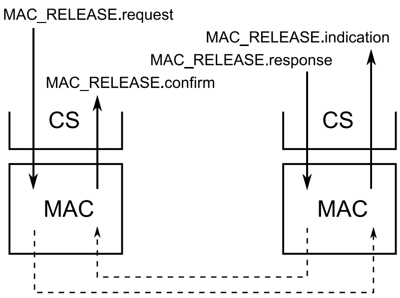


Figure 75 – Release of a Connection

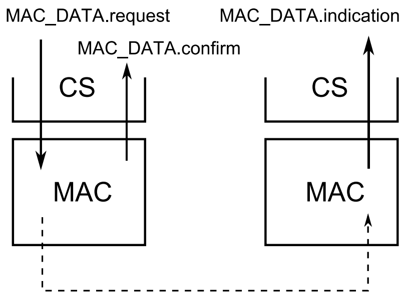


Figure 76- Transfer of Data

Table 42 represents the list of available primitives in the MAC-SAP:

Table 42 – List of MAC primitives

Service Node primitives	Base Node primitives
MAC_ESTABLISH.request	MAC_ESTABLISH.request
MAC_ESTABLISH.indication	MAC_ESTABLISH.indication
MAC_ESTABLISH.response	MAC_ESTABLISH.response
MAC_ESTABLISH.confirm	MAC_ESTABLISH.confirm
MAC_RELEASE.request	MAC_RELEASE.request
MAC_RELEASE.indication	MAC_RELEASE.indication
MAC_RELEASE.response	MAC_RELEASE.response
MAC_RELEASE.confirm	MAC_RELEASE.confirm
MAC_JOIN.request	MAC_JOIN.request
MAC_JOIN.Response	MAC_JOIN.response

Service Node primitives
MAC_JOIN.indication
MAC_JOIN.confirm
MAC_LEAVE.request
MAC_LEAVE.indication
MAC_LEAVE.confirm
MAC_DATA.request
MAC_DATA.confirm
MAC_DATA.indication

Base Node primitives
MAC_JOIN.indication
MAC_JOIN.confirm
MAC_LEAVE.request
MAC_LEAVE.indication
MAC_LEAVE.confirm
MAC_REDIRECT.response
MAC_DATA.request
MAC_DATA.confirm
MAC_DATA.indication

4.5.2 Service Node and Base Node signalling primitives

4.5.2.1 General

The following subsections describe primitives which are available in both the Service Node and Base Node MAC-SAP. These are signaling primitives only and used for establishing and releasing MAC connections.

4.5.2.2 MAC_ESTABLISH

4.5.2.2.1 General

The MAC_ESTABLISH primitives are used to manage a connection establishment.

4.5.2.2.2 MAC_ESTABLISH.request

The MAC_ESTABLISH.request primitive is passed to the MAC layer entity to request the connection establishment.

The semantics of this primitive are as follows:

MAC_ESTABLISH.request{EUI-48, Type, Data, DataLength, ARQ, CfBytes, AE}

The *EUI-48* parameter of this primitive is used to specify the address of the Node to which this connection will be addressed. The MAC will internally transfer this to an address used by the MAC layer. When the CL of a Service Node wishes to connect to the Base Node, it uses the EUI-48 00:00:00:00:00:00. However, when the CL of a Service Node wishes to connect to another Service Node on the Subnetwork, it uses the EUI-48 of that Service Node. This will then trigger a direct connection establishment. However, whether a normal or a directed connection is established is transparent to the Service Node MAC SAP. As the EUI-48 of the Base Node is the SNA, the connection could also be requested from the Base Node using the SNA.

The *Type* parameter is an identifier used to define the type of the Convergence layer that should be used for this connection (see Annex E). This parameter is 1 byte long and will be transmitted in the CON.TYPE field of the connection request.

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the local CL and the remote CL. This parameter will be transmitted in the CON.DATA field of the connection request.

The *DataLength* parameter is the length of the *Data* parameter in bytes.

The *ARQ* parameter indicates whether or not the ARQ mechanism should be used for this connection. It is a Boolean type with a value of true indicating that ARQ will be used.

The *CfBytes* parameter is used to indicate whether or not the connection should use the contention or contention-free channel access scheme. When *CfBytes* is zero, contention-based access should be used. When *CfBytes* is not zero, it indicates how many bytes per frame should be allocated to the connection using CFP packets.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

4.5.2.2.3 MAC_ESTABLISH.indication

The MAC_ESTABLISH.indication is passed from the MAC layer to indicate that a connection establishment was initiated by a remote Node.

The semantics of this primitive are as follows:

MAC_ESTABLISH.indication{ConHandle, EUI-48, Type, Data, DataLength, CfBytes, AE}

The *ConHandle* is a unique identifier interchanged to uniquely identify the connection being indicated. It has a valid meaning only in the MAC SAP, used to have a reference to this connection between different primitives.

The *EUI-48* parameter indicates which device on the Subnetwork wishes to establish a connection.

The *Type* parameter is an identifier used to define the type of the Convergence layer that should be used for this connection. This parameter is 1 byte long and it is received in the CON.TYPE field of the connection request.

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the local CL. This parameter is received in the CON.DATA field of the connection request.

The *DataLength* parameter is the length of the Data parameter in bytes.

The *CfBytes* parameter is used to indicate if the connection should use the contention or contention-free channel access scheme. When *CfBytes* is zero, contention-based access will be used. When *CfBytes* is not zero, it indicates how many bytes per frame the connection would like to be allocated.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

4.5.2.2.4 MAC_ESTABLISH.response

The MAC_ESTABLISH.response is passed to the MAC layer to respond with a MAC_ESTABLISH.indication.

The semantics of this primitive are as follows:

MAC_ESTABLISH.response{ConHandle, Answer, Data, DataLength, AE}

The *ConHandle* parameter is the same as the one that was received in the MAC_ESTABLISH.indication.

The *Answer* parameter is used to notify the MAC of the action to be taken for this connection establishment. This parameter may have one of the values in Table 43.

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the local CL. This parameter is received in the CON.DATA field of the connection response.

The *DataLength* parameter is the length of the Data parameter in bytes.

Data may be passed to the caller even when the connection is rejected, i.e. Answer has the value 1. The data may then optionally contain more information as to why the connection was rejected.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

Table 43 – Values of the *Answer* parameter in MAC_ESTABLISH.response primitive

Answer	**Description**
Accept = 0	The connection establishment is accepted.
Reject = 1	The connection establishment is rejected.

4.5.2.2.5 MAC_ESTABLISH.confirm

The MAC_ESTABLISH.confirm is passed from the MAC layer as the remote answer to a MAC_ESTABLISH.request.

The semantics of this primitive are as follows:

MAC_ESTABLISH.confirm{ConHandle, Result, EUI-48, Type, Data, DataLength, AE}

The *ConHandle* is a unique identifier to uniquely identify the connection being indicated. It has a valid meaning only in the MAC SAP, used to have a reference to this connection between different primitives. The value is only valid if the *Result* parameter is 0.

The *Result* parameter indicates the result of the connection establishment process. It may have one of the values in Table 44 .

The *EUI-48* parameter indicates which device on the Subnetwork accepted or refused to establish a connection.

The *Type* parameter is an identifier used to define the type of the Convergence layer that should be used for this connection. This parameter is 1 byte long and it is received in the CON.TYPE field of the connection request

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the local CL. This parameter is received in the CON.DATA field of the connection response.

The *DataLength* parameter is the length of the Data parameter in bytes.

Data may be passed to the caller even when the connection is rejected, i.e. Result has the value 1. The data may then optionally contain more information as to why the connection was rejected.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

Table 44 – Values of the *Result* parameter in MAC_ESTABLISH.confirm primitive

Result	**Description**
Success = 0	The connection establishment was successful.
Reject = 1	The connection establishment failed because it was rejected by the remote Node.
Timeout = 2	The connection establishment process timed out.
No bandwidth = 3	There is insufficient available bandwidth to accept this contention-free connection.
No Such Device = 4	A device with the destination address cannot be found.
Redirect failed =5	The Base Node attempted to perform a redirect which failed.
Not Registered = 6	The Service Node is not registered.
No More LCIDs = 7	All available LCIDs have been allocated.
Unsupported SP = 14	Device doesn't support SP > 0 but asked for an encrypted connection establishment

4.5.2.3 MAC_RELEASE

4.5.2.3.1 General

The MAC_RELEASE primitives are used to release a connection.

4.5.2.3.2 MAC_RELEASE.request

The MAC_RELEASE.request is a primitive used to initiate the release process of a connection.

The semantics of this primitive are as follows:

MAC_RELEASE.request{ConHandle}

The *ConHandle* parameter specifies the connection to be released. This handle is the one that was obtained during the MAC_ESTABLISH primitives.

4.5.2.3.3 MAC_RELEASE.indication

The MAC_RELEASE.indication is a primitive used to indicate that a connection is being released. It may be released because of a remote operation or because of a connectivity problem.

The semantics of this primitive are as follows:

MAC_RELEASE.indication{ConHandle, Reason}

The *ConHandle* parameter specifies the connection being released. This handle is the one that was obtained during the MAC_ESTABLISH primitives.

The *Reason* parameter may have one of the values given in Table 45.

Table 45 – Values of the *Reason* parameter in MAC_RELEASE.indication primitive

Reason	**Description**
Success = 0	The connection release was initiated by a remote service.
Error = 1	The connection was released because of a connectivity problem.

4.5.2.3.4 MAC_RELEASE.response

The MAC_RELEASE.response is a primitive used to respond to a connection release process.

The semantics of this primitive are as follows:

MAC_RELEASE.response{ConHandle, Answer}

The *ConHandle* parameter specifies the connection being released. This handle is the one that was obtained during the MAC_ESTABLISH primitives.

The *Answer* parameter may have one of the values given in Table 46 This parameter may not have the value "*Reject* = 1" because a connection release process cannot be rejected.

Table 46 – Values of the *Answer* parameter in MAC_RELEASE.response primitive

Answer	**Description**
Accept = 0	The connection release is accepted.

After sending the MAC_RELEASE.response the ConHandle is no longer valid and should not be used.

4.5.2.3.5 MAC_RELEASE.confirm

The MAC_RELEASE.confirm primitive is used to confirm that the connection release process has finished.

The semantics of this primitive are as follows:

MAC_RELEASE.confirm{ConHandle, Result}

The *ConHandle* parameter specifies the connection released. This handle is the one that was obtained during the MAC_ESTABLISH primitives.

The *Result* parameter may have one of the values given in Table 47

Table 47 – Values of the Result parameter in MAC_RELEASE.confirm primitive

Result	Description
Success = 0	The connection release was successful.
Timeout = 2	The connection release process timed out.
Not Registered = 6	The Service Node is no longer registered.

After the reception of the MAC_RELEASE.confirm the ConHandle is no longer valid and should not be used.

4.5.2.4 MAC_JOIN

4.5.2.4.1 General

The MAC_JOIN primitives are used to join to a broadcast or multicast connection and allow the reception of such packets.

4.5.2.4.2 MAC_JOIN.request

The MAC_JOIN.request primitive is used:

- By all Nodes : to join broadcast traffic of a specific CL and start receiving these packets
- By Service Nodes : to join a particular multicast group
- By Base Node : to invite a Service Node to join a particular multicast group

Depending on which device makes the join-request, this SAP can have two different variants. First variant shall be used on Base Nodes and second on Service Nodes:

The semantics of this primitive are as follows:

MAC_JOIN.request{Broadcast, ConHandle, EUI-48, Type, Data, DataLength, AE}

MAC_JOIN.request(Broadcast, Type, Data, DataLength, AE }

The *Broadcast* parameter specifies whether the JOIN operation is being performed for a broadcast connection or for a multicast operation. It should be 1 for a broadcast operation and 0 for a multicast operation. In case of broadcast operation, EUI-48, Data, DataLength are not used.

ConHandle indicates the handle to be used with for this multicast join. In case of first join request for a new multicast group, ConHandle will be set to 0. For any subsequent EUI additions to an existing multicast group, ConHandle will serve as index to respective multicast group.

The EUI-48 parameter is used by the Base Node to specify the address of the Node to which this join request will be addressed. The MAC will internally transfer this to an address used by the MAC layer. When the CL of a Service Node initiates the request, it uses the EUI-48 00:00:00:00:00:00.

The Type parameter defines the type of the Convergence layer that will send/receive the data packets. This parameter is 1 byte long and will be transmitted in the MUL.TYPE field of the join request.

The Data parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the local CL. This parameter is received in the MUL.DATA field of the connection request. In case the CL supports several multicast groups, this Data parameter will be used to uniquely identify the group

The DataLength parameter is the length of the Data parameter in bytes.

If Broadcast is 1, the MAC will immediately issue a MAC_JOIN.confirm primitive since it does not need to perform any end-to-end operation. For a multicast operation the MAC_JOIN.confirm is only sent once signaling with the uplink Service Node/Base Node is complete.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

4.5.2.4.3 MAC_JOIN.confirm

The MAC_JOIN.confirm primitive is received to confirm that the MAC_JOIN.request operation has finished.

The semantics of this primitive are as follows:

MAC_JOIN.confirm{ConHandle, Result, AE}

The *ConHandle* is a unique identifier to uniquely identify the connection being indicated. It has a valid meaning only in the MAC SAP, used to have a reference to this connection between different primitives. The value is only valid if the *Result* parameter is 0. When the MAC receives packets on this connection, they will be passed upwards using the MAC_DATA.indication primitive with this *ConHandle*.

The Result parameter indicates the result of multicast group join process. It may have one of the values given in Table 48.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

Table 48 – Values of the *Result* parameter in MAC_JOIN.confirm primitive

Result	**Description**
Success = 0	The connection establishment was successful.
Reject = 1	The connection establishment failed because it was rejected by the upstream Service Node/Base Node.
Timeout = 2	The connection establishment process timed out.
Unsupported SP = 14	Device doesn’t support SP >0 but asked to join a multicas group with an encrypted connection

4.5.2.4.4 MAC_JOIN.indication

On the Base Node, the MAC_JOIN.indication is passed from the MAC layer to indicate that a multicast group join was initiated by a Service Node. On a Service Node, it is used to indicate that the Base Node is inviting to join a multicast group.

Depending on device type, this primitive shall have two variants. The first variant below shall be used in Base Nodes and the second variant is for Service Nodes:

MAC_JOIN.indication{ConHandle, EUI-48, Type, Data, DataLength, AE}

MAC_JOIN.indication(ConHandle, Type, Data, DataLength, AE}

The *ConHandle* is a unique identifier interchanged to uniquely identify the multicast group being indicated. It has a valid meaning only in the MAC SAP, used to have a reference to this connection between different primitives.

The *EUI-48* parameter indicates which device on the Subnetwork wishes to establish a connection.

The *Type* parameter is an identifier used to define the type of the Convergence layer that should be used for this request. This parameter is 1 byte long and it is received in the MUL.TYPE field of the connection request.

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the local CL. This parameter is received in the MUL.DATA field of the connection request.

The *DataLength* parameter is the length of the Data parameter in bytes.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

4.5.2.4.5 MAC_JOIN.response

The MAC_JOIN.response is passed to the MAC layer to respond with a MAC_ JOIN.indication. Depending on device type, this primitive could have either of the two forms given below. The first one shall be used in Service Node and the second on in Base Node implementations.

The semantics of this primitive are as follows:

MAC_JOIN.response{ConHandle, Answer, AE}

MAC_JOIN.response (ConHandle, EUI, Answer, AE)

The *ConHandle* parameter is the same as the one that was received in the MAC_ JOIN.indication.

EUI is the EUI-48 of Service Node that requested the multicast group join.

The *Answer* parameter is used to notify the MAC of the action to be taken for this join request. This parameter may have one of the values depicted below.

The *AE* parameter indicates whether or not the information transmitted in this connection is encrypted. It is a Boolean type with a value of true indicating that encryption will be used.

Table 49 – Values of the *Answer* parameter in MAC_ESTABLISH.response primitive

Answer	Description
Accept = 0	The multicast group join is accepted.

Reject = 1	The multicast group join is rejected.

4.5.2.5 MAC_LEAVE

4.5.2.5.1 General

The MAC_LEAVE primitives are used to leave a broadcast or multicast connection.

4.5.2.5.2 MAC_LEAVE.request

The MAC_LEAVE.request primitive is used to leave a multicast or broadcast traffic. Depending on device type, this primitive could have either of the two forms given below. The first one shall be used in Service Node and the second on in Base Node implementations.

The semantics of this primitive are as follows:

MAC_LEAVE.request{ConHandle}

MAC_LEAVE.request{ConHandle, EUI}

The *ConHandle* parameter specifies the connection to be left. This handle is the one that was obtained during the MAC_JOIN primitives.

EUI is the EUI-48 of Service Node to remove from multicast group.

4.5.2.5.3 MAC_LEAVE.confirm

The MAC_LEAVE.confirm primitive is received to confirm that the MAC_LEAVE.request operation has finished.

The semantics of this primitive are as follows:

MAC_LEAVE.confirm{ConHandle, Result}

The *ConHandle* parameter specifies the connection released. This handle is the one that was obtained during the MAC_JOIN primitives.

The *Result* parameter may have one of the values in Table 50.

Table 50 – Values of the *Result* parameter in MAC_LEAVE.confirm primitive

Result	**Description**
Success = 0	The connection leave was successful.
Timeout = 2	The connection leave process timed out.

After the reception of the MAC_LEAVE.confirm, the ConHandle is no longer valid and should not be used.

4.5.2.5.4 MAC_LEAVE.indication

The MAC_LEAVE.indication primitive is used to leave a multicast or broadcast traffic. Depending on device type, this primitive could have either of the two forms given below. The first one shall be used in Service Node and the second on in Base Node implementations.

The semantics of this primitive are as follows:

MAC_LEAVE.indication{ConHandle}

MAC_LEAVE.indication{ConHandle, EUI}

The ConHandle parameter is the same as that received in MAC_JOIN.confirm or MAC_JOIN.indication. This handle is the one that was obtained during the MAC_JOIN primitives.

EUI is the EUI-48 of Service Node to remove from multicast group.

4.5.3 Base Node signalling primitives

4.5.3.1 General

This section specifies MAC-SAP primitives that are only available in the Base Node.

4.5.3.2 MAC_REDIRECT.response

The MAC_REDIRECT.response primitive is used to answer to a MAC_ESTABLISH.indication and redirects the connection from the Base Node to another Service Node on the Subnetwork.

The semantics of this primitive are as follows:

MAC_REDIRECT.reponse{ConHandle, EUI-48, Data, DataLength}

The *ConHandle* is the one passed in the MAC_ESTABLISH.indication primitive to which it is replying.

EUI-48 indicates the Service Node to which this connection establishment should be forwarded. The Base Node should perform a direct connection setup between the source of the connection establishment and the Service Node indicated by *EUI-48.*

The *Data* parameter is a general purpose buffer to be interchanged for the negotiation between the remote CL and the Base Node CL. This parameter is received in the CON.DATA field of the connection request.

The *DataLength* parameter is the length of the Data parameter in bytes.

Once this primitive has been used, the ConHandle is no longer valid.

4.5.4 Service and Base Nodes data primitives

4.5.4.1 General

The following subsections describe how a Service Node or Base Node passes data between the Convergence layer and the MAC layer.

4.5.4.2 MAC_DATA.request

The MAC_DATA.request primitive is used to initiate the transmission process of data over a connection.

The semantics of the primitive are as follows:

MAC_DATA.request{ConHandle, Data, DataLength, Priority, TimeReference}

The *ConHandle* parameter specifies the connection to be used for the data transmission. This handle is the one that was obtained during the connection establishment primitives.

The *Data* parameter is a buffer of octets that contains the CL data to be transmitted through this connection.

The *DataLength* parameter is the length of the *Data* parameter in octets.

Priority indicates the priority of the data to be sent when using the PLC CSMA access scheme, i.e. the parameter only has meaning when the connection was established with CfBytes = 0. When SUN FSK profile is supported and a data packet is transmitted over RF, this value is ignored by the RF CSMA.

The *TimeReference* parameter is the time reference to interchange with the data. This *TimeReference* parameter is optional; it is possible not sending any time reference. From the primitive point of view the act of not including a time reference will be considered a *NULL* time reference. The way to interchange this parameter in the primitive not loosing precision and its absolute meaning are specific to the implementation.

4.5.4.3 MAC_DATA.confirm

The MAC_DATA.confirm primitive is used to confirm that the transmission process of the data has completed.

The semantics of the primitive are as follows:

MAC_DATA.confirm{ConHandle, Data, Result}

The *ConHandle* parameter specifies the connection that was used for the data transmission. This handle is the one that was obtained during the connection establishment primitives.

The *Data* parameter is a buffer of octets that contains the CL data that where to be transmitted through this connection.

The Result parameter indicates the result of the transmission. This can take one of the values given in Table 51.

Table 51 – Values of the *Result* parameter in MAC_DATA.confirm primitive

Result	**Description**
Success = 0	The send was successful.
Timeout = 2	The send process timed out.

4.5.4.4 MAC_DATA.indication

The MAC_DATA.indication primitive notifies the reception of data through a connection to the CL.

The semantics of the primitive are as follows:

MAC_DATA.indication{ConHandle, Data, DataLength,TimeReference}

The *ConHandle* parameter specifies the connection where the data was received. This handle is the one that was obtained during the connection establishment primitives.

The *Data* parameter is a buffer of octets that contains the CL data received through this connection.

The *DataLength* parameter is the length of the *Data* parameter in octets.

The *TimeReference* parameter is the time reference interchanged with the data. This *TimeReference* parameter is optional; it is possible not receiving any time reference. From the primitive point of view the act of not indicating a time reference will be considered a *NULL* time reference. The way to interchange this parameter in the primitive not loosing precision and its absolute meaning are specific to the implementation.

4.5.5 MAC Layer Management Entity SAPs

4.5.5.1 General

The following primitives are all optional.

The aim is to allow an external management entity to control Registration and Promotion of the Service Node, demotion and Unregistration of a Service Node. The MAC layer would normally perform this automatically; however, in some situations/applications it could be advantageous if this could be externally controlled. Indications are also defined so that an external entity can monitor the status of the MAC.

4.5.5.2 MLME_REGISTER

4.5.5.2.1 General

The MLME_REGISTER primitives are used to perform Registration and to indicate when Registration has been performed.

4.5.5.2.2 MLME_REGISTER.request

The MLME_REGISTER.request primitive is used to trigger the Registration process to a Subnetwork through a specific Switch Node. This primitive may be used for enforcing the selection of a specific Switch Node that may not necessarily be used if the selection is left automatic. The Base Node MLME function does not export this primitive.

The semantics of the primitive could be either of the following:

MLME_REGISTER.request{ }

Invoking this primitive without any parameter simply invokes the Registration process in MAC and leaves the selection of the Subnetwork and Switch Node to MAC algorithms. Using this primitive enables the MAC to perform fully automatic Registration if such a mode is implemented in the MAC.

MLME_REGISTER.request{SNA}

The *SNA* parameter specifies the Subnetwork to which Registration should be performed. Invoking the primitive in this format commands the MAC to register only to the specified Subnetwork.

MLME_REGISTER.request{SID}

The *SID* parameter is the SID (Switch Identifier) of the Switch Node through which Registration needs to be performed. Invoking the primitive in this format commands the MAC to register only to the specified Switch Node. In the case of a PLC+RF node, when SID = 0, the choice of the medium (PLC or RF) used to register is taken by the lower layers and is left to individual implementations.

4.5.5.2.3 MLME_REGISTER.confirm

The MLME_REGISTER.confirm primitive is used to confirm the status of completion of the Registration process that was initiated by an earlier invocation of the corresponding request primitive. The Base Node MLME function does not export this primitive.

The semantics of the primitive are as follows:

MLME_REGISTER.confirm{Result, SNA, SID}

The Result parameter indicates the result of the Registration. This can take one of the values given in

Table 52.

Table 52 – Values of the *Result* parameter in MLME_REGISTER.confirm primitive

Result	**Description**
Done = 0	Registration to specified SNA through specified Switch is completed successfully.
Timeout =2	Registration request timed out .
Rejected=1	Registration request is rejected by Base Node of specified SNA.
NoSNA=8	Specified SNA is not within range.
NoSwitch=9	Switch Node with specified EUI-48 is not within range.

The *SNA* parameter specifies the Subnetwork to which Registration is performed. This parameter is of significance only if *Result=0*.

The *SID* parameter is the SID (Switch Identifier) of the Switch Node through which Registration is performed. This parameter is of significance only if *Result=0*.

4.5.5.2.4 MLME_REGISTER.indication

The MLME_REGISTER.indication primitive is used to indicate a status change in the MAC. The Service Node is now registered to a Subnetwork.

The semantics of the primitive are as follows:

MLME_REGISTER.indication{SNA, SID}

The *SNA* parameter specifies the Subnetwork to which Registration is performed.

The *SID* parameter is the SID (Switch Identifier) of the Switch Node through which Registration is performed.

4.5.5.3 MLME_UNREGISTER

4.5.5.3.1 General

The MLME_UNREGISTER primitives are used to perform deregistration and to indicate when deregistration has been performed.

4.5.5.3.2 MLME_UNREGISTER.request

The MLME_UNREGISTER.request primitive is used to trigger the Unregistration process. This primitive may be used by management entities if they require the Node to unregister for some reason (e.g. register through another Switch Node or to another Subnetwork). The Base Node MLME function does not export this primitive.

The semantics of the primitive are as follows:

MLME_UNREGISTER.request{}

4.5.5.3.3 MLME_UNREGISTER.confirm

The MLME_UNREGISTER.confirm primitive is used to confirm the status of completion of the unregister process initiated by an earlier invocation of the corresponding request primitive. The Base Node MLME function does not export this primitive.

The semantics of the primitive are as follows:

MLME_UNREGISTER.confirm{Result}

The *Result* parameter indicates the result of the Registration. This can take one of the values given in Table 53.

Table 53 – Values of the *Result* parameter in MLME_UNREGISTER.confirm primitive

Result	**Description**
Done = 0	Unregister process completed successfully.
Timeout =2	Unregister process timed out .
Redundant=10	The Node is already in *Disconnected* functional state and does not need to unregister.

On generation of MLME_UNREGISTER.confirm, the MAC layer shall not perform any automatic actions that may invoke the Registration process again. In such cases, it is up to the management entity to restart the MAC functionality with appropriate MLME_REGISTER primitives.

4.5.5.3.4 MLME_UNREGISTER.indication

The MLME_UNREGISTER.indication primitive is used to indicate a status change in the MAC. The Service Node is no longer registered to a Subnetwork.

The semantics of the primitive are as follows:

MLME_UNREGISTER.indication{}

4.5.5.4 MLME_PROMOTE and MLME_MP_PROMOTE

4.5.5.4.1 General

The MLME_PROMOTE primitives are used to perform promotion and to indicate when promotion has been performed. They are used to trigger a promotion process in a Service Node (Terminal or Switch) in the medium (PLC or RF) the node is connected to the network. They may also be used for the beacon modulation change on the PLC medium.

The MLME_MP_PROMOTE primitives have a similar scope and are only available in nodes that support Multi-PHY promotion (REG_CAP.MP=1). They are used to trigger a promotion process in a Service Node (Terminal or Switch) in a medium (PLC or RF) different from the one the node is connected to the network. They may also be used for the beacon modulation change on the PLC medium.

4.5.5.4.2 MLME_PROMOTE.request

The MLME_PROMOTE.request primitive is used to trigger the promotion process in a Service Node that is in a *Terminal* functional state. Implementations may use such triggered promotions to optimize Subnetwork topology from time to time. The value of PRO.PNA in the promotion message sent to the Base Node is undefined and implementation-specific.

The MLME_PROMOTE.request primitive can also be used from a node that is already in a *Switch* state to ask the BN for a Beacon PDU modulation change.

Base Node can use this primitive to ask a node to change its state from *Terminal* to *Switch* or, if the node is already in the *Switch* state, to adopt a new Beacon PDU modulation scheme.

The semantics of the primitive can be either of the following:

MLME_PROMOTE.request{}

MLME_PROMOTE.request{BCN_MODE}

MLME_PROMOTE.request{EUI-48, BCN_MODE}

The EUI-48 parameter shall be used only by the Base Node to specify the address of the Node to which this promotion request shall be addressed. The MAC shall internally transfer this to an address used by the MAC layer.

The BCN_MODE parameter specifies the Beacon PDU modulation scheme. If the primitive is called by a node in Switch state, this parameter indicates the requested Beacon PDU modulation scheme from the Switch node to the Base Node. If the primitive is called by the Base Node, this parameter indicates the modulation scheme that shall be communicated to the node during the promotion process or during the Beacon PDU modulation change process.

Allowed values for BCN_MODE parameter are listed in Table 54.

Table 54 - Values of the BCN_MODE parameter in MLME_PROMOTE.request primitive.

BCN_MODE	***Description***
DBPSK_F = 0	BCN will be sent using DBPSK modulation with convolutional encoding enabled and robust mode disabled.
R_DBPSK = 1	BCN will be sent using DBPSK modulation with robust mode enabled.
R_DQPSK = 2	BCN will be sent using DQPSK modulation with robust mode enabled.

4.5.5.4.3 MLME_PROMOTE.confirm

The MLME_PROMOTE.confirm primitive is used to confirm the status of completion of a promotion process that was initiated by an earlier invocation of the corresponding request primitive.

The semantics of the primitive are as follows:

MLME_PROMOTE.confirm{Result}

The *Result* parameter indicates the result of the Registration. This can take one of the values given in Table 55.

Table 55 – Values of the Result parameter in MLME_PROMOTE.confirm primitive

Result	**Description**
Done = 0	Node is promoted to Switch function successfully.
Timeout =1	Promotion process timed out.
Rejected=2	The Base Node rejected promotion request.
No Such Device = 4	A device with the destination address cannot be found.
Redundant=10	This device is already functioning as Switch Node.
OutofRange=12	Specified BCN_MODE is out of acceptable range.

In case an already promoted switch, which is requesting a Beacon PDU modulation change, receives an MLME_PROMOTE.confirm{} rejecting the request, only the change request is supposed to be rejected, so the node shall continue sending the Beacon PDU as previously.

4.5.5.4.4 MLME_PROMOTE.indication

The MLME_PROMOTE.indication primitive is used to indicate a status change in the MAC. The Service Node is now operating as a Switch. This primitive is not generated if a Beacon PDU modulation change occurs.

The semantics of the primitive are as follows:

MLME_PROMOTE.indication{}

4.5.5.4.5 MLME_MP_PROMOTE.request

The MLME_MP_PROMOTE.request primitive is used to trigger a promotion process in a Service Node (Terminal or Switch) in a medium (PLC or RF) different from the one the node is connected to the network. Implementations may use such triggered promotions to optimize Subnetwork topology from time to time. The value of PRO.PNA in the promotion message sent to the Base Node is undefined and implementation-specific. The semantic used in this case is

MLME_MP_PROMOTE.request{PCH}

where, here and in the rest of this section, PCH is encoded in the same way as described in 4.4.2.6.5.1. For the different physical medium, every band (PLC) or channel (RF) available in the Service Node PLC Band Plan and RF band, respectively, can be used. This use of the primitive is associated to the process described in section 4.6.3.3.

If a Service Node is connected to the network through the RF medium and is already a switch on the PLC medium (due to a successful Multi-PHY promotion, see 4.6.3.3), the MLME_MP_PROMOTE.request primitive can also be used to ask the BN for a Beacon PDU modulation change. The semantic used in this case is

MLME_MP_PROMOTE.request*{BCN_MODE}*

where, here and in the rest of this section, the BCN_MODE parameter follows the same rules described in 4.5.5.4.2. This use of the primitive is associated to the process described in section 4.6.3.1.

Base Node can use this primitive to ask a node (Terminal or Switch) to promote in a medium (PLC or RF) different from the one the node is connected to the network. The semantic used in this case is

MLME_MP_PROMOTE.request*{EUI48, BCN_MODE, PCH}*

where, here and in the rest of this section, the EUI48 parameter follows the same rules described in 4.5.5.4.2. For the different physical medium, every band (PLC) or channel (RF) available in the Service Node PLC Band Plan and RF band, respectively, can be used. This use of the primitive is associated to the process described in section 4.6.3.3.

Base Node may also use this primitive to ask a Service Node that is connected to the network through the RF medium and is already a switch on the PLC medium to adopt a new Beacon PDU modulation scheme. The semantic used in this case is

MLME_MP_PROMOTE.request*{EUI48, BCN_MODE}*

This use of the primitive is associated to the process described in section 4.6.3.1.

4.5.5.4.6 MLME_MP_PROMOTE.confirm

The MLME_MP_PROMOTE.confirm primitive is used to confirm the status of completion of a promotion process that was initiated by an earlier invocation of the corresponding request primitive.

The semantics of the primitive are as follows:

MLME_MP_PROMOTE.confirm{Result}

The *Result* parameter can take one of the values given in Table 55.

Result	*Description*
Done = 0	Node is promoted successfully.
Timeout =1	Promotion process timed out.
Rejected=2	The Base Node rejected promotion request.
No Such Device = 4	A device with the destination address cannot be found.
Wrong Medium = 9	This device is connected to the network with the requested medium. MLME_PROMOTE primitives shall be considered for this request.
Redundant=10	This device is already functioning as Switch Node in the requested medium.
OutofRange=12	Specified BCN_MODE is out of acceptable range or the band (PLC)/channel(RF) encoded in the PCH is out of the device's PLC band plan/RF band.

4.5.5.4.7 MLME_MP_PROMOTE.indication

The MLME_MP_PROMOTE.indication primitive is used to indicate a status change in the MAC. The Service Node is operating as a Switch in a medium (PLC or RF) different from the one the node is connected to the network. This primitive is not generated if a Beacon PDU modulation change occurs.

The semantics of the primitive are as follows:

MLME_MP_PROMOTE.indication{PCH}

where PCH is encoded in the same way as described in 4.4.2.6.5.1.

4.5.5.5 MLME_DEMOTE and MLME_MP_DEMOTE

4.5.5.5.1 General

The MLME_DEMOTE primitives are used to perform demotion and to indicate when demotion has been performed. They are used to trigger a demotion process in a Switch in the medium (PLC or RF) the Switch is connected to the network.

The MLME_MP_DEMOTE primitives have a similar scope and are only available in nodes that support Multi-PHY promotion (REG_CAP.MP=1). They are used to trigger a demotion process in a Switch based upon the LSIDs the Switch is using.

4.5.5.5.2 MLME_DEMOTE.request

The MLME_DEMOTE.request primitive is used to trigger a demotion process in a Service Node that is in a *Switch* functional state. This primitive may be used by management entities to enforce demotion in cases where the Node's default functionality does not automatically perform the process.

The semantics of the primitive are as follows:

MLME_DEMOTE.request{}

4.5.5.5.3 MLME_DEMOTE.confirm

The MLME_DEMOTE.confirm primitive is used to confirm the status of completion of a demotion process that was initiated by an earlier invocation of the corresponding request primitive.

The semantics of the primitive are as follows:

MLME_DEMOTE.confirm{Result}

The *Result* parameter indicates the result of the demotion. This can take one of the values given in Table 56.

Table 56 – Values of the *Result* parameter in MLME_DEMOTE.confirm primitive

Result	**Description**
Done = 0	Node is demoted to Terminal function successfully. For nodes that support Multi-PHY promotion, node is demoted successfully and it is a Terminal or, in the case it was a Switch on two media, it is a Switch in one medium (different from the one it is connected to the network).
Timeout =1	Demotion process timed out.
Redundant=10	This device is not a Switch on the medium it is connected to the network.

When a demotion has been triggered using the MLME_DEMOTE.request, the Terminal will remain demoted.

4.5.5.5.4 MLME_DEMOTE.indication

The MLME_DEMOTE.indication primitive is used to indicate a status change in the MAC. The Service Node is now operating as a Terminal.For nodes that support Multi-PHY promotion, it may also indicate that the Service Node previously acting as a Switch on two media is now a Switch only in one medium (different from the one it is connected to the network).

The semantics of the primitive are as follows:

MLME_DEMOTE.indication{}

4.5.5.5.5 MLME_MP_DEMOTE.request

The MLME_MP_DEMOTE.request primitive is used to trigger a demotion process in a Service Node that is in a *Switch* functional state. This primitive may be used by management entities to enforce demotion in cases where the Node's default functionality does not automatically perform the process.

The semantics of the primitive are as follows:

MLME_MP_DEMOTE.request{LSID}

Here, LSID is a Local Switch Identifier. Note that, as the Service Node may be Switch on two media (PLC and RF), it may have two LSIDs (see 4.6.4).

4.5.5.5.6 MLME_MP_DEMOTE.confirm

The MLME_MP_DEMOTE.confirm primitive is used to confirm the status of completion of a demotion process that was initiated by an earlier invocation of the corresponding request primitive.

The semantics of the primitive are as follows:

MLME_MP_DEMOTE.confirm{Result}

The *Result* parameter indicates the result of the demotion. This can take one of the values given in Table 57.

Table 57. Values of the *Result* parameter in MLME_MP_DEMOTE.confirm primitive

Result	**Description**
Done = 0	Node is demoted successfully. Node is a Terminal or, in the case it was a Switch on two media, it is a Switch in one medium.
Timeout = 1	Demotion process timed out.
Wrong LSID = 15	This device is not a Switch with this LSID.

4.5.5.5.7 MLME_MP_DEMOTE.indication

The MLME_MP_DEMOTE.indication primitive is used to indicate a status change in the MAC. The Service Node is now operating as a Terminal. It may also indicate that the Service Node previously acting as a Switch on two media is now a Switch only in one medium.

The semantics of the primitive are as follows:

MLME_MP_DEMOTE.indication{LSID}

where LSID is the demoted Local Switch Identifier.

4.5.5.6 MLME_RESET

4.5.5.6.1 General

The MLME_RESET primitives are used to reset the MAC into a known good status.

4.5.5.6.2 MLME_RESET.request

The MLME_RESET.request primitive results in the flushing of all transmit and receive buffers and the resetting of all state variables. As a result of invoking of this primitive, a Service Node will transit from its present functional state to the *Disconnected* functional state.

The semantics of the primitive are as follows:

MLME_RESET.request{}

4.5.5.6.3 MLME_RESET.confirm

The MLME_RESET.confirm primitive is used to confirm the status of completion of a reset process that was initiated by an earlier invocation of the corresponding request primitive. On the successful completion of the reset process, the MAC entity shall restart all functions starting from the search for a Subnetwork (4.3.1).

The semantics of the primitive are as follows:

MLME_RESET.confirm{Result}

The *Result* parameter indicates the result of the reset. This can take one of the values given below.

Table 58 – Values of the *Result* parameter in MLME_RESET.confirm primitive

Result	**Description**
Done = 0	MAC reset completed successfully.
Failed =1	MAC reset failed due to internal implementation reasons.

4.5.5.7 MLME_GET

4.5.5.7.1 General

The MLME_GET primitives are used to retrieve individual values from the MAC, such as statistics.

4.5.5.7.2 MLME_GET.request

The MLME_GET.request queries information about a given PIB attribute.

The semantics of the primitive are as follows:

MLME_GET.request{PIBAttribute}

The *PIBAttribute* parameter identifies specific attributes as listed in the *Id* fields of tables that list PIB attributes (Section 6.2.3).

4.5.5.7.3 MLME_GET.confirm

The MLME_GET.confirm primitive is generated in response to the corresponding MLME_GET.request primitive.

The semantics of this primitive are as follows:

MLME_GET.confirm{status, PIBAttribute, PIBAttributeValue}

The *status* parameter reports the result of requested information and can have one of the values given in Table 59.

Table 59 – Values of the *status* parameter in MLME_GET.confirm primitive

Result	**Description**
Done = 0	Parameter read successfully.
Failed =1	Parameter read failed due to internal implementation reasons.
BadAttr=11	Specified *PIBAttribute* is not supported.

The *PIBAttribute* parameter identifies specific attributes as listed in *Id* fields of tables that list PIB attributes (Section 6.2.3.5).

The *PIBAttributeValue* parameter specifies the value associated with a given *PIBAttribute*

4.5.5.8 MLME_LIST_GET

4.5.5.8.1 General

The MLME_LIST_GET primitives are used to retrieve a list of values from the MAC.

4.5.5.8.2 MLME_LIST_GET.request

The MLME_LIST_GET.request queries for a list of values pertaining to a specific class. These special classes of PIB attributes are listed in Table 109.

The semantics of the primitive are as follows:

MLME_LIST_GET.request{PIBListAttribute}

The *PIBListAttribute* parameter identifies a specific list that is requested by the management entity. The possible values of *PIBListAttribute* are listed in 6.2.3.5.

4.5.5.8.3 MLME_LIST_GET.confirm

The MLME_LIST_GET.confirm primitive is generated in response to the corresponding MLME_LIST_GET.request primitive.

The semantics of this primitive are as follows:

MLME_LIST_GET.confirm{status, PIBListAttribute, PIBListAttributeValue}

The *status* parameter reports the result of requested information and can have one of the values given in Table 60

Table 60 – Values of the *status* parameter in MLME_LIST_GET.confirm primitive

Result	Description
Done = 0	Parameter read successfully.
Failed =1	Parameter read failed due to internal implementation reasons.
BadAttr=11	Specified *PIBListAttribute* is not supported.

The *PIBListAttribute* parameter identifies a specific list as listed in the *Id* field of Table 109.

The *PIBListAttributeValue* parameter contains the actual listing associated with a given *PIBListAttribute*

4.5.5.9 MLME_SET

4.5.5.9.1 General

The MLME_SET primitives are used to set configuration values in the MAC.

4.5.5.9.2 MLME_SET.request

The MLME_SET.requests information about a given PIB attribute.

The semantics of the primitive are as follows:

MLME_SET.request{PIBAttribute, PIBAttributeValue}

The *PIBAttribute* parameter identifies a specific attribute as listed in the *Id* fields of tables that list PIB attributes (Section 6.2.3).

The *PIBAttributeValue* parameter specifies the value associated with given *PIBAttribute.*

4.5.5.9.3 MLME_SET.confirm

The MLME_SET.confirm primitive is generated in response to the corresponding MLME_SET.request primitive.

The semantics of this primitive are as follows:

MLME_SET.confirm{result}

The *result* parameter reports the result of requested information and can have one of the values given in Table 61.

Table 61 – Values of the *Result* parameter in MLME_SET.confirm primitive

Result	Description
Done = 0	Given value successfully set for specified attribute.
Failed =1	Failed to set the given value for specified attribute.
BadAttr=11	Specified *PIBAttribute* is not supported.

Result	**Description**
OutofRange=12	Specified *PIBAttributeValue* is out of acceptable range.
ReadOnly=13	Specified PIBAttributeValue is read only.

The *PIBAttribute* parameter identifies a specific attribute as listed in the *Id* fields of tables that list PIB attributes (Section 6.2.3).

The *PIBAttributeValue* parameter specifies the value associated with a given *PIBAttribute.*

4.6 MAC procedures

4.6.1 Registration process

4.6.1.1 General

The initial Service Node start-up (4.3.1) is followed by a Registration process. A Service Node in a *Disconnected* functional state shall transmit a REG control packet to the Base Node in order to get itself included in the Subnetwork. Since no LNID or SID is allocated to a Service Node at this stage, the PKT.LNID field shall be set to all 1s and the PKT.SID field shall contain the SID of the Switch Node through which it seeks attachment to the Subnetwork.

Base Nodes may use a Registration request as an authentication mechanism. However this specification does not recommend or forbid any specific authentication mechanism and leaves this choice to implementations.

For all successfully accepted Registration requests, the Base Node shall allocate an LNID that is unique within the domain of the Switch Node through which the attachment is realized. This LNID shall be indicated in the PKT.LNID field of response (REG_RSP). The assigned LNID, in combination with the SID of the Switch Node through which the Service Node is registered, would form the NID of the registering Node.

Registration is a three-way process. The Base Node answers to the REG_REQ - registration request - sent by a Service Node by means of a REG_RSP message, which shall be acknowledged by the Service Node with a REG_ACK message.

Service Nodes report their capabilities to the Base Node during registration (REG_REQ), as specified in 4.4.2.6.3. On top of that, a Base Node is able to configure some parameters in Service Nodes when answering (REG_RSP) to a registration request.

- Dynamic robustness-management is enabled by default. Nonetheless, the Base Node may disable dynamic robustness-management and fix a specific modulation scheme, thus not allowing Service Node(s) to dynamically switch to a different modulation scheme.

  The configured value is stored by the Service Node as *"macRobustnessManagement"*.

- *Segmentation And Reassembly (SAR)* packet size: The packet size used by Convergence Layer's SAR Service is not configured by the Base Node by default. Nonetheless, a Base Node may fix a specific

SAR packet size if required. For more information about Convergence Layer's SAR Service, please refer to section 5.6.2.1.3

The configured value is stored by the Service Node as *"macSARsize"*.

Configuration of the two parameters mentioned above during registration provides a static network configuration. This configuration can be changed by the Base Node, either starting a new registration process or setting the corresponding Service Node's PIB variables remotely.

Figure 77 represents a successful Registration process and Figure 78 shows a Registration request that is rejected by the Base Node. Details on specific fields that distinguish one Registration message from the other are given in Table 21. The registration process security-related steps are explained in Section 4.6.1.2.

The REG control packet, in all its usage variants, is transmitted unencrypted, but specified fields (REG.SWK and REG.WK) are encrypted with context-specific encryption keys as explained in Section 4.4.2.6.3. The encryption of REG.WK in REG_RSP, its decryption at the receiving end and subsequent encrypted retransmission using a different encryption key authenticates that the REG_ACK is from the intended destination.

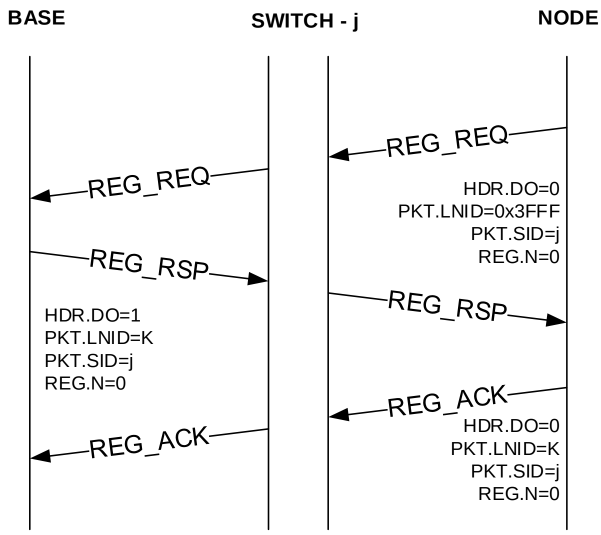


Figure 77 – Registration process accepted

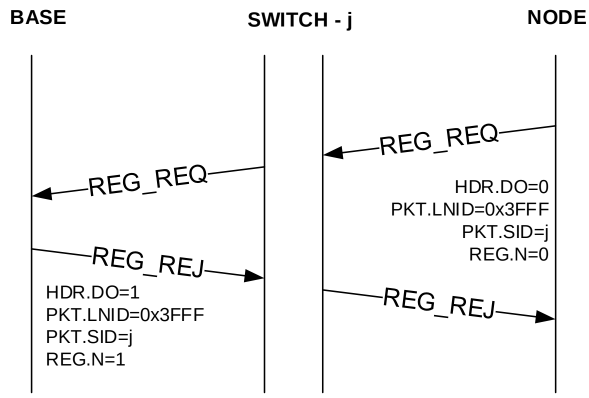


Figure 78 – Registration process rejected

When assigning an LNID, the Base Node shall not reuse an LNID released by an unregister process before (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds, to ensure that all retransmitted packets have left the

Subnetwork. Similarly, the Base Node shall not reuse an LNID released by the Keep-Alive process before T_{keep_alive} seconds, using the last known acknowledged T_{keep_alive} value, or if larger, the last unacknowledged T_{keep_alive}, for the Service Node using the LNID. When security is being used in the network, the Base Node shall not reuse a LNID without first changing the Subnetwork Working Key.

During network startup where the whole network is powered on at once, there will be considerable contention for the medium. It is recommended to add randomness to the first REG_REQ transmission, as well as to all subsequent retransmissions. It is recommended to wait a random delay before the first REG_REQ message. This delay should be in range from 0 to at least 10% of *macCtrlMsgFailTime*. Similarly a random delay may be added to each retransmission.

4.6.1.2 Security registration process

Figure 77 represents the registration process. When security profile 1 or 2 is utilized, additional action is required by the Base and Terminal Nodes to ensure successful registration.

1. The Terminal Node generates a challenge (see Section 4.3.8.2.2.2.3).
2. The challenge is included in the REG_REQ and the REG_REQ is authenticated with REGK.
3. The Base Node validates that REG_REQ is properly authenticated.
4. The SWK and WK are key wrapped with KWK. The REG_RSP is authenticated with REGK and the Terminal Node challenge is concatenated.
5. The Terminal Node validates that REG_RSP is properly authenticated, including the concatenated challenge
6. The Terminal Node updates WK and SWK.
7. The REG_ACK is authenticated with WK. The first Nonce is required for AES-CCM (Set to 0, then counted up for every packet.)
8. The Base Node validates REG_ACK. The registration is invalidated on error

4.6.2 Unregistration process

At any point in time, either the Base Node or the Service Node may decide to close an existing registration. This version of the specification does not provide provision for rejecting an unregistration request. The Service Node or Base Node that receives an unregistration request shall acknowledge its receipt and take appropriate actions.

Following a successful unregistration, a Service Node shall move back from its present functional state to a *Disconnected* functional state and the Base Node may re-use any resources that were reserved for the unregistered Node.

Figure 79 shows a successful unregistration process initiated by a Service Node and Figure 80 shows an unregistration process initiated by the Base Node. Details on specific fields that identify unregistration requests in REG control packets are given in Table 22.

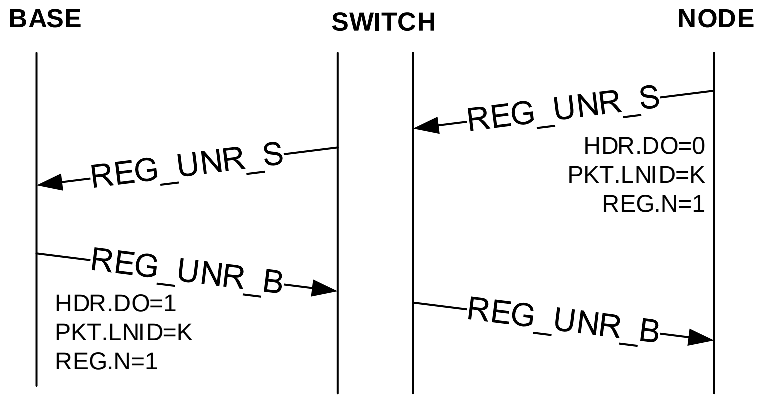


Figure 79 – Unregistration process initiated by a Terminal Node

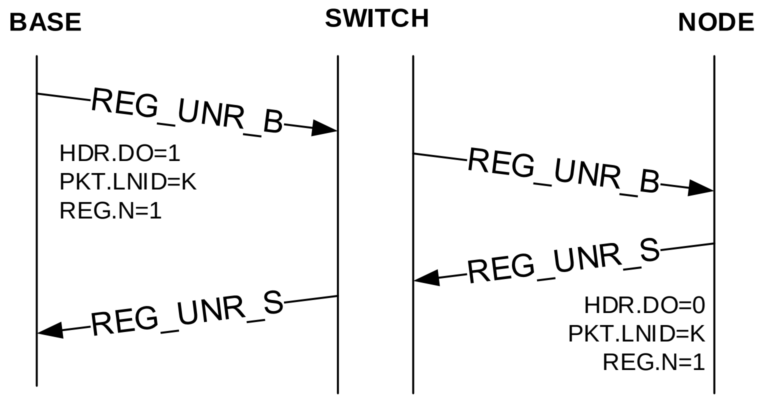


Figure 80 – Unregistration process initiated by the Base Node

4.6.3 Promotion process

The promotion process described in this section occurs on the same medium and on the same band (PLC) or channel (RF) a Service Node is connected to the network. The process, as well as the related messages (e.g. see 4.4.2.6.5) and primitives (e.g. see 4.5.5.4.2) are described for a Terminal becoming Switch. For nodes that support Multi-PHY promotion (see 4.6.3.3), this process may also apply to a Service Node that it is already a Switch on a medium different from the one it is connected to the network.

A Service Node that does not receive any BPDUs may transmit PNPDUs. Any Terminal Node receiving PNPDUs may generate a promotion request towards Base Node, which upon acceptance from Base Node, will result in transition of the requesting Terminal Node to Switch and therefore scale the Subnetwork to facilitate PNPDU transmitting Service Node to join.

Note: A Subnetwork that operates in backward compatibility-mode as enumerated in 4.8, shall silently discard PNPDUs that indicate lack of support for backward compatibility-mode i.e. PNH.VER = 1 and PNH.CAP_BC = 0.

The Base Node examines promotion requests during a period of time. It may use the address of the new Terminal, provided in the promotion-request packet, to decide whether or not to accept the promotion. It decides which Service Node shall be promoted, if any, sending a promotion response. The other Nodes do not receive any response to their promotion request to avoid Subnetwork saturation. Eventually, the Base

Node may send a rejection if any special situation occurs. If the Subnetwork is specially preconfigured, the Base Node may send Terminal Node promotion requests directly to a Terminal Node.

When a Terminal Node requests promotion, the PRO.NSID field in the PRO_REQ_S message shall be set to all 1s. The PRO.NSID field shall contain an LSID allocated to the promoted Node in the PRO_REQ_B message. The acknowledging Switch Node shall set the PRO.NSID field in its PRO_ACK to the newly allocated LSID. This final PRO_ACK shall be used by intermediate Switch Nodes to update their switching tables.

When reusing LSIDs that have been released by a demotion process, the Base Node shall not allocate the LSID until after (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds to ensure all retransmit packets that might use that LSID have left the Subnetwork.

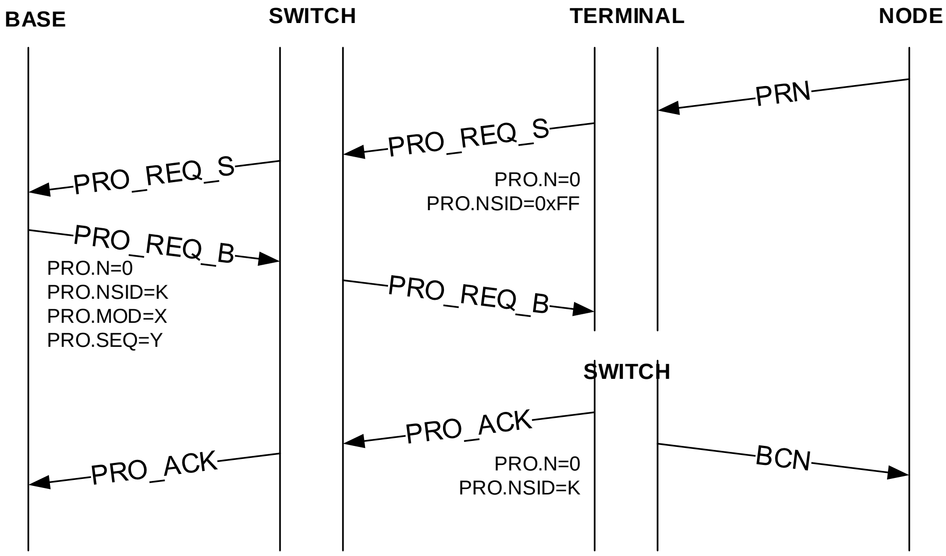


Figure 81 – Promotion process initiated by a Service Node

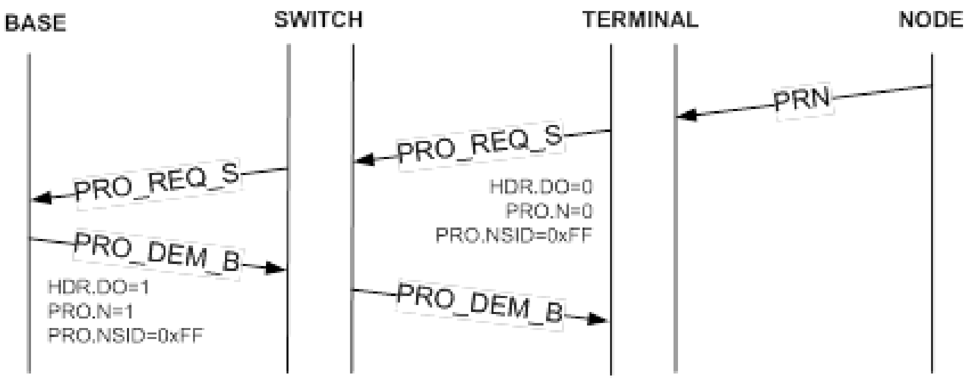


Figure 82 – Promotion process rejected by the Base Node

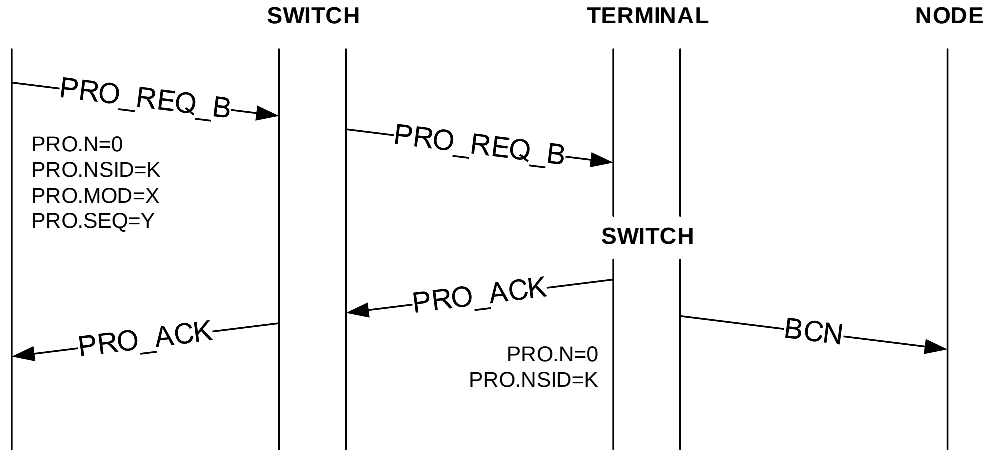


Figure 83 – Promotion process initiated by the Base Node

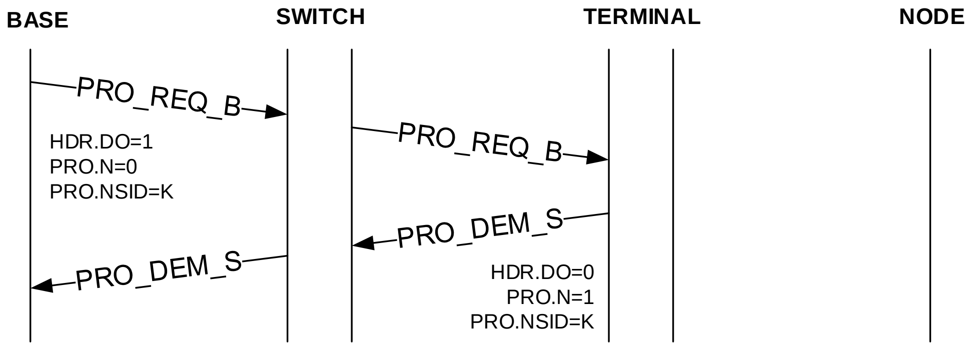
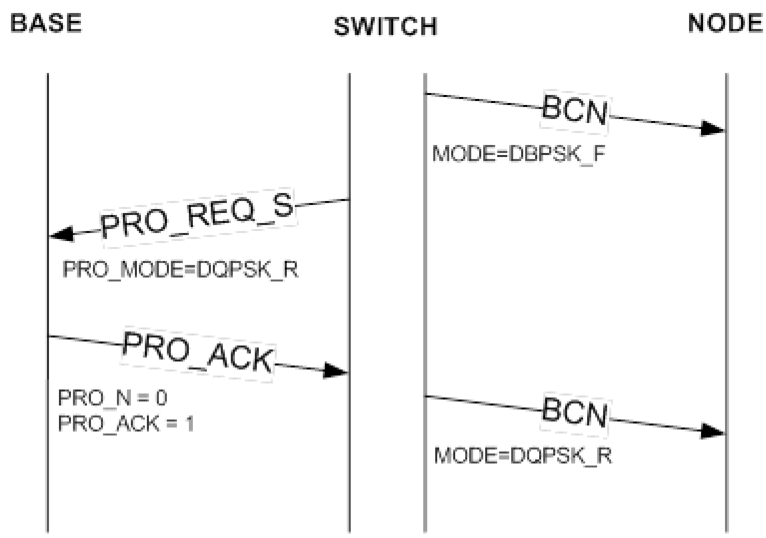


Figure 84 – Promotion process rejected by a Service Node

4.6.3.1 BPDU modulation change

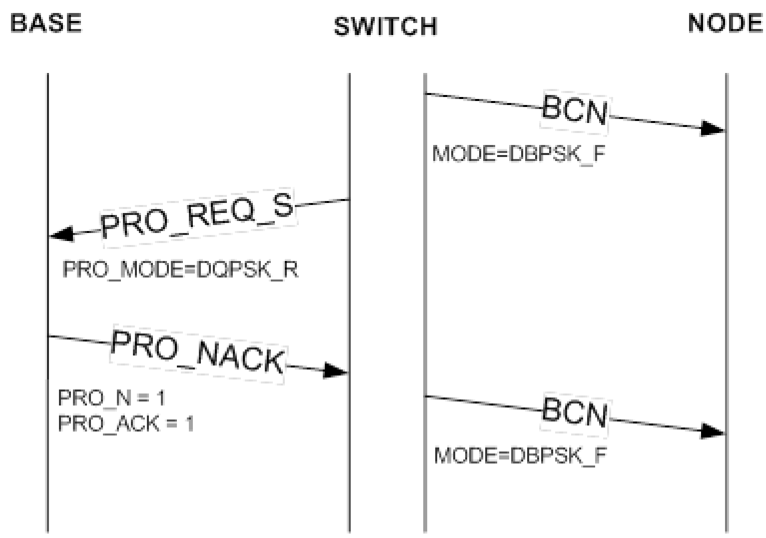
In the PLC medium, it is possible, for the Switch Node, to change modulation scheme used to send BPDUs. In order to do so a new PRO_REQ_S message is sent with an indication of the new desired modulation scheme to be used in PRO.MOD field. On reception of this PRO_REQ_S the Base Node shall send a PRO_ACK packet to accept the change request, or send a PRO_NACK packet to reject the change request. The Base Node can not indicate a new BPDU modulation scheme in the PRO.MOD field that is different from the requested one. In such a case the Base Node can accept the requested modulation and initiate another beacon modulation change by itself. The Switch would then either acknowledge the reception by sending a PRO_ACK (accept the new modulation) or a PRO_NACK packet (reject the new modulation). In case an explicit denial is issued by the Base Node, the Switch shall keep on sending the Beacon PDUs without changing to the new modulation scheme. Switch Node shall not sent PRO_ACK packet in case of explicit reject.

The Beacon PDU modulation change process can also be initialized by the Base Node. In this case the Switch Node shall send a PRO_ACK packet if it can perform the Beacon PDU modulation change otherwise it shall send a PRO_NACK.



3193

3194 **Figure 85 – BCN modulation change request initiated by the Switch.**



3195

3196 **Figure 86 – BCN modulation change request initiated by the Switch and rejected by the Base Node.**

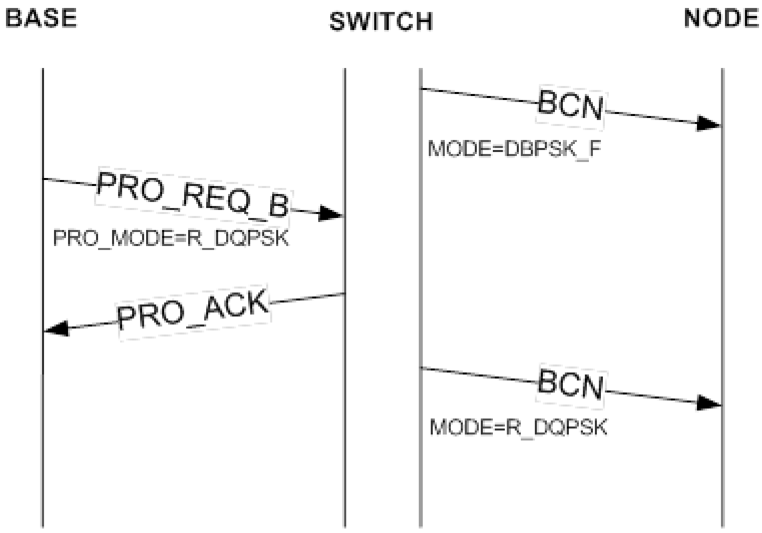


Figure 87 - BCN modulation change request initiated by the Base Node.

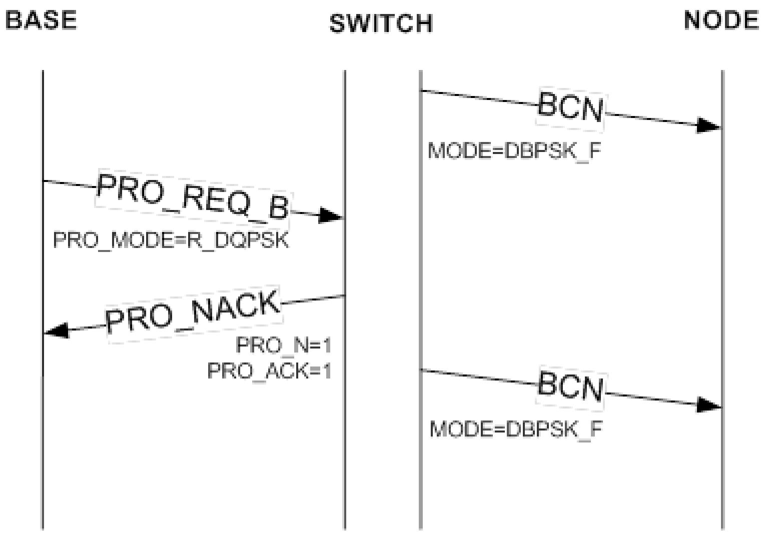


Figure 88 - BCN modulation change request initiated by the Base Node and rejected by the Switch

During a Promotion procedure the Base Node assigns resources to new Switch Node in order to transmit its BPDU. These changes shall take effect only on a super-frame boundary. In case these changes require a change in frame structure, the Base Node shall send a FRA packet to inform the entire network.

4.6.3.2 Double switching procedure

This section has been written considering that the support of robust modes is optional for PLC-only devices. For PLC+RF devices, the support of robust modes is mandatory (these devices indicate REG.CAP_R=1, PRO.PN_R=1, PNH.CAP_R=1, BCN.CAP_R=1). Moreover, more generally, PLC+RF devices shall be part of networks where robust modes are supported on the PLC medium (these networks may also include PLC-only devices supporting robust modes).

With the previous considerations, the procedure described in what follows, named double switching, is not supported by PLC+RF devices (and, obviously, by RF devices) and will be described for PLC-only devices in the context of PLC-only Subnetworks.

Certain PLC-only Subnetworks may have a mix of device-types between ones that can support Type A PHY frames only and ones that support both Type A and Type B PHY frames. In such cases, a Switch Node that acts as switching point for both kinds of devices, may need to transmit BPDUs using both types of PHY frames.

In order to be able to transmit BPDUs using both types of PHY frames, a Switch Node needs to undergo a second promotion procedure. The first promotion is carried out in the usual manner as enumerated 4.6.3. When a Switch Node identifies need to transmit its BPDU in additional modulation scheme, it starts a second promotion procedure. The Switch Node uses PRO packets with the PRO.DS bit set to one. Additionally, the PRO_REQ_S packet shall fill LSID of the requesting Switch Node in PRO.SID field.

When a Switch Node has two BPDUs to send it may ask to change modulation scheme only for the robust beacon, passing from the DBPSK_R to DQPSK_R or viceversa following procedure enumerated in 4.6.3.1.

To stop sending one type of BPDU, the demotion procedure is used. In this case the PRO.MOD field indicates which beacon shall not be transmit and the PRO.DS field set to 1 idicates that the node is asking to stop sending one type of beacon. If the PRO.DS field is set to 0 the node is asking for a full demotion, stop sending both BPDUs and transit back to *Terminal* funcional state.

By having possibility to provide connectivity for Type A only devices and for devices that require Type B frames, the Switch Node shall guarantee delivery of multicast and broadcast packets. In simplified implementations, the Switch Node can transmit these types of packets twice, one with the Type A frame and one with the Type B. Multicast data shall be switched in conformance to procedures enumerated in 4.6.7.4.3.

For broacast data, the Switch Node shall start to send packets twice after it succesfully performs the double beacon slot allocation, and it shall stop sending one of the two type of packets when the demotion procedure is completed for that specific type of frame.

Devices that are able to understand both frames, Type A or Type B may receive same data twice, at each modulation scheme. Such devices shall be intelligent enough to discard the duplicate receipt of data..

4.6.3.3 Extension for Multi-PHY promotion procedure

When the base node notifies through the registration process that the multiPHY promotion is supported: REG.CAP_MP=1, if also supported by a service node, the latter can start a promotion process in a different physical medium (PLC or RF) than the one through which it is connected to the network. For the different physical medium, it can select every band (PLC) or channel (RF) available in its PLC Band Plan and RF band, respectively.

If a node (terminal or switch) can hear PNPDUs in a different medium (PLC or RF), it may send a new promotion request to be switch in other medium, to do that, It must use the PRO_REQ_S_MultiPHY message.

The physical medium and the band (PLC) or channel (RF) will be coded in the PRO.PCH field of the message. When the network is configured to use channel hopping (see 4.6.10) on the RF PHY medium, the PRO.PCH field has a fixed coding with all bits equal to 1.

The PRO.NSID field in the PRO_REQ_S_MultiPHY message shall be set to all 1s. If the Base Node accepts a promotion request, it allocates an LSID to the requesting node (terminal or switch) using the field PRO.NSID of the PRO_REQ_B_MultiPHY message. This LSID shall be different from the one possibly already allocated through PRO_REQ_B using the promotion process described in 4.6.3, so that a switch could have two LSIDs. The physical medium coded in the PRO.PCH field of PRO_REQ_B_MultiPHY message shall be the same as the one coded in the PRO_REQ_S_MultiPHY message (e.g. the Base Node shall not accept a promotion request on the PLC medium with an RF PRO.PCH field in the PRO_REQ_B_MultiPHY).

If the Base Node is specially configured, it may send a PRO_REQ_B_MultiPHY message to a node (terminal or switch) to promote it in a physical medium (PLC or RF) different from the one through which the node is connected to the network. For the different physical medium, it can select every band (PLC) or channel (RF) available in its PLC Band Plan and RF band, respectively.

With this method, all the normal operations (promotion acknowledgement/not acknowledgement, demotion, change of modulation) could be done with the PRO_REQ_S and PRO_REQ_B messages using the LSID allocated through PRO_REQ_B_MultiPHY message.

A switch shall use on the same medium (i.e. PLC or RF) 1 band (PLC) and/or 1 channel (RF). The use of multiple RF channels is admitted under the channel hopping procedure.

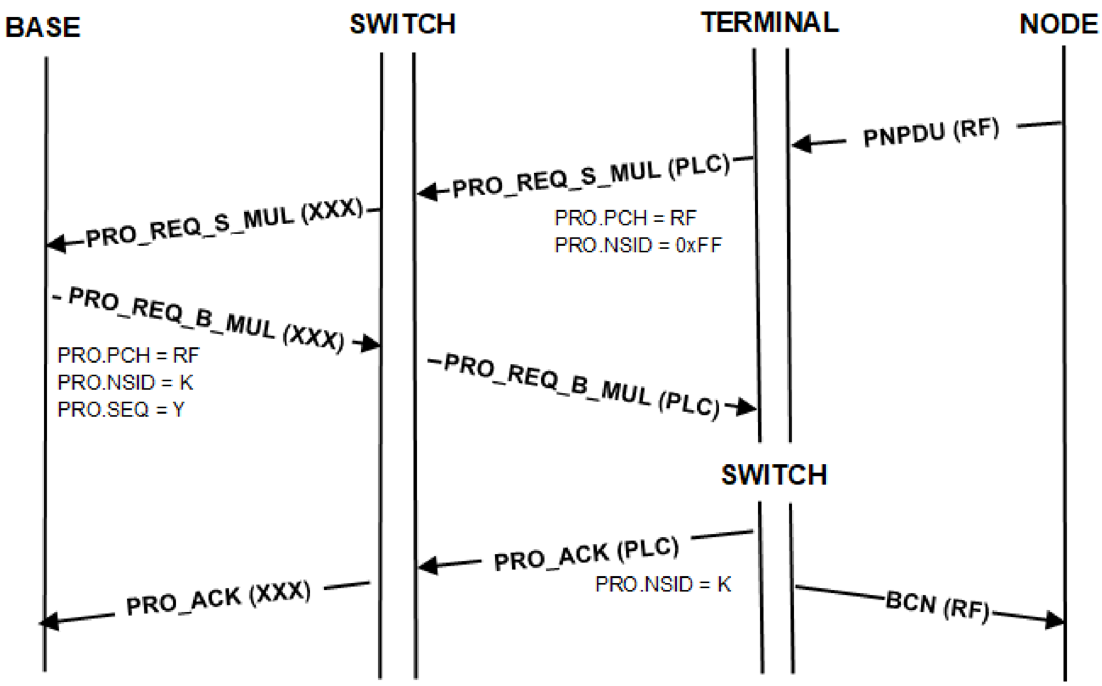


Figure 89 – Multi-PHY promotion process initiated by Service Node with the most relevant values

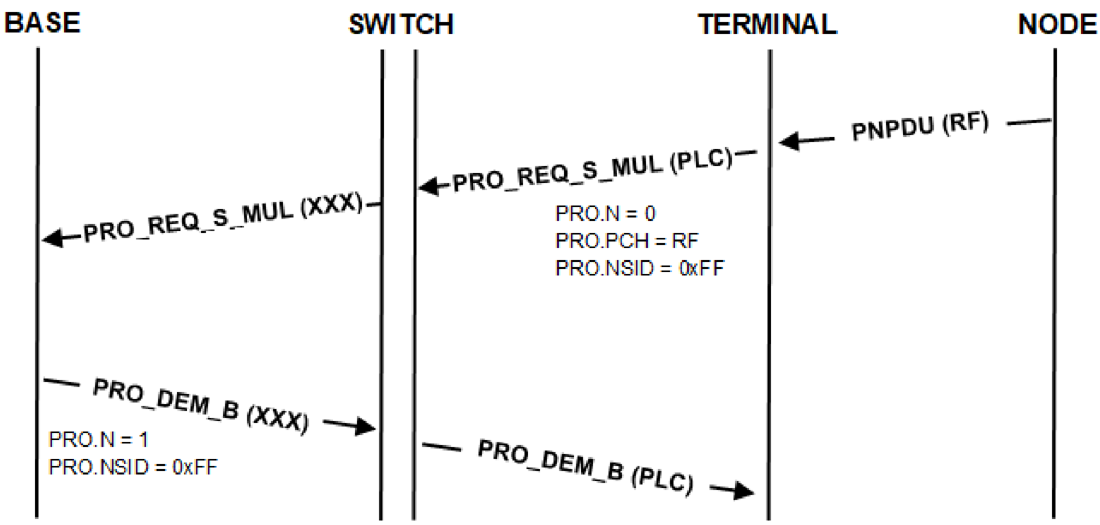


Figure 90 - Multi-PHY promotion process rejected by Base Node with the most relevant values

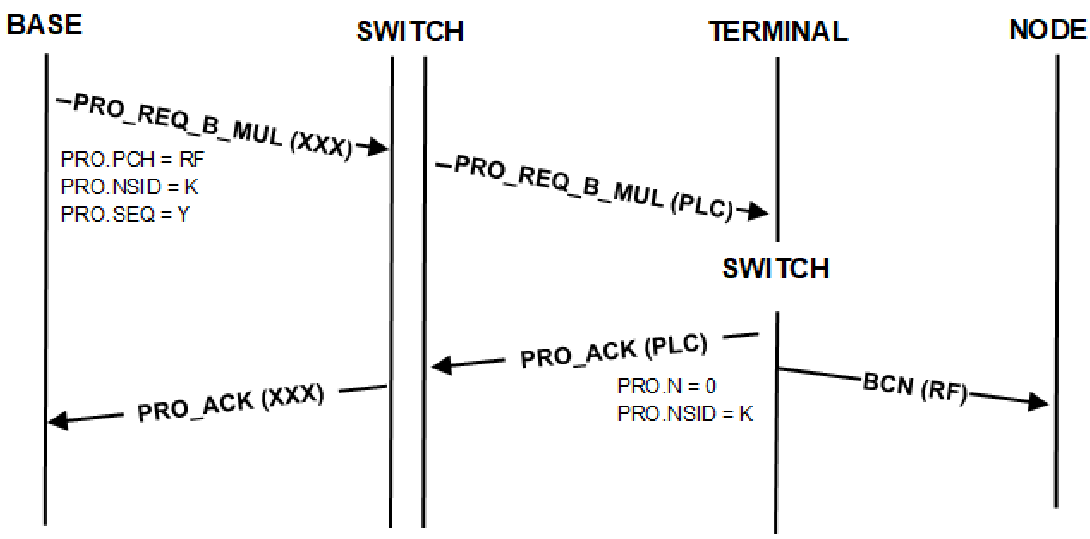
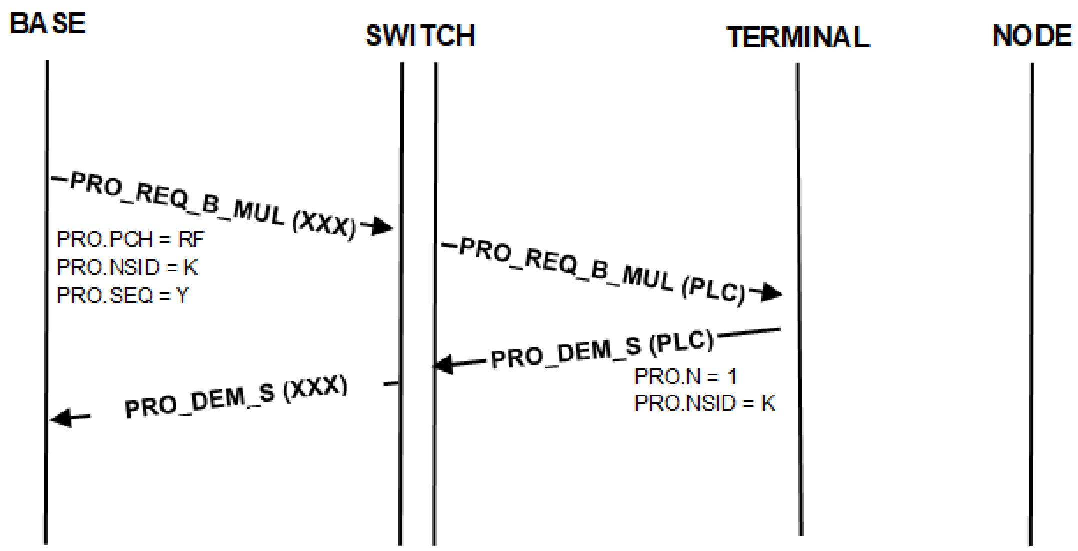
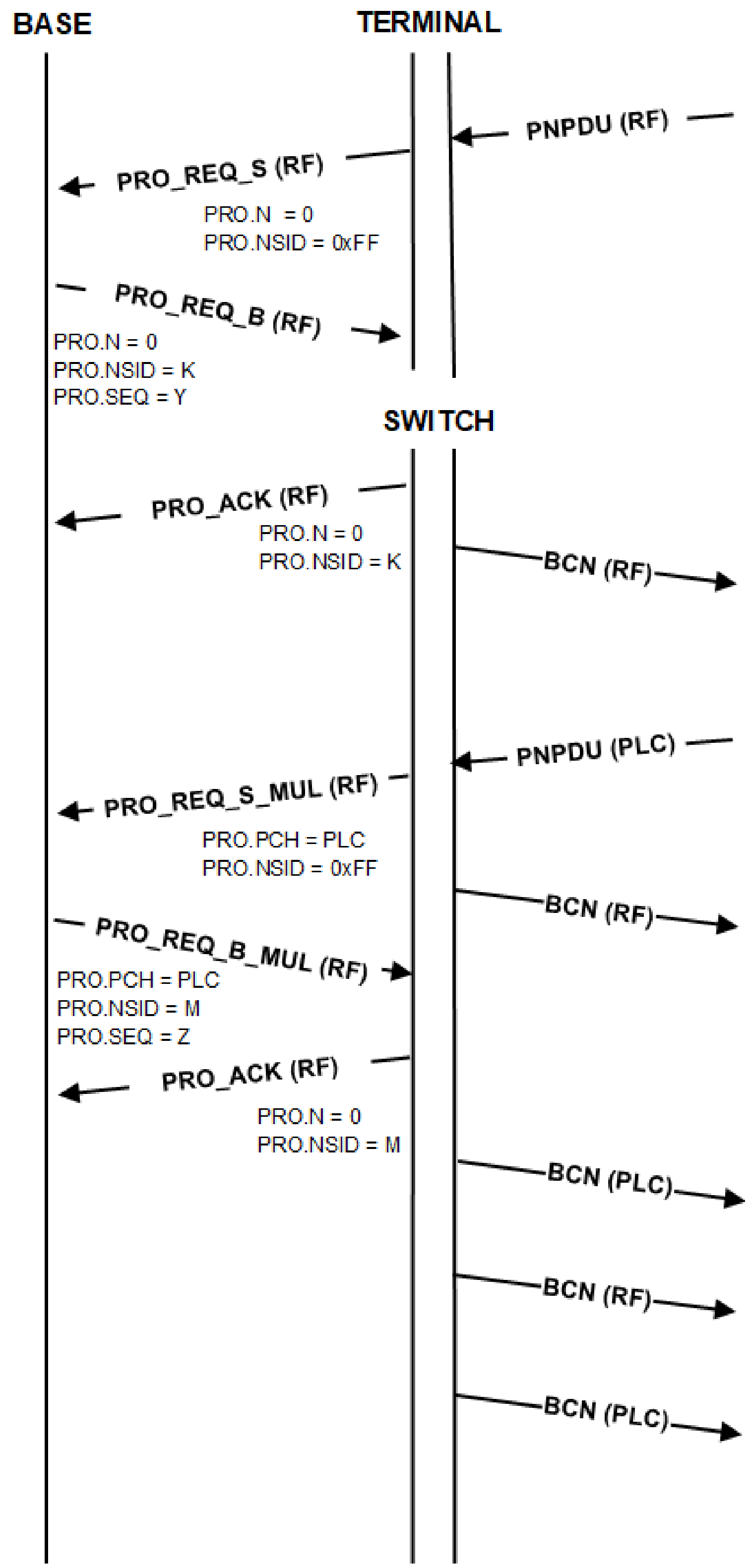


Figure 91 – Multi-PHY promotion process initiated by Base Node with the most relevant values



3276

3277 **Figure 92 – Multi-PHY promotion process rejected by Service Node with the most relevant values**



3278

3279 **Figure 93 – Two promotion processes initiated by Service Node, one with PRO_REQ_S the other with PRO_REQ_S_MultiPHY**

3280 ### 4.6.4 Demotion process

3281 The Base Node or a Switch Node may decide to discontinue a switching function at anytime. The demotion
3282 process provides for such a mechanism. The PRO control packet is used for all demotion transactions.

The PRO.NSID field shall contain the SID of the Switch Node that is being demoted as part of the demotion transaction. The PRO.PNA field is not used in any demotion process transaction and its contents are not interpreted at either end. PRO.MOD field is not used, it shall be set to zero and not interpreted at either end.

Following successful completion of a demotion process, a Switch Node shall immediately stop the transmission of beacons and change from a *Switch* functional state to a *Terminal* functional state (see Figure 94 and Figure 95). Nodes that support Multi-PHY promotion (see 4.6.3.3) may be Switch on two media. In this case, the Switch Node will immediately stop the transmission of beacons in the medium interested by the successful demotion process (which is uniquely associated to a PRO.NSID) keeping the Switch functional state on the other medium (see Figure 96 and Figure 97).

The present version of this specification does not specify any explicit message to reject a demotion requested by a peer at the other end.

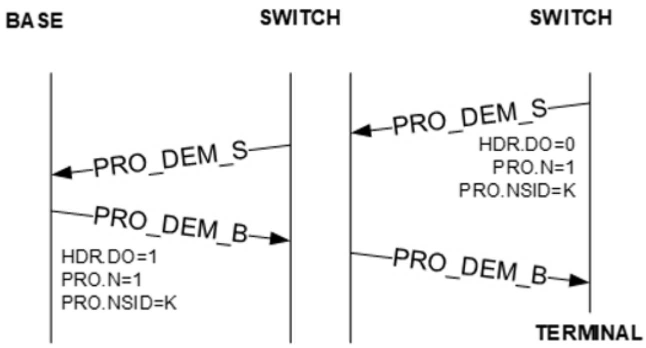


Figure 94 – Demotion process initiated by a Service Node. From Switch to Terminal.

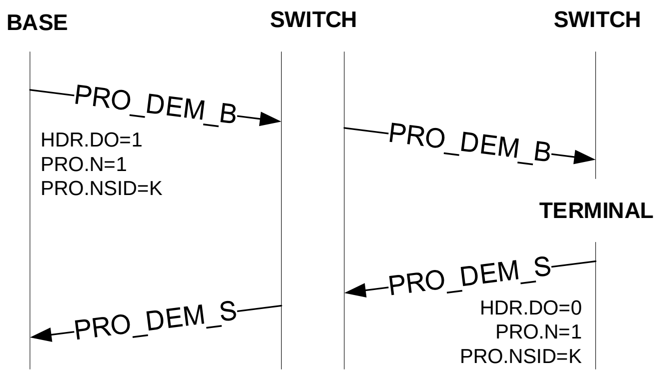


Figure 95 – Demotion process initiated by the Base Node. From Switch to Terminal.

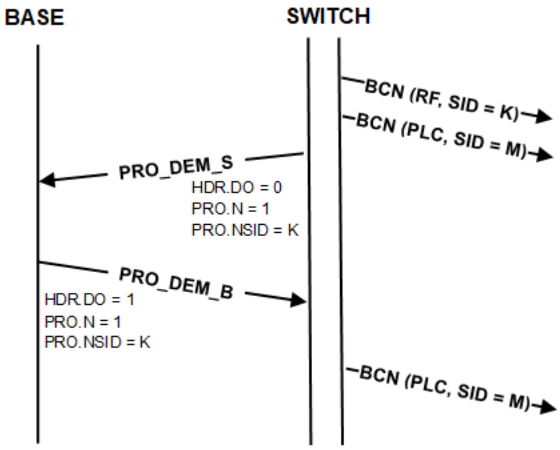


Figure 96. Demotion process initiated by a Service Node. From Switch in two media to Switch in one medium.

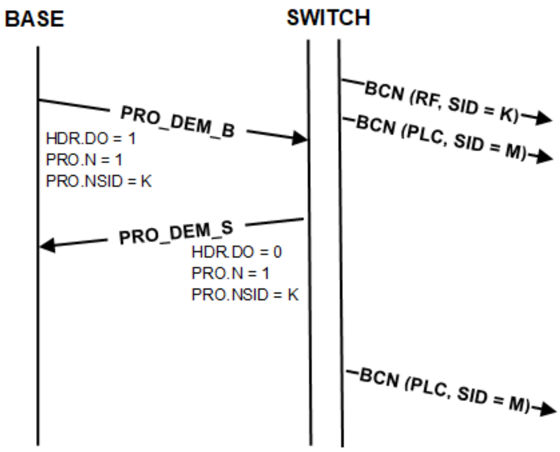


Figure 97. Demotion process initiated by a Base Node. From Switch in two media to Switch in one medium.

4.6.5 Keep-Alive process

4.6.5.1 General

The Keep-Alive process is used to perform two operations:

- To detect when a Service Node has left the Subnetwork because of changes to the network configuration or because of fatal errors it cannot recover from.
- To perform robustness management on each hop in the path to the Service Node.

Service Node shall use one timer, $T_{keep\text{-}alive}$, to detect if it is no longer part of the Subnetwork. If $T_{keep\text{-}alive}$ expires, the Service Node assumes it has been unregistered by the Base Node and shall enter in the *Disconnected* functional state. The timer is started when the Service Node receives the REG_RSP packet with value encoded in the REG.TIME field.

The timer is refreshed when any of the following packets has been received with the TIME information provided in those packets:

- REG_RSP packet (repetition).
- ALV_REQ_B packet.
- PRO_REQ packet.

The timer is also restarted with the last time received in one of the above packets according to the following rules:

- Service nodes which are the final destination of a message, the timer is restarted on reception of
  - data on an ARQ connection, which fulfills the following conditions: is originated from the Base Node, is addressed to the node itself and has not yet been acknowledged. Repetitions of the same packet shall not update the timer.
  - a CON_REQ_B, CON_CLS_B, MUL_JOIN_B, MUL_LEAVE_B or SEC_REQ control packet which is addressed to the node itself.
- Intermediate Switch nodes restart their timer when transmitting an ALV_RSP_S from an ALV procedure of a node below them. The timer is restarted with the last time information received in a REG_RSP, ALV_REQ_B or PRO_REQ packet addressed to the switch node itself.

Each switch along the path to a node keeps track of the switches that are being promoted below it as described in section 4.3.4.3

The keep alive process has a link level acknowledge, each switch in the path to the target Service Node is responsible for the retransmissions with the next node, up to *macALVHopRepetitions* retransmissions (*macALVHopRepetitions + 1* packets sent). Each retransmission shall be performed in a time equal to a frame time. On a reception of an ALV_REQ_B/ALV_RSP_S the receiving node shall respond with an ALV_ACK_S/ALV_ACK_B as soon as possible and with a priority of 0. These retransmissions shall be used to perform robustness management according to section 4.6.8.3.

If the Service Node identifies that the received ALV_REQ_B/ALV_RSP_S is a retransmit of an already received packet, the node shall send the related ACK but shall not switch the Alive to the next hop (since it already did it). The algorithm to detect this situation is up to the manufacturer, as a guideline, it could store the last ALV operation's data and check if it matches.

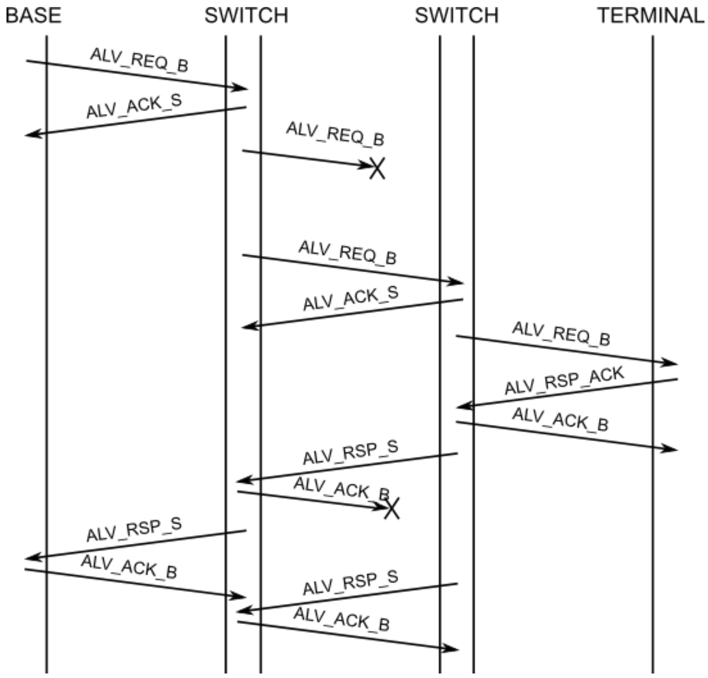


Figure 98 - Successful ALV procedure

If the retransmissions reach the maximum during ALV_REQ_B process, the switch node shall start the ALV_RSP_S procedure.

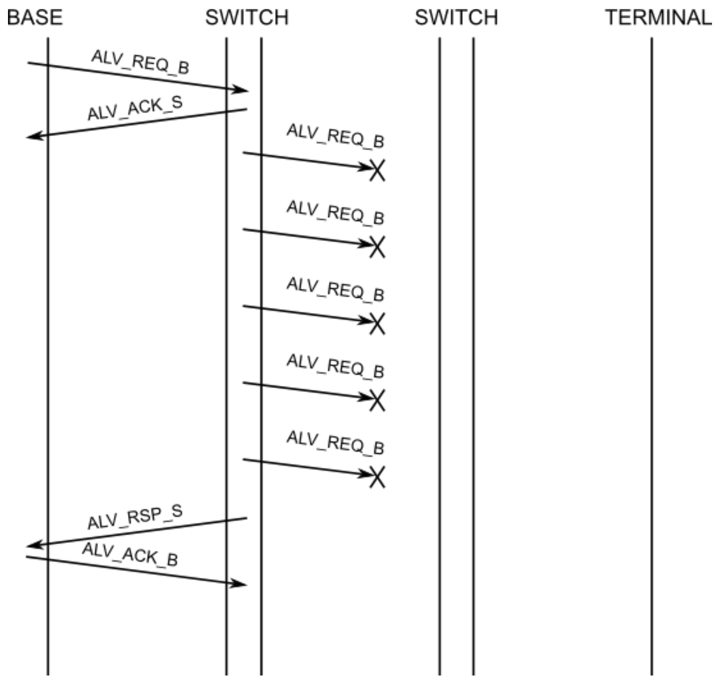


Figure 99 - Failed ALV procedure

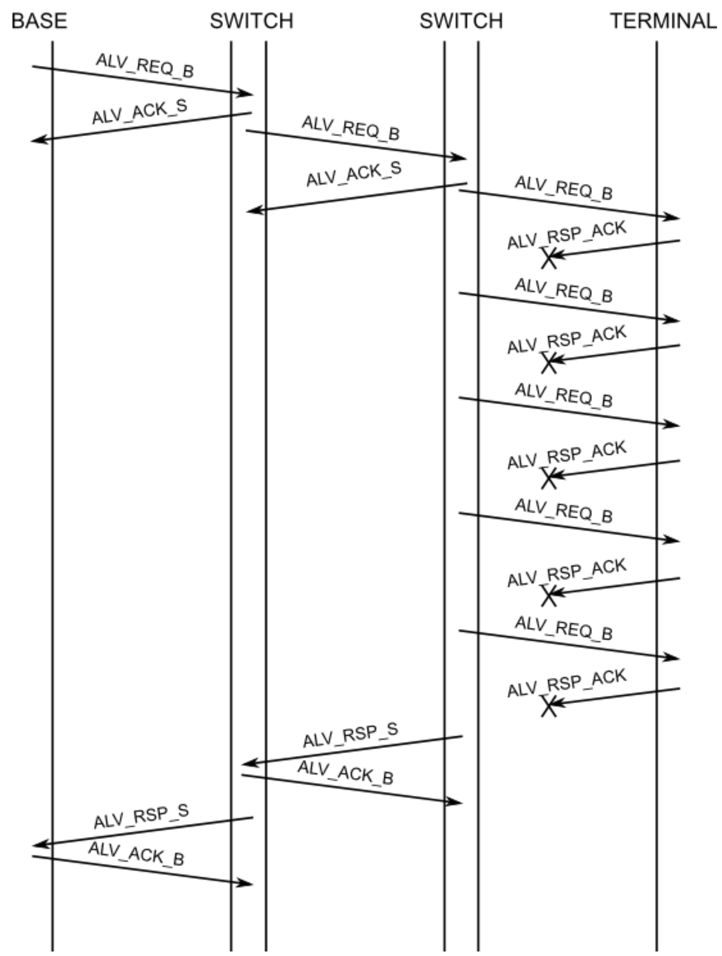


Figure 100 - Failed ALV procedure (uplink)

Every time a switch performs a retransmission, it shall decrease the ALV.RTL field before sending the packet, and fill the record of local retransmissions accordingly. When ALV.RTL reaches 0 and the switch has to perform a retransmission, it shall discard the packet.

Every switch shall add the information of the retransmissions needed to reach the node in the ALV.REP_D and ALV.REP_U fields, filling the array with the retransmissions needed for each link, both downlink and uplink. The Base Node shall form the ALV message with all the registries and the Service Nodes shall fill it with the values. The rule to know in which record a switch shall add its repetitions is the following.

- Uplink
  - If the switch's (or terminal's) level is equal or lower than ALV.MIN_LEVEL it shall sum its repetitions to the first record.
  - If the switch's (or terminal's) level is greater than ALV.MIN_LEVEL it shall use the records sequentially from the beginning. A formula to compute which record shall be used: subtract ALV.MIN_LEVEL from its own level. E.g.: If ALV.MIN_LEVEL = 2 and the switch is at level 3 it shall use the record ALV.REP_U(1).
- Downlink
  - Base node always uses the first record (record number 0: ALV.REP_D(0)).
  - If the switch's level+1 is equal or lower than ALV.MIN_LEVEL it shall sum its repetitions to the first record (record number 0: ALV.REP_D(0)/ALV.REP_U(0)).

- If the switch's level+1 is greater than ALV.MIN_LEVEL it shall use the records sequentially from the beginning. A formula to compute which record shall be used: subtract ALV.MIN_LEVEL from its own level+1. E.g.: If ALV.MIN_LEVEL = 2 and the switch is at level 3 it shall use the record ALV.REP_D(2).

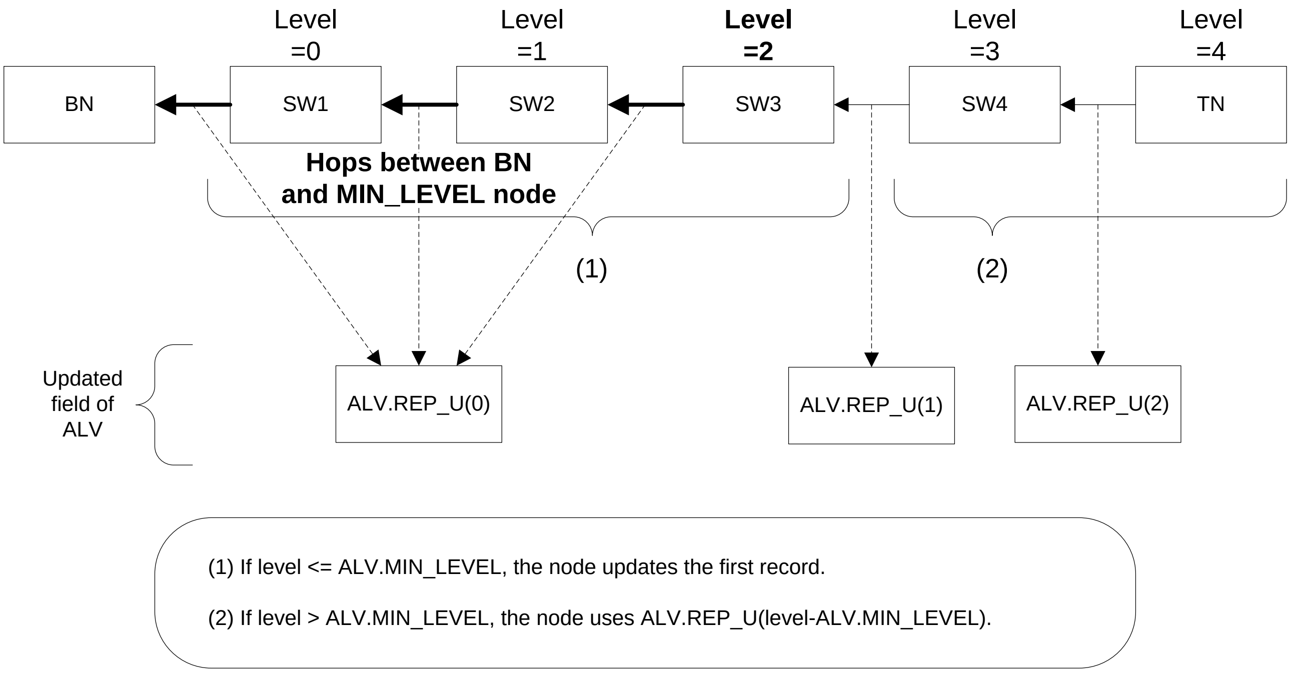


Figure 101 - ALV.REP_U Example (ALV.MIN_LEVEL = 2)

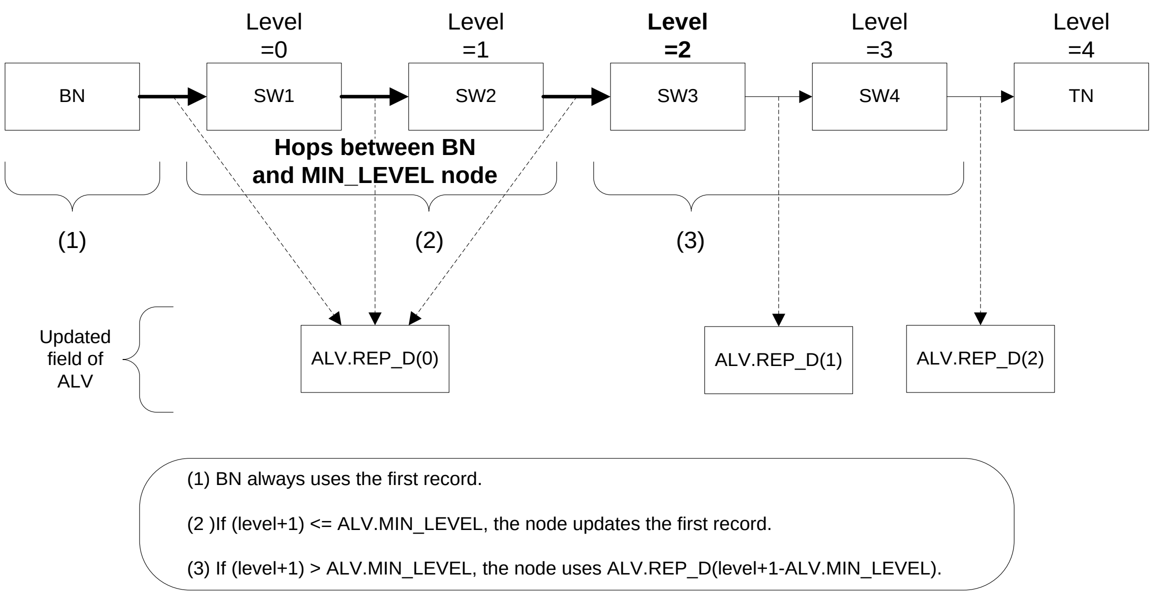


Figure 102 - ALV.REP_D Example (ALV.MIN_LEVEL = 2)

The Base Node shall provide the uplink information whenever available in the ALV.REP_U(*) fields using the ALV_REQ_B message, this provides connection quality information to the service node. If the retransmission at any hop is not available at the time the ALV_REQ_B is sent, the Base Node shall set the ALV.VALU(*) value to 0 for that hop, and the Service Node shall ignore this record. The first ALV procedure for a hop after registration of a Service Node shall be mark as invalid.

At the end of the process the Base Node receives the ALV_RSP_S of the last switch with information of the connectivity of the node and all the hops in its path. If any of the ALV.VAL_D or ALV.VAL_U are marked as invalid (equal to 0) or the number of repetitions in ALV.REP_D or ALV_REP_U fields are finished in any hop (equal to 7), the base node will consider the ALV process as failed.

This operation is more robust than round-trip control packet transaction (CON, REG), so the base node can decide that the node does not have enough connectivity and start an unregistration process with it.

The algorithm used by the Base Node to determine when to send ALV_REQ_B messages to registered Service Nodes and how to determine the value ALV.TIME, PRO.TIME and REG.TIME is left to implementers.

A Switch Node is required to be able to queue *MACConcurrentAliveProcedure* of each ALV_REQ_B and ALV_RSP_S messages at a time. The base node is shall space the ALV_REQ_B queries appropriately.

4.6.5.2 Use of legacy PRIME 1.3.6 keep-alive mechanism

In some particular network configurations, including exclusively PLC-only nodes, the use of legacy PRIME 1.3.6 Keep-Alive process instead of the PRIME 1.4 Keep-Alive process can be required. For this reason, all PRIME 1.4 PLC-only implementations must be able to implement support for REG.ALV_F field (Section 4.4.2.6.3) in REG control packet. This implies that the Base Node shall have the ability to move the entire Subnetwork to ALV procedure listed in Section K.2.5. The Subnetwork Keep-Alive process in use can be determined by reading the Base Node PIB attribute *macAliveTimeMode (Section 6.2.3.2)*. The configuration of the Keep-Alive process is left to Base Node implementations.

For simplification, PLC+RF and RF-only nodes support one alive process, i.e. the PRIME 1.4 Keep-Alive. Hence, Subnetworks including PLC+RF and/or RF-only nodes are managed using the PRIME 1.4 Keep-Alive process. For these subnetworks, the Base Node shall insure that the REG.ALV_F field in REG control packet is set to 1. Similarly, the Base Node PIB attribute *macAliveTimeMode* is set to 0.

4.6.6 Connection establishment

Connection establishment works end-to-end, connecting the application layers of communicating peers. Owing to the tree topology, most connections in a Subnetwork will involve the Base Node at one end and a Service Node at the other. However, there may be cases when two Service Nodes within a Subnetwork need to establish connections. Such connections are called direct connections and are described in section 4.3.6.

All connection establishment messages use the CON control packet. The various control packets types and specific fields that unambiguously identify them are given in Table 23.

Each successful connection established on the Subnetwork is allocated an LCID. The Base Node shall allocate an LCID that is unique for a given LNID.

Note. *Either of the negotiating ends may decide to reject a connection establishment request. The receipt of a connection rejection does not amount to any restrictions on making future connection requests; it may however be advisable.*

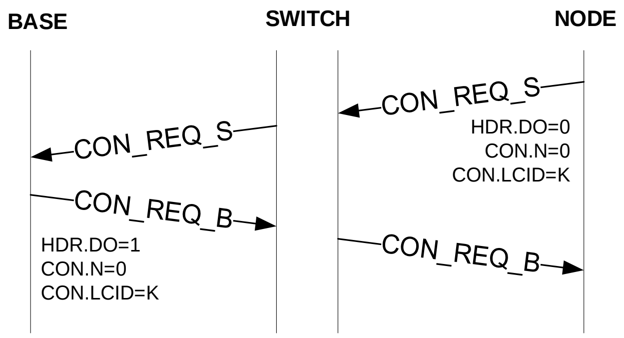


Figure 103 – Connection establishment initiated by a Service Node

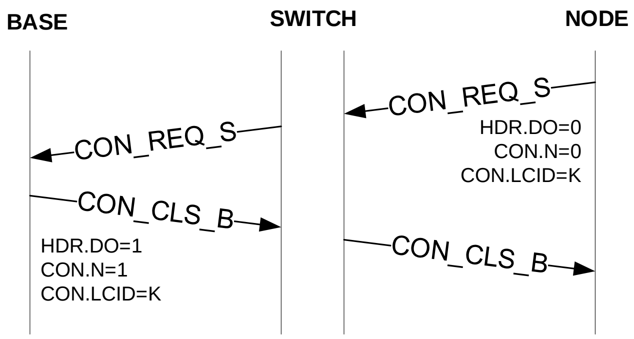


Figure 104 – Connection establishment rejected by the Base Node

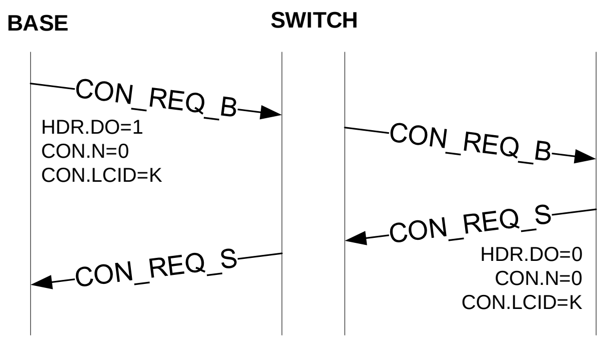


Figure 105 – Connection establishment initiated by the Base Node

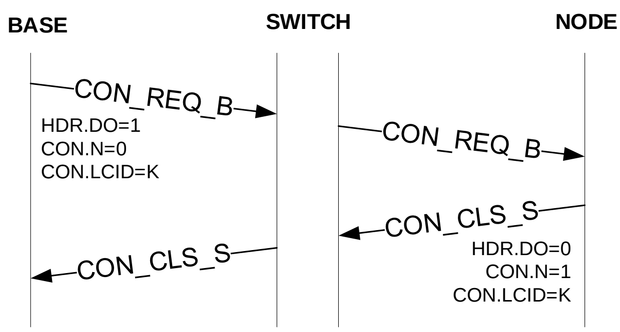


Figure 106 – Connection establishment rejected by a Service Node

4.6.6.1 Connection closing

Either peer at both ends of a connection may decide to close the connection at anytime. The CON control packet is used for all messages exchanged in the process of closing a connection. The relevant CON control packet fields in closing an active connection are CON.N, CON.LCID and CON.TYPE. All other fields shall be set to 0x0.

A connection closure request from one end is acknowledged by the other end before the connection is considered closed. The present version of this specification does not have any explicit message for rejecting a connection termination requested by a peer at the other end.

Figure 107 and Figure 108 show message exchange sequences in a connection closing process.

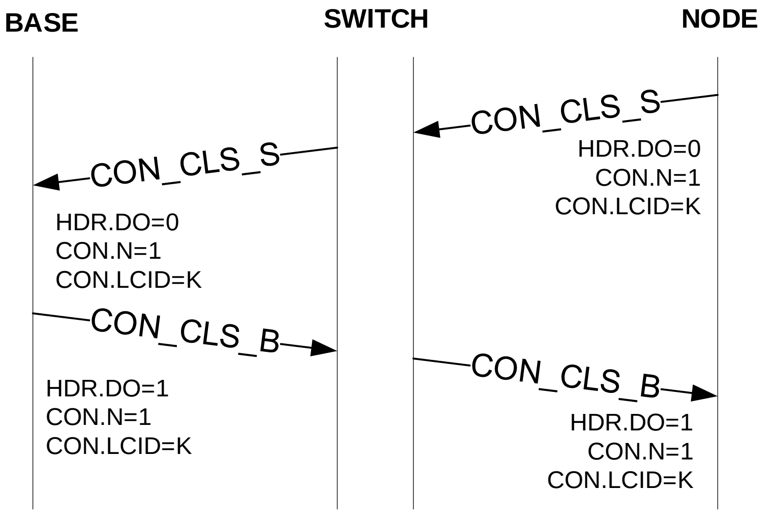


Figure 107 – Disconnection initiated by a Service Node

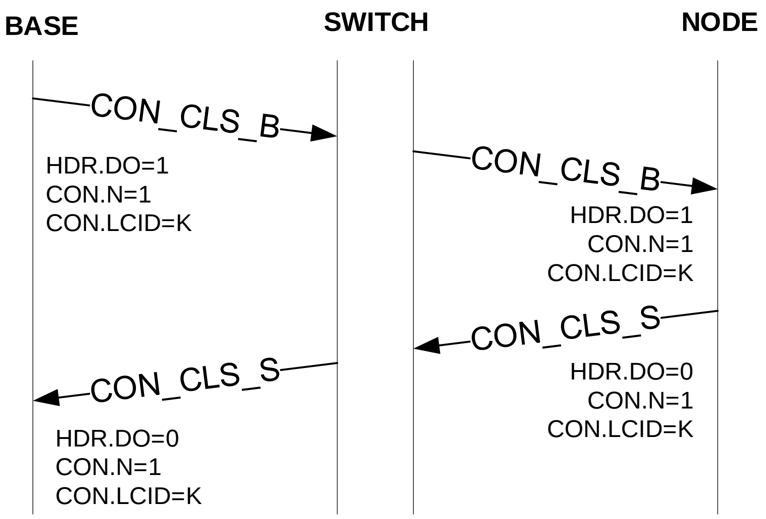


Figure 108 – Disconnection initiated by the Base Node

4.6.7 Multicast group management

4.6.7.1 General

The joining and leaving of a multicast group can be initiated by the Base Node or the Service Node. The MUL control packet is used for all messages associated with multicast and the usual retransmit mechanism for control packets is used. These control messages are unicast between the Base Node and the Service Node.

4.6.7.2 Group Join

Multicast group join maybe initiated from either the Base Node or Service Node. A device shall not start a new join procedure before an existing join procedure started by itself is completed.

Certain applications may require the Base Node to selectively invite certain Service Nodes to join a specific multicast group. In such cases, the Base Node starts a new group and invites Service Nodes as required by application.

Successful and failed group joins initiated from Base Node are shown in Figure 109 and Figure 110.

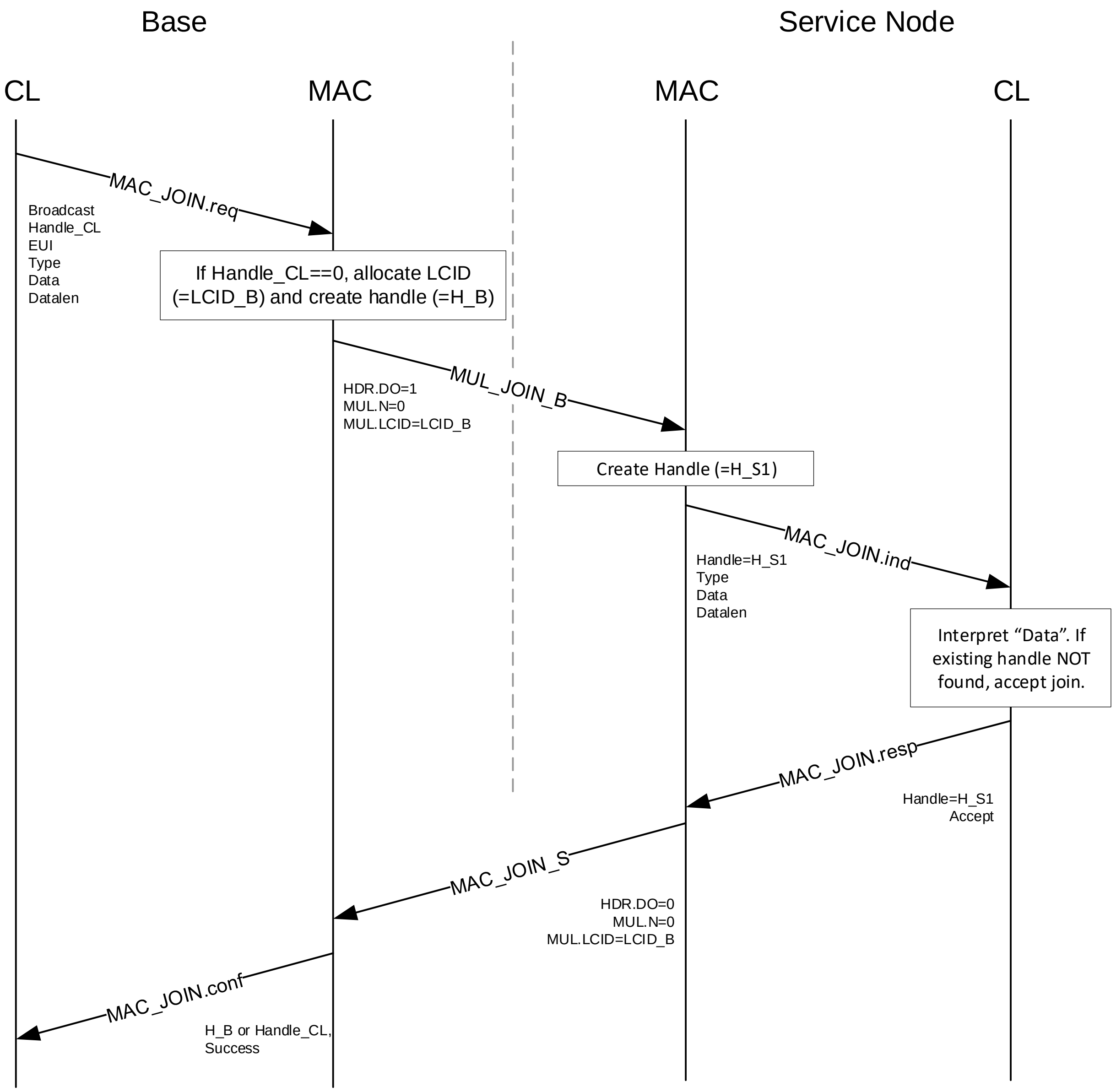
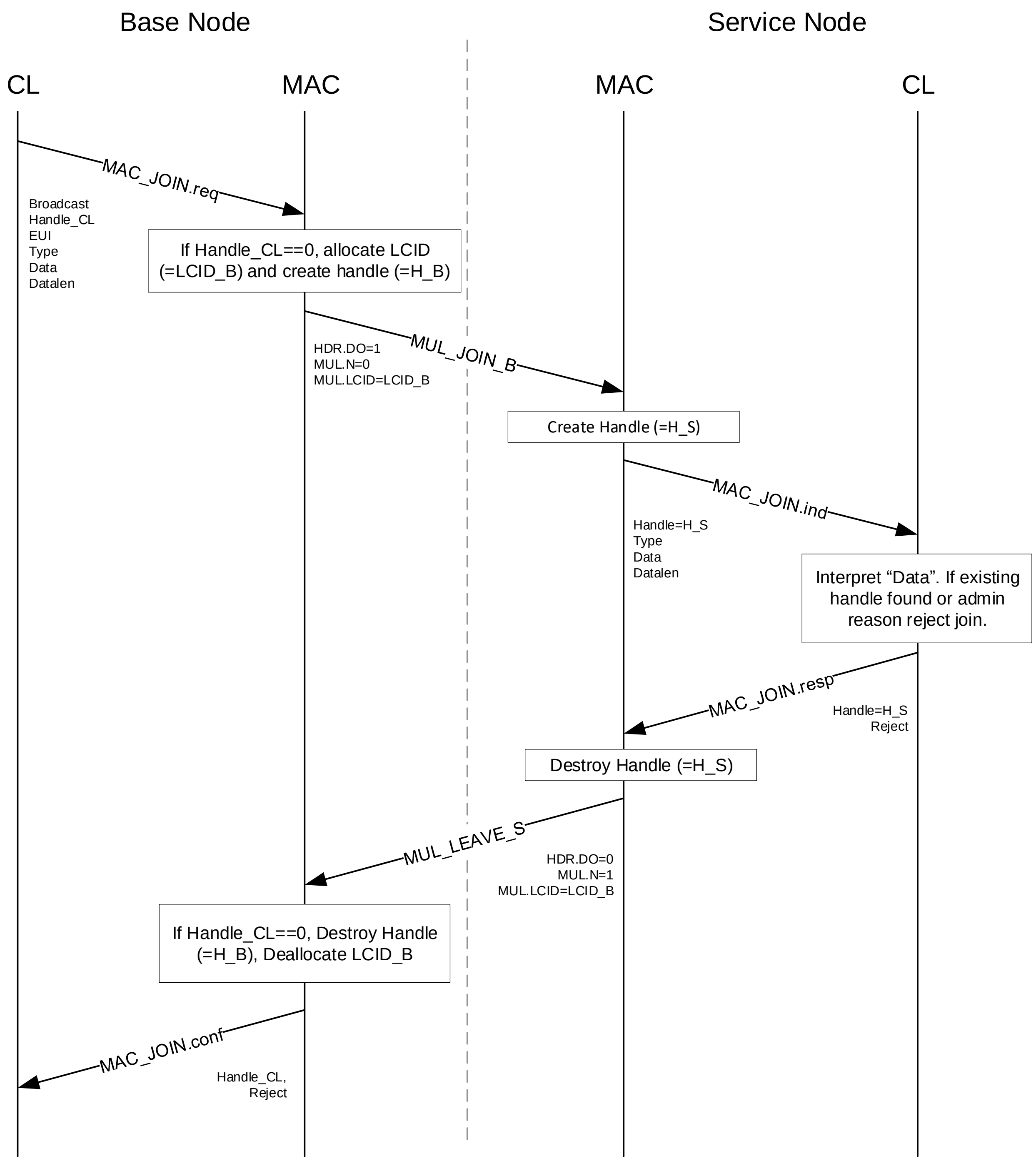


Figure 109 – Successful group join initiated by Base Node

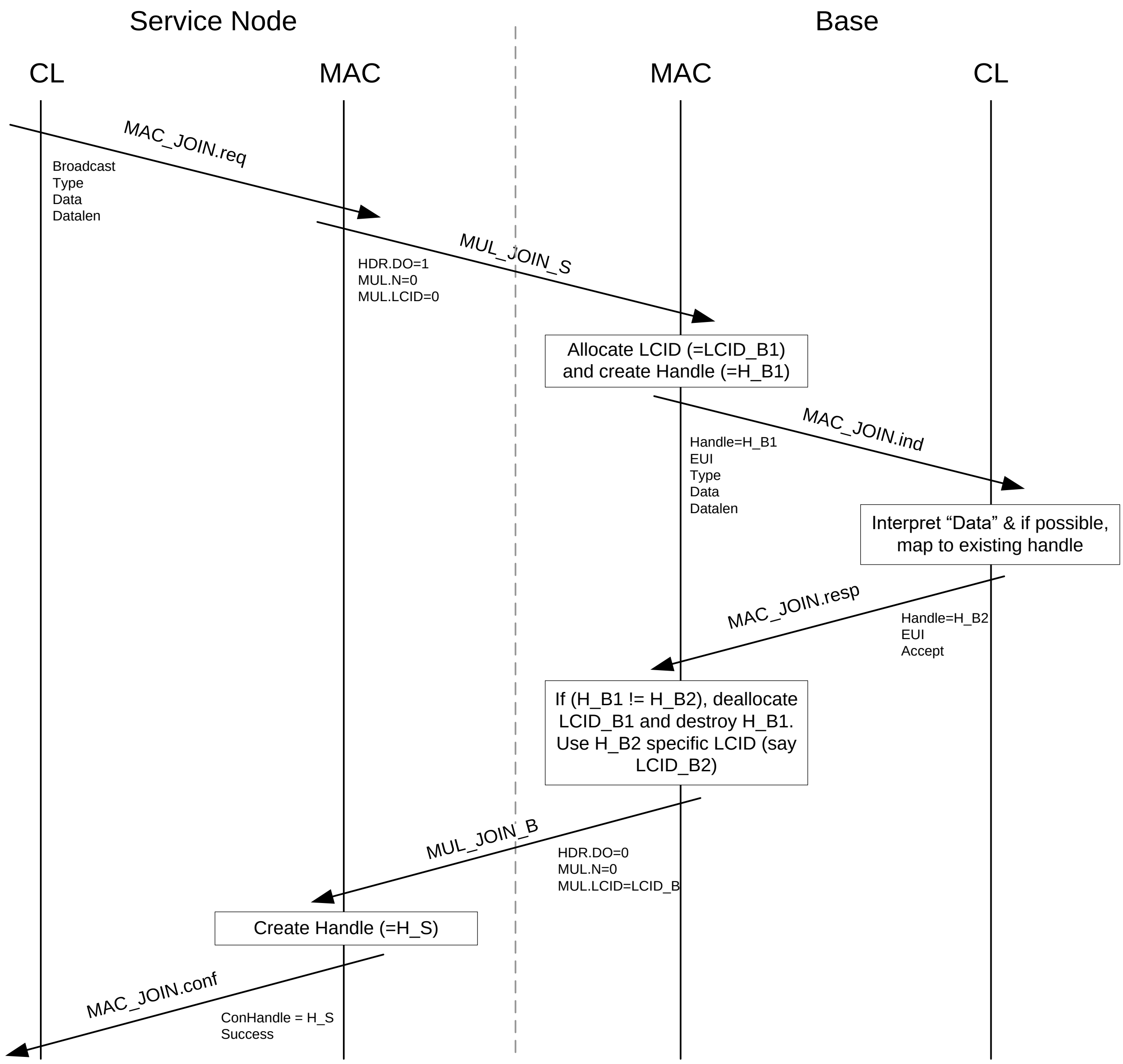


3455

3456 **Figure 110 – Failed group join initiated by Base Node**

3457 Successful and failed group joins initiated from Service Node are shown in Figure 111 and Figure 112

3458



3459

3460 **Figure 111 – Successful group join initiated by Service Node**

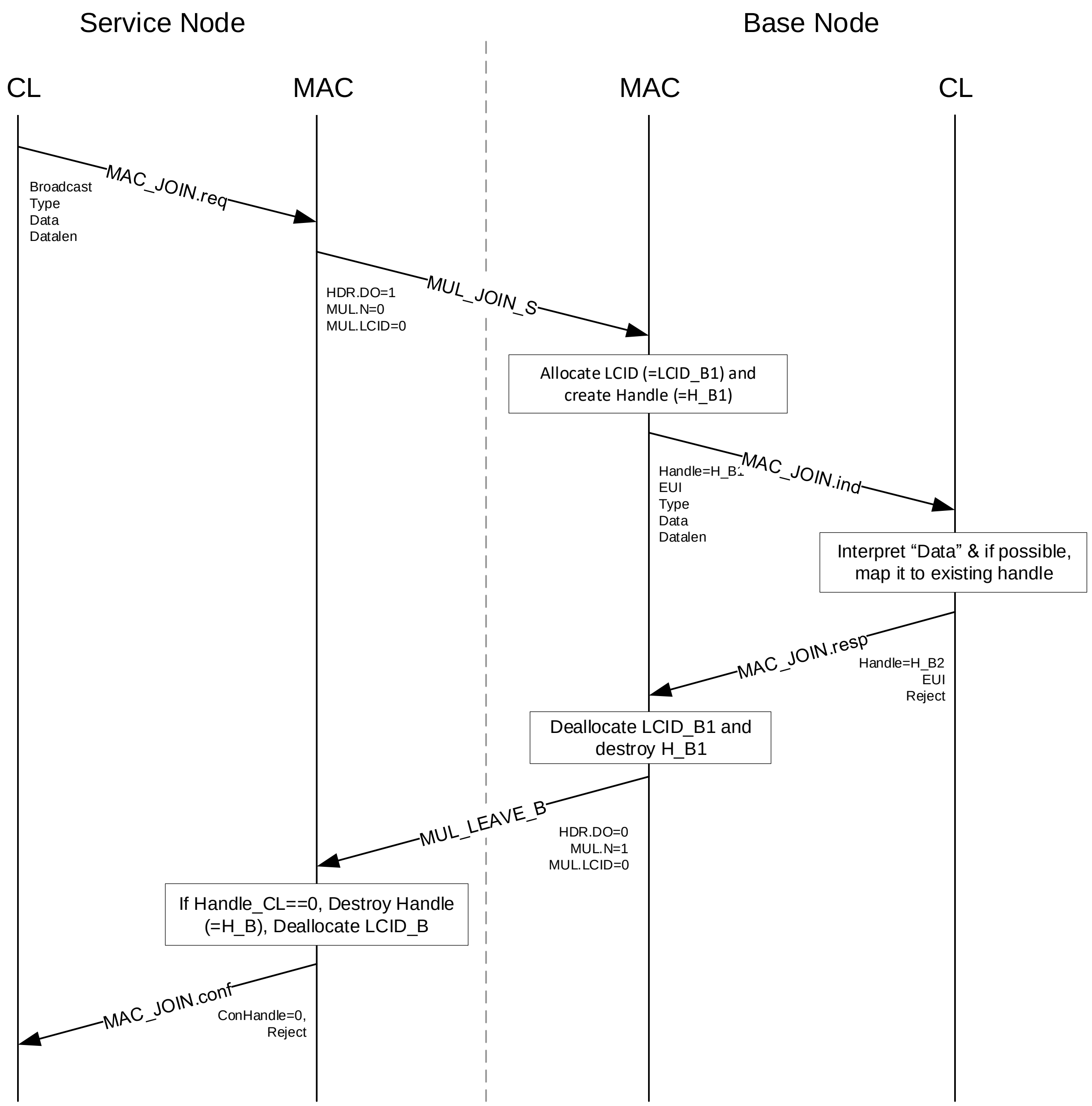


Figure 112 – Failed group join initiated by Service Node.

4.6.7.3 Group Leave

Leaving a multicast group operates in the same way as connection removal. Either the Base Node or Service Node may decide to leave the group. A notable difference in the group leave process as compared to a group join is that there is no message sequence for rejecting a group leave request.

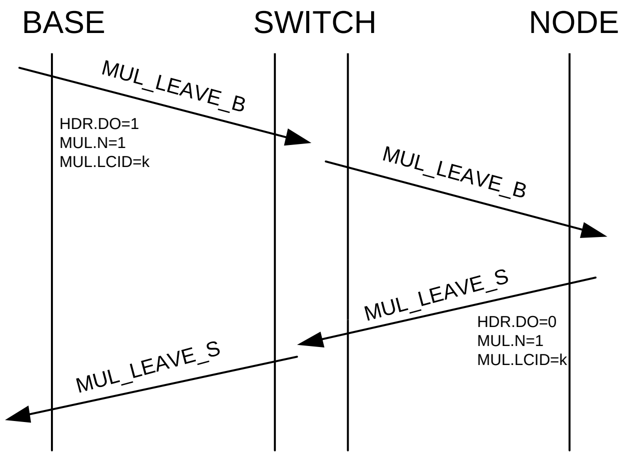


Figure 113 – Leave initiated by the Base Node

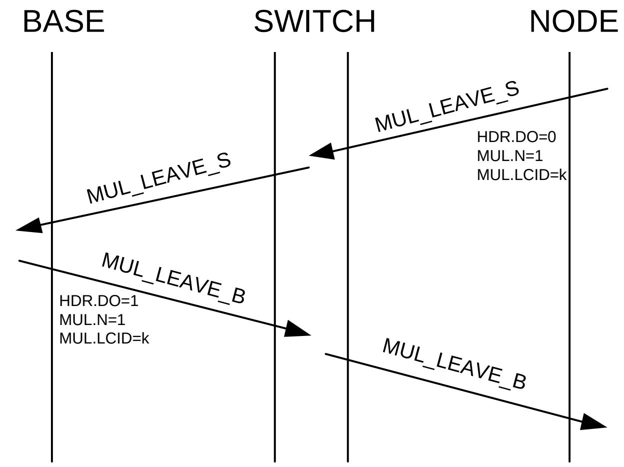


Figure 114 – Leave initiated by the Service Node

4.6.7.4 Multicast Switching Tracking

Switch Nodes need to be aware of the multicast groups under their switching domain. Instead of having to store all the tracking information on the switches themselves, they just need to have a simple multicast table which is managed by both the Switch Node and the Base Node.

Switch Nodes should just monitor muticast join operations through MUL_JOIN messages in order to start switching multicast traffic, and monitor MUL_SW_LEAVE messages in order to stop switching multicast traffic.

4.6.7.4.1 Multicast Switching Tracking for Group Join

The following rules apply for switching of traffic on a multicast group join:

- On a successful group join from a Service Node in its control hierarchy, a Switch Node adds a new multicast Switch entry for the group LCID, where necessary. For this purpose, MUL_JOIN messages are used.

- From that moment on, the Switch Node will switch multicast traffic for that LCID, and stops keeping track of any control message related to that group.
- The Base Node shall track all the Switch Nodes that switch multicast traffic for every multicast group.

Figure 115 exemplifies the process and interactions, for the both cases of the group join initiated by the Base Node and by the Service Node and complements the processes illustrated in the figures of section 4.6.7.2.

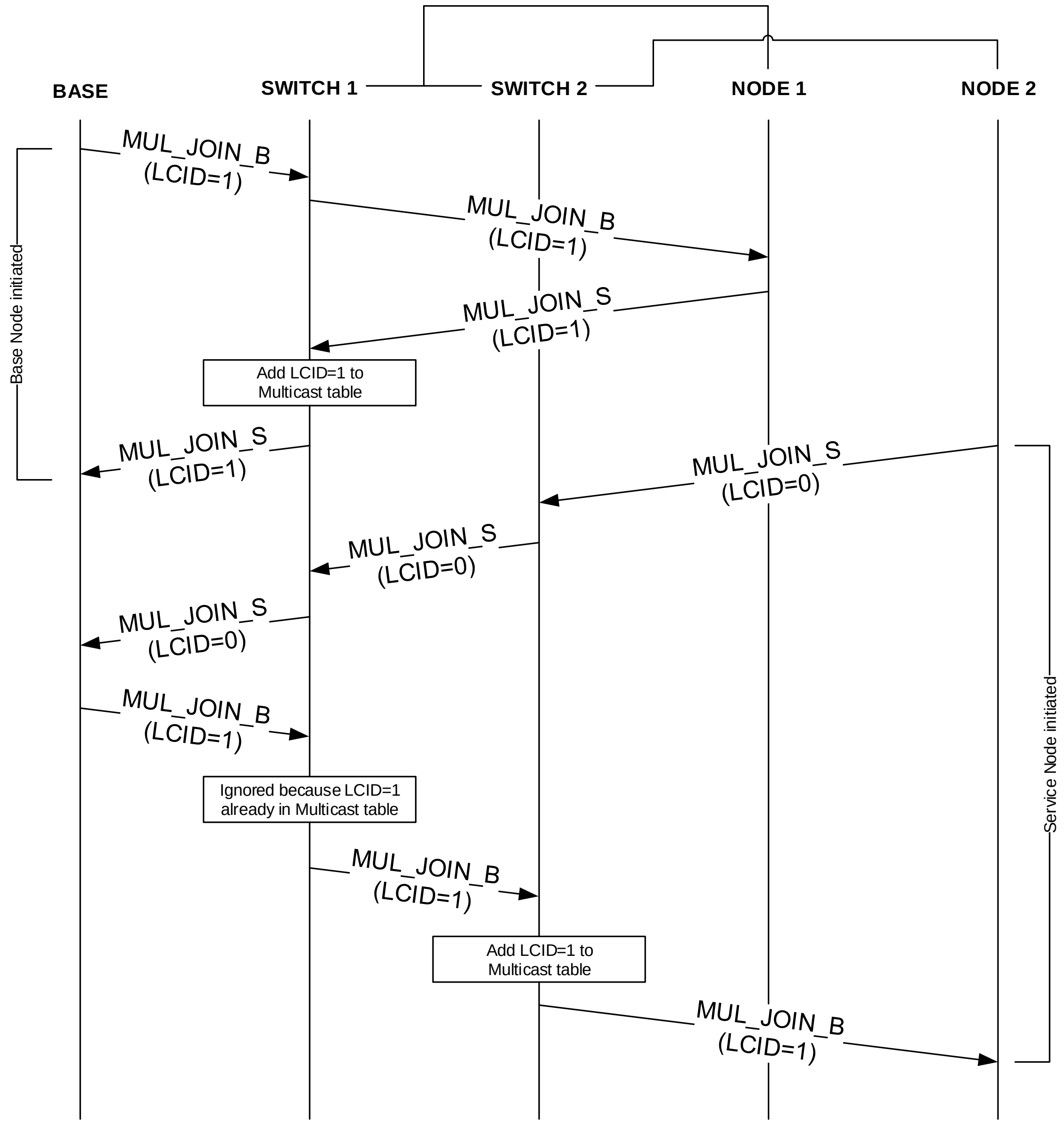


Figure 115 - Multicast Switching Tracking for Group Join.

4.6.7.4.2 Multicast Switching Tracking for Group Leave

For switching of traffic on a multicast group leave, the Base Node shall monitor when all nodes depending on a Switch Node leave a given multicast group, and start a MUL_SW_LEAVE procedure to remove that multicast entry for that Switch Node and group.

Figure 116 exemplifies the process and interactions; when they are executed, they take place after the processes illustrated in the figures of section 4.6.7.3.

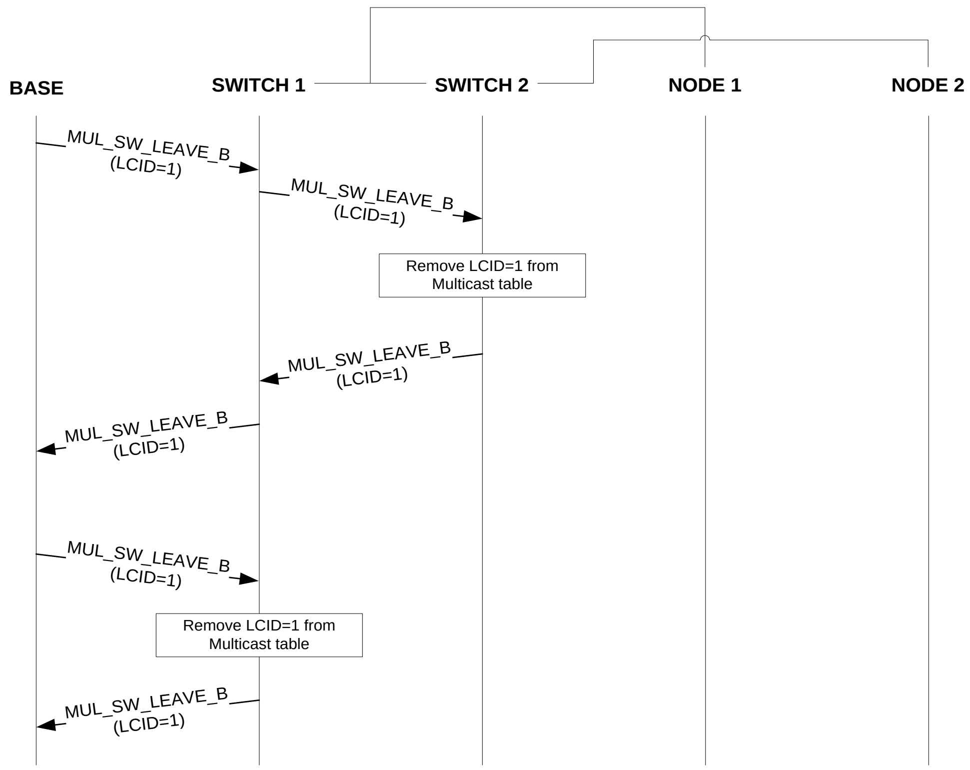


Figure 116 - Multicast Switching Tracking for Group Leave.

4.6.7.4.3 Multicast Switching with double switching

A Switch Node that is transmitting BPDUs on both Type A and Type B PHY frames can switch all data arriving on a multicast connection using both types of PHY frames. This implies replicating data while transmitting twice but this will enable coverage across its entire control domain. Future versions of this specification can further optimize on this to avoid some unwanted traffic that maybe generated by taking this generic approach. This version leaves it open for implementions to either optimize their decision process or replicate data using both modulation schemes.

No matter the policy implemented by the double switch, the device that receives the same broadcast or multicast packet with both modulations shall be able to discard one replica (see section 4.6.3.2).

On receipt of a MUL_SW_LEAVE message, the Switch Node shall stop further switching of multicast data for the corresponding connection, on both PHY frame types.

4.6.8 Robustness Management

4.6.8.1 General

The Robustness-management (RM) mechanism is designed on the PLC medium to select the most suitable transmission scheme from the eight available ones (Robust DBPSK, Robust DQPSK, DBPSK_CC, DBPSK, DQPSK_CC, DQPSK, D8PSK_CC and D8PSK). Depending on the transmission channel conditions, the nodes shall decide either to increase the robustness or to select faster transmission modes.

Note that the mechanism described here shall be used to decrease and increase the robustness of Generic DATA packets. MAC control packets shall be transmitted in conformance with specification in Section 4.3.3.3.4.

By default, decision about applicable transmission mode is taken locally. That is, dynamic adaptation of the transmission mode is performed taking into account link level channel information, which is exchanged between any pair of nodes in direct vision (parent and child). As an exception to this rule, a Base Node may decide to disable dynamic robustness-management and force a specific transmission mode in the Service Node(s). This static configuration shall be fixed during registration, as explained in 4.6.1.

The robustness-management mechanism comprises two main features:

- Link quality information embedded in the packet header of any Generic packets
- Link level ACK-ed ALIVE mechanism, as explained in 4.6.8.3 and 4.6.5.

4.6.8.2 Link quality information embedded in the packet header

All Generic packets shall convey link quality related information. Four bits in the packet header - “PKT.RM”, see 4.4.2.3 – are used by the transmitting device to notify the other peer of the weakest modulation scheme that the transmitter considers it could receive. The transmitting device calculates this value processing the received packets sent by the other peer. The calculation of PKT.RM value is implementation dependent.

Whenever a node receives a Generic packet from a peer, it shall update the peer related info contained in *macListPhyComm* (and macListMPPhyComm when supported) PIB as follows:

- Store “PKT.RM” from the received packet in *macListPhyComm. phyCommTxModulation*
- Reset *macListPhyComm.phyCommRxAge* (time [seconds] since the last update of *phyCommTxModulation*).

Whenever a node wants to transmit DATA to an existing peer, it shall check validity of the robustness-management information it stores related to that peer. The maximum amount of time that robustness-management information is considered to be valid without any further update is specified in PIB *macUpdatedRMTimeout*. Consequently, the node shall compare *phyCommRxAge* (time since the last update) with *macUpdatedRMTimeout*:

- *macListPhyComm.phyCommRxAge* ≥ *macUpdatedRMTimeout*: The node shall transmit using the most robust modulation scheme available for the PHY frame type in use. Note: the first time a node sends DATA to one peer, RM information is automatically considered to be “out of date” and consequently the most robust modulation scheme available shall be used.
- *macListPhyComm.phyCommRxAge* < *macUpdatedRMTimeout*: The node shall check the value stored in the *phyCommTxModulation* field:
    - Different from 0xF: The modulation to be used shall be the same as specified in *phyCommTxModulation*.
    - Equal to 0xF: The node shall transmit using the most robust modulation scheme available for the PHY frame type in use.

4.6.8.3 Link level ACK-ed ALIVE mechanism

Alive procedure defines repetitions that are performed in every hop as described in 4.6.5. An ALV_REQ_B/ALV_RSP_S transmitting device shall use this fact to assume a delivery failure if it does not receive the corresponding ACK packet. In this case the transmitting device shall re-transmit the packet: the first repetition shall be performed with the same robustness, which will be successively increased after every link level repetition. Once the maximum number of repetitions is reached, the most robust modulation in which the node can transmit shall be stored for that link, even if the repetitions were due to the ACK packets.

The device receiving the ALV_REQ_B/ALV_RSP_S, on reception of a packet being sent more than twice (ALV.TX_SEQ > 1), shall send the ACK packet with at least the same robustness as the received packet.

The ALV packets shall be transmitted in one of the following encodings: DBPSK_CC, Robust DQPSK and Robust DBPSK. The robustness increase should be performed in that order.

In the Terminal Node a three way handshake is performed, once the ALV_REQ_B has arrived the Service Node shall start a regular ALV_RSP_S send transaction following the same rules.

In every case the ALV.RX_SNR, ALV.RX_POW and ALV.RX_ENC shall send those PHY parameters of the last received ALV_REQ_B/ALV_RSP_S packet, and in the PKT.RM they shall send the least robust modulation in which it should be able to receive.

4.6.8.4 PHY robustness changing

From the PHY point of view there are several parameters that may be adjusted and which affect the transmission robustness: the transmission power and modulation parameters (convolutional encoding and constellation). As a general rule the following rules should be followed:

- **Increase robustness:** increase the power and, if it is not possible, improve the modulation scheme robustness (reducing throughput).
- **Reduce robustness:** reduce the modulation scheme robustness (increasing throughput) and, if it is not possible, reduce the transmission power.

4.6.9 Channel allocation

Allocation of specific channel resources is possible in the CFP. Each MAC frame shall include a contention free period with a minimum duration of (*MACBeaconLength1* + 2 x *macGuardTime)*, which may be used for beacon transmission and/or allocation of specific application data transmissions. Any kind of CFP usage, either beacon transmission or allocation of channel resources for data, shall be always granted by the Base Node.

4.6.9.1 Beacon channel allocation

As part of a promotion procedure, a Terminal node may be promoted to Switch status and gain the ability to transmit its own beacons. These beacons shall be allocated in the CFP as explained in 4.6.3.

4.6.9.2 Data channel allocation

A CFP allocation / de-allocation request to transport application data may be initiated either by the Base Node or the Service Node. The CFP MAC control packet described in 4.4.2.6.7 shall be used for that purpose. Figure 117 below shows a successful channel allocation sequence. All channel allocation requests initiated by Service Node are forwarded to the Base Node. Note that in order to assure a contention-free channel allocation along the entire path, the Base Node allocates non-overlapping times to intermediate Switch Nodes. In a multi-level Subnetwork, the Base Node may also reuse the allocated time at different levels. While reusing the said time, the Base Node needs to ensure that the levels that use the same time slots have sufficient separation so that there is no possible interference.

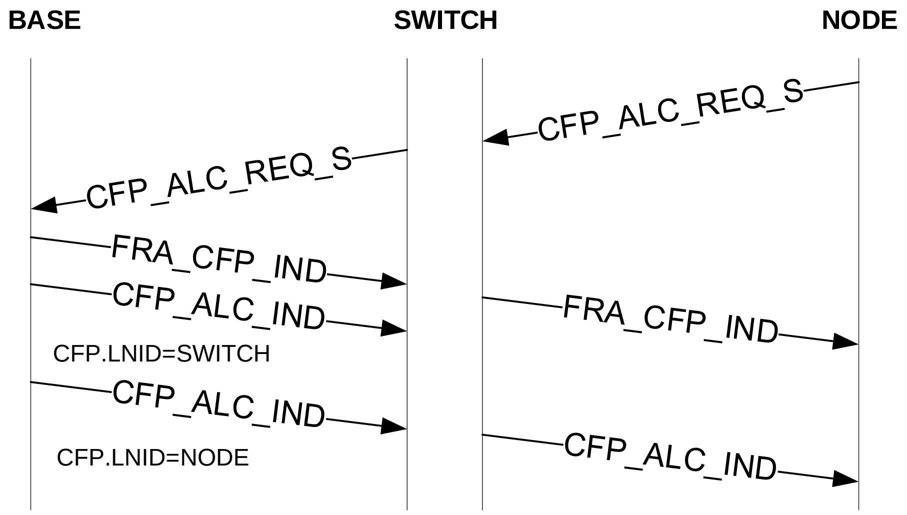


Figure 117 – Successful allocation of CFP period

Figure 118 below shows a channel de-allocation request from a Terminal device and the resulting confirmation from the Base Node.

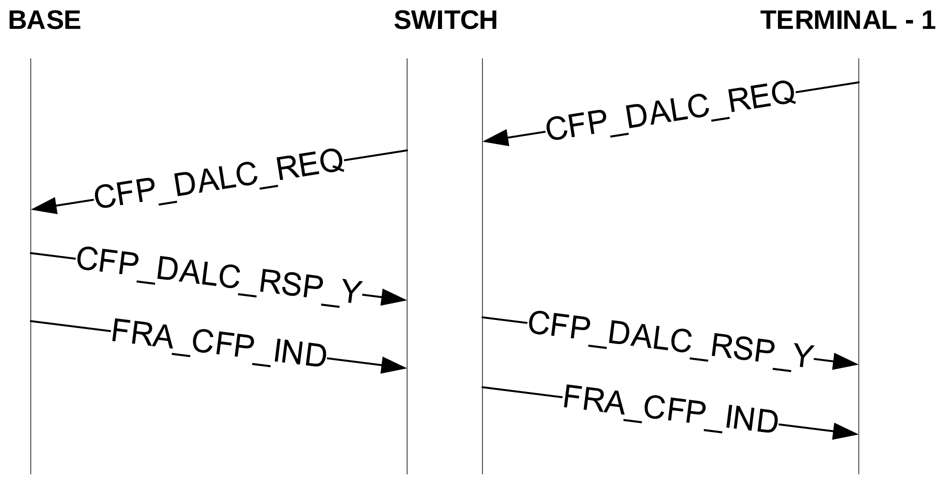


Figure 118 – Successful channel de-allocation sequence

Figure 119 below shows a sequence of events that may lead to a Base Node re-allocation contention-free slot to a Terminal device that already has slots allocated to it. In this example, a de-allocation request from Terminal-2 resulted in two changes: firstly, in global frame structure, this change is conveyed to the

Subnetwork in the FRA_CFP_IND (a standard FRA packet intended to change CFP duration only) packet; secondly, it is specific to the time slot allocated to Terminal-1 within the CFP.

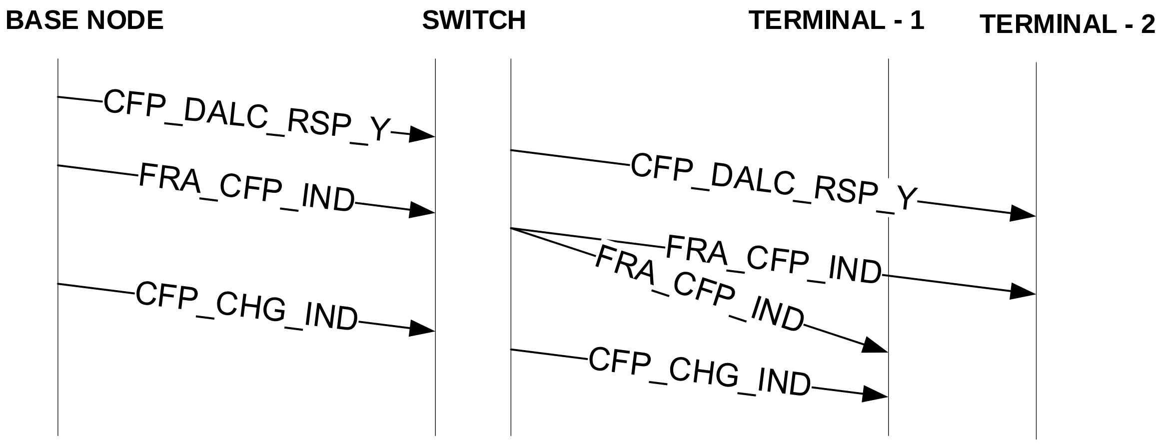


Figure 119 – Deallocation of channel to one device results in the change of CFP allocated to another

4.6.10 Programmed Configuration Change

In addition to indication events associated to FRA_CFP_IND/FRA_BCN_IND control packets, the Base Node can inform the network about a future change of other relevant parameters at network level using the PCC (Programmed Configuration Change) MAC control packet.

An example is a change in the Physical layer channel/band used by Base Node on a specific medium to communicate with directly connected child Nodes. The PCC MAC control packet described in 4.4.2.6.11 shall be used to inform all the network about the change. This information can be used by Service Nodes to automatically change their own Physical Layer channel/band in order to minimize the impact of the chnage at MAC level. The actions to be performed in Service Nodes following the reception of a PCC_PHY_CH packet are specific to the implementation.

4.6.11 Channel hopping

Channel hopping is a feature configured at network level for the RF PHY medium, i.e. in a Prime network all the nodes use it or not. The channel hopping mechanism uses network coordination with the MAC frame, via a shared hop sequence to which devices synchronize. This synchronization is performed upon the reception of a BCN frame, which contains all the information necessary for a node to generate the pseudo-random hop sequences shared by all nodes within the network, thus allowing the node to communicate with other nodes within the network.

Two network pre-shared channel lists, macHoppingInitialChannelList and macHoppingBCNInitialChannelList, are used for channel hopping. Depending on choices performed at network level, these lists may be disjoint or may have common elements.

From these two lists, two channel hopping sequences are generated:

- The main channel sequence is used for all the packets transmitted in the SCP (see 4.6.11.1 and 4.6.11.2) . It is derived from macHoppingInitialChannelList
- The beacon channel sequence is used for all the packets transmitted in the CFP (see 4.6.11.3 and 4.6.11.4) . It is derived from macHoppingBCNInitialChannelList

For the main channel sequence, the dwell time is set to 138 symbols or 309.12 milliseconds, which allows for the division of the MAC frame in 2, 4 , 6 or 8 slots depending on the configured frame length.

For the beacon channel sequence, the dwell time is equal to the macFrameLength (in symbols) in use in the network.

Guard-times of macGuardTime duration are present at the CFP boundary as described in 4.3.3.1.

In addition, to help transitions from one RF channel to another in the main channel sequence, specific RF channel hopping guard-times of macGuardTime are also defined at symbols 138n where n=1,...,macFrameLength(in symbols)/138 - 1.

During guard-times, transmission is forbidden.

Examples of channel transitions with different frame and CFP/SCP lengths can be seen in Annex M.

4.6.11.1 Main channel sequence generation

The main network hopping sequence is used in the SCP and is a pseudo-randomly shuffled set of all of the channels reported as used for hopping in macHoppingInitialChannelList. The selection of channels used for main sequence hopping is implementation-specific and should be pre-shared by all nodes within the network.

The mechanism to generate the main sequence is based on the one defined on clause 6.2.10 of IEEE 802.15.4-2015 [28]:

- SHUFFLE is a macHoppingSequenceLength-sized array. The contents of this array are equivalent to the first macHoppingSequenceLength outputs of a 9-bit linear feedback shift register (LFSR) with polynomial $x^9 + x^5 + 1$ and a starting seed of 255:
  - In order for different PRIME networks to use different sequences the SNA of the network is used as an input for the LFSR.
  - For each LFSR value generated a byte of the SNA prepended with a 0 is used as input.
  - The SNA bytes are used in order from least significant to most significant.
  - If the number of channels is higher than the number of SNA bytes these will be reused as inputs cyclically.
  - Each LFSR output is modulo macHoppingSequenceLength, so that each entry of SHUFFLE is between 0 and (macHoppingSequenceLength – 1), inclusive.
- CHANNELS is a macHoppingSequenceLength-sized array that is initially populated with the monotonically increasing set of channels reported as used for hopping in macHoppingInitialChannelList.
- CHANNELS is shuffled as per Figure 110. Elements may wind up being swapped multiple times in this process.

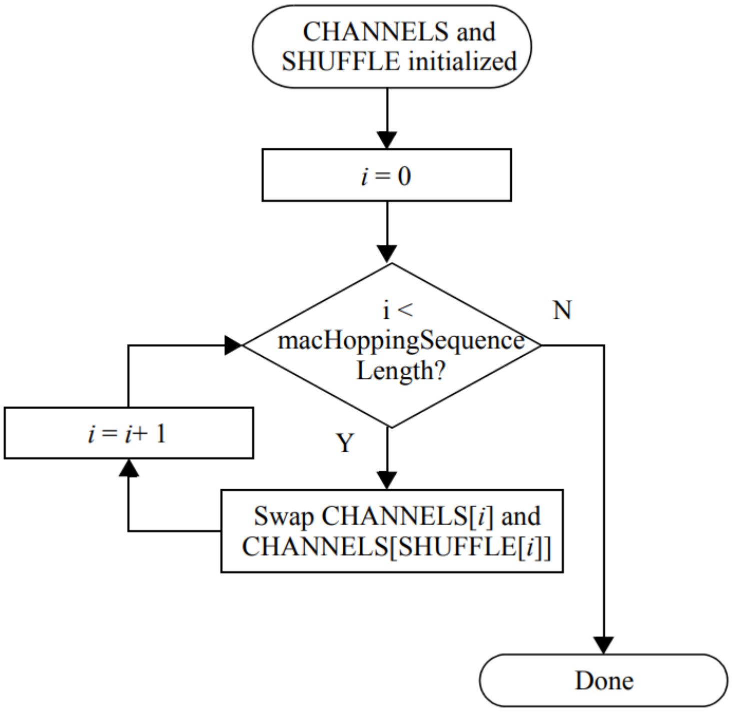


Figure 120 – CHANNELS shuffle algorithm

For cases where macHoppingSequenceLength is lower than the number of channels available to the PHY, some channels available to the RF PHY medium will be excluded from the array.

Channel sequence generation examples can be seen in ANNEX M.

4.6.11.2 Main channel sequence and level

For the Base Node the main channel sequence is determined using the following formula:

CHANNELS[mod(macHoppingSequencePosition, macHoppingSequenceLength)].

In order to optimize the usage of the of the multiple channels of a RF PHY medium, and also to reduce the collision domain, the level of the Service Nodes is used as an offset in the channels sequence. The channel to use at each level will be:

CHANNELS[mod(macHoppingSequencePosition + level + 1, macHoppingSequenceLength)].Where macHoppingSequencePosition is the current position in the channel sequence. This way two adjacent levels will not use the same frequency channels at any point in time.

This implies that nodes will use different channels for reception and transmission at all times. The nodes will be receiving in their corresponding channel and will have to switch to the previous channel in the sequence for uplink transmission, and to the next channel for downlink transmission.

This also implies that nodes will be unable to receive once they switch channel for transmission.

4.6.11.3 Beacon channel sequence generation

In order to reduce service node start-up times, and to optimize channel usage, a separate channel sequence will be defined for all the frames transmitted in the CFP, including the beacon frames as the most important case. This channel sequence will be generated in the same way as the main channel sequence, but using only a subset (maximum 32 elements) of the total number of channels available to the PHY layer. The subset (and its cardinality) needs to be chosen considering a compromise among simplicity of management, connection time for disconnected nodes, channel usage, specific country regulations. This subset is implementation-specific and should be pre-shared by all nodes within the network. The subset consists of all the channels reported as used for hopping in macHoppingBCNInitialChannelList.

The beacon channel sequence generation mechanism works as follows:

SHUFFLE is a macHoppingBCNSequenceLength-sized array. The contents of this array are equivalent to the first macHoppingBCNSequenceLength outputs of a 9-bit linear feedback shift register (LFSR) with polynomial x9 + x5 + 1 and a starting seed of 255:

  - In order for different PRIME networks to use different sequences the SNA of the network is used as an input for the LFSR.
  - For each LFSR value generated a byte of the SNA prepended with a 0 is used as input.
  - The SNA bytes are used in order from least significant to most significant.
  - If the number of channels is higher than the number of SNA bytes these will be reused as inputs cyclically.
  - Each LFSR output is modulo macHoppingBCNSequenceLength, so that each entry of SHUFFLE is between 0 and (macHoppingBCNSequenceLength – 1), inclusive.
- CHANNELS is a macHoppingBCNSequenceLength-sized array that is initially populated with the monotonically increasing set of channels available in the beacon channel subset.
- CHANNELS is shuffled as per Figure 110. Elements may wind up being swapped multiple times in this process.

For the beacon channel sequence macHoppingBCNSequenceLength shall match the number of channels available in the beacon channel subset. This implies the all channels in the subset will appear only once in the beacon channel sequence array.

4.6.11.4 Beacon channel sequence and BCN.SEQ

For all the nodes, the beacon channel sequence is determined using the following formula:

CHANNELS[mod(BCN.SEQ, macHoppingBCNSequenceLength)]

As BCN.SEQ is present in every beacon, all the nodes will use the same channels for reception and transmission for beacons (and all CFP packets) at all times. Note that for the Base Node, the formula only refers to the transmitted beacons.

4.6.11.5 Service node start-up and synchronization

Upon starting up, a service node will start scanning for beacons in the different RF channels available in the beacon channel list. The maximum time for a network to send beacons in all channels available is macHoppingBCNSequenceLength times the maximum superframe length (32*1104 symbols, 79.13472 seconds). It is recommended that service nodes scan each channel for the maximum time required for the network to send beacons in all channels. The algorithm used to decide which channel is being scanned by a service node is left to the implementer.

Upon reception of a BCN frame a service node will generate both the main sequence and the beacon sequence by using the BCN.SNA field. The macHoppingBCNSequencePosition can be derived by the node by reading the BCN.SEQ of the received beacon (see 4.6.11.3). This allows all the nodes to be coordinated on the RF channel used to transmit their RF beacon. For beacons received on the RF medium, the node may also derive the macHoppingBCNSequencePosition looking for the channel where the beacon was received in the beacon sequence.

For the main channel sequence, the macHoppingSequencePosition is included in the BCN.HOP_POS field, when the beacon is received on the RF medium. The main channel sequence is autonomously started from macHoppingSequencePosition = 0, by a node registered trough PLC medium. For the transmission of PNPDUs disconnected nodes will sweep through all available channels sending a PNPDU frame in each of them in the shortest possible amount of time.

In order to randomize the channel usage, the channel sequence used for the PNPDU transmission shall be a pseudo-random sequence generated using the previously described algorithm but replacing the SNA with the EUI48 of the node.

Disconnected nodes shall not transmit less than one PNPDU per channel per macHoppingPromotionMaxTxPeriod units of time, and no more than one PNPDU per channel per macHoppingPromotionMinTxPeriod. The algorithm used to decide the transmission rate of PNPDUs is left to the implementer.

4.7 Automatic Repeat Request (ARQ)

4.7.1 General

Devices complying with this specification may either implement an ARQ scheme as described in this section or no ARQ at all. This specification provides for low-cost Switch and Terminal devices that choose not to implement any ARQ mechanism at all.

4.7.2 Initial negotiation

ARQ is a connection property. During the initial connection negotiation, the originating device indicates its preference for ARQ or non-ARQ in CON.ARQ field. The responding device at the other end can indicate its acceptance or rejection of the ARQ in its response. If both devices agree to use ARQ for the connection, all traffic in the connection will use ARQ for acknowledgements, as described in Section 4.7.3. If the responding device rejects the ARQ in its response, the data flowing through this connection will not use ARQ.

4.7.3 ARQ mechanism

4.7.3.1 General

The ARQ mechanism works between directly connected peers (original source and final destination), as long as both of them support ARQ implementation. This implies that even for a connection between the Base Node and a Terminal (connected via one or more intermediate Switch devices), ARQ works on an end-to-end basis. The behavior of Switch Nodes in an ARQ-enabled connection is described in Section 4.7.4. When using ARQ, a unique packet identifier is associated with each packet, to aid in acknowledgement. The packet identifier is 6 bits long and can therefore denote 64 distinct packets. ARQ windowing is supported, with a maximum window size of 32 (5 bits), as described in Section 4.7.3.3.

4.7.3.2 ARQ PDU

4.7.3.2.1 General

The ARQ subheader contains a set of bytes, each byte containing different subfields. The most significant bit of each byte, the M bit, indicates if there are more bytes in the ARQ subheader.

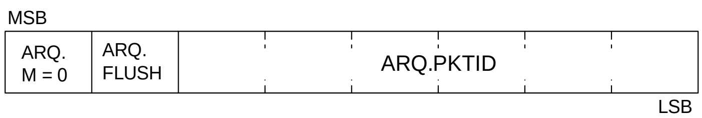


Figure 121 - ARQ subheader only with the packet id

Figure 121 shows an ARQ subheader with the first M bit of 0 and so the subheader is a single byte and contains only the packet ID for the transmitted packet.

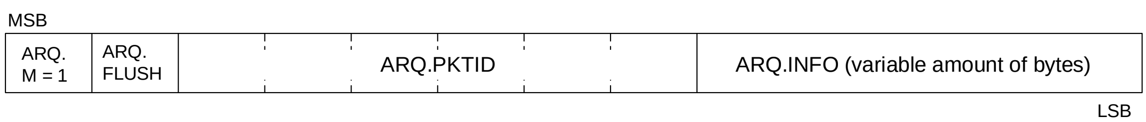


Figure 122 - ARQ subheader with ARQ.INFO

Figure 122 has the M bit in the first byte of the ARQ subheader set, and so the subheader contains multiple bytes. The first byte contains the packet ID of the transmitted packet and then follows the ARQ.INFO which is a list of one or more bytes, where each byte could have one of the following meanings:

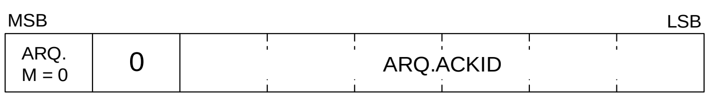


Figure 123 - ARQ.ACK byte fields

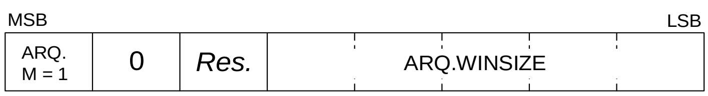


Figure 124 - ARQ.WIN byte fields

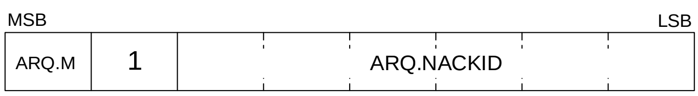


Figure 125 - ARQ.NACK byte fields

If there are multiple packets lost, an ARQ.NACK is sent for each of them, from the first packet lost to the last packet lost. When there are several ARQ.NACK they implicitly acknowledge the packets before the first

ARQ.NACK, and the packets in between the ARQ.NACKs. If an ARQ.ACK is present, it shall be placed at the end of the ARQ subheader, and shall reference to an ARQ.ACKID that is later than any other ARQ.NACKID, if present. If there is at least an ARQ.NACK and an ARQ.ACK they also implicitly acknowledge any packet in the middle between the last ARQ.NACKID and the ARQ.ACK.

For interoperability, a device shall be able to receive any well-formed ARQ subheader and shall process at least the first ARQ.ACK or ARQ.NACK field.

The subfields have the following meanings as described in Table 62

Table 62 - ARQ fields

Field	Description
ARQ.FLUSH	ARQ.FLUSH = 1 If an ACK must be sent immediately. ARQ.FLUSH = 0 If an ACK is not needed.
ARQ.PKTID	The id of the current packet, if the packet is empty (with no data) this is the id of the packet that will be sent next.
ARQ.ACKID	The identifier with the next packet expected to be received.
ARQ.WINSIZE	The window size available from the last acknowledged packet. After a connection is established its window is 1.
ARQ.NACKID	Ids of the packets that need to be retransmitted.

4.7.3.2.2 ARQ subheader example

MSB

ARQ. M = 1	ARQ. FLUSH = 1	ARQ.PKTID = 23	ARQ. M = 1	0	*Res*	ARQ.WINSIZE = 16
ARQ. M = 1	1	ARQ.NACKID = 45	ARQ. M = 1	1	ARQ.NACKID = 47	
ARQ. M = 1	1	ARQ.NACKID = 48	ARQ. M = 1	1	ARQ.NACKID = 52	
ARQ. M = 1	1	ARQ.NACKID = 55	ARQ. M = 1	1	ARQ.NACKID = 56	
ARQ. M = 1	1	ARQ.NACKID = 57	ARQ. M = 0	0	ARQ.ACKID = 60	

LSB

Figure 126 - Example of an ARQ subheader with all the fields present

In this example all the ARQ subheader fields are present. To make it understandable, since both Nodes are both transmitters and receivers, the side receiving this header will be called A and the other side transmitting B. The message has the packet ID of 23 if it contains data; otherwise the next data packet to be sent has the packet ID of 23. Since the flush bit is set it needs to be ACKed/NACKed.

B requests the retransmission of packets 45, 47, 48, 52, 55, 56 and 57. ACK = 60, so it has received packets <45, 46, 49, 50, 51, 53, 54, 58 and 59.

The window is 16 and it has received and processed up to packet 44 (first NACK = 45), so A can send all packets <= 60; that is, as well as sending the requested retransmits, it can also send packet ID = 60.

4.7.3.3 Windowing

A new connection between two peer devices starts with an implicit initial receiver window size of 1 and a packet identifier 0. This window size is a limiting case and the transaction (to start with) shall behave like a “Stop and Wait” ARQ mechanism.

On receipt of an ARQ.WIN, the sender would adapt its window size to *ARQ.WINSIZE.* This buffer size is counted from the first packet completely ACK-ed, so if there is a NACK list and then an ACK the window size defines the number of packets from the first NACK-ed packet that could be sent. If there is just an ACK in the packet (without any NACK) the window size determines the number of packets that can be sent from that ACK.

An *ARQ.WINSIZE* value of 0 may be transmitted back by the receiver to indicate congestion at its end. In such cases, the transmitting end should wait for at least *ARQCongClrTime* before re-transmitting its data.

4.7.3.4 Flow control

The transmitter must manage the ACK sending algorithm by the flush bit; it is up to it having a proper ARQ communication. The receiver is only forced to send ACKs when the transmitter has sent a packet with the flush bit set, although the receiver could send more ACKs even if not forced to do it, because the flow control is only a responsibility of the transmitter. The transmitter shall close the connection latest if the Packet acknowledgement is missing after ARQMaxTxCount Packet retransmissions. The transmitter may choose to use lower maximum retransmit value than ARQMaxTxCount and it may also close the connection any time earlier if it determines proper data exchange cannot be restored.

These are the requisites to be interoperable, but the algorithm is up to the manufacturer. It is strongly recommended to piggyback data-ACK information in outgoing packets, to avoid the transmission of unnecessary packets just for ACK-ing. In particular in order to allow consolidated ACKs or piggybacking, the maximum time for each implementation before sending an ACK is ARQMaxAckHoldTime.

4.7.3.5 Algorithm recommendation

No normative algorithm is specified, for a recommendation see Annex I.

4.7.3.6 Usage of ARQ in resource limited devices

Resource limited devices may have a low memory and simple implementation of ARQ. They may want to use a window of 1 packet. They work as a “Stop and Wait” mechanism.

The ARQ subheader to be generated shall be one of the followings:

If there is nothing to acknowledge:

MSB		LSB
ARQ. M = 0	ARQ. FLUSH=1	ARQ.PKTID

Figure 127 - Stop and wait ARQ subheader with only packet ID

If there is something to acknowledge carrying data:

MSB

ARQ. M = 1	ARQ. FLUSH=1	ARQ.PKTID	ARQ. M = 0	0	ARQ.ACKID

LSB

Figure 128 - Stop and wait ARQ subheader with an ACK

If there is something to acknowledge but without any data in the packet:

MSB

ARQ. M = 1	ARQ. FLUSH=0	ARQ.PKTID	ARQ. M = 0	0	ARQ.ACKID

LSB

Figure 129 - Stop and wait ARQ subheader without data and with an ACK

The ARQ.WINSIZE is not generally transmitted because the window size is already 1 by default, it only may be transmitted to handle congestion and to resume the transmission again.

4.7.4 ARQ packets switching

All Switch Nodes shall support transparent bridging of ARQ traffic, whether or not they support ARQ for their own transmission and reception. In this mode, Switch Nodes are not required to buffer the packets of the ARQ connections for retransmission.

Some Switch Nodes may buffer the packets of the ARQ connections, and perform retransmission in response to NACKs for these packets if the subnetwork is working with security profile 0. If the subnetwork is working with security profile 1 or 2, the switch node shall not perform retransmission in response to NACKs for these packets. The following general principles shall be followed.

- The acknowledged packet identifiers shall have end-to-end coherency.

- The buffering of packets in Switch Nodes and their retransmissions shall be transparent to the source and Destination Nodes, i.e., a Source or Destination Node shall not be required to know whether or not an intermediate Switch has buffered packets for switched data.

4.8 Time Reference

Packets in PRIME may interchange time references by providing a TREF subheader. Due to the frame and superframe structure of the MAC layer, when a node is registered to a PRIME subnetwork it is already synchronized. The TREF subheader includes a time reference that is relative to the beginning of a frame in order to make reference to a specific moment in time.

Table 63 - Time Reference subheader fields

Name	Length	Description
TREF.SEQ	5 bits	Sequence number of the MAC Frame that is used as reference time of the event to notify.
Reserved	3 bits	Always 0 for this version of the specification. Reserved for future use.

TREF.TIME	32 bits	Signed number in 10s of microseconds between the moment of the event, and the beginning of the frame. Positive for events after the beginning of the MAC frame, and negative for events before the beginning of the MAC frame. 0x80000000 is a special value that means that it is an invalid time reference.

During the transmission of a new packet, the transmitter of a TREF subheader should always keep the TREF.SEQ as updated as possible.

During the switching of a packet with a TREF subheader, the Switch Node may update the TREF.TIME and TREF.SEQ to change the MAC frame this reference is based on, as long as it makes reference to the same instant in time. A switch shall update the fields if (RX_SEQ – TREF.SEQ) & 31 > (TX_SEQ – TREF.SEQ) & 31, where RX_SEQ is the frame sequence number when the packet is received by the switch and TX_SEQ is the sequence number when a packet is transmitted by the switch. In this case, this field may be easily updated by subtracting the length of a superframe to the TREF.TIME field, leaving the same TREF.SEQ. This mechanism is in order to avoid a superframe overlapping.

If the time reference cannot be represented in the TREF.TIME field, then the field TREF.TIME should have the value 0x80000000 that means that it is an invalid reference

4.9 Backward Compatibility with PRIME 1.3.6

In order to interoperate with Service Nodes conforming to v1.3.6 of specifications, v1.4 conformant devices can implement a backward-compatibility mode. This mode is optional for PLC-only devices, while it is not supported by PLC+RF and RF-only devices (PLC+RF and RF-only devices do not support this section and Annex K and indicate REG.CAP_BC=0, PRO.PN_BC=0, PNH.CAP_BC=0). As a consequence, a network including PLC+RF and/or RF-only devices shall use the normal 1.4 MAC mode described in this specification (BCN.MACBC=0, BCN.CSMA=0). In what follows, the MAC backward-compatibility mode, that can be optionally supported in PRIME 1.4 networks exclusively including PLC-only devices, is described.

Since PRIME v1.3.6 Service Nodes will not understand v1.4 message formats, v1.4 compliant devices implementing backward-compatibility mode shall support additional messaging capabilities that enable them to communicate with PRIME v1.3.6 devices. Any Subnetwork that allows registration of one or more PRIME v1.3.6 device/s shall be termed to be running in “backward-compatibility” mode and will operate with the following characteristics:

- Base Node shall always be a v1.4 compliant implementation i.e. a PRIME v1.3.6 Base Node is incapable of managing a Subnetwork in backward-compatibility mode.
- All robust mode PDUs shall be transmitted using PHY BC Frames as defined in Annex K.
- To accommodate for size restrictions in PHY BC Frames, the Base Node shall limit the maximum SAR segment size to be less or equal than 64 bytes for all service nodes located, directly or indirectly, behind a robust link

4.9.1 Frame Structure and Channel Access

A Subnetwork in “backward-compatibility” mode shall abide by principles laid down in points below:

- Fixed frame length of 276 symbols shall be used. The frames include up to five consecutive non-robust beacon slots, each of them having a length of 11.008ms.

- Transition to longer frames is prohibited. The base node transmits a beacon using DBPSK_CC modulation in every frame in beacon slot 0. The frame format is shown in Figure 130.

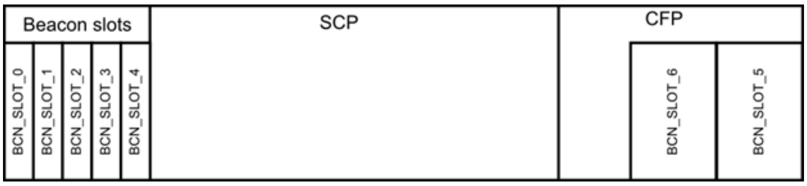


Figure 130 - CBCN Frame format for backwards compatibility mode

- PRIME v1.4 compatibility mode allows the Base Node to place up to two robust mode beacons per frame at the end of the CBCN Frame. They are located at the end of CFP, respecting the guard times (macGuardTime) before each one and at the end of the frame, as shown in the Figure 131.
- Robust beacon allocation policy is up to the manufacturer, it could be 0 to 2 robust beacons and can be allocated from the beginning or on demand.
- The robust beacons shall be sent in DBPSK_R encoding with the PHY frame type BC.

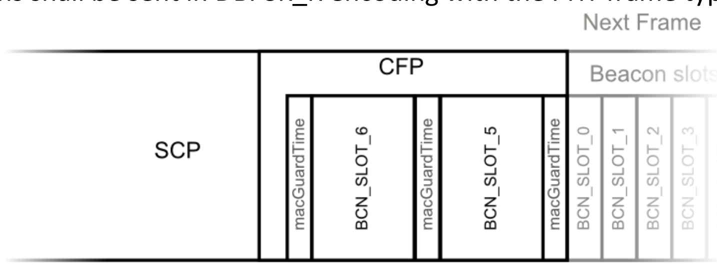


Figure 131 - Robust beacon allocation in 1.4 BC

- The Base Node shall set the CFP duration to a value which guarantees that the robust mode beacons are fully located within CBCN.CFP.

- For a Switch Node using DBPSK_CC for beacon transmission, the Base Node allocates space from the non-robust beacon slots (slot 0 to 4). Beacon slot allocation rules according to PRIME v1.3.6 shall apply for allocation of non-robust beacon slots.
- For allocation of robust beacons the Base Node should not update the beacon slot count, as the robust beacons shall be placed in the CFP.

- The Base Node can also transmit robust beacons but it is not mandated to do so.
- If a switch or Base Node transmits robust beacons, it shall transmit at least once every 32 sub-frames.
- Frame format shall respect the same restrictions on SCP and CFP durations defined in PRIME v1.3.6.

- CSMA/CA algorithm defined in 1.3.6 shall be used.

4.9.2 Switching

In a network running in PRIME v1.4 compatibility mode, uplink (HDR.DO=0) Multicast and Broadcast packets shall follow the same rules as the ones described in PRIME version 1.3.6:

- The node shall only switch the packet that has a broadcast or multicast destination (PKT.LNID = 0x3FFF or 0x3FFE) and that was transmitted by a Node registered through this Switch Node (PKT.SID=LSID of this Switch Node).
- In case a broadcast or multicast packet is switched up, the Switch Node shall replace the PKT.SID with Switch Node's SID.

For the rest of the packet types the Switch Node shall follow the rules and actions described in chapter 4.3.5.

4.9.3 PDU Frame Formats

4.9.3.1 General Format

In a network running in PRIME v1.4 compatibility mode, all nodes shall use the standard Generic Mac Header (see Section 4.4.2.4) and the Compatibility Packet Header (CPKT, see Annex K). The CRC calculation follows the standard procedure described in Section 4.4.2. These headers and CRC calculation follow the PRIME v1.3.6 specification.

In a compatibility mode network, some control messages need a different format from the standard PRIME v1.4 format. This is for example the case for messages which are sniffed by PRIME v1.3.6 devices. These special messages are listed in the following sub-sections. On the other hand, the standard PRIME v1.4 payload format is used for the CON, CFP, MUL and SEC control packets.

4.9.3.2 Registration and Unregistration control messages

A mixture of compatibility mode registration messages (CREG, Annex K.1.1.1.1), which follow the following PRIME v1.3.6 message format, and PRIME v1.4 format REG control messages shall be used. For a detailed description of the registration procedure in a compatibility mode network see Annex K.2.1.

The messages used during unregistration shall follow the CREG frame format specified in Annex K.1.1.1.1.

4.9.3.3 Promotion and Beacon Slot Indication control messages

For all promotion messages the compatibility mode format CPRO (see Annex K.1.1.1.2) shall be used. The CREG messages resemble PRIME v1.3.6 messages. This is important as switches on the branch need to sniff these packets in order to refresh their switch tables. The compatibility mode promotion procedure, which is described in Annex K.2.3, requires also compatibility BSI packets (CBSI). The BSI packets are no longer used in PRIME v1.4. A compatibility mode network does not support a modulation change of a switch.

The messages used during demotion shall follow the CPRO frame format specified in Annex K.1.1.1.2.

4.9.3.4 Keep-Alive control messages

PRIME v1.3.6 service nodes do not know about the new link level keep-alive process. Therefore, for networks operating in backward compatibility mode, the keep-alive process shall remain the same as in PRIME v1.3.6. The process is described in Annex K.2.5. In addition, the CALV control messages are also enumerated in K.1.1.1.5.

5 Convergence layer

5.1 Overview

Figure 132 shows the overall structure of the Convergence layer.

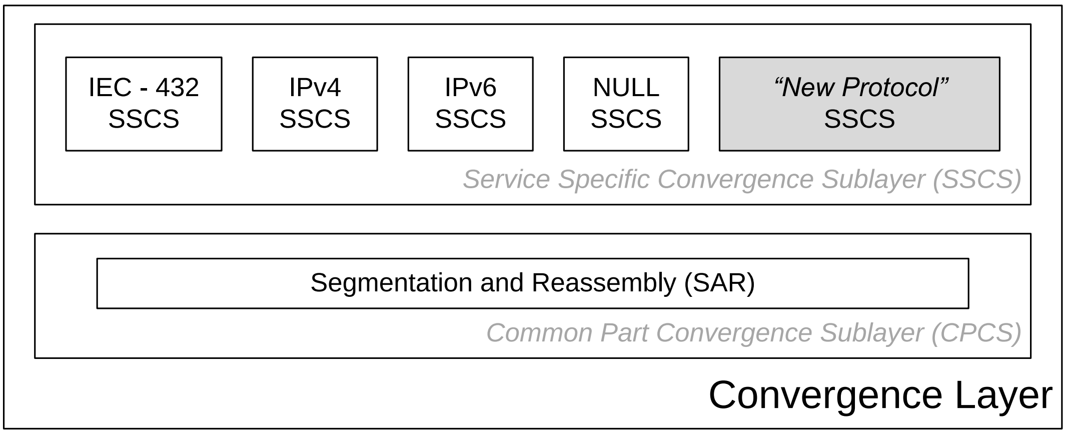


Figure 132 - Structure of the Convergence layer

The Convergence layer is separated into two sublayers. The Common Part Convergence Sublayer (CPCS) provides a set of generic services. The Service Specific Convergence Sublayer (SSCS) contains services that are specific to one communication profile. There are several SSCSs, typically one per communication profile, but only one CPCS. The use of CPCS services is optional in that a certain SSCS will use the services it needs from the CPCS, and omit services which are not needed.

5.2 Common Part Convergence Sublayer (CPCS)

5.2.1 General

This specification defines only one CPCS service: Segmentation and Reassembly (SAR).

5.2.2 Segmentation and Reassembly (SAR)

5.2.2.1 General

CPCS SDUs which are larger than 'macSARSize-1' bytes are segmented at the CPCS. CPCS SDUs which are equal or smaller than 'macSARSize -1' bytes may also optionally be segmented. Segmentation means breaking up a CPCS SDU into smaller parts to be transferred by the MAC layer. At the peer CPCS, the smaller parts (segments) are put back together (i.e. reassembled) to form the complete CPCS SDU. All segments except the last segment of a segmented SDU must be the same size and at most macSARSize bytes in length. Segments may be decided to be smaller than 'macSARSize -1' bytes e.g. when the channel is poor. The last segment may of course be smaller than 'macSARSize -1' bytes.

In order to keep SAR functionality simple, the macSARSize is a constant value for all possible modulation/coding combinations at PHY layer. The value of macSARSize is such that with any modulation/coding combination, it is always possible to transmit a single segment in one PPDU. Therefore, there is no need for discovering a specific MTU between peer CPCSs or modifying the SAR configuration for every change in the modulation/coding combination. In order to increase efficiency, a Service Node which supports packet aggregation may combine multiple segments into one PPDU when communicating with its peer.

Segmentation always adds a 1-byte header to each segment. The first 2 bits of SAR header identify the type of segment. The semantics of the rest of the header information then depend on the type of segment. The structure of different header types is shown in Figure 133 and individual fields are explained in Table 64. Not all fields are present in each SAR header. Either SAR.NSEGS or SAR.SEQ is present, but not both.

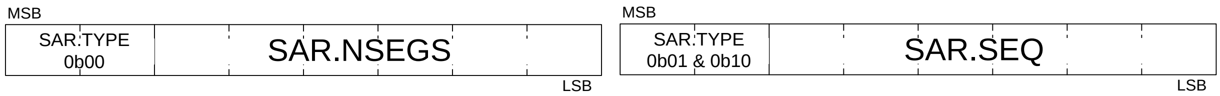


Figure 133 – Segmentation and Reassembly Headers

Table 64 - SAR header fields

Name	**Length**	**Description**
SAR.TYPE	2 bits	Type of segment. • 0b00: first segment; • 0b01: intermediate segment; • 0b10: last segment; • 0b11: Last segment with SAR.CRC field at the end of the segment.
SAR.NSEGS	6 bits	'Number of Segments' – 1. Note: This field is only present in segments with SAR.TYPE=0b00
SAR.SEQ	6 bits	Sequence number of segment. Note: This field is only present in segments with SAR.TYPE=0b01, SAR.TYPE=0b10 and SAR.TYPE=0b11.

Every segment (except for the first one) includes a sequence number so that the loss of a segment could be detected in reassembly. The sequence numbering shall start from zero with every new CPCS SDU. The first segment which contains a SAR.SEQ field must have SAR.SEQ = 0. All subsequent segments from the same CPCS SDU shall increase this sequence number such that the SAR.SEQ field adds one with every transmission.

The value SAR.NSEGS indicates the total number of segments, minus one. So when SAR.NSEGS = 0, the CPCS SDU is sent in one segment. SAR.NSEGS = 63 indicates there will be 64 segments to form the full CPCS SDU. When SAR.NSEGS = 0, it indicates that this first segment is also the last segment. No further segment with SAR.TYPE = 0b01 or 0b10 is to be expected for this one-segment CPCS SDU.

Using segments with SAR.TYPE=0b11 instead of SAR.TYPE=0b10 will be recommended for the last segments of connections without ARQ, multicast and broadcast. Connections with ARQ may use SAR.TYPE=0b10 safely (this reduces overhead and guarantees backward compatibility). The 32 bits CRC is computed using the polynomial generator in the and appended at the end of the last segment.

Table 65 – SAR.CRC

Name	Length	Description
SAR.CRC	32 bits	CRC32 of the SAR CPCS PDU. This field is only present in segments with SAR.TYPE=0b11. The input polynomial M(x) is formed as a polynomial whose coefficients are bits of the data being checked (the first bit to check is the highest order coefficient and the last bit to check is the coefficient of order zero). The Generator polynomial for the CRC is $G(x)=x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1$. The remainder R(x) is calculated as the remainder from the division of $M(x)\cdot x^{32}$ by G(x). The coefficients of the remainder will then be the resulting CRC.

SAR at the receiving end shall buffer all segments and deliver only fully reassembled CPCS SDUs to the SSCS above. Should reassembly fail due to a segment not being received or too many segments being …received etc., SAR shall not deliver any incomplete CPCS SDU to the SSCS above.

5.2.2.2 SAR constants

Table shows the constants for the SAR service.

Table 66 - SAR Constants

Constant	Value
ClMaxAppPktSize	Max Value (SAR.NSEGS) x macSARSize.

5.3 NULL Service-Specific Convergence Sublayer (NULL SSCS)

5.3.1 Overview

Null SSCS provides the MAC layer with a transparent path to upper layers, being as simple as possible and minimizing overhead. It is intended for applications that do not need any special convergence capability.

The unicast and multicast connections of this SSCS shall use the SAR service, as defined in 5.2.2. If they do not need the SAR service they shall still include the SAR header (notifying just one segment).

The CON.TYPE and MUL.TYPE (see Annex E) for unicast connections and multicast groups shall use the same type that has been already defined for the application that makes use of this Null SSCS.

5.3.2 Primitives

Null SSCS primitives are just a direct mapping of the MAC primitives. A full description of every primitive is avoided, because the mapping is direct and they will work as the ones of the MAC layer.

The directly mapped primitives have exactly the same parameters as the ones in the MAC layer and perform the same functionality. The set of primitives that are directly mapped are shown below.

Table 67 - Primitive mapping between the Null SSCS primitives and the MAC layer primitives

Null SSCS mapped to …	… a MAC primitive
CL_NULL_ESTABLISH.request	MAC_ESTABLISH.request
CL_NULL_ESTABLISH.indication	MAC_ESTABLISH.indication
CL_NULL_ESTABLISH.response	MAC_ESTABLISH.response
CL_NULL_ESTABLISH.confirm	MAC_ESTABLISH.confirm
CL_NULL_RELEASE.request	MAC_RELEASE.request
CL_NULL_RELEASE.indication	MAC_RELEASE.indication
CL_NULL_RELEASE.response	MAC_RELEASE.response
CL_NULL_RELEASE.confirm	MAC_RELEASE.confirm
CL_NULL_JOIN.request	MAC_JOIN.request
CL_NULL_JOIN.indication	MAC_JOIN.indication
CL_NULL_JOIN.response	MAC_JOIN.response
CL_NULL_JOIN.confirm	MAC_JOIN.confirm
CL_NULL_LEAVE.request	MAC_LEAVE.request
CL_NULL_LEAVE.indication	MAC_LEAVE.indication
CL_NULL_LEAVE.response	MAC_LEAVE.response
CL_NULL_LEAVE.confirm	MAC_LEAVE.confirm
CL_NULL_DATA.request	MAC_DATA.request
CL_NULL_DATA.indication	MAC_DATA.indication
CL_NULL_DATA.confirm	MAC_DATA.confirm

5.4 IPv4 Service-Specific Convergence Sublayer (IPv4 SSCS)

5.4.1 Overview

The IPv4 SSCS provides an efficient method for transferring IPv4 packets over the PRIME Subnetworks. Several conventions do apply:

- A Service Node can send IPv4 packets to the Base Node or to other Service Nodes.
- It is assumed that the Base Node acts as a router between the PRIME Subnetwork and any other network. The Base Node could also act as a NAT. How the Base Node connects to the other networks is beyond the scope of this specification.
- In order to keep implementations simple, only one single route is supported per local IPv4 address.
- Service Nodes may use statically configured IPv4 addresses or DHCP to obtain IPv4 addresses.
- The Base Node performs IPv4 to EUI-48 address resolution. Each Service Node registers its IPv4 address and EUI-48 address with the Base Node (see section 5.4.2). Other Service Nodes can then query the Base Node to resolve an IPv4 address into a EUI-48 address. This requires the establishment of a dedicated connection with the Base Node for address resolution.
- The IPv4 SSCS performs the routing of IPv4 packets. In other words, the IPv4 SSCS will decide whether the packet should be sent directly to another Service Node or forwarded to the configured gateway.

- Although IPv4 is a connectionless protocol, the IPv4 SSCS is connection-oriented. Once address resolution has been performed, a connection is established between the source and destination Service Node for the transfer of IPv4 packets. This connection is maintained while traffic is being transferred and may be closed after a period of inactivity.
- The CPCS (see section 5.2) SAR sublayer shall always be present with the IPv4 Convergence layer. Generated MSDUs are at most 'macSARSize' bytes long and upper layer PDU messages are not expected must not to be longer than ClMaxAppPktSize.
- Optionally TCP/IPv4 headers may be compressed. Compression is negotiated as part of the connection establishment phase.
- The broadcasting of IPv4 packets is supported using the MAC broadcast mechanism.
- The multicasting of IPv4 packets is supported using the MAC multicast mechanism.

The IPv4 SSCS has a number of connection types. For address resolution there is a connection to the Base Node. For IPv4 data transfer there is one connection per Destination Node: with the Base Node that acts as the IPv4 gateway to other networks or to/with any other Node in the same Subnetwork. This is shown in Figure 134.

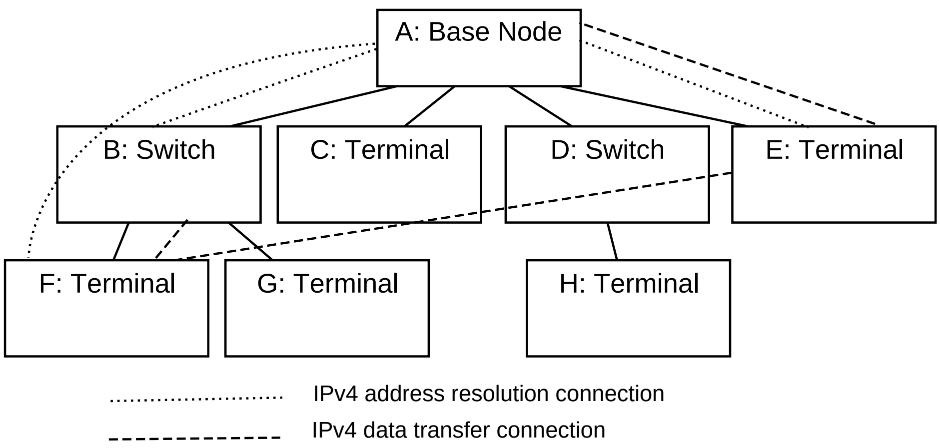


Figure 134 - IPv4 SSCS connection example

Here, Nodes B, E and F have address resolution connections to the Base Node. Node E has a data connection to the Base Node and Node F. Node F is also has a data connection to Node B. The figure does not show broadcast and multicast connections.

5.4.2 Address resolution

5.4.2.1 General

The IPv4 layer will present the IPV4 SSCS with an IPv4 packet to be transferred. The IPV4 SSCS is responsible for determining which Service Node the packet should be delivered to using the IPv4 addresses in the packet. The IPV4 SSCS must then establish a connection to the destination if one does not already exist so that the packet can be transferred. Three classes of IPv4 addresses can be used and the following subsections describe how these addresses are resolved into EUI-48 addresses.

5.4.2.2 Unicast addresses

5.4.2.2.1 General

IPv4 unicast addresses must be resolved into unicast EUI-48 addresses. The Base Node maintains a database of IPv4 addresses and EUI-48 addresses. Address resolution then operates by querying this database. A Service Node must establish a connection to the address resolution service running on the Base Node, using the connection type value TYPE (see Annex E) TYPE_CL_IPv4_AR. No data should be passed in the connection establishment. Using this connection, the Service Node can use two mechanisms as defined in the following paragraphs.

5.4.2.2.2 Address registration and unregistration

A Service Node uses the AR_REGISTER_S message to register an IPv4 address and the corresponding EUI-48 address meaning request from the base node to record inside its registration table, the IPv4 address and its corresponding service node EUI-48. The Base Node will acknowledge an AR_REGISTER_B message. The Service Node may register multiple IPv4 addresses for the same EUI-48 address.

A Service Node uses the AR_DEREGISTER_S message to unregister an IPv4 address and the corresponding EUI-48 address meaning requests from the base node to delete inside its registration table, the entry corresponding to the concerned IPv4 address. The Base Node will acknowledge it with an AR_DEREGISTER_B message.

When the IPv4 address resolution connection between the Service Node and the Base Node is closed, the Base Node should remove all addresses associated to that connection.

5.4.2.2.3 Address lookup

A Service Node uses the AR_LOOKUP_S message to perform a lookup. The message contains the IPv4 address to be resolved. The Base Node will respond with an AR_LOOKUP_B message that contains an error code and, if there is no error, the EUI-48 address associated with the IPv4 address. If the Base Node has multiple entries in its database for the same IPv4 address, the possible returned EUI-48 address is undefined.

5.4.2.3 Broadcast Address

IPv4 broadcast address 255.255.255.255 maps to a MAC broadcast connection with LCID equal to LCI_CL_IPv4_BROADCAST. All IPv4 broadcast packets will be sent to this connection. When an IPv4 broadcast packet is received on this connection, the IPv4 address should be examined to determine if it is a broadcast packet for the Subnetwork in which the Node has an IPv4 address. Only broadcast packets from member subnets should be passed up the IPv4 protocol stack.

5.4.2.4 Multicast Addresses

Multicast IPv4 addresses are mapped to a PRIME MAC multicast connection by the Base Node using an address resolution protocol.

To join a multicast group, AR_MCAST_REG_S is sent from the Service Node to the Base Node with the IPv4 multicast address. The Base Node will reply with an AR_MCAST_REG_B that contains the LCID value assigned to the said multicast address. However, the Base Node may also allocate other LCIDs which are not in use if it so wishes. The Service Node can then join a multicast group (see 4.6.7.2) for the given LCID to receive IPv4 multicast packets. These LCID values can be reused so that multiple IPv4 destination multicast addresses can be seen on the same LCID. To leave the multicast group, AR_MCAST_UNREG_S is sent from the Service Node to the Base Node with the IPv4 multicast address. The Base Node will acknowledge it with an AR_MCAST_UNREG_B message.

When a Service Node wants to send an IPv4 multicast datagram, it just uses the appropriate LCID. If the Service Node has not joined the multicast group, it needs first to learn the LCID to be used. The process with AR_MCAST_REG_{S|B} messages as described above can be used. While IPv4 multicast packets are still being sent, the Service Node remains registered to the multicast group. T_{mcast_reg} after the last IPv4 multicast datagram was sent, the Service Node should unregister from the multicast group, by means of AR_MCAST_UNREG_{S|B} messages. The nominal value of T_{mcast_reg} is 10 minutes; however, other values may be used.

5.4.2.5 Retransmission of address resolution packets

The connection between the Service Node and the Base Node for address resolution is not reliable if the MAC ARQ is not used. The Service Node is responsible for making retransmissions if the Base Node does not respond in one second. It is not considered an error when the Base Node receives the same registration requests multiple times or is asked to remove a registration that does not exist. These conditions can be the result of retransmissions.

5.4.3 IPv4 packet transfer

For packets to be transferred, a connection needs to be established between source and Destination Nodes. The IPV4 SSCS will examine each IPv4 packet to determine the destination EUI-48 address. If a data connection to the destination already exists, the packet is sent. To establish this, IPv4 SSCS keeps a table for each connection, with information shown in Table 68 (see RFC 1144).. To use this table, it is first necessary to determine if the IPv4 destination address is in the local Subnetwork or if a gateway has to be used. The netmask associated with the local IPv4 address is used to determine this. If the IPv4 destination address is not in the local Subnetwork, the address of the default gateway is used instead of the destination address when the table is searched.

Table 68 - IPV4 SSCS Table Entry

Parameter	Description
CL_IPv4_Con.Remote_IP	Remote IPv4 address of this connection.
CL_IPv4_Con.ConHandle	MAC Connection handle for the connection.
CL_IPv4_Con.LastUsed	Timestamp of last packet received/transmitted .
CL_IPv4_Con.HC	Header Compression scheme being used.
CL_IPv4_CON.RxSeq	Next expected Receive sequence number.
CL_IPv4_CON.TxSeq	Sequence number for next transmission.

The IPV4 SSCS may close a connection when it has not been used for an implementation-defined time period. When the connection is closed the entry for the connection is removed at both ends of the connection.

When a connection to the destination does not exist, more work is necessary. The address resolution service is used to determine the EUI-48 address of the remote IPv4 address if it is local or the gateway associated with the local address if the destination address is in another Subnetwork. When the Base Node replies with the EUI-48 address of the destination Service Node, a MAC connection is established to the remote device. The TYPE value of this connection is TYPE_CL_IPv4_UNICAST. The data passed in the request message is defined in section 5.4.7.4. The local IPv4 address is provided so that the remote device can add the new connection to its cache of connections for sending data in the opposite direction. The use of Van Jacobson Header Compression is also negotiated as part of the connection establishment. Once the connection has been established, the IPv4 packet can be sent.

When the packet is addressed to the IPv4 broadcast address, the packet has to be sent using the MAC broadcast service. When the IPV4 SSCS is opened, a broadcast connection is established for transferring all broadcast packets. The broadcast IPv4 packet is simply sent to this connection. Any packet received on this broadcast connection is passed to the IPv4 protocol stack.

5.4.4 Segmentation and reassembly

The IPV4 SSCS should support IPv4 packets with an MTU of 1500 bytes. This requires the use of SAR (see 5.2.2).

5.4.5 Header compression

Van Jacobson TCP/IP Header Compression is an optional feature in the IPv4 SSCS. The use of VJ compression is negotiated as part of the connection establishment phase of the connection between two Service Nodes.

VJ compression is designed for use over a point-to-point link layer that can inform the decompressor when packets have been corrupted or lost. When there are errors or lost packets, the decompressor can then resynchronize with the compressor. Without this resynchronization process, erroneous packets will be produced and passed up the IPv4 stack.

The MAC layer does not provide the facility of detecting lost packets or reporting corrupt packets. Thus, it is necessary to add this functionality in the IPV4 SSCS. The IPV4 SSCS maintains two sequence numbers when VJ compression is enabled for a connection. These sequence numbers are 8 bits in size. When transmitting an IPv4 packet, the CL_IPv4_CON.TxSeq sequence number is placed in the packet header, as shown in Section 5.4.3. The sequence number is then incremented. Upon reception of a packet, the sequence number in the received packet is compared against CL_IPv4_CON.RxSeq. If they differ, TYPE_ERROR, as defined in RFC1144, is passed to the decompressor. The CL_IPv4_CON.RxSeq value is always updated to the value received in the packet header.

Header compression should never be negotiated for broadcast or multicast packets.

5.4.6 Quality of Service mapping

The PRIME MAC specifies that the contention-based access mechanism supports 4 priority levels (1-4). Level 1 is used for MAC control messages, but not exclusively so.

IPv4 packets include a TOS field in the header to indicate the QoS the packet would like to receive. Three bits of the TOS indicate the IP Precedence. The following table specifies how the IP Precedence is mapped into the PRIME MAC priority.

Table 69 - Mapping IPv4 Precedence to PRIME MAC priority

IP Precedence	MAC Priority
000 – Routine	3
001 – Priority	3
010 – Immediate	2
011 – Flash	2
100 – Flash Override	1
101 – Critical	1
110 – Internetwork Control	0
111 – Network Control	0

5.4.7 Packet formats and connection data

5.4.7.1 General

This section defines the format of IPV4 SSCS PDUs.

5.4.7.2 Address resolution PDUs

5.4.7.2.1 General

The following PDUs are transferred over the address resolution connection between the Service Node and the Base Node. The following sections define AR.MSG values in the range of 0 to 11. All higher values are reserved for later versions of this specification.

5.4.7.2.2 AR_REGISTER_S

Table 70 shows the address resolution register message sent from the Service Node to the Base Node.

Table 70 - AR_REGISTER_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_REGISTER_S = 0.
AR.IPv4	32-bits	IPv4 address to be registered.

AR.EUI-48	48-bits	EUI-48 to be registered.

5.4.7.2.3 AR_REGISTER_B

Table 71 shows the address resolution register acknowledgment message sent from the Base Node to the Service Node.

Table 71 - AR_REGISTER_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_REGISTER_B = 1.
AR.IPv4	32-bits	Registered IPv4 address.
AR.EUI-48	48-bits	EUI-48 registered.

The AR.IPv4 and AR.EUI-48 fields are included in the AR_REGISTER_B message so that the Service Node can perform multiple overlapping registrations.

5.4.7.2.4 AR_UNREGISTER_S

Table 72 shows the address resolution unregister message sent from the Service Node to the Base Node.

Table 72 - AR_UNREGISTER_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_UNREGISTER_S = 2.
AR.IPv4	32-bits	IPv4 address to be unregistered.
AR.EUI-48	48-bits	EUI-48 to be unregistered.

5.4.7.2.5 AR_UNREGISTER_B

Table 73 shows the address resolution unregister acknowledgment message sent from the Base Node to the Service Node.

Table 73 - AR_UNREGISTER_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_UNREGISTER_B = 3.

AR.IPv4	32-bits	Unregistered IPv4 address .
AR.EUI-48	48-bits	Unregistered EUI-48.

The AR.IPv4 and AR.EUI-48 fields are included in the AR_UNREGISTER_B message so that the Service Node can perform multiple overlapping Unregistrations.

5.4.7.2.6 AR_LOOKUP_S

Table 74 shows the address resolution lookup message sent from the Service Node to the Base Node.

Table 74 - AR_LOOKUP_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_LOOKUP_S = 4.
AR.IPv4	32-bits	IPv4 address to lookup.

5.4.7.2.7 AR_LOOKUP_B

Table 75 shows the address resolution lookup response message sent from the Base Node to the Service Node.

Table 75 - AR_LOOKUP_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_LOOKUP_B = 5.
AR.IPv4	32-bits	IPv4 address looked up.
AR.EUI-48	48-bits	EUI-48 for IPv4 address.
AR.Status	8-bits	Lookup status, indicating if the address was found or an error occurred. • 0 = found, AR.EUI-48 valid; • 1 = unknown, AR.EUI-48 undefined.

The lookup may fail if the requested address has not been registered. In that case, AR.Status will have a value other than zero and the contents of AR.EUI-48 will be undefined. The lookup is only successful when AR.Status is zero. In that case, the EUI-48 field contains the resolved address.

5.4.7.2.8 AR_MCAST_REG_S

Table 76 shows the multicast address resolution register message sent from the Service Node to the Base Node.

Table 76 - AR_MCAST_REG_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_MCAST_REG_S = 8.
AR.IPv4	32-bits	IPv4 multicast address to be registered.

5.4.7.2.9 AR_MCAST_REG_B

Table 77 shows the multicast address resolution register acknowledgment message sent from the Base Node to the Service Node.

Table 77 - AR_MCAST_REG_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_MCAST_REG_B = 9.
AR.IPv4	32-bits	IPv4 multicast address registered.
Reserved	2-bits	Reserved. Should be encoded as 0.
AR.LCID	6-bits	LCID assigned to this IPv4 multicast address.

The AR.IPv4 field is included in the AR_MCAST_REG_B message so that the Service Node can perform multiple overlapping registrations.

5.4.7.2.10 AR_MCAST_UNREG_S

Table 78 shows the multicast address resolution unregister message sent from the Service Node to the Base Node.

Table 78 - AR_MCAST_UNREG_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_MCAST_UNREG_S = 10.
AR.IPv4	32-bits	IPv4 multicast address to be unregistered.

5.4.7.2.11 AR_MCAST_UNREG_B

Table 79 shows the multicast address resolution unregister acknowledgment message sent from the Base Node to the Service Node.

Table 79 - AR_MCAST_UNREG_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type. • For AR_MCAST_UNREG_B = 11;
AR.IPv4	32-bits	IPv4 multicast address unregistered.

The AR.IPv4 field is included in the AR_MCAST_UNREG_B message so that the Service Node can perform multiple overlapping Unregistrations.

5.4.7.3 IPv4 packet format

5.4.7.3.1 General

The following PDU formats are used for transferring IPv4 packets between Service Nodes. Two formats are defined. The first format is for when header compression is not used. The second format is for Van Jacobson Header Compression.

5.4.7.3.2 IPv4 Packet Format, No Negotiated Header Compression

When no header compression has been negotiated, the IPv4 packet is simply sent as is, without any header.

Table 80 - IPv4 Packet format without negotiated header compression

Name	Length	Description
IPv4.PKT	n-octets	The IPv4 Packet.

5.4.7.3.3 IPv4 Packet Format with VJ Header Compression

With Van Jacobsen header compression, a one-octet header is needed before the IPv4 packet.

Table 81 - IPv4 Packet format with VJ header compression negotiated

Name	Length	Description
IPv4.Type	2-bits	Type of compressed packet. • IPv4.Type = 0 – TYPE_IP; • IPv4.Type = 1 – UNCOMPRESSED_TCP; • IPv4.Type = 2 – COMPRESSED_TCP; • IPv4.Type = 3 – TYPE_ERROR.
IPv4.Seq	6-bits	Packet sequence number.
IPv4.PKT	n-octets	The IPv4 Packet.

The IPv4.Type value TYPE_ERROR is never sent. It is a pseudo packet type used to tell the decompressor that a packet has been lost.

5.4.7.4 Connection Data

5.4.7.4.1 General

When a connection is established between Service Nodes for the transfer of IPv4 packets, data is also transferred in the connection request packets. This data allows the negotiation of compression and notification of the IPv4 address.

5.4.7.4.2 Connection Data from the Initiator

Table 82 shows the connection data sent by the initiator.

Table 82 - Connection data sent by the initiator

Name	Length	Description
Reserved	6-bits	Should be encoded as 0 in this version of the IPV4 SSCS protocol.
Data.HC	2-bit	Header Compression . • Data.HC = 0 – No compression requested; • Data.HC = 1 – VJ Compression requested; • Data.HC = 2, 3 – Reserved for future versions of the specification.
Data.IPv4	32-bits	IPv4 address of the initiator

If the device accepts the connection, it should copy the Data.IPv4 address into a new table entry along with the negotiated Data.HC value.

5.4.7.4.3 Connection Data from the Responder

Table 83 shows the connection data sent in response to the connection request.

Table 83 - Connection data sent by the responder

Name	Length	Description
Reserved	6-bits	Should be encoded as zero in this version of the IPV4 SSCS protocol.
Data.HC	2-bit	Header Compression negotiated. • Data.HC = 0 – No compression permitted; • Data.HC = 1 – VJ Compression negotiated; • Data.HC = 2,3 – Reserved.

A header compression scheme can only be used when it is supported by both Service Nodes. The responder may only set Data.HC to 0 or the same value as that received from the initiator. When the same value is used, it indicates that the requested compression scheme has been negotiated and will be used for the connection.

Setting Data.HC to 0 allows the responder to deny the request for that header compression scheme or force the use of no header compression.

5.4.8 Service Access Point

5.4.8.1 General

This section defines the service access point used by the IPv4 layer to communicate with the IPV4 SSCS.

5.4.8.2 Opening and closing the IPv4 SSCS

5.4.8.2.1 General

The following primitives are used to open and close the IPv4 SSCS. The IPv4 SSCS may be opened once only. The IPv4 layer may close the IPv4 SSCS when the IPv4 interface is brought down. The IPv4 SSCS will also close the IPv4 SSCS when the underlying MAC connection to the Base Node has been lost.

5.4.8.2.2 CL_IPv4_ESTABLISH.request

The CL_IPv4_ESTABLISH.request primitive is passed from the IPv4 layer to the IPV4 SSCS. It is used when the IPv4 layer brings the interface up.

The semantics of this primitive are as follows:

CL_IPv4_ESTABLISH.request{AE}

The AE parameter indicates whether the interface will be authenticated and encrypted or not.

On receiving this primitive, the IPV4 SSCS will form the address resolution connection to the Base Node and join the broadcast group used for receiving/transmitting broadcast packets.

5.4.8.2.3 CL_IPv4_ESTABLISH.confirm

The CL_IPv4_ESTABLISH.confirm primitive is passed from the IPV4 SSCS to the IPv4 layer. It is used to indicate that the IPv4 SSCS is ready to access IPv4 packets to be sent to peers.

The semantics of this primitive are as follows:

CL_IPv4_ESTABLISH.confirm{AE}

The AE parameter indicates whether the interface will be authenticated and encrypted or not.

Once the IPv4 SSCS has established all the necessary connections and is ready to transmit and receive IPv4 packets, this primitive is passed to the IPv4 layer. If the IPV4 SSCS encounters an error while opening, it responds with a CL_IPv4_RELEASE.confirm primitive, rather than a CL_IPv4_ESTABLISH.confirm.

5.4.8.2.4 CL_IPv4_RELEASE.request

The CL_IPv4_RELEASE.request primitive is used by the IPv4 layer when the interface is put down. The IPV4 SSCS closes all connections so that no more IPv4 packets are received and all resources are released.

The semantics of this primitive are as follows:

CL_IPv4_RELEASE.request{}

Once the IPV4 SSCS has released all its connections and resources it returns a CL_IPv4_RELEASE.confirm.

5.4.8.2.5 CL_IPv4_RELEASE.confirm

The CL_IPv4_RELEASE.confirm primitive is used by the IPv4 SSCS to indicate to the IPv4 layer that the IPv4 SSCS has been closed. This can be as a result of a CL_IPv4_RELEASE.request primitive, a CL_IPv4_ESTABLISH.request primitive, or because the MAC layer indicates the address resolution connection has been lost, or the Service Node itself is no longer registered.

The semantics of this primitive are as follows:

CL_IPv4_RELEASE.confirm{result}

The result parameter has the meanings defined in Table 151.

5.4.8.3 Unicast address management

5.4.8.3.1 General

The primitives defined here are used for address management, i.e. the registration and Unregistration of IPv4 addresses associated with this IPv4 SSCS .

When there are no IPv4 addresses associated with the IPv4 SSCS, the IPv4 SSCS will only send and receive broadcast and multicast packets; unicast packets may not be sent. However, this is sufficient for BOOTP/DHCP operation to allow the device to gain an IPv4 address. Once an IPv4 address has been registered, the IPv4 layer can transmit unicast packets that have a source address equal to one of its registered addresses.

5.4.8.3.2 CL_IPv4_REGISTER.request

This primitive is passed from the IPv4 layer to the IPv4 SSCS to register an IPv4 address.

The semantics of this primitive are as follows:

CL_IPv4_REGISTER.request{IPv4, netmask, gateway}

The IPv4 address is the address to be registered.

The netmask is the network mask, used to mask the network number from the address. The netmask is used by the IPv4 SSCS to determine whether the packet should be delivered directly or the gateway should be used.

The gateway is an IPv4 address of the gateway to be used for packets with the IPv4 local address but the destination address is not in the same Subnetwork as the local address.

Once the IPv4 address has been registered to the Base Node, a CL_IPv4_REGISTER.confirm primitive is used. If the registration fails, the CL_IPv4_RELEASE.confirm primitive will be used.

5.4.8.3.3 CL_IPv4_REGISTER.confirm

This primitive is passed from the IPv4 SSCS to the IPv4 layer to indicate that a registration has been successful.

The semantics of this primitive are as follows:

CL_IPv4_REGISTER.confirm{IPv4}

The IPv4 address is the address that was registered.

Once registration has been completed, the IPv4 layer may send IPv4 packets using this source address.

5.4.8.3.4 CL_IPv4_UNREGISTER.request

This primitive is passed from the IPv4 layer to the IPv4 SSCS to unregister an IPv4 address.

The semantics of this primitive are as follows:

CL_IPv4_UNREGISTER.request{IPv4}

The IPv4 address is the address to be unregistered.

Once the IPv4 address has been unregistered to the Base Node, a CL_IPv4_UNREGISTER.confirm primitive is used. If the unregistration fails, the CL_IPv4_RELEASE.confirm primitive will be used.

5.4.8.3.5 CL_IPv4_UNREGISTER.confirm

This primitive is passed from the IPv4 SSCS to the IPv4 layer to indicate that an Unregistration has been successful.

The semantics of this primitive are as follows:

CL_IPv4_UNREGISTER.confirm{IPv4}

The IPv4 address is the address that was unregistered.

Once Unregistration has been completed, the IPv4 layer may not send IPv4 packets using this source address.

5.4.8.4 Multicast group management

5.4.8.4.1 General

This section describes the primitives used to manage multicast groups.

5.4.8.4.2 CL_IPv4_IGMP_JOIN.request

This primitive is passed from the IPv4 layer to the IPv4 SSCS. It contains an IPv4 multicast address that is to be joined.

The semantics of this primitive are as follows:

CL_IPv4_IGMP_JOIN.request{IPv4, AE }

The IPv4 address is the IPv4 multicast group that is to be joined.

The AE parameter indicates whether messages in this group will be authenticated and encrypted or not.

When the IPv4 SSCS receives this primitive, it will arrange for IPv4 packets sent to this group to be multicast in the PRIME network and receive packets using this address to be passed to the IPv4 stack. If the IPv4 SSCS cannot join the group, it uses the CL_IPv4_IGMP_LEAVE.confirm primitive. Otherwise the CL_IPv4_IGMP_JOIN.confirm primitive is used to indicate success.

5.4.8.4.3 CL_IPv4_IGMP_JOIN.confirm

This primitive is passed from the IPv4 SSCS to the IPv4. It contains a result status and an IPv4 multicast address that was joined.

The semantics of this primitive are as follows:

CL_IPv4_IGMP_JOIN.confirm{IPv4, AE }

The IPv4 address is the IPv4 multicast group that was joined. The IPv4 SSCS will start forwarding IPv4 multicast packets for the given multicast group.

The AE parameter indicates whether messages in this group will be authenticated and encrypted or not.

5.4.8.4.4 CL_IPv4_IGMP_LEAVE.request

This primitive is passed from the IPv4 layer to the IPv4 SSCS. It contains an IPv4 multicast address to be left.

The semantics of this primitive are as follows:

CL_IPv4_IGMP_LEAVE.request{IPv4}

The IPv4 address is the IPv4 multicast group to be left. The IPv4 SSCS will stop forwarding IPv4 multicast packets for this group and may leave the PRIME MAC multicast group.

5.4.8.4.5 CL_IPv4_IGMP_LEAVE.confirm

This primitive is passed from the IPv4 SSCS to the IPv4. It contains a result status and an IPv4 multicast address that was left.

The semantics of this primitive are as follows:

CL_IPv4_IGMP_LEAVE.confirm{IPv4, Result}

The IPv4 address is the IPv4 multicast group that was left. The IPv4 SSCS will stop forwarding IPv4 multicast packets for the given multicast group.

The Result takes a value from Table 151.

This primitive can be used by the IPv4 SSCS as a result of a CL_IPv4_IGMP_JOIN.request, CL_IPv4_IGMP_LEAVE.request or because of an error condition resulting in the loss of the PRIME MAC multicast connection.

5.4.8.5 Data transfer

5.4.8.5.1 General

The following primitives are used to send and receive IPv4 packets.

5.4.8.5.2 CL_IPv4_DATA.request

This primitive is passed from the IPv4 layer to the IPv4 SSCS. It contains one IPv4 packet to be sent.

The semantics of this primitive are as follows:

CL_IPv4_DATA.request{IPv4_PDU}

The IPv4_PDU is the IPv4 packet to be sent.

5.4.8.5.3 CL_IPv4_DATA.confirm

This primitive is passed from the IPv4 SSCS to the IPv4 layer. It contains a status indication and an IPv4 packet that has just been sent.

The semantics of this primitive are as follows:

CL_IPv4_DATA.confirm{IPv4_PDU, Result}

The IPv4_PDU is the IPv4 packet that was to be sent.

The Result value indicates whether the packet was sent or an error occurred. It takes a value from Table 151.

5.4.8.5.4 CL_IPv4_DATA.indicate

This primitive is passed from the IPv4 SSCS to the IPv4 layer. It contains an IPv4 packet that has just been received.

The semantics of this primitive are as follows:

CL_IPv4_DATA.indicate{IPv4_PDU }

The IPv4_PDU is the IPv4 packet that was received.

5.5 IEC 61334-4-32 Service-Specific Convergence Sublayer (IEC 61334-4-32 SSCS)

5.5.1 General

For all the service required, the IEC 61334-4-32 SSCS supports the DL_DATA primitives as defined in the IEC 61334-4-32 standard. IEC 61334-4-32 should be read at the same time as this section, which is not standalone text.

5.5.2 Overview

The IEC 61334-4-32 SSCS provides convergence functions for applications that use IEC 61334-4-32 services. Implementations conforming to this SSCS shall offer all LLC basic and management services as specified in IEC 61334-4-32 (1996-09 Edition), subsections 2.2.1 and 2.2.3. Additionally, the IEC 61334-4-32 SSCS specified in this section provides extra services that help mapping this connection-less IEC 61334-4-32 LLC protocol to the connection-oriented nature of MAC.

- A Service Node can only exchange data with the Base Node and not with other Service Nodes. This meets all the requirements of IEC 61334-4-32, which has similar restrictions.
- Each IEC 61334-4-32 SSCS session establishes a dedicated PRIME MAC connection for exchanging unicast data with the Base Node.
- The Service Node SSCS session is responsible for initiating this connection to the Base Node. The Base Node SSCS cannot initiate a connection to a Service Node.
- Each IEC 61334-4-32 SSCS listens to a PRIME broadcast MAC connection dedicated to the transfer of IEC 61334-4-32 broadcast data from the Base Node to the Service Nodes. This broadcast connection is used when applications in the Base Node using IEC 61334-4-32 services make a transmission request with the Destination_address used for broadcast or the broadcast SAP functions are used. When there are multiple SSCS sessions within a Service Node, one PRIME broadcast MAC connection is shared by all the SSCS sessions.
- A CPCS session is always present with a IEC 61334-4-32 SSCS session. The SPCS sublayer functionality is as specified in Section 5.2.2. Thus, the MSDUs generated by IEC 61334-4-32 SSCS are always less than *macSARSize* bytes and application messages shall not be longer than *ClMaxAppPktSize*.

5.5.3 Address allocation and connection establishment

Each 4-32 connection will be identified with the "Application unique identifier" that will be communicating through this 4-32 connection. It is the scope of the communication profile based on these lower layers to define the nature and rules for, this unique identifier. Please refer to the future prTS/EN52056-8-4 for the DLMS/COSEM profile unique identifier. As long as the specification of the 4-32 Convergence layer concerns this identifier will be called the "Device Identifier".

The protocol stack as defined in IEC 61334 defines a Destination address to identify each device in the network. This Destination address is specified beyond the scope of the IEC 61334-4-32 document. However, it is used by the document. So that PRIME devices can make use of the 4-32 layer, this Destination address is also required and is specified here. For more information about this Destination address, please see IEC 61334-4-1 section 4.3, MAC Addresses.

The Destination address has a scope of one PRIME Subnetwork. The Base Node 4-32 SSCP layer is responsible for allocating these addresses dynamically and associating the Device Identifier of the Service Nodes SSCP session device with the allocated Destination address, according to the IEC-61334-4-1 standard. The procedure is as follows:

When the Service Node IEC 61334-4-32 SSCS session is opened by the application layer, it passes the Device Identifier of the device. The IEC 61334-4-32 SSCS session then establishes its unicast connection to the Base Node. This unicast connection uses the PRIME MAC TYPE value TYPE_CL_432, as defined in Table 149. The connection request packet sent from the Service Node to the Base Node contains a data parameter. This data parameter contains the Device Identifier. The format of this data is specified in section 5.5.4.2.

On receiving this connection request at the Base Node, the Base Node allocates a unique Subnetwork Destination address to the Service Nodes SSCS session. The Base Node sends back a PRIME MAC connection response packet that contains a data parameter. This data parameter contains the allocated Destination address and the address being used by the Base Node itself. The format of this data parameter is defined in section 5.5.4.2. A 4-32 CL SAP primitive is used in the Base Node to indicate this new Service Node SSCS session mapping of Device Identifier and Destination_address to the 4-32 application running in the Base Node.

On receiving the connection establishment and the Destination_address passed in the PRIME MAC connection establishment packet, the 4-32 SSCS session confirms to the application that the Convergence layer session has been opened and indicates the Destination_address allocated to the Service Node SSCS session and the address of the Base Node. The Service Node also opens a PRIME MAC broadcast connection with LCID equal to LCI_CL_432_BROADCAST, as defined in Table 150, if no other SSCS session has already opened such a broadcast connection. This connection is used to receive broadcast packets sent by the Base Node 4-32 Convergence layer to all Service Node 4-32 Convergence layer sessions.

If the Base Node has allocated all its available Destination_addresses, due to the exhaustion of the address space or implementation limits, it should simply reject the connection request from the Service Node. The Service Node may try to establish the connection again. However, to avoid overloading the PRIME Subnetwork with such requests, it should limit such connection establishments to one attempt per minute when the Base Node rejects a connection establishment.

When the unicast connection between a Service Node and the Base Node is closed (e.g. because the Convergence layer on the Service Node is closed or the PRIME MAC level connection between the Service Node and the Base Node is lost), the Base Node will deallocate the Destination_address allocated to the Service Node SSCS session. The Base Node will use a 4-32 CL SAP (CL_432_Leave.indication) primitive to indicate the deallocation of the Destination_address to the 4-32 application running on the Base Node

5.5.4 Connection establishment data format

5.5.4.1 General

As described in section 5.5.3, the MAC PRIME connection data is used to transfer the Device Identifier to the Base Node and the allocated Destination_address to the Service Node SSCS session. This section describes the format used for this data.

5.5.4.2 Service Node to Base Node

The Service Node session passes the Device Identifier to the Base Node as part of the connection establishment request. The format of this message is shown in Table 84.

Table 84 - Connection Data sent by the Service Node

Name	Length	Description
Data.SN	n-Octets	Device Identifier. “COSEM logical device name" of the "Management logical device" of the DLMS/COSEM device as specified in the DLMS/COSEM, which will be communicating through this 4-32 connection.

5.5.4.3 Base Node to Service Node

The Base Node passes the allocated Destination_address to the Service Node session as part of the connection establishment request. It also gives its own address to the Service Node. The format of this message is shown in Table 85.

Table 85 - Connection Data sent by the Base Node

Name	Length	Description
Reserved	4-bits	Reserved. Should be encoded as zero in this version of the specification.
Data.DA	12-bits	Destination_address allocated to the Service Node.
Reserved	4-bits	Reserved. Should be encoded as zero in this version of the specification.
Data.BA	12-bits	Base_address used by the Base Node.

5.5.5 Packet format

The packet formats are used as defined in IEC 61334-4-32, Clause 4, LLC Protocol Data Unit Structure (LLC_PDU).

5.5.6 Service Access Point

5.5.6.1 Opening and closing the Convergence layer at the Service Node

5.5.6.1.1 CL_432_ESTABLISH.request

This primitive is passed from the application to the 4-32 Convergence layer. It is used to open a Convergence layer session and initiate the process of registering the Device Identifier with the Base Node and the Base Node allocating a Destination_address to the Service Node session.

The semantics of this primitive are as follows:

CL_432_ESTABLISH.request{ DeviceIdentifier, AE }

The Device Identifier is that of the device to be registered with the Base Node.

The AE parameter indicates whether the session will be authenticated and encrypted or not.

If the Device Identifier is registered and the Convergence layer session is successfully opened, the primitive CL_432_ESTABLISH.confirm is used. If an error occurs the primitive CL_432_RELEASE.confirm is used.

5.5.6.1.2 CL_432_ESTABLISH.confirm

This primitive is passed from the 4-32 Convergence layer to the application. It is used to confirm the successful opening of the Convergence layer session and that data may now be passed over the Convergence layer.

The semantics of this primitive are as follows:

CL_432_ESTABLISH.confirm{ DeviceIdentifier, Destination_address, Base_address, AE }

The Device Identifier is used to identify which CL_432_ESTABLISH.request this CL_432_ESTABLISH.confirm is for.

The Destination_address is the address allocated to the Service Node 4-32 session by the Base Node.

The Base_address is the address being used by the Base Node.

The AE parameter indicates whether the session will be authenticated and encrypted or not.

5.5.6.1.3 CL_432_RELEASE.request

This primitive is passed from the application to the 4-32 Convergence layer. It is used to close the Convergence layer and release any resources it may be holding.

The semantics of this primitive are as follows:

CL_432_RELEASE.request{Destination_address}

The Destination_address is the address allocated to the Service Node 4-32 session which is to be closed.

The Convergence layer will use the primitive CL_432_RELEASE.confirm when the Convergence layer session has been closed.

5.5.6.1.4 CL_432_RELEASE.confirm

This primitive is passed from the 4-32 Convergence layer to the application. The primitive tells the application that the Convergence layer session has been closed. This could be because of a CL_432_RELEASE.request or because an error has occurred, forcing the closure of the Convergence layer session.

The semantics of this primitive are as follows:

CL_432_RELEASE.confirm{Destination_address, result}

The Handle identifies the session which has been closed.

The result parameter has the meanings defined in Table 151.

5.5.6.2 Opening and closing the Convergence layer at the Base Node

No service access point primitives are defined at the Base Node for opening or closing the Convergence layer. None are required since the 4-32 application in the Base Node does not need to pass any information to the 4-32 Convergence layer in the Base Node.

5.5.6.3 Base Node indications

5.5.6.3.1 General

The following primitives are used in the Base Node 4-32 Convergence layer to indicate events to the 4-32 application in the Base Node. They indicate when a Service Node session has joined or left the network.

5.5.6.3.2 CL_432_JOIN.indicate

CL_432_JOIN.indicate{ Device Identifier, Destination_address, AE}

The Device Identifier is that of the device connected to the Service Node that has just joined the network.

The Destination_address is the address allocated to the Service Node by the Base Node.

The AE parameter indicates whether messages in this session will be authenticated and encrypted or not.

5.5.6.3.3 CL_432_LEAVE.indicate

CL_432_LEAVE.indicate{Destination_address}

The Destination_address is the address of the Service Node session that just left the network.

5.5.6.4 Data Transfer Primitives

The data transfer primitives are used as defined in IEC 61334-4-32, sections 2.2, 2.3, 2.4 and 2.11, LLC Service Specification. As stated earlier, PRIME 432 SSCS make the use of IEC61334-4-32 DL_Data service (.req, .conf, .ind) for carrying out all the data involved during data transfer. Only DL_DATA service is mandatory

5.6 IPv6 Service-Specific Convergence Sublayer (IPv6 SSCS)

5.6.1 Overview

5.6.1.1 General

The IPv6 convergence layer provides an efficient method for transferring IPv6 packets over the PRIME network.

A Service Node can pass IPv6 packets to the Base Node or directly to other Service Nodes.

By default, the Base Node acts as a router between the PRIME subnet and the backbone network. All the Base Nodes must have at least this connectivity capability. Any other node inside the Subnetwork can also act as a gateway. The Base Node could also act as a NAT router. However given the abundance of IPv6 addresses this is not expected. How the Base Node connects to the backbone is beyond the scope of this standard.

5.6.1.2 IPv6 unicast addressing assignment

- IPv6 Service Nodes (and Base Nodes) shall support the standard IPv6 protocol, as described in RFC 2460.
- IPv6 Service Nodes (and Base Nodes) shall support the standard IPv6 addressing architecture, as described in RFC 4291.
- IPv6 Service Nodes (and Base Nodes) shall support global unicast IPv6 addresses, link-local IPv6 addresses and multicast IPv6 addresses, as described in RFC 4291.
- IPv6 Service Nodes (and Base Nodes) shall support automatic address configuration using stateless address configuration [RFC 2462]. They may also support automatic address

configuration using stateful address configuration [RFC 3315] and they may support manual configuration of IPv6 addresses. The decision of which address configuration scheme to use is deployment specific.

- Service Node shall support DHCPv6 client, when Base Nodes have to support DHCPv6 server as described in RFC 3315 for stateless address configuration

5.6.1.3 Address management in PRIME Subnetwork

Packets are routed in PRIME Subnetwork according to the node identifier NID. Node identifier is a combination of Service Node's LNID and SID (see section 4.2). The Base Node is responsible of assigning LNID to Service Nodes. During the registration process which leads to a LNID assignment to the related Service Node, the Base Node registers the Service Node EUI-48, and the assigned LNID together with SID.

At the convergence layer level, addressing is performed using the EUI-48 of the related Service Node. The role of the convergence sublayer is to resolve the IPv6 address into EUI-48 of the Service Node. This is done using the address resolution service set of the Base Node.

5.6.1.4 Role of the Base Node

At the convergence sublayer level, the Base Node maintains a table containing all the IPv6 unicast addresses and the EUI-48 related to them. One of the roles of the Base Node is to perform IPv6 to EUI-48 address resolution. Each Service Node belonging to the Subnetwork managed by the Base Node, registers its IPv6 address and EUI-48 address with the Base Node. Other Service Nodes can then query the Base Node to resolve an IPv6 address into a EUI-48 address. This requires the establishment of a dedicated connection to the Base Node for address resolution, which is shared by both IPv4 and IPv6 address resolution.

Optionally UDP/IPv6 headers may be compressed. Currently one header compression technique is described in the present specification that used for transmission of IPv6 packets over IEEE 802.15.4 networks, as defined in RFC6282. This is also known as LOWPAN_IPHC1.

The multicasting of IPv6 packets is supported using the MAC multicast mechanism

5.6.2 IPv6 Convergence layer

5.6.2.1 Overview

5.6.2.1.1 General

The convergence layer has a number of connection types. For address resolution there is a connection to the Base Node. For IPv6 data transfer there are one up to many connections per destination node, depending on how many source's and destination's IPv6 addresses are in use. This is shown in Figure 135.

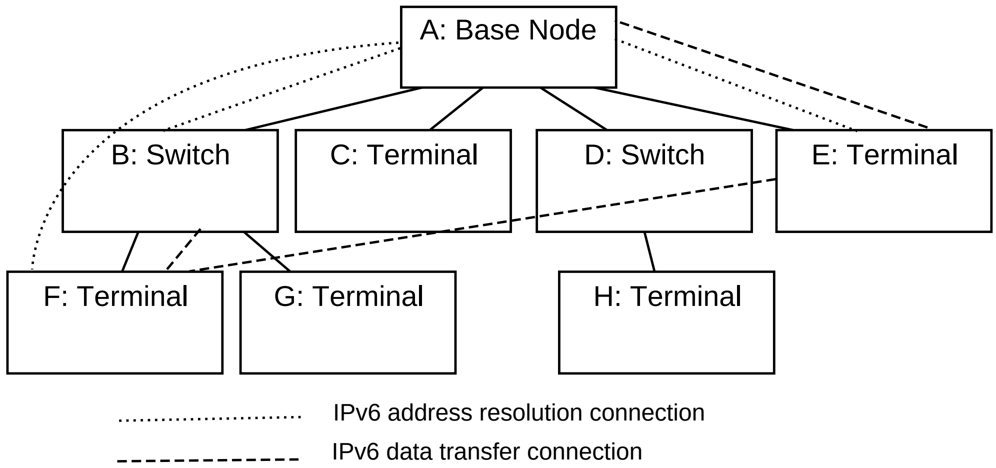


Figure 135 - IPv6 SSCS connection example

Here, nodes B, E and F have address resolution connections to the Base Node. Node E has a data connection to the Base Node and node F. Node F is also has a data connection to node B. The figure does not show broadcast-traffic and multicast-traffic connections.

5.6.2.1.2 Routing in the Subnetwork

Routing IPv6 packets is the scope of the Convergence layer. In other words, the convergence layer will decide whether the packet should be sent directly to another Service Node or forwarded to the configured gateway depending on the IPv6 destination address.

Although IPv6 is a connectionless protocol, the IPv6 convergence layer is connection-oriented. Once address resolution has been performed, a connection is established between the source and destination Service Nodes for the transfer of IP packets. This connection is maintained all the time the traffic is being transferred and may be removed after a period of inactivity.

5.6.2.1.3 SAR

The CPCS sublayer shall always be present with the IPv6 convergence layer allowing segmentation and reassembly facilities. The SAR sublayer functionality is given in Section 5.2. Thus, the MSDUs generated by the IPv6 convergence layer are always less than macSARSize bytes and application messages are expected to be no longer than ClMaxAppPktSize.

5.6.3 IPv6 Address Configuration

5.6.3.1 Overview

The Service Nodes may use statically configured IPv6 addresses, link local addresses, stateless or stateful auto-configuration according to RFC 2462, or DHCPv6 to obtain IPv6 addresses. All the Nodes shall support the unicast link local address, in addition with at least one other address from those described below, and multicast addresses, if ever the node belong to multicast groups.

5.6.3.2 Interface identifier

In order to make use of stateless address auto configuration and link local addresses it is necessary to define how the Interface identifier, as defined in RFC4291, is derived. Each PRIME node has a unique EUI-48. This

EUI-48 is converted into a EUI-64 in the same way as for Ethernet networks as defined in RFC2464. This EUI-64 is then used as the Interface Identifier.

5.6.3.3 IPv6 Link local address configuration

The IPv6 Link local address of a PRIME interface is formed by appending the Interface Identifier as defined above to the Prefix FE80::/64.

5.6.3.4 Stateless address configuration

An IPv6 address prefix used for stateless auto configuration, as defined in RFC4862, of a PRIME interface shall have a length of 64 bits. The IPv6 prefix is obtained by the Service Nodes from the Base Node via Router Advertisement messages (RFC 4861), which are send periodically or on request by the Base Node.

5.6.3.5 Stateful address configuration

An IPv6 address can be alternatively configured using DHCPv6, as described in RFC 3315. DHCPv6 can provide a device with addresses assigned by a DHCPv6 server and other configuration information, which are carried in options.

5.6.3.6 Multicast address

IPv6 Service Nodes (and Base Nodes) shall support the multicast IPv6 addressing, as described in RFC 4291 section 2.7.

5.6.3.7 Address resolution

5.6.3.7.1 Overview

The IPv6 layer will present the convergence layer with an IPv6 packet to be transferred. The convergence layer is responsible for determining which Service Node the packet should be delivered to, using the IPv6 addresses in the packet. The convergence layer shall then establish a connection to the destination if one does not already exist so that the packet can be transferred. Two classes of IPv6 addresses can be used and the following section describes how these addresses are resolved into PRIME EUI-48 addresses. It should be noted that IPv6 does not have a broadcast address. However broadcasting is possible using multicast all nodes addresses.

5.6.3.7.2 Unicast address

5.6.3.7.2.1 General

IPv6 unicast addresses shall be resolved into PRIME unicast EUI-48 addresses. The Base Node maintains a central database Node of IPv6 addresses and EUI-48 addresses. Address resolution functions are performed by querying this database. The Service Node shall establish a connection to the address resolution service running on the Base Node, using the TYPE value TYPE_CL_IPv6_AR. No data should be passed in the connection establishment. Using this connection, the Service Node can use two mechanisms as defined in the present specification.

5.6.3.7.2.2 Address registration and deregistration

A Service Node uses the AR_REGISTERv6_S message to register an IPv6 address and the corresponding EUI-48 address. The Base Node will acknowledge an AR_REGISTERv6_B message. The Service Node may register multiple IPv6 addresses for the same EUI-48.

A Service Node uses the AR_UNREGISTERv6_S message to unregister an IPv6 address and the corresponding EUI-48 address. The Base Node will acknowledge with an AR_UNREGISTERv6_B message.

When the address resolution connection between the Service Node and the Base Node is closed, the Base Node should remove all addresses associated with that connection.

5.6.3.7.2.3 Address lookup

A Service Node uses the AR_LOOKUPv6_S message to perform a lookup. The message contains the IPv6 address to be resolved. The Base Node will respond with an AR_LOOKUPv6_B message that contains an error code and, if there is no error, the EUI-48 associated with the IPv6 address. If the Base Node has multiple entries in its database Node for the same IPv6 address, the possible EUI-48 returned is undefined.

It should be noted that, for the link local addresses, due to the fact that the EUI-48 can be obtained from the IPv6 address, the lookup can simply return this value by extracting it from the IPv6 address.

5.6.3.7.3 Multicast address

Multicast IPv6 addresses are mapped to connection handles (ConnHandle) by the Convergence Layer (see Table 87).

5.6.3.7.4 Retransmission of address resolution packets

The connection between the Service Node and the Base Node for address resolution is not reliable. The MAC ARQ is not used. The Service Node is responsible for making retransmissions if the Base Node does not respond in one second. It is not considered an error when the Base Node receives the same registration requests multiple times or is asked to remove a registration that does not exist. These conditions can be the result of retransmissions.

5.6.4 IPv6 Packet Transfer

5.6.4.1 Unicast transfer

5.6.4.1.1 Gateway info

The two endopoints exchanging unicast IPv6 datagrams may both be placed within a PRIME network, or one of them can be outside. In the latter case a PRIME node shall act as gateway to route the IPv6 traffic in and out the PRIME network. It shall take 6LoWPAN encoded outgoing datagrams and reconstruct the full IPv6 counterparts before sending them to the outside; and, viceversa, it shall take incoming IPv6 datagrams and 6LoWPAN encoding them before injecting them into the PRIME network.

The IPv6 layer registers its addresses using the primitive CL_IPv6_Register.request (5.6.9.3.2). For each one, the subnet mask and the gateway IPv6 address are provided. As soon as the address registration (5.6.4.1.2) to the BN is successful, the SSCS must store these info in an internal table like the one in Table 86.

Table 86 – Node addresses table entry

Parameter	Description
CL_IPv6_Addr.Local_IP	Node's registered IPv6 address.
CL_IPv6_Addr.Subnet_Mask	Subnet mask of the IPv6 subnetwork the node IPv6 address belongs to.
CL_IPv6_Addr.Gateway_IP	IPv6 address of the subnet's gateway.

5.6.4.1.2 Both endpoints in the same PRIME network

For packets to be transferred, a connection needs to be established between the source and destination nodes. Considering that any node may be given with one to many IPv6 addresses, a different connection shall be established between two IPv6-communicating PRIME nodes for each pair of their IPv6 addresses exchanging datagrams. The IPv6 convergence layer will examine each IP packet to determine pair of source and destination IPv6 addresses. By matching the destination IPv6 address against the subnet mask stored in Table 86 for the datagram's source IPv6 address, the SSCS determines that both endpoints are two PRIME nodes in the same PRIME network:

source IPv6 addr & CL_IPv6_Addr.Subnet_Mask == destination IPv6 addr & CL_IPv6_Addr.Subnet_Mask

If a connection between PRIME nodes owning these addresses has already been established by the SSCS, the packet is simply sent over that connection. To verify this, the convergence layer keeps a table for each connection it has with information shown in Table 87.

Table 87– IPv6 convergence layer table entry

Parameter	Description
CL_IPv6_Con.Local_IP	Local IP address of this connection
CL_IPv6_Con.Remote_IP	Remote IP address of this connection
CL_IPv6_Con.ConHandle	MAC Connection handle for the connection
CL_IPv6_Con.LastUsed	Timestamp of last packet received/transmitted
CL_IPv6_Con	Header Compression scheme being used

The convergence layer may close a connection when it has not been used for an implementation-defined time period. When the connection is closed the entry for the connection is removed at both ends of the connection.

When a connection to the destination does not exist, more work is necessary. The address resolution service is used to determine the EUI-48 address of the remote IP address. When the Base Node replies with the EUI-48 address of the destination Service Node, a MAC connection is established to the remote device. The TYPE value of this connection is TYPE_CL_IPv6_DATA. The data passed in the request message is defined in section 5.6.8.3. Both local source IP address and the destination remote IPv6 address are provided so that the remote device can properly set up its own IPv6 convergence layer table entry, thus adding the new connection to its cache of connections for sending data in the opposite direction. Once the connection has been established, the IP packet can be sent.

5.6.4.1.3 One endpoint outside the PRIME network

If the communication involves an endpoint external to the PRIME network, datagrams shall pass through a border PRIME node acting as the gateway. In this scenario a PRIME connection shall be established between the gateway and the PRIME node, and 6LoWPAN compressed datagrams shall be transmitted over it.

Following subsections cover the connection establishment and usage in the two possible scenarios, depending on which endpoint sends the first datagram.

5.6.4.1.3.1 Connection initiated by the PRIME endpoint

As for the PRIME internal data exchange (5.6.4.1.2), SSCS discovers whether the destination is outside the PRIME network by matching the destination IPv6 address against the netmask associated with the source IPv6 address in Table 86

source IPv6 addr & CL_IPv6_Addr.Subnet_Mask != destination IPv6 addr & CL_IPv6_Addr.Subnet_Mask

Once the gateway IPv6 address is retrieved from the Table 86's row of the source IPv6 address, SSCS looks up the addresses couple (source IPv6 address, gateway IPv6 address) in the Table 87 to get the connection ID with the gateway – if a connection has not been established yet, same procedures (address resolution, connection establishment and entry addition in Table 87) as with PRIME network internal communication (5.6.4.1.2) shall be undergone, using the gateway IPv6 address as the remote endpoint address. Once the connection ID is retrieved, the 6LoWPAN encoded version of the datagram shall be sent over it.

5.6.4.1.3.2 Connection initiated by the external endpoint

The SSCS discovers that the datagram is coming from the outside by failing at looking up the source IPv6 address in Table 86.

By scanning rows in Table 86, the SSCS finds the gateway IPv6 address the PRIME node owning the destination IPv6 address refers to. It is the IPv6 address stored in the table's entry for which the following relationship holds:

CL_IPv6_Addr. Gateway_IP & CL_IPv6_Addr.Subnet_Mask ==
destination IPv6 addr & CL_IPv6_Addr.Subnet_Mask

Once the gateway IPv6 address is retrieved, SSCS looks up the addresses couple (gateway IPv6 address, destination IPv6 address) in the Table 87to get the connection ID with the destination PRIME node – if a connection has not been established yet, same procedures (address resolution, connection establishment and entry addition in Table 87) as with PRIME network internal communication (5.6.4.1.2) shall be undergone, using the gateway IPv6 address as the local endpoint address. Once the connection ID is retrieved, the 6LoWPAN encoded version of the datagram shall be sent over it.

5.6.4.2 Multicast transfer

To join a multicast group, CL uses the MAC_JOIN.request primitive with the IPv6 address specified in the data field. A corresponding MAC_JOIN.Confirm primitive will be generated by the MAC after completion of the join process. The MAC_Join.Confirm primitive will contain the result (success/failure) and the corresponding ConnHandle to be used by the CL. The MAC layer will handle the transfer of data for this connection using the appropriate LCIDs. To leave the multicast group, the CL at the service node shall use the MAC-LEAVE.Request{ConnHandle} primitive.

To send an IPv6 multicast packet, the CL will simply send the packet to the group, using the allocated ConnHandle.

Table 88 – Ipv6 convergence layer multicast table entry

Parameter	Description
CL_Ipv6_Mul.Address	Multicast Ipv6 address for this connection
CL_Ipv6_Mul.ConHandle	MAC Connection handle for the connection

5.6.5 Segmentation and reassembly

The Ipv6 convergence layer should support Ipv6 packets with an MTU of at least 1500 bytes. This requires the use of the common part convergence sublayer segmentation and reassembly service.

5.6.6 Compression

Any PRIME device being compliant with this Service-Specific Convergence Sublayer shall be able to decode any valid 6LoWPAN encoded packet.

All the Service Nodes and the Base Node shall support IPv6 Header Compression using source and destination Addresses stateless compression as defined in RFC 6282. Source and destination IPv6 addresses using stateful compressionshall also be supported, but the way contexts are shared is outside the scope of this document.

As far as the stateless compression of either source address or unicast destination address is concerned, the 6LoWPAN implementation in this Service-Specific Convergence Sublayer shall allow following modes only (refer to RFC 6282 for fields' meaning):

- Full address is carried inline (e.g. no compression) (SAM=0b00 and/or DAM=0b00).
- Address is fully elided (SAM=0b11 and/or DAM=0b11).

Remaining two modes – address compressed down to 64 bits (SAM=0b01 and/or DAM=0b01) and down to 16 bits (SAM=0b10 and/or DAM=0b10) – are forbidden as PRIME own characteristics don't allow for such kind of compression. The full address compression (SAM=0b11 and/or DAM=0b11) is enabled by the information added in the Table 88 once the connection between the two is established. Such a table enables a direct mapping between the connection handle and the IPv6 addresses. When a node receives a PRIME packet, it uses its connection handle as table's lookup key: once found, it can retrieve both IPv6 source and destination addresses and hence restore them in the IPv6 datagram. If both IPv6 endopoints are in the same PRIME network, both their addresses may be fully compressed by the sender. When instead one node is outside the PRIME network, and hence the PRIME connection involves the gateway, the outer node's IPv6 address cannot be compressed, because such an address is not the one of the PRIME node being involved in the connection; in such a situation, only the IPv6 address of the PRIME endpoint can be fully elided.

5.6.7 Quality of Service Mapping

The PRIME MAC specifies that the contention-based access mechanism supports 4 priority levels (1-4). Level 1 is used for MAC control messages, but not exclusively so.

IPv6 packets include a Traffic Class field in the header to indicate the QoS the packet would like to receive. This traffic class can be used in the same way that IPv4 TOS (see [7]). That is, three bits of the TOS indicate the IP Precedence. The following table specifies how the IP Precedence is mapped into the PRIME MAC priority.

Table 89 – Mapping Ipv6 precedence to PRIME MAC priority

IP Precedence	MAC Priority
000 – Routine	3
001 – Priority	3
010 – Immediate	2
011 – Flash	2
100 – Flash Override	1
101 – Critical	1
110 – Internetwork Control	0
111 – Network Control	0

5.6.8 Packet formats and connection data

5.6.8.1 Overview

This section defines the format of convergence layer PDUs.

5.6.8.2 Address resolution PDU

5.6.8.2.1 General

The following PDUs are transferred over the address resolution connection between the Service Node and the Base Node. The following sections define a number of AR.MSG values. All other values are reserved for later versions of this standard.

5.6.8.2.2 AR_REGISTERv6_S

Table 90 shows the address resolution register message sent from the Service Node to the Base Node.

Table 90 - AR_REGISTERv6_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type • For AR_REGISTERv6_S = 16
AR.IPv6	128-bits	IPv6 address to be registered
AR.EUI-48	48-bits	EUI-48 to be registered

5.6.8.2.3 AR_REGISTERv6_B

Table 91 shows the address resolution register acknowledgment message sent from the Base Node to the Service Node.

Table 91 - AR_REGISTERv6_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type • For AR_REGISTERv6_B = 17
AR.IPv6	128-bits	IPv6 address registered
AR.EUI-48	48-bits	EUI-48 registered

The AR.IPv6 and AR.EUI-48 fields are included in the AR_REGISTERv6_B message so that the Service Node can perform multiple overlapping registrations.

5.6.8.2.4 AR_UNREGISTERv6_S

Table 92 shows the address resolution unregister message sent from the Service Node to the Base Node.

Table 92 - AR_UNREGISTERv6_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type • For AR_UNREGISTERv6_S = 18
AR.IPv6	128-bits	IPv6 address to be unregistered

AR.EUI-48	48-bits	EUI-48 to be unregistered

5.6.8.2.5 AR_UNREGISTERv6_B

Table 93 shows the address resolution unregister acknowledgment message sent from the Base Node to the Service Node.

Table 93 - AR_UNREGISTERv6_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type • For AR_UNREGISTERv6_B = 19
AR.IPv6	128-bits	IPv6 address unregistered
AR.EUI-48	48-bits	EUI-48 unregistered

The AR.IPv6 and AR.EUI-48 fields are included in the AR_UNREGISTERv6_B message so that the Service Node can perform multiple overlapping unregistrations.

5.6.8.2.6 AR_LOOKUPv6_S

Table 94 shows the address resolution lookup message sent from the Service Node to the Base Node.

Table 94 - AR_LOOKUPv6_S message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type • For AR_LOOKUPv6_S = 20
AR.IPv6	128-bits	IPv6 address to lookup

5.6.8.2.7 AR_LOOKUPv6_B

Table 95 shows the address resolution lookup response message sent from the Base Node to the Service Node.

Table 95 - AR_LOOKUPv6_B message format

Name	Length	Description
AR.MSG	8-bits	Address Resolution Message Type

		• For AR_LOOKUPv6_B = 21
AR.IPv6	128-bits	IPv6 address looked up
AR.EUI-48	48-bits	EUI-48 for IPv6 address
AR.Status	8-bits	Lookup status, indicating if the address was found or an error occurred. • 0 = found, AR.EUI-48 valid. • 1 = unknown, AR.EUI-48 undefined

The lookup may fail if the requested address has not been registered. In that case, AR.Status will have a value equal to 1, and the contents of AR.EUI-48 will be undefined. The lookup is only successful when AR.Status is zero. In that case, the EUI-48 field contains the resolved address.

5.6.8.3 IPv6 Packet format

5.6.8.3.1 General

The following PDU formats are used for transferring IPv6 packets between Service Nodes.

5.6.8.3.2 No header compression

When no header compression is used, the IP packet is simply sent as it is, without any header.

Table 96 - IPv6 Packet format without header compression

Name	Length	Description
IPv6.PKT	n-octets	The IPv6 Packet

5.6.8.3.3 Header compression

When LOWPAN_IPHC1 header compression is used, the UDP/IPv6 packet is sent as shown in Table 97.

Table 97 - UDP/IPv6 Packet format with LOWPAN_IPHC1 header compression and LOWPAN_NHC

Name	Length	Description
IPv6.IPHC	2-octet	Dispatch + LOWPAN_IPHC encoding. With bit 5=1 indicating that the next is compressed ,using LOWPAN_NHC format
IPv6.ncIPv6	n.m-octets	Non-Compressed IPv6 fields (or elided)
IPv6.HC_UDP	1-octet	Next header encoding

IPv6.ncUDP	n.m-octets	Non-Compressed UDP fields
Padding	0.m-octets	Padding to byte boundary
IPv6.DATA	n-octets	UDP data

Note that these fields are not necessarily aligned to byte boundaries. For example the IPv6.ncIPv6 field can be any number of bits. The IPv6.IPHC_UDP field follows directly afterwards, without any padding. Padding is only applied at the end of the complete compressed UDP/IPv6 header such that the UDP data is byte aligned.

When the IPv6 packet contains data other than UDP the following packet format is used as shown in Table 98.

Table 98 - IPv6 Packet format with LOWPAN_IPHC negotiated header compression

Name	Length	Description
IPv6.IPHC	2-octet	HC encoding. Bits 5 contain 0 indicating the next header byte is not compressed.
IPv6.ncIPv6	n.m-octets	Non-Compressed IPv6 fields
Padding	0.m-octets	Padding to byte boundary
IPv6.DATA	n-octets	IP Data

5.6.8.4 Connection data

5.6.8.4.1 Overview

When a connection is established between Service Nodes for the transfer of IP packets, data is also transferred in the connection request packets. This data allows the negotiation of compression and notification of the IP address.

5.6.8.4.2 Unicast connection data from the initiator

Table 99 shows the connection data sent by the initiator.

Table 99 - IPv6 Unicast connection data sent by the initiator

Name	Length	Description
Data.localIPv6	128-bits	Local IPv6 address
Data.remoteIPv6	128-bits	Remote IPv6 address

If the device accepts the connection, it should copy both Data.localIPv6 and Data.remoteIPv6 addresses into a new table entry , respectively in CL_IPv6_Con.Remote_IP and CL_IPv6_Con.Local_IP.

5.6.8.4.3 Unicast connection data from the responder

No information is carried in the response's CON.DATA field.

5.6.8.4.4 Multicast connection data from the initiator

Table 100 - IPv6 Multicast connection data sent by the initiator

Name	Length	Description
Data.IPv6	128-bits	IPv6 multicast address

It includes only IPv6 multicast address.

5.6.8.4.5 Multicast connection data from the responder

No information is carried in the response's CON.DATA field.

5.6.9 Service access point

5.6.9.1 Overview

This section defines the service access point used by the IPv6 layer to communicate with the IPv6 convergence layer.

5.6.9.2 Opening and closing the convergence layer

The following primitives are used to open and close the convergence layer. The convergence layer may be opened once only. The IPv6 layer may close the convergence layer when the IPv6 interface is brought down. The convergence layer will also close the convergence layer when the underlying MAC connection to the Base Node has been lost.

5.6.9.2.1 CL_IPv6_Establish.request

The CL_IPv6_ESTABLISH.request primitive is passed from the IPv6 layer to the IPv6 convergence layer. It is used when the IPv6 layer brings the interface up.

The semantics of this primitive are as follows:

CL_IPv6_ESTABLISH.request{AE}

The AE parameter indicates whether the interface will be authenticated and encrypted or not.

On receiving this primitive, the convergence layer will form the address resolution connection to the Base Node.

5.6.9.2.2 CL_IPv6_Establish.confirm

The CL_IPv6_ESTABLISH.confirm primitive is passed from the IPv6 convergence layer to the IPv6 layer. It is used to indicate that the convergence layer is ready to access IPv6 packets to be sent to peers.

The semantics of this primitive are as follows:

CL_IPv6_ESTABLISH.confirm{AE}

The AE parameter indicates whether the interface will be authenticated and encrypted or not.

Once the convergence layer has established all the necessary connections and is ready to transmit and receive IPv6 packets, this primitive is passed to the IPv6 layer. If the convergence layer encounters an error while opening, it responds with a CL_IPv6_RELEASE.confirm primitive, rather than a CL_IPv6_ESTABLISH.confirm.

5.6.9.2.3 CL_IPv6_Release.request

The CL_IPv6_RELEASE.request primitive is used by the IPv6 layer when the interface is put down. The convergence layer closes all connections so that no more IPv6 packets are received and all resources are released.

The semantics of this primitive are as follows:

CL_IPv6_RELEASE.request{}

Once the convergence layer has released all its connections and resources it returns a CL_IPv6_RELEASE.confirm.

5.6.9.2.4 CL_IPv6_Release.confirm

The CL_IPv6_RELEASE.confirm primitive is used by the IPv6 convergence layer to indicate to the IPv6 layer that the convergence layer has been closed. This can be as a result of a CL_IPv6_RELEASE.request primitive, a CL_IPv6_ESTABLISH.request primitive, or because the MAC layer indicates the address resolution connection has been lost, or the Service Node itself is no longer registered.

The semantics of this primitive are as follows:

CL_IPv6_RELEASE.confirm{result}

The result parameter has the meanings defined in Table 132.

5.6.9.3 Unicast address management

5.6.9.3.1 General

The primitives defined here are used for address management, i.e. the registration and unregistration of IPv6 addresses associated with this convergence layer.

When there are no IPv6 addresses associated with the convergence layer, the convergence layer will only send and receive multicast packets; unicast packets may not be sent. However, this is sufficient for various address discovery protocols to be used to gain an IPv6 address. Once an IPv6 address has been registered, the IPv6 layer can transmit unicast packets that have a source address equal to one of its registered addresses.

5.6.9.3.2 CL_IPv6_Register.request

This primitive is passed from the IPv6 layer to the IPv6 convergence layer to register an IPv6 address.

The semantics of this primitive are as follows:

CL_IPv6_REGISTER.request{ipv6, netmask, gateway}

The ipv6 address is the address to be registered.

The netmask is the network mask, used to mask the network number from the address. The netmask is used by the convergence layer to determine whether the packet should deliver directly or the gateway should be used.

The IPv6 address of the gateway, to which packets with destination address that are not in the same subnet as the local address are to be sent.

Once the IPv6 address has been registered to the Base Node, a CL_IPv6_REGISTER.confirm primitive is used. If the registration fails, the CL_IPv6_RELEASE.confirm primitive will be used.

5.6.9.3.3 CL_IPv6_Register.confirm

This primitive is passed from the IPv6 convergence layer to the IPv6 layer to indicate that a registration has been successful.

The semantics of this primitive are as follows:

CL_IPv6_REGISTER.confirm{ipv6}

The ipv6 address is the address that was registered.

Once registration has been completed, the IPv6 layer may send IPv6 packets using this source address.

5.6.9.3.4 CL_IPv6_Unregister.request

This primitive is passed from the IPv6 layer to the IPv6 convergence layer to unregister an IPv6 address.

The semantics of this primitive are as follows:

CL_IPv6_UNREGISTER.request{ipv6}

The ipv6 address is the address to be unregistered.

Once the IPv6 address has been unregistered to the Base Node, a CL_IPv6_UNREGISTER.confirm primitive is used. If the registration fails, the CL_IPv6_RELEASE.confirm primitive will be used.

5.6.9.3.5 CL_IPv6_Unregister.confirm

This primitive is passed from the IPv6 convergence layer to the IPv6 layer to indicate that an unregistration has been successful.

The semantics of this primitive are as follows:

CL_IPv6_UNREGISTER.confirm{ipv6}

The IPv6 address is the address that was unregistered.

Once unregistration has been completed, the IPv6 layer may not send IPv6 packets using this source address.

5.6.9.4 Multicast group management

5.6.9.4.1 General

This section describes the primitives used to manage multicast groups.

5.6.9.4.2 CL_IPv6_MUL_Join.request

This primitive is passed from the IPv6 layer to the IPv6 convergence layer. It contains an IPv6 multicast address that is to be joined.

The semantics of this primitive are as follows:

CL_IPv6_MUL_JOIN.request{IPv6 , AE }

The IPv6 address is the IPv6 multicast group that is to be joined.

The AE parameter indicates whether messages in this group will be authenticated and encrypted or not.

When the convergence layer receives this primitive, it will arrange for IP packets sent to this group to be multicast in the PRIME network and receive packets using this address to be passed to the IPv6 stack. If the convergence layer cannot join the group, it uses the CL_IPv6_MUL_LEAVE.confirm primitive. Otherwise the CL_IPv6_MUL_JOIN.confirm primitive is used to indicate success.

5.6.9.4.3 CL_IPv6_MUL_Join.confirm

This primitive is passed from the IPv6 convergence layer to the IPv6. It contains a result status and an IPv6 multicast address that was joined.

The semantics of this primitive are as follows:

CL_IPv6_MUL_JOIN.confirm{IPv6, AE}

The IPv6 address is the IPv6 multicast group that was joined. The convergence layer will start forwarding IPv6 multicast packets for the given multicast group.

The AE parameter indicates whether messages in this group will be authenticated and encrypted or not.

5.6.9.4.4 CL_IPv6_MUL_Leave.request

This primitive is passed from the IPv6 layer to the IPv6 convergence layer. It contains an IPv6 multicast address to be left.

The semantics of this primitive are as follows:

CL_IPv6_MUL_LEAVE.request{IPv6}

The IPv6 address is the IPv6 multicast group to be left. The convergence layer will stop forwarding IPv6 multicast packets for this group and may leave the PRIME MAC multicast group.

5.6.9.4.5 CL_IPv6_MUL_Leave.confirm

This primitive is passed from the IPv6 convergence layer to the IPv6. It contains a result status and an IPv6 multicast address that was left.

The semantics of this primitive are as follows:

CL_IPv6_MUL_LEAVE.confirm{IPv6, Result}

The IPv6 address is the IPv6 multicast group that was left. The convergence layer will stop forwarding IPv6 multicast packets for the given multicast group.

The Result takes a value from Table 151.

This primitive can be used by the convergence layer as a result of a CL_IPv6_MUL_JOIN.request, CL_IPv6_MUL_LEAVE.request or because of an error condition resulting in the loss of the PRIME MAC multicast connection.

5.6.9.5 Data transfer

5.6.9.5.1 General

The following primitives are used to send and receive IPv6 packets.

5.6.9.5.2 CL_IPv6_DATA.request

This primitive is passed from the IPv6 layer to the IPv6 convergence layer. It contains one IPv6 packet to be sent.

The semantics of this primitive are as follows:

CL_IPv6_DATA.request{IPv6_PDU}

The IPv6_PDU is the IPv6 packet to be sent.

5.6.9.5.3 CL_IPv6_DATA.confirm

This primitive is passed from the IPv6 convergence layer to the IPv6 layer. It contains a status indication and an IPv6 packet that has just been sent.

The semantics of this primitive are as follows:

CL_IPv6_DATA.confirm{IPv6_PDU, Result}

The IPv6_PDU is the IPv6 packet that was to be sent.

The Result value indicates whether the packet was sent or an error occurred. It takes a value from Table 151.

5.6.9.5.4 CL_IPv6_DATA.indicate

This primitive is passed from the IPv6 convergence layer to the IPv6 layer. It contains an IPv6 packet that has just been received.

The semantics of this primitive are as follows:

CL_IPv6_DATA.indicate{IPv6_PDU }

The IPv6_PDU is the IPv6 packet that was received.

6 Management plane

6.1 Introduction

This chapter specifies the Management plane functionality. The picture below highlights the position of Management plane in overall protocol architecture.

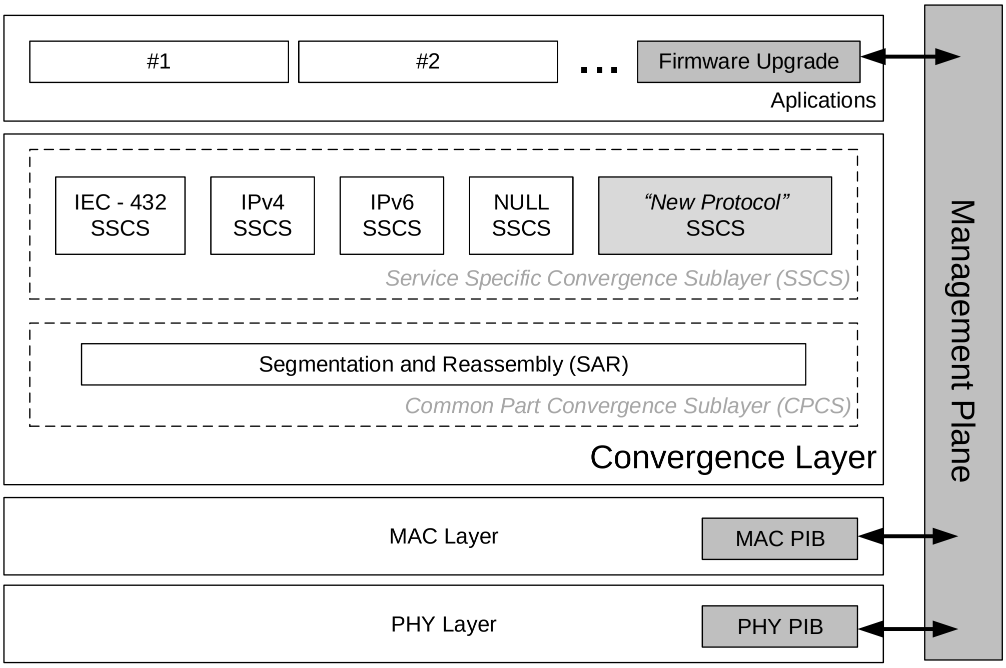


Figure 136 - Management plane. Introduction.

All nodes shall implement the management plane functionality enumerated in this section. Management plane enables a local or remote control entity to perform actions on a Node.

Present version of this specification enumerates management plane functions for Node management and firmware upgrade. Future versions may include additional management functions.

- To enable access to management functions on a Service Node, Base Node shall open a management connection after successful completion of registration (refer to 6.4)
- The Base Node may open such a connection either immediately on successful registration or sometime later.
- Unicast management connection shall be identified with CON.TYPE = TYPE_CL_MGMT.
- Multicast management connections can also exist. At the time of writing of this document, multicast management connection shall only be used for firmware upgrade.
- There shall be no broadcast management connection.
- In case Service Node supports ARQ connections, the Base Node shall preferentially try to open an ARQ connection for management functions.
- Management plane functions shall use NULL SSCS as specified in section 0

6.2 Node management

6.2.1 General

Node management is accomplished through a set of attributes. Attributes are defined for both PHY and MAC layers. The set of these management attributes is called PLC Information Base (PIB). Some attributes are read-only while others are read-write.

PIB Attribute identifiers are 16 bit values. This allows for up to 65535 PIB Attributes to be specified.

- PIB Attribute identifier values from 0 to 32767 are open to be standardized. No proprietary attributes may have identifiers in this range.
- Values in the range 32768 to 65535 are open for vendor specific usage.

PIB Attributes identifiers in standard range (0 to 32767) that are not specified in this version are reserved for future use.

Note: *PIB attribute tables below indicate type of each attribute. For integer types the size of the integer has been specified in bits. An implementation may use a larger integer for an attribute; however, it must not use a smaller size.*

6.2.2 PHY PIB attributes

6.2.2.1 General

The PHY layer implementation in each device may optionally maintain a set of attributes which provide detailed information about its working. The PHY layer attributes are part of the PAN Information Base (PIB).

6.2.2.2 Statistical attributes

The PHY may provide statistical information for management purposes. Next table lists the statistics that PHY should make available to management entities across the PLME_GET primitive. The Id field in this table is the service parameter of the PLME_GET primitive specified in section 3.5.4.

Table 101 - PHY read-only variables that provide statistical information

Attribute Name	Size (in bits)	Id	Description
phyStatsCRCIncorrectCount	16	0x00A0	Number of bursts received on the PLC PHY layer for which the CRC was incorrect.
phyStatsCRCFailCount	16	0x00A1	Number of bursts received on the PLC PHY layer for which the CRC was correct, but the *Protocol* field of PHY header had an invalid value. This count would reflect number of times corrupt data was received and the CRC calculation failed to detect it.
phyStatsTxDropCount	16	0x00A2	Number of times when PLC PHY layer received new data to transmit (PHY_DATA.request) and had to

			either overwrite on existing data in its transmit queue or drop the data in new request due to full queue.
phyStatsRxDropCount	16	0x00A3	Number of times when PLC PHY layer received new data on the channel and had to either overwrite on existing data in its receive queue or drop the newly received data due to full queue.
phyStatsRxTotalCount	32	0x00A4	Total number of PLC PPDUs correctly decoded. Useful for PHY layer test cases, to estimate the FER.
phyStatsBlkAvgEvm	16	0x00A5	Exponential moving average of the EVM over the past 16 PPDUs, as returned by the PHY_SNR primitive. Note that the PHY_SNR primitive returns a 3-bit number in dB scale. So first each 3-bit dB number is converted to linear scale (number k goes to 2^(k/2)), yielding a 7 bit number with 3 fractional bits. The result is just accumulated over 16 PPDUs and reported. This PIB only applies to the PLC PHY layer.
phyEmaSmoothing	8	0x00A8	Smoothing factor divider for values that are updated as exponential moving average (EMA). Next value is `V`***`next`*** `= S*NewSample+(1-S)*V`***`prev`*** Where `S=1/(2^phyEMASmoothing).` This PIB only applies to the PLC PHY layer.
phyRFStatsIncorrectCount	16	0x101A	Total number of RF PPDUs incorrectly decoded. Useful for PHY layer test cases, to estimate the FER.
phyRFStatsTxDropCount	16	0x101B	Number of times when RF PHY layer received new data to transmit (PHY_DATA.request) and had to either overwrite on existing data in its transmit queue or drop the data in new request due to full queue.
phyRFStatsRxDropCount	16	0x101C	Number of times when RF PHY layer received new data on the channel and had to either overwrite on existing data in its receive queue or drop the newly received data due to full queue.

phyRFStatsRxTotalCount	32	0x101D	Total number of RF PPDUs correctly decoded. Useful for PHY layer test cases, to estimate the FER.

6.2.2.3 Implementation attributes

It is possible to implement PHY functions conforming to this specification in multiple ways. The multiple implementation options provide some degree of unpredictability for MAC layers. PHY implementations may optionally provide specific information on parameters which are of interest to MAC across the PLME_GET primitive. A list of such parameters for the PLC medium which may be queried across the PLME_GET primitives by MAC is provided in Table 102 - . All of the attributes listed in Table 102 - are implementation constants and shall not be changed.

Table 102 - PHY read-only parameters, providing information on specific implementation

Attribute Name	Size (in bits)	Id	Description
phyTxQueueLen	10	0x00B0	Number of concurrent MPDUs that the PHY transmit buffers can hold.
phyRxQueueLen	10	0x00B1	Number of concurrent MPDUs that the PHY receive buffers can hold.
phyTxProcessingDelay	20	0x00B2	Time elapsed from the instance when data is received on MAC-PHY communication interface to the time when it is put on the physical channel. This shall not include communication delay over the MAC-PHY interface. Value of this attribute is in unit of microseconds.
phyRxProcessingDelay	20	0x00B3	Time elapsed from the instance when data is received on physical channel to the time when it is made available to MAC across the MAC-PHY communication interface. This shall not include communication delay over the MAC-PHY interface. Value of this attribute is in unit of microseconds.
phyAgcMinGain	8	0x00B4	Minimum gain for the AGC <= 0dB.
phyAgcStepValue	3	0x00B5	Distance between steps in dB <= 6dB.
phyAgcStepNumber	8	0x00B6	Number of steps so that phyAgcMinGain +((phyAgcStepNumber – 1) * phyAgcStepValue) >= 21dB.

6.2.2.4 PHY constants of RF SUN FSK Layer

The PHY layer implementation in each device that implements SUN FSK PHY needs to include the following constants defined on clause 11.2 of IEEE 802.15.4-2015 [28]. These constants are hardware dependent and cannot be changed during operation:

Table 103 - PHY read-only parameters of RF Layer, providing information on specific implementation

Attribute Name	Id	Description	Value
aMaxPhyPacketSize	0x1000	The maximum PSDU size (in octets) the PHY shall be able to receive	2047 for SUN FSK PHY
aTurnaroundTime	0x1001	RX-to-TX or TX-to-RX turnaround time (in symbol periods), as defined in 10.2.1 and 10.2.2 of [28]	For the SUN FSK PHYs, the value is 1 ms expressed in symbol periods, rounded up to the next integer number of symbol periods using the ceiling() function.

6.2.2.5 PHY PIB attributes of RF SUN FSK Layer

The parameters described here, are defined in the clause 11.3 of IEEE 802.15.02-2015 [28]

Table 104 - Configuration Parameters RF SUN FSK phy layer

Attribute Name	Id	Type	Range	Description
phyCurrentChannel	0x1010	Integer	-	The value is the *NumChan* defined in 10.1.2.8 of [28], setting the RF channel to use for all following transmissions and receptions.
phyTxPower	0x1011	Signed integer	-	The transmit power of the device in dBm.
phyFskFecEnabled	0x1012	Boolean	TRUE, FALSE	A value of TRUE indicates that FEC is turned on. A value of FALSE indicates that FEC is turned off. This attribute is only valid for the SUN FSK and TVWS FSK PHY.
phyFskFecInterleavingRsc	0x1013	Boolean	TRUE, FALSE	A value of TRUE indicates that interleaving is enabled for RSC. A value of FALSE indicates that interleaving is disabled for RSC. This attribute is only valid for the SUN FSK and TVWS FSK PHY. Not relevant when phyFskFecScheme = 0.

phyFskFecScheme	0x1014	Integer	0	A value of zero indicates that a non-recursive and non-systematic code (NRNSC) is employed, as described in Table 9.
phyFskPreambleLength	0x1015	Integer	8	The number of repetitions of the preamble pattern, as described in Table 9.
phySunFskSfd	0x1016	Integer	0	Determines which group of SFDs is used, as described in Table 9.
phyFskScramblePsdu	0x1017	Boolean	TRUE	A value of TRUE indicates that data whitening of the PSDU is enabled, as described in Table 9.
phyCCADuration	0x1018	Integer	0-1000	The duration for CCA, specified in symbols for the SUN PHYs, the default value duration is of 8 symbol periods.
phyCCAThreshold	0x1019	Integer	0-100	Number of dB above the specified receiver sensitivity for that PHY defined on 20.6.7 of [28].

6.2.3 MAC PIB attributes

6.2.3.1 General

Note: *Note that the "M"(Mandatory) column in the tables below specifies if the PIB attributes are mandatory for all devices (both Service Node and Base Node, specified as "All"), only for Service Nodes ("SN"), only for Base Nodes ("BN"), only for BN and SN supporting SUN FSK PHY ("RF") or not mandatory at all ("No").*

6.2.3.2 MAC variable attributes

MAC PIB variables include the set of PIB attributes that influence the functional behavior of an implementation. These attributes may be defined external to the MAC, typically by the management entity and implementations may allow changes to their values during normal running, i.e. even after the device start-up sequence has been executed.

An external management entity can have access to these attributes through the MLME_GET (4.5.5.7) and MLME_SET (4.5.5.9) set of primitives. The Id field in the following table would be the *PIBAttribute* that needs to be passed MLME SAP while working on these parameters

Table 105 - Table of MAC read-write variables

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macVersion	0x0001	Integer8	All	0x01	The current MAC Version. This is a 'read-only' attribute	0x01

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macMinSwitchSearchTime	0x0010	Integer8	No	16 – 32 seconds	Minimum time for which a Service Node in *Disconnected* status should scan the initial Band for Beacons before it can broadcast PNPDU. This attribute is not maintained in Base Nodes.	24
macMaxPromotionPdu	0x0011	Integer8	No	1 – 4	Maximum number of PNPDUs that may be transmitted by a Service Node in a period of *macPromotionPduTxPeriod* seconds. This attribute is not maintained in Base Node.	2
macPromotionPduTxPeriod	0x0012	Integer8	No	2 – 8 seconds	Time quantum for limiting a number of PNPDUs transmitted from a Service Node. No more than *macMaxPromotionPdu* may be transmitted in a period of *macPromotionPduTxPeriod* seconds.	5
macSCPMaxTxAttempts	0x0014	Integer8	No	2 – 5	Number of times the PLC CSMA algorithm would attempt to transmit requested data when a previous attempt was withheld due to PHY indicating channel busy.	5
macMinCtlReTxTimer	0x0015	Integer8	All	2 sec	Minimum number of seconds for which a MAC entity waits for acknowledgement of receipt of MAC Control Packet from its peer entity. On expiry of this time, the MAC entity may retransmit the MAC Control Packet.	2

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macTrafficBandTimeout	0x0016	Integer8	No	32 – 120	Period of time in seconds for which a Disconnected Node shall listen on a specific band before moving to another one when traffic has been detected in current band.	60
macCtrlMsgFailTime	0x0018	Integer8	No	6 - 100	Number of seconds for which a MAC entity in Switch Nodes waits before declaring a children's transaction procedures expired	45
macEMASmoothing	0x0019	Integer8	All	0 - 7	Smoothing factor divider for values that are updated as exponential moving average (EMA). Next value is V***next*** = S*NewSample+(1–S)*V***prev*** Where S=1/(2^macEMASmoothing).	3
macMinBandSearchTime	0x001A	Integer8	No	4 - 32	Period of time in seconds for which a Disconnected Node shall listen on a specific band before moving to another one when traffic has not been detected in current band.	10
macPromotionMaxTxPeriod	0x001B	Integer8	SN	16-120	Period of time in seconds for which at least one PNPDU shall be sent Note: This attribute is deprecated in v1.4 and only maintained by devices implementing v1.3.6	32

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macPromotionMinTxPeriod	0x001C	Integer8	SN	2-16	Period of time in seconds for which at no more than one PNPDU shall be sent.	2
macSARSize	0x001D	Integer8	All	0-7	Maximum Data packet size that can be accepted with the MCPS-DATA.Request 0: Not mandated by BN (SAR operates normally) 1: SAR = 16 bytes 2: SAR =32 bytes 3: SAR = 48 bytes 4: SAR =64 bytes 5: SAR =128 bytes 6: SAR =192 bytes 7: SAR =255 bytes This attribute can be modified only in Base Node. Read-only for Service Nodes	0
macMaxBandSearchTime	0x001E	Integer16	No	300 – 3600	Maximum period of time in seconds for which a Disconnected Node shall listen on a specific band before moving to another.	1800

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macRobustnessManagement	0x004A	Integer8	No	0-3	Force the network to operate only with one specific modulation 0 – No forcing automatic robustness-management 1 – Use only DBPSK_CC 2 - Use only DQPSK_R 3 - Use only DBPSK_R This attribute can be modified only in Base Node. Read-only for Service Nodes	0
macUpdatedRMTimeout	0x004B	Integer16	All	60-3600	Period of time in seconds for which an entry in the	240
macALVHopRepetitions	0x004C	Integer8	All	0-7	Number of repletion for the ALV packets	5
macPhyChannelChange	0x004D	3x Integer8	No		Change the Physical layer channel/band used by Base Node on a specific medium and notify the event through a PCC MAC control packet This attribute is not maintained in Service Nodes.	-
			Entry Element	**Size**	**Description**	
			PCH	Integer16	New Physical layer channel/band that will be used by the Base Node on a specific medium, as described in 4.4.2.6.11. The 10 least significant bits of the entry element are used to store the value	

Attribute Name	Id	Type	M	Valid Range	Description	Def.
			SeqOffset	Integer8	An offset, to be added to current Beacon Sequence number, used to select the frame when the specified change takes effect (range 1-31)	
macMinBe	0x0098	Integer8	RF	0 - macMaxBe	Description in Table 8-81 of [28]	3
macMaxBe	0x0099	Integer8	RF	3 -8	Description in Table 8-81 of [28]	5
macMaxCsmaBackoffs	0x009A	Integer8	RF	0-5	Description in Table 8-81 of [28]	4
macHoppingPromotionMaxTxPeriod	0x009B	Integer8	RF SN	16-120	Period of time in seconds for which at least one PNPDU per RF medium channel shall be sent Note: This attribute is deprecated in v1.4 and only maintained by devices implementing v1.3.6	32
macHoppingPromotionMinTxPeriod	0x009C	Integer8	RF SN	2-16	Period of time in seconds for which at no more than one PNPDU per RF medium channel shall be sent.	2
macHoppingInitialChannelList	0x009D	512 bits	RF	bitmap	RF channels used to generate the main hopping sequence. Representing macHoppingInitialChannelList by $b_{511}b_{510}\ldots b_2b_1b_0$, b_k=1 indicates that channel k is used. b0 is the lsb and byte convention is big endian.	-

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macHoppingBCNInitialChannelList	0x009E	512 bits	RF	bitmap	RF channels used to generate the beacon hopping sequence. Representing macHoppingBCNInitialChannelList by $b_{511}b_{510}...b_2b_1b_0$, b_k=1 indicates that channel k is used. b0 is the lsb and byte convention is big endian.	-

Table 106 - Table of MAC read-only variables

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macSCPChSenseCount	0x0017	Integer8	No	2 – 5	Number of times for which an implementation has to perform channel-sensing. This is a 'read-only' attribute.	-
macEUI-48	0x001F	EUI-48	All		EUI-48 of the Node	-
macCSMAR1	0x0034	Integer8	All	0 - 4	Control how fast the CSMA contention window shall increase. Controls exponential increase of initial CSMA contention window size	3
macCSMAR2	0x0035	Integer8	All	1 - 4	Control initial CSMA contention window size. Controls linear increase of initial CSMA contention window size.	1
macCSMADelay	0x0038	Integer8	All	3ms – 9ms	The delay between two consecutive CSMA channel senses.	3 ms

Attribute Name	Id	Type	M	Valid Range	Description	Def.
macCSMAR1Robust	0x003B	Integer8	All	0 - 5	Control how fast the CSMA contention window shall increase when node supports Robust Mode. Controls exponential increase of initial CSMA contention window size.	4
macCSMAR2Robust	0x003C	Integer8	All	1 - 8	Control initial CSMA contention window size when node supports Robust Mode. Controls linear increase of initial CSMA contention window size.	2
macCSMADelayRobust	0x003D	Integer8	All	3ms – 9ms	The delay between two consecutive CSMA channel senses when node supports Robust Mode.	6 ms
macAliveTimeMode	0x003E	Integer8	BN	0 - 1	Selects the *MACAliveTime* value mapping for network Alive time. 0 – 1.4 mode 1 – BC mode	-
macNumberOfRFChannels	0x0090	Integer16	RF	0x0000-0x0200	Number of channels supported by the RF PHY.	-
macHoppingSequenceLength	0x0091	Integer16	RF	0x0000-0x0200	The number of channels in the hopping sequence. It can be lower than or equal to macNumberOfRFChannels.	-
macHoppingSequencePosition	0x0092	Integer16	No	0x0000-0x01ff	The current position in the main sequence for RF channel hopping.	-
macHoppingBCNSequenceLength	0x0093	Integer8	RF	0x00-0x20	The number of channels in the beacon hopping sequence.	-
macHoppingBCNSequencePosition	0x0094	Integer8	No	0x00-0x1f	The current position in the beacon sequence for RF channel hopping.	-

6.2.3.3 Functional attributes

Some PIB attributes belong to the functional behavior of MAC. They provide information on specific aspects. A management entity can only read their present value using the MLME_GET primitives. The value of these attributes cannot be changed by a management entity through the MLME_SET primitives.

The Id field in the table below would be the *PIBAttribute* that needs to be passed MLME_GET SAP for accessing the value of these attributes.

Table 107 - Table of MAC read-only variables that provide functional information

Attribute Name	Id	Type	M	Valid Range	Description
macLNID	0x0020	Integer16	SN	0 – 16383	LNID allocated to this Node at time of its registration. (0x0000 is reserved for Base Node)
macLSID	0x0021	Integer8	SN	0 – 255	LSID allocated to this Node at time of its promotion. This attribute is not maintained if a Node is in a *Terminal* functional state. (0x00 is reserved for Base Node). This attribute is maintained only for a promotion accomplished using the PRO_REQ_x message.
macSID	0x0022	Integer8	SN	0 – 255	SID of the Switch Node through which this Node is connected to the Subnetwork. This attribute is not maintained in a Base Node.
macSNA	0x0023	EUI-48	SN		Subnetwork address to which this Node is registered. The Base Node returns the SNA it is using.
macState	0x0024	Enumerate	SN		Present functional state of the Node.
				0	DISCONNECTED.
				1	TERMINAL.
				2	SWITCH.
				3	BASE.

Attribute Name	Id	Type	M	Valid Range	Description
macSCPLength	0x0025	Integer16	SN		The SCP length, in symbols, in present frame.
macNodeHierarchyLevel	0x0026	Integer8	SN	0 – 63	Level of this Node in Subnetwork hierarchy.
macBeaconRxPos	0x0039	Integer16	SN	0 – 1104	Beacon Position on which this device's Switch Node transmits its beacon. Position is expressed in terms of symbols from the start of the frame. This attribute is not maintained in a Base Node.
macBeaconTxPos	0x003A	Integer8	SN	0 – 1104	Beacon Position in which this device transmits its beacon. Position is expressed in terms of symbols from the start of the frame. This attribute is not maintained in Service Nodes that are in a *Terminal* functional state. This attribute is maintained only for a promotion accomplished using the PRO_REQ_x message.
macBeaconRxFrequency	0x002A	Integer8	SN	0 – 5	Number of frames between receptions of two successive beacons. A value of 0x0 indicates beacons are received in every frame. This attribute is not maintained in Base Node. Use the same encoding of FRQ field in the packets
macBeaconTxFrequency	0x002B	Integer8	SN	0 – 5	Number of frames between transmissions of two successive beacons. A value of 0x0 indicates beacons are transmitted in every frame. This attribute is not maintained in Service Nodes that are in a *Terminal* functional state. Use the same encoding of FRQ field in the packets. This attribute is maintained only for a promotion accomplished using the PRO_REQ_x message.

Attribute Name	Id	Type	M	Valid Range	Description
macCapabilities	0x002C	Integer16	All	Bitmap	Bitmap of MAC capabilities of a given device. This attribute shall be maintained on all devices. Bits in sequence of right-to-left shall have the following meaning: **Bit0:** Robust mode Capable; **Bit1:** Backward Compatible Capable; **Bit2:** Switch Capable; **Bit3:** Packet Aggregation Capable; **Bit4:** Connection Free Period Capable; **Bit5:** Direct Connection Capable; **Bit6:** ARQ Capable; **Bit7:** Multi-PHY Promotion Capable; **Bit8:** Direct Connection Switching; **Bit9:** Multicast Switching Capability; **Bit10:** Robust promotion device Capable; **Bit11:** ARQ Buffering Switching Capability; **Bits12 to 15:** Reserved for future use.
macFrameLength	0x002D	Integer16	All	0 – 3	Frame Length in the present super-frame 0 - 276 symbols 1 - 552 symbols 2 - 828 symbols 3 - 1104 symbols
macCFPLength	0x002E	Integer16	All		The CFP length in symbols, in present frame

Attribute Name	Id	Type	M	Valid Range	Description
macGuardTime	0x002F	Integer16	All	1 symbol	The guard time between portion of the frame in symbols
macBCMode	0x0030	Integer16	All	0 or 1	MAC is operating in Backward Compatibility Mode
macBeaconRxQlty	0x0032	Integer16	All		The BCN.QLTY field this device's Switch Node transmits in its beacon.
macBeaconTxQlty	0x0033	Integer16	All		The BCN.QLTY field transmitted by this device in its beacon.

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5139 #### 6.2.3.4 Statistical attributes

5140 The MAC layer shall provide statistical information for management purposes. Table 108 lists the statistics
5141 MAC shall make available to management entities across the MLME_GET primitive.

5142 The Id field in table below would be the *PIBAttribute* that needs to be passed MLME_GET SAP for accessing
5143 the value of these attributes.

5144 **Table 108 - Table of MAC read-only variables that provide statistical information**

Attribute Name	Id	M	Type	Description
macTxDataPktCount	0x0040	No	Integer32	Count of successfully transmitted MSDUs.
MacRxDataPktCount	0x0041	No	Integer32	Count of successfully received MSDUs whose destination address was this Node.
MacTxCtrlPktCount	0x0042	No	Integer32	Count of successfully transmitted MAC control packets.
MacRxCtrlPktCount	0x0043	No	Integer32	Count of successfully received MAC control packets whose destination address was this Node.
MacCSMAFailCount	0x0044	No	Integer32	Count of failed PLC CSMA transmitted attempts.
MacCSMAChBusyCount	0x0045	No	Integer32	Count of number of times this Node had to back off SCP transmission due to channel busy state, when PLC CSMA is used
MacRFCSMAFailCount	0x0046	No	Integer32	Count of failed RF CSMA transmitted attempts.

Attribute Name	Id	M	Type	Description
MacRFCSMAChBusyCount	0x0047	No	Integer32	Count of number of times this Node had to back off SCP transmission due to channel busy state, when RF CSMA is used

6.2.3.5 MAC list attributes

MAC layer shall make certain lists available to the management entity across the MLME_LIST_GET primitive. These lists are given in Table 109. Although a management entity can read each of these lists, it cannot change the contents of any of them.

The Id field in table below would be the *PIBListAttribute* that needs to be passed MLME_LIST_GET primitive for accessing the value of these attributes.

Table 109 - Table of read-only lists made available by MAC layer through management interface

<table>
<tr><th>List Attribute Name</th><th>Id</th><th>M</th><th colspan="3">Description</th></tr>
<tr><td rowspan="8">macListRegDevices</td><td rowspan="8">0x0050</td><td rowspan="8">BN</td><td colspan="3">List of registered devices. This list is maintained by the Base Node only. Each entry in this list shall comprise the following information.</td></tr>
<tr><td>Entry Element</td><td>Type</td><td>Description</td></tr>
<tr><td>regEntryID</td><td>EUI-48</td><td>EUI-48 of the registered Node.</td></tr>
<tr><td>regEntryLNID</td><td>Integer16</td><td>LNID allocated to this Node.</td></tr>
<tr><td>regEntryState</td><td>TERMINAL=1, SWITCH=2</td><td>Functional state of this Node.</td></tr>
<tr><td>regEntryLSID</td><td>Integer8</td><td>SID allocated to this Node.</td></tr>
<tr><td>regEntrySID</td><td>Integer8</td><td>SID of Switch through which this Node is connected.</td></tr>
<tr><td>regEntryLevel</td><td>Interger8</td><td>Hierarchy level of this Node.</td></tr>
</table>

<table>
<tr><th>List Attribute Name</th><th>Id</th><th>M</th><th colspan="3">Description</th></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>regEntryTCap</td><td>Integer8</td><td>Bitmap of MAC Capabilities of Terminal functions in this device.

Bits in sequence of right-to-left shall have the following meaning:
Bit0: Robust mode Capable; Bit1: Backward Compatible Capable;
Bit2: Switch Capable; Bit3: Packet Aggregation Capable;
Bit4: Connection Free Period Capable;
Bit5: Direct Connection Capable;
Bit6: ARQ Capable; Bit7: Multi-PHY Promotion Capable.</td></tr>
<tr><td>regEntrySwCap</td><td>Integer8</td><td>Bitmap of MAC Switching capabilities of this device

Bits in sequence of right-to-left shall have the following meaning:
Bit0: Direct Connection Switching;
Bit1:Reserved;
Bit2:Reserved;
Bit3: ARQ Buffering Switching Capability;
Bit4 to 7:Reserved for future use.</td></tr>
<tr><td rowspan="2">macListActiveConn</td><td rowspan="2">0x0051</td><td rowspan="2">BN</td><td colspan="3">List of active non-direct connections. This list is maintained by the Base Node only.</td></tr>
<tr><td>Entry Element</td><td>Type</td><td>Description</td></tr>
</table>

List Attribute Name	Id	M	Description		
			connEntrySID	Integer8	SID of Switch through which the Service Node is connected.
			connEntryLNID	Integer16	NID allocated to Service Node.
			connEntryLCID	Integer16	LCID allocated to this connection.
			connEntryID	EUI-48	EUI-48 of Service Node.
macListMcastEntries	0x0052	No	List of entries in multicast switching table. This list is not maintained by Service Nodes in a *Terminal* functional state.		
			Entry Element	**Type**	**Description**
			mcastEntryLCID	Integer16	LCID of the multicast group.
			mcastEntryMembers	Integer16	Number of child Nodes (including the Node itself) that are members of this group.
macListSwitchTable	0x005A	SN	List the Switch table. This list is not maintained by Service Nodes in a *Terminal* functional state.		
			Entry Element	**Type**	**Description**
			stblEntryLNID	Integer 16	LNID of attached Switch Node.
			stblEntryLSID	Integer8	LSID assigned to the attached Switch Node.
			stbleEntrySID	Integer8	SID of attached Switch Node
			stblEntryALVTime	Integer8	The TIME value used for the Keep Alive process
macListDirectConn	0x0054	No	List of direct connections that are active. This list is maintained only in the Base Node.		
			Entry Element	**Type**	**Description**
			dconnEntrySrcSID	Integer8	SID of Switch through which the source Service Node is connected.
			dconEntrySrcLNID	Integer16	NID allocated to the source Service Node.

List Attribute Name	Id	M	Description		
			dconnEntrySrcLCID	Integer16	LCID allocated to this connection at the source.
			dconnEntrySrcID	EUI-48	EUI-48 of source Service Node.
			dconnEntryDstSID	Integer8	SID of Switch through which the destination Service Node is connected.
			dconnEntryDstLNID	Integer16	NID allocated to the destination Service Node.
			dconnEntryDstLCID	Integer16	LCID allocated to this connection at the destination.
			dconnEntryDstID	EUI-48	EUI-48 of destination Service Node.
			dconnEntryDSID	Integer8	SID of Switch that is the direct Switch.
			dconnEntryDID	EUI-48	EUI-48 of direct switch.
macListDirectTable	0x0055	No	List the direct Switch table		
			Entry Element	**Type**	**Description**
			dconnEntrySrcSID	Integer8	SID of Switch through which the source Service Node is connected.
			dconEntrySrcLNID	Integer16	NID allocated to the source Service Node.
			dconnEntrySrcLCID	Integer16	LCID allocated to this connection at the source.
			dconnEntryDstSID	Integer8	SID of Switch through which the destination Service Node is connected.
			dconnEntryDstLNID	Integer16	NID allocated to the destination Service Node.

<table>
<tr><th>List Attribute Name</th><th>Id</th><th>M</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td><table>
<tr><td>dconnEntryDstLCID</td><td>Integer16</td><td>LCID allocated to this connection at the destination.</td></tr>
<tr><td>dconnEntryDID</td><td>EUI-48</td><td>EUI-48 of direct switch.</td></tr>
</table></td></tr>
<tr><td>macListAvailableSwitches</td><td>0x0056</td><td>SN</td><td>List of Switch Nodes whose beacons are received. Note that this list is extended in 6.2.3.5.1 to better address the case where Multi-PHY promotion is supported.<table>
<tr><th>Entry Element</th><th>Type</th><th>Description</th></tr>
<tr><td>slistEntrySNA</td><td>EUI-48</td><td>EUI-48 of the Subnetwork.</td></tr>
<tr><td>slistEntryLSID</td><td>Integer8</td><td>SID of this Switch.</td></tr>
<tr><td>slistEntryLevel</td><td>Integer8</td><td>Level of this Switch in Subnetwork hierarchy.</td></tr>
<tr><td>slistEntryRxLvl</td><td>Integer8
EMA</td><td>Received signal level for this Switch. EMA output is determined using values that correspond to the Level parameter defined in 3.5.2.4.2.</td></tr>
<tr><td>slistEntryRxSNR</td><td>Integer8
EMA</td><td>Signal to Noise Ratio for this Switch. EMA output is determined using values that correspond to the SNR parameter defined in 3.5.3.12.2.</td></tr>
</table></td></tr>
<tr><td></td><td>0x0057</td><td></td><td>Deprecated since v1.3.6 of specs and reserved for future use</td></tr>
<tr><td>macListActiveConnEX</td><td>0x0058</td><td>All</td><td>List of active non-direct connections. This list is maintained by the
Base Node only. Extended version.<table>
<tr><th>Entry Element</th><th>Type</th><th>Description</th></tr>
<tr><td>connEntrySID</td><td>Integer16</td><td>SID of Switch through which the Service Node is connected.</td></tr>
<tr><td>connEntryLNID</td><td>Integer16</td><td>NID allocated to Service Node.</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>List Attribute Name</th><th>Id</th><th>M</th><th colspan="3">Description</th></tr>
<tr><td></td><td></td><td></td><td>connEntryLCID</td><td>Integer16</td><td>LCID allocated to this connection.</td></tr>
<tr><td></td><td></td><td></td><td>connEntryID</td><td>EUI-48</td><td>EUI-48 of Service Node.</td></tr>
<tr><td></td><td></td><td></td><td>connType</td><td>Integer8</td><td>Type of connection.</td></tr>
<tr><td rowspan="7">macListPhyComm</td><td rowspan="7">0x0059</td><td rowspan="7">All</td><td colspan="3">List of PHY communication parameters. This table is maintained in every Node. For Terminal Nodes it contains only one entry for the Switch the Node is connected through. For other Nodes is contains also entries for every directly connected child Node. Note that this list is extended in 6.2.3.5.1 to better address the case where Multi-PHY promotion is supported.</td></tr>
<tr><td>Entry Element</td><td>Type</td><td>Description</td></tr>
<tr><td>phyCommLNID</td><td>Integer16</td><td>LNID of the peer device</td></tr>
<tr><td>phyCommSID</td><td>Integer8</td><td>SID of the peer device</td></tr>
<tr><td>phyCommTxPwr</td><td>Integer8</td><td>Tx power of GPDU packets sent to the device.</td></tr>
<tr><td>phyCommRxLvl</td><td>Integer8 EMA</td><td>Rx power level of GPDU packets received from the device. EMA output is determined using values that correspond to the Level parameter defined in 3.5.2.4.2.</td></tr>
<tr><td>phyCommSNR</td><td>Integer8 EMA</td><td>SNR of GPDU packets received from the device. EMA output is determined using values that correspond to the SNR parameter defined in 3.5.3.12.2.</td></tr>
</table>

List Attribute Name	Id	M	Description		
			phyCommTxModulation	Integer8	For PLC, modulation scheme to be used for communicating with this node. For RF this field is reserved for future use.
			phyCommPhyTypeCapability	Integer8	For PLC, capability of the node to receive only PHY Type A or PHY Type A+B frames 0: Type A only node 1: Type A+B capable node For RF this field is reserved for future use.
			phyCommRxAge	Integer16	For PLC, time [seconds] since last update of phyCommTxModulation. For RF this field is reserved for future use.

6.2.3.5.1 Extension for Multi-PHY MAC list attributes

In addition to the lists reported in 6.2.3.5, when Multi-PHY promotion is supported, the following lists are also supported.

Table 110 Read-only lists only available for Multi-PHY extension

List Attribute Name	Id	M	Description		
macListMPSwitches	0x2000	SN	List with the characteristics when a Service Node is a switch in different mediums. This list is not maintained by Service Nodes in a *Terminal* functional state and it is associated to promotions accomplished using PRO_REQ_x and/or PRO_REQ_x_MultiPHY messages.		
			Entry Element	**Type**	**Description**
			switchLSID	Integer8	LSID allocated to this Node at time of its promotion.

List Attribute Name	Id	M	Description		
			switchBeaconTxPos	Integer16	Beacon Position in which this Switch transmits its beacon. Position is expressed in terms of symbols from the start of the frame.
			switchBeaconTxFrequency	Integer8	Number of frames between transmissions of two successive beacons. A value of 0x0 indicates beacons are transmitted in every frame. Use the same encoding of FRQ field in the packets.
			switchPCH	Integer16	The medium and the band (PLC) or channel (RF) corresponding to the allocated LSID. This field is coded as the PRO.PCH field of Table 28 of 4.4.2.6.5.1.
macListMPAvailableSwitches	0x2056	SN	List of Switch Nodes whose beacons are received.		
			Entry Element	**Type**	**Description**
			slistEntrySNA	EUI-48	EUI-48 of the Subnetwork.
			slistEntryLSID	Integer8	SID of this Switch.
			slistEntryLevel	Integer8	Level of this Switch in Subnetwork hierarchy.
			slistEntryRxLvl	Integer8 EMA	Received signal level for this Switch. EMA output is determined using values that correspond to the Level parameter defined in 3.5.2.4.2.
			slistEntryRxSNR	Integer8 EMA	Signal to Noise Ratio for this Switch. EMA output is determined using values that correspond to the SNR parameter defined in 3.5.3.12.2.
			slistEntryPCH	Integer16	The medium and the band (PLC) or channel (RF) of the received beacon. This field is coded as the PRO.PCH field of Table 28 of 4.4.2.6.5.1.

List Attribute Name	Id	M	Description		
macListMPPhyComm	0x2059	All	List of PHY communication parameters. This table is maintained in every Node. For Terminal Nodes it contains only one entry for the Switch the Node is connected through. For other Nodes is contains also entries for every directly connected child Node.		
			Entry Element	**Type**	**Description**
			phyCommLNID	Integer16	LNID of the peer device
			phyCommSID	Integer8	SID of the peer device
			phyCommTxPwr	Integer8	Tx power of GPDU packets sent to the device.
			phyCommRxLvl	Integer8 EMA	Rx power level of GPDU packets received from the device. EMA output is determined using values that correspond to the Level parameter defined in 3.5.2.4.2.
			phyCommSNR	Integer8 EMA	SNR of GPDU packets received from the device. EMA output is determined using values that correspond to the SNR parameter defined in 3.5.3.12.2.
			phyCommTxModulation	Integer8	For PLC, modulation scheme to be used for communicating with this node. For RF this field is reserved for future use.
			phyCommPhyTypeCapability	Integer8	For PLC, capability of the node to receive only PHY Type A or PHY Type A+B frames 0: Type A only node 1: Type A+B capable node For RF this field is reserved for future use.

List Attribute Name	Id	M	Description		
			phyCommRxAge	Integer16	For PLC, time [seconds] since last update of phyCommTxModulation. For RF this field is reserved for future use.
			phyCommPCH	Integer16	The medium and the band (PLC) or channel (RF) used to communicate with this node. This field is coded as the PRO.PCH field of Table 28 of 4.4.2.6.5.1.

6.2.3.6 MAC security attributes

Table 111 – MAC security attributes

Attribute Name	Id	Size	Description
macSecDUK	0x005B	128 bits	Device Unique Key to use in initial key derivation functions. The key shall be updated immediately; it shall not require re-registering the node. As a guideline, the Base Node should store both the old and new keys until the node has complete a successful registration with the new one, in the reception of a REG_REQ the Base Node should authenticate with the new key and if failed try again with the old one. Access to this PIB shall have the following restrictions: • Is write only, shall not be read. • Shall only be available if the underlying connection is encrypted, authenticated and unicast.
MACUpdateKeysTime	0x005C	32 bits	Maximum time in seconds allowed using the same SWK or WK. After that time the keys shall no longer be considered valid. The maximum allowed value for this PIB is defined in Table 14, the value depends on the number of channels.

6.2.3.7 Action PIB attributes

Some of the conformance tests require triggering certain actions on Service Nodes and Base Nodes. The following table lists the set of action attributes that need to be supported by all implementations.

Table 112 - Action PIB attributes

<table>
<tr><th>Attribute Name</th><th>Id</th><th>M</th><th>Size (bytes)</th><th colspan="3">Description</th></tr>
<tr><td>MACActionTxData</td><td>0x0060</td><td>SN</td><td>1</td><td colspan="3">Total number of PPDUs correctly decoded. Useful for PHY layer to estimate FER.</td></tr>
<tr><td>MACActionConnClose</td><td>0x0061</td><td>SN</td><td>1</td><td colspan="3">Trigger to close one of the open connections.</td></tr>
<tr><td>MACActionRegReject</td><td>0x0062</td><td>SN</td><td>1</td><td colspan="3">Trigger to reject incoming registration request.</td></tr>
<tr><td>MACActionProReject</td><td>0x0063</td><td>SN</td><td>1</td><td colspan="3">Trigger to reject incoming promotion request.</td></tr>
<tr><td>MACActionUnregister</td><td>0x0064</td><td>SN</td><td>1</td><td colspan="3">Trigger to unregister from the Subnetwork.</td></tr>
<tr><td>MACActionPromote</td><td>0x0065</td><td>BN</td><td>6</td><td colspan="3">Trigger to promote a given Service Node from the Subnetwork. This action refers to a promotion process on the same medium and on the same band (PLC) or channel (RF) a Service Node is connected to the Subnetwork.

PARAM: EUI-48 of the node being promoted.</td></tr>
<tr><td>MACActionDemote</td><td>0x0066</td><td>BN</td><td>6</td><td colspan="3">Trigger to demote a given Service Node from the Subnetwork. This action refers to a demotion process on the same medium and on the same band (PLC) or channel (RF) a Service Node is connected to the Subnetwork.

PARAM: EUI-48 of the node being demoted.</td></tr>
<tr><td>MACActionReject</td><td>0x0067</td><td>BN</td><td></td><td colspan="3">Rejects or stops (toggles) rejecting packets of a certain type</td></tr>
<tr><td colspan="4" rowspan="4"></td><td>Entry Element</td><td>Size</td><td>Description</td></tr>
<tr><td>Node</td><td>6</td><td>EUI 48 of the Node</td></tr>
<tr><td>Reject</td><td>1</td><td>1 – Reject
0 – Stop Rejecting</td></tr>
<tr><td>Type</td><td>1</td><td>0 – rejects PRO_REQ_S
1 – rejects PRM
2 – rejects CON_REQ_S

3- rejects REG_REQ</td></tr>
<tr><td>MACAliveTime</td><td>0x0068</td><td>BN</td><td>1</td><td colspan="3">Forces alive time for the network or sets it as automatic.
<table><tr><th>Value</th><th>macAliveTimeMode</th></tr></table></td></tr>
</table>

<table>
<tr><th>Attribute Name</th><th>Id</th><th>M</th><th>Size (bytes)</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td></td><td>
<table>
<tr><th></th><th>0</th><th>1</th></tr>
<tr><td>0x00</td><td>128s</td><td>32s</td></tr>
<tr><td>0x01</td><td>256s</td><td>64s</td></tr>
<tr><td>0x02</td><td>512s</td><td>128s</td></tr>
<tr><td>0x03</td><td>2048s</td><td>256s</td></tr>
<tr><td>0x04</td><td>4096s</td><td>512s</td></tr>
<tr><td>0x05</td><td>8192s</td><td>1024s</td></tr>
<tr><td>0x06</td><td>16384s</td><td>2048s</td></tr>
<tr><td>0x07</td><td>32768s</td><td>4096s</td></tr>
<tr><td>0xFF</td><td colspan="2">Reset alive time to the configured value.</td></tr>
</table>
</td></tr>
<tr><td></td><td>0x0069</td><td></td><td></td><td>Deprecated since v1.3.6 and reserved for future use</td></tr>
<tr><td>MACActionBroadcastDataBurst</td><td>0x006A</td><td>BN</td><td></td><td>Send a burst of data PDU-s with a test sequence using broadcast</td></tr>
<tr><td colspan="4"></td><td>
<table>
<tr><th>Entry Element</th><th>Size</th><th>Description</th></tr>
<tr><td>Number</td><td>4</td><td>Number of PDUs to be sent</td></tr>
<tr><td>DataLength</td><td>1</td><td>Size of data packet to send</td></tr>
<tr><td>DutyCycle</td><td>1</td><td>Average duty cycle (%). It must be the average because of the randomness of the CSMA/CA</td></tr>
<tr><td>LCID</td><td>2</td><td>LCID of the broadcast data to be sent</td></tr>
<tr><td>Priority</td><td>1</td><td>Priority of data packets to be sent</td></tr>
</table>
</td></tr>
<tr><td>MACActionMgmtCon</td><td>0x006B</td><td>BN</td><td></td><td>Forces establishment/close of the management connection</td></tr>
<tr><td colspan="4"></td><td>
<table>
<tr><th>Entry Element</th><th>Size</th><th>Description</th></tr>
<tr><td>Node</td><td>6</td><td>EUI-48 of the Service Node</td></tr>
<tr><td>Connect</td><td>1</td><td>0 – Close the management connection</td></tr>
</table>
</td></tr>
</table>

Attribute Name	Id	M	Size (bytes)	Description		
						1 – Open the management connection
MACActionMgmtMul	0x006C	BN		Forces establishment/close of the management multicast connection		
				Entry Element	**Size**	**Description**
				Node	6	EUI-48 of the Service Node
				Join	1	0 – Leave the management multicast connection 1 – Join the management multicast connection
MACActionUnregisterBN	0x006D	BN	6	Trigger to unregister a given Service Node from the Subnetwork. PARAM: EUI-48 of the node being unregistered.		
MACActionConnCloseBN	0x006E	BN		Trigger to close an open connection.		
				Entry element	**Size**	**Description**
				node	6	Eui48 of the node
				LCID	2	LCID of the connection to be closed.
MACActionSegmented 4-32	0x006F	BN		• Trigger data transfer whit segmentation mechanism working (Convergence Layer) • Transmit PPDUs over established CL 4-32 Connection (with segmentation) • Trigger at least 1 packet segmented in at least 3 frames		
				Entry Element	**Size**	**Description**
				Node	6	EUI-48 of the Service Node
				Length	2	Length of the data being transmitted (number or segments will depend on this length)
MACActionAppemuDataBurst	0x0080	BN		Send a burst of data PDU-s with a test sequence using the Appemu connection to the node (if any)		

Attribute Name	Id	M	Size (bytes)	Description		
				The data shall be transmitted with the flush bit to cero (0) when possible.		
				Entry Element	**Size**	**Description**
				Node	6	EUI-48 of the Service Node
				Number	4	Number of PDU-s to be sent
				DataLength	1	Size of the data packets to be sent
				DutyCycle	1	Average duty cycle (percentage). It must be the average because of the randomness of the CSMA/CA
MACActionMgmtData Burst	0x0081	M		Send a burst of data PDU-s with a test sequence using the Management connection to the node (if any). The data shall be transmitted with the flush bit set to zero (0) when possible.		
				Entry Element	**Size**	**Description**
				Node	6	EUI-48 of the Service Node, In service node this field will be ignored
				Number	4	Number of PDU-s to be sent
				DataLength	1	Size of the data packets to be sent
				DutyCycle	1	Average duty cycle (percentage). It must be the average because of the randomness of the CSMA/CA

5163 #### 6.2.3.8 MAC Network performance attributes

Attribute Name	Id	M	Size (bytes)	Valid Range	Description
macNetworkUpTime	0x0100	BN	4	0 – 0xFFFFFFFF	Period in seconds from the instant when the BN started to send beacons. This attribute is maintained only in the Base Node.

Attribute Name	Id	M	Size (bytes)	Valid Range	Description
macNetworkAllocatedBeacons	0x0101	BN	2	0 - 16256	Allocated beacons in a superframe, calculated as the sum of all beacons transmitted in the Subnetwork during a superframe. The number of beacons transmitted by a device in a superframe depends on the transmission frequency (BCN.FRQ) associated to BPDU. This attribute is maintained only in the Base Node.
macNetworkPromotionsCounter	0x0102	BN	4	0 – 0xFFFFFFFF	Number of successful Promotions processes (single and double) since last network reset. This attribute is maintained only in the Base Node.
macNetworkDemotionsCounter	0x0103	BN	4	0 – 0xFFFFFFFF	Number of Demotions events since last network reset. This attribute is maintained only in the Base Node.
macNetworkRegistrationsCounter	0x0104	BN	4	0 – 0xFFFFFFFF	Number of successful Registration processes since last network reset. This attribute is maintained only in the Base Node.
macNetworkUnregistrationsCounter	0x0105	BN	4	0 – 0xFFFFFFFF	Number of Unregistration events since last network reset. This attribute is maintained only in the Base Node.
macNetworkCoverage	0x0106	BN	2	0-10000	Network coverage value expressed in percentage hundredths. TBD: How to calculate it. This attribute is maintained only in the Base Node.

Attribute Name	Id	M	Size (bytes)	Valid Range	Description
macNetworkNodesCount	0x0107	BN	2	0-65535	Number of unique Service Nodes that completed registration process with success at least once since last network reset. This attribute is maintained only in the Base Node.
macNetworkAvailability	0x0108	BN	6		• Time, in seconds, in which Service Nodes were in registered state, calculated as follow: $\sum_{i=1}^{n}(Treg_i)$ Where: Treg: is the time in which a particular node was considered in registered state since the previous reading of the attribute. The Treg time can be referred to more than a single time interval, e.g. if an unregistration and a following new registration events associated to the same node occur both after the previous reading of the attribute and before the current reading, the Treg value associated to node will be the sum of 2 different time intervals. n: is the number of unique nodes that were considered in registered state at least once since the previous reading of the attribute. The number is not decreased in case an unregistration event occurs after the previous reading of the attribute and before the current reading. • Number of nodes involved in previous calculation (n). This attribute is reset after each reading. This attribute is maintained only in the Base Node.

<table>
<tr><th>Attribute Name</th><th>Id</th><th>M</th><th>Size (bytes)</th><th>Valid Range</th><th colspan="3">Description</th></tr>
<tr><td colspan="5"></td><td>Entry Element</td><td>Size (bytes)</td><td>Description</td></tr>
<tr><td colspan="5"></td><td>LastPeriodAvailability</td><td>4</td><td>$\sum_{i=1}^{n}(Treg_i)$</td></tr>
<tr><td colspan="5"></td><td>NodesNum</td><td>2</td><td>N</td></tr>
</table>

macListExtDevicesInfo	0x0150	List of Service Nodes registered successfully at least once since last reset of Base Node. This list is maintained by the Base Node only. TBD: Entries.

6.2.4 Application PIB attributes

The following PIB attributes are used for general administration and maintenance of a OFDM PRIME compliant device. These attributes do not affect the communication functionality, but enable easier administration.

These attributes shall be supported by both Base Node and Service Node devices.

Table 113 - Applications PIB attributes

Attribute Name	Size (in bits)	Id	Description
AppFwVersion	128	0x0075	Textual description of firmware version running on device.
AppVendorId	16	0x0076	PRIME Alliance assigned unique vendor identifier.
AppProductId	16	0x0077	Vendor assigned unique identifier for specific product.

<table>
<tr><th>Attribute Name</th><th>Size (in bits)</th><th>Id</th><th>Description</th></tr>
<tr><td>AppListZCStatus</td><td></td><td>0x0078</td><td>Zero Cross Status list. This list contains entry for each available zero cross detection circuits available in the system. Each element is sent together with reference time of zero cross close to frame beginning. If multiple entries are requested at the same time only first will be replied.
<table>
<tr><th>Entry element</th><th>Type</th><th>Description</th></tr>
<tr><td>ZCStatus</td><td>Byte</td><td>Bit 7 : reserved, always 0
Bits 5-6 : Terminal Block number
0 : invalid
1 : terminal block 1
2 : terminal block 2
3 : terminal block 3
Bits 3-4 : Direction
0 : unknown direction
1 : falling
2 : raising
3 : reserved
Bits 0-2: Status
0 : available but unknown status
1 : regular at 50Hz
2 : regular at 60Hz
3-5: reserved
6: irregular intervals
7: not available</td></tr>
</table>
</td></tr>
</table>

6.3 Firmware upgrade

6.3.1 General

The present section specifies firmware upgrade. Devices supporting PRIME may have several firmware inside them, at least one supporting the Application itself, and the one related to the PRIME protocol. Although it is possible that the application can perform the firmware upgrade of all the firmware images of the device, for instance DLMS/COSEM image transfer, using COSEM image transfer object, supporting PRIME firmware upgrade is mandatory in order to process to PRIME firmware upgrade independently of the application.

6.3.2 Requirements and features

This section specifies the firmware upgrade application, which is unique and mandatory for Base Nodes and Service Nodes.

The most important features of the Firmware Upgrade mechanism are listed below. See following chapters for more information. The FU mechanism:

- Shall be a part of management plane and therefore use the NULL SSCS, as specified in section 0

- Is able to work in unicast (default mode) and multicast (optional mode). The control messages are always sent using unicast connections, whereas data can be transmitted using both unicast and multicast. No broadcast should be used to transmit data.
- May change the data packet sizes according to the channel conditions. The packet size will not be changed during the download process.
- Is able to request basic information to the Service Nodes at anytime, such as device model, firmware version and FU protocol version.
- Shall be abortable at anytime.
- Shall check the integrity of the downloaded FW after completing the reception. In case of failure, the firmware upgrade application shall request a new retransmission.
- The new firmware shall be executed in the Service Nodes only if they are commanded to do so. The FU application shall have to be able to set the moment when the reset takes place.
- Must be able to reject the new firmware after a "test" period and switch to the old version. The duration of this test period has to be fixed by the FU mechanism.

6.3.3 General Description

6.3.3.1 General

The Firmware Upgrade mechanism is able to work in unicast and multicast modes. All control messages are sent using unicast connections, whereas the data can be sent via unicast (by default) or multicast (only if supported by the manufacturer). Note that in order to ensure correct reception of the FW when Service Nodes from different vendors are upgraded, data packets shall not be sent via broadcast. Only unicast and multicast are allowed. A Node will reply only to messages sent via unicast. See chapter 0 for a detailed description of the control and information messages used by the FU mechanism.

The unicast and multicast connections are set up by the Base Node. In case of supporting multicast, the Base Node shall request the Nodes from a specific vendor to join a specific multicast group, which is exclusively created to perform the firmware upgrade and is removed after finishing it.

As said before, it is up to the vendor to use unicast or multicast for transmitting the data. In case of unicast data transmission, please note that the use of ARQ is an optional feature. Some examples showing the traffic between the Base Node and the Service Nodes in unicast and multicast are provided in 6.3.5.4.

After completing the firmware download, each Service Node is committed by the Base Node to perform an integrity check on it. The firmware download will be restarted if the firmware image results to be corrupt. In other case, the Service Nodes will wait until they are commanded by the Base Node to execute the new firmware.

The FU mechanism can setup the instant when the recently downloaded firmware is executed on the Service Nodes. Thus, the Base Node can choose to restart all Nodes at the same time or in several steps. After restart, each Service Node runs the new firmware for a time period specified by the FU mechanism. If this period expires without receiving any confirmation from the Base Node, or the Base Node decides to abort the upgrade process, the Service Nodes will reject the new firmware and switch to the old version. In any other case (a confirmation message is received) the Service Nodes will consider the new firmware as the only valid version and delete the old one.

This is done in order to leave an “open back-door” in case that the new firmware is defect or corrupt. Please note that the Service Nodes are not allowed to discard any of the stored firmware versions until the final confirmation from the Base Node arrives or until the safety time period expires. The two last firmware upgrade steps explained above are shown in 0. See chapter 6.3.5.3 for a detailed description of the control messages.

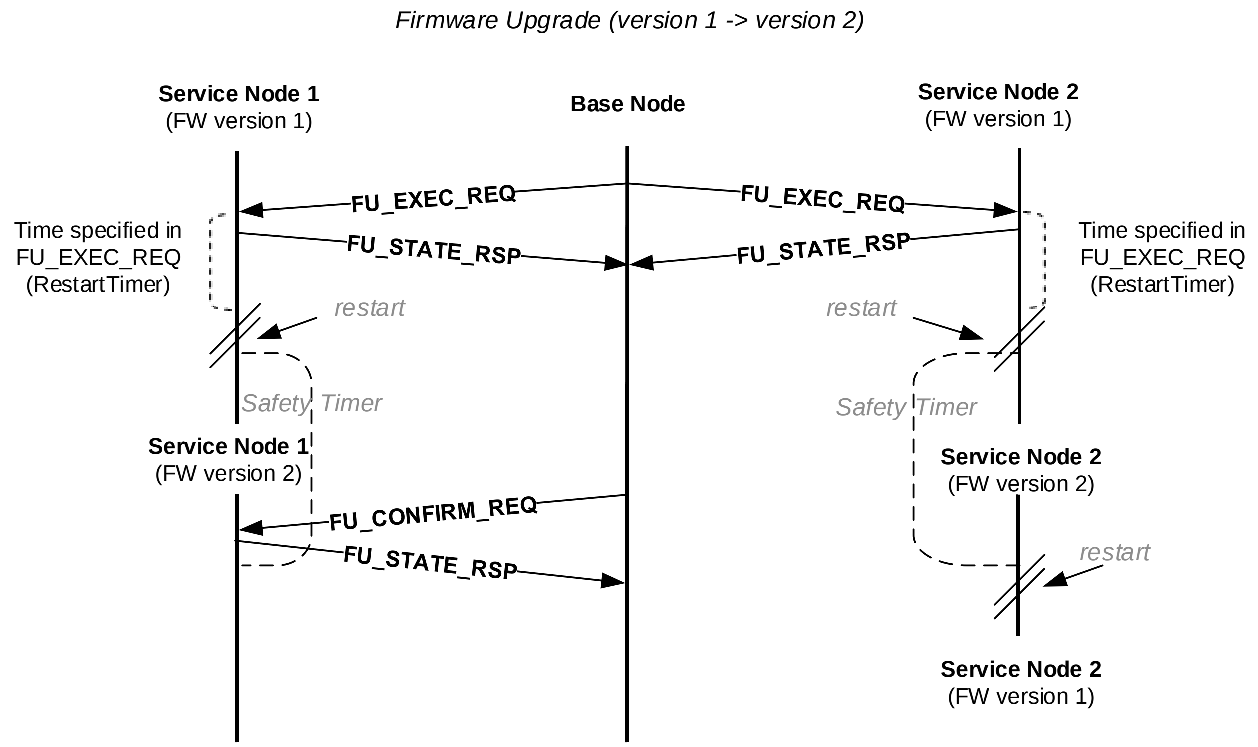

Figure 137 – Restarting de nodes and running the new firmware

Note: In normal circumstances, both Service Nodes should either accept or reject the new firmware version. Both possibilities are shown above simultaneously for academic purposes.

6.3.3.2 Signed firmware

The ”signed firmware” refers to the concatenation of the Firmware Image and the signature as shown in the Figure 138. For now on in the document will be refered as signed firmware.

Figure 138 – Signed firmware diagram

The payload transmitted in the Firmware Upgrade process shall be the signed firmware. For the SN to be able to differentiate both, the signature will have a length defined in the FU_INIT_REQ’s “Signature length” field.

6.3.3.3 Segmentation

The signed image is the information to be transferred, in order to process a firmware upgrade. The size of the signed image will be called "*ImageSize*", and is measured in bytes. This image is divided in smaller elements called pages that are easier to be transferred in packets. The "*PageSize*" may be one of the following: 32 bytes, 64 bytes, 128 bytes or 192 bytes. This implies that the number of pages in a signed image is calculated by the following formula:

$$PageCount = \left\lceil \frac{ImageSize}{PageSize} \right\rceil + 1$$

Every page will have a size specified by *PageSize,* except the last one that will contain the remaining bytes up to *ImageSize.*

The *PageSize* is configured by the Base Node and notified during the initialization of the Firmware Upgrade process, and imposes a condition in the size of the packets being transferred by the protocol.

6.3.4 Firmware upgrade PIB attributes

The following PIB attributes shall be supported by Service Nodes to support the firmware download application.

Table 114 - FU PIB attributes

Attribute Name	Size (in bits)	Id	Description
AppFwdlRunning	16	0x0070	Indicate if a firmware download is in progress or not. 0 = No firmware download; 1 = Firmware download in progress.
AppFwdlRxPktCount	16	0x0071	Count of firmware download packets that have been received until the time of query.

6.3.5 State machine

6.3.5.1 General

A Service Node using the Firmware Upgrade service will be in one of five possible states: *Idle, Receiving, Complete, Countdown* and *Upgrade*. These states, the events triggering them and the resulting actions/output messages are detailed below.

Table 115 - FU State Machine

	Description	Event	Output (or action to be performed)	Next state
Idle	The FU application is doing nothing.	Receive FU_INFO_REQ	FU_INFO_RSP	*Idle*
		Receive FU_STATE_REQ	FU_STATE_RSP (.State = 0)	*Idle*
		Receive FU_MISS_REQ	FU_STATE_RSP (.State = 0)	*Idle*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 1)	*Receiving*
		Receive FU_DATA	(ignore)	*Idle*
		Receive FU_EXEC_REQ	FU_STATE_RSP (.State = 0)	*Idle*
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 0)	*Idle*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0)	*Idle*
		Any exception		*Exception*
Receiving	The FU application is receiving the Signed firmware.	Complete FW received, CRC OK and Signature OK		*Complete*
		Complete FW received and CRC not Ok or signature not OK		*Exception*
		Receive FU_INFO_REQ	FU_INFO_RSP	*Receiving*
		Receive FU_STATE_REQ	FU_STATE_RSP (.State = 1)	*Receiving*
		Receive FU_MISS_REQ	FU_MISS_LIST or FU_MISS_BITMAP	*Receiving*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 1)	*Receiving*
		Receive FU_DATA	(receiving data, normal behavior)	*Receiving*
		Receive FU_EXEC_REQ	FU_STATE_RSP (.State = 1)	*Receiving*
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 1)	*Receiving*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0); (switch to *Idle)*	*Idle*
		Any exception		*Exception*
Complete	Upgrade completed, image integrity ok, the SN is waiting to reboot with the new FW version.	Receive FU_INFO_REQ	FU_INFO_RSP	*Complete*
		Receive FU_STATE_REQ	FU_STATE_RSP (.State = 2)	*Complete*
		Receive FU_MISS_REQ	FU_STATE_RSP (.State = 2)	*Complete*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 2)	*Complete*
		Receive FU_DATA	(ignore)	*Complete*
		Receive FU_EXEC_REQ with *RestartTimer* != 0	FU_STATE_RSP (.State = 3)	*Countdown*
		Receive FU_EXEC_REQ with *RestartTimer* = 0	FU_STATE_RSP (.State = 4)	*Upgrade*

	Description	Event	Output (or action to be performed)	Next state
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 2)	*Complete*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0); (switch to *Idle*)	*Idle*
		Any exception		*Exception*
Countdown	Waiting until *RestartTimer* expires.	*RestartTimer* expires	(switch to *Upgrade)*	*Upgrade*
		Receive FU_INFO_REQ	FU_INFO_RSP	*Countdown*
		Receive FU_STATE_REQ	FU_STATE_RSP (.State = 3)	*Countdown*
		Receive FU_MISS_REQ	FU_STATE_RSP (.State = 3)	*Countdown*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 3)	*Countdown*
		Receive FU_DATA	(ignore)	*Countdown*
		Receive FU_EXEC_REQ with *RestartTimer* != 0	FU_STATE_RSP (.State = 3); (update *RestartTimer* and *SafetyTimer*)	*Countdown*
		Receive FU_EXEC_REQ with *RestartTimer* = 0	FU_STATE_RSP (.State = 4); (update *RestartTimer* and *SafetyTimer*)	*Upgrade*
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 3)	*Countdown*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0); (switch to *Idle*)	*Idle*
		Any exception		*Exception*
Upgrade	The FU mechanism reboots using the new FW image and tests it for *SafetyTimer* seconds.	*SafetyTimer* expires	FU_STATE_RSP (.State = 4); (switch to *Exception*, FW rejected)	*Exception*
		Receive FU_INFO_REQ	FU_INFO_RSP	*Upgrade*
		Receive FU_STATE_REQ	FU_STATE_RSP (.State = 4)	*Upgrade*
		Receive FU_MISS_REQ	FU_STATE_RSP (.State = 4)	*Upgrade*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 4)	*Upgrade*
		Receive FU_DATA	(ignore)	*Upgrade*
		Receive FU_EXEC_REQ	FU_STATE_RSP (.State = 4)	*Upgrade*
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 0); (switch to *Idle*, FW accepted)	*Idle*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0); (switch to *Idle*, FW rejected)	*Idle*
		Any exception		*Exception*
Exception		Receive FU_INFO_REQ	FU_INFO_RSP	*Exception*

	Description	Event	Output (or action to be performed)	Next state
	Upon any exception on the firmware upgrade service node will go into this state	Receive FU_STATE_REQ	FU_STATE_RSP (.State = 5)	*Exception*
		Receive FU_MISS_REQ	FU_STATE_RSP (.State = 5)	*Exception*
		Receive FU_INIT_REQ	FU_STATE_RSP (.State = 5)	*Exception*
		Receive FU_DATA	(ignore)	*Exception*
		Receive FU_EXEC_REQ	FU_STATE_RSP (.State = 5)	*Exception*
		Receive FU_CONFIRM_REQ	FU_STATE_RSP (.State = 5)	*Exception*
		Receive FU_KILL_REQ	FU_STATE_RSP (.State = 0)	*Idle*

The state diagram is represented below. Please note that only the most relevant events are shown in the state transitions. See 6.3.5.3 for a detailed description of each state's behavior and the events and actions related to them. A short description of each state is provided in 6.3.5.2.

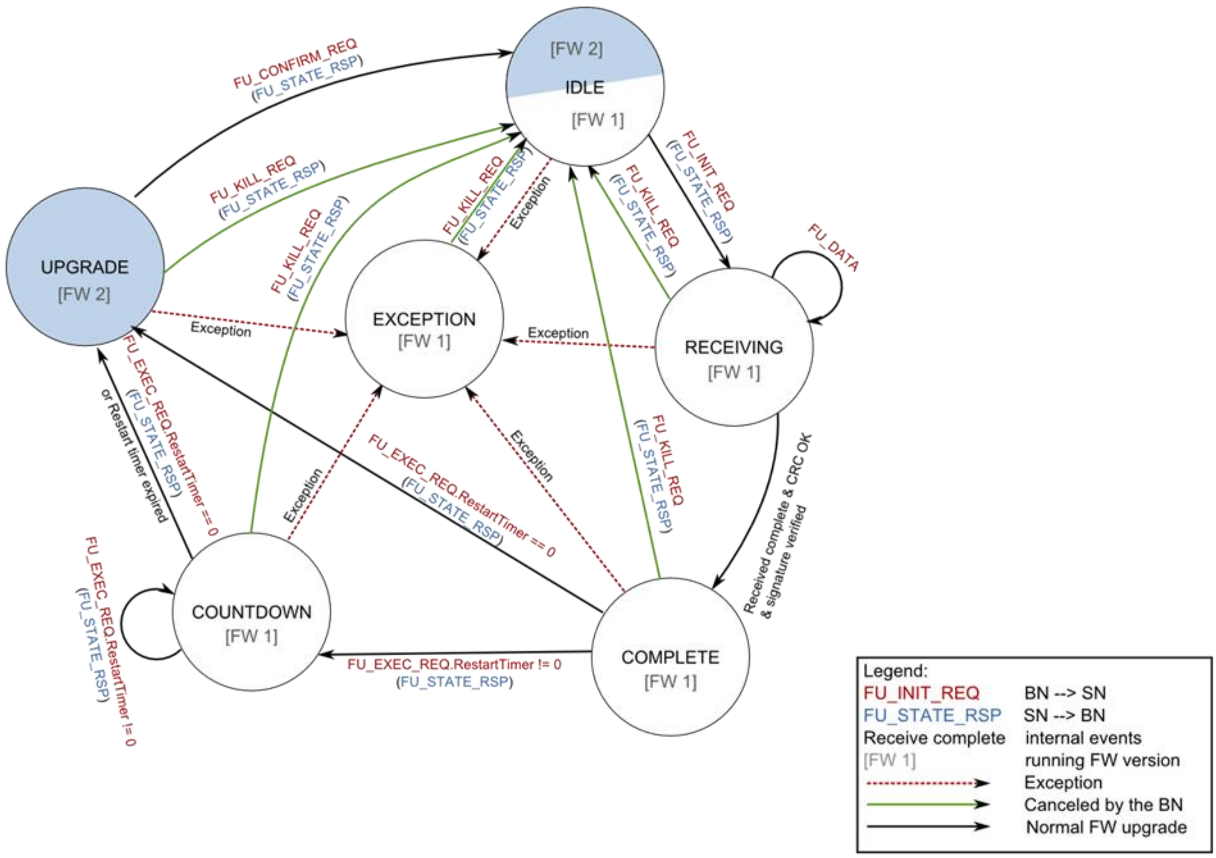

Figure 139 - Firmware Upgrade mechanism, state diagram

6.3.5.2 State description

6.3.5.2.1 Idle

The Service Nodes are in “Idle” state when they are not performing a firmware upgrade. The reception of a FU_INIT_REQ message is the only event that forces the Service Node to switch to the next state (“*Receiving*”). FU_KILL_REQ aborts the upgrade process and forces the Service Nodes to switch from any state to “*Idle*”.

6.3.5.2.2 Receiving

The Service Nodes receive the signed firmware via FU_DATA messages. Service Nodes report complete reception of the image answering with either an empty FU_MISS_LIST or an empty FU_MISS_BITMAP to the FU_MISS_REQ requests sent by the BN.

If during the reception of the signed firmware the Service Node receives a block with a length that differs from the one configured in FU_INIT_REQ or a with an packet index out of bounds it should switch to “Exception” state with “Protocol” code.

Once the download is complete, a Service Node shall check the integrity of the signed firmware by CRC calculation. If the CRC is wrong, the SN shall drop the signed firmware and switch to “Exception” state with “CRC verification fail” exception code.

If the CRC results to be ok, the SN shall verify that the signed image is correctly signed with the manufacturer’s key. In case this verification fails, the SN shall drop the signed firmware and switch to “Exception” state with “Signature verification fail” exception code.

If the signature is verified successfully, the SN shall switch to “Complete” state.

The CRC check on the complete signed firmware and the later signature verification is mandatory, and is automatically started by the SNs. The service node shall not accept any image that is not properly signed.

Note that these checks at SN side are not immediate. There may be a not negligible time interval between the message sent by the SN reporting that the reception is complete and the transition to “Complete”.

6.3.5.2.3 Complete

A Service Node in “*Complete*” state waits until reception of a FU_EXEC_REQ message. The Service Node may switch either to “*Countdown*” or “*Upgrade*” depending on the field *RestartTimer,* which specifies in which instant the Service Node has to reboot using the new firmware. If *RestartTimer =* 0, the Service Node immediately switches to “*Upgrade*”; else, the Service Node switches to “Countdown”.

6.3.5.2.4 Countdown

A Service Node in “*Countdown*” state waits a period of time specified in the *RestartTimer* field of a previous FU_EXEC_REQ message. When this timer expires, it automatically switches to “*Upgrade*”.

FU_EXEC_REQ can be used in “*Countdown*” state to reset *RestartTimer* and *SafetyTimer*. In this case, both timers have to be specified in FU_EXEC_REQ because both will be overwritten. Note that it is possible to force the Node to immediately switch from “*Countdown*” to “*Upgrade*” state setting *RestartTimer* to zero.

6.3.5.2.5 Upgrade

A Service Node in *"Upgrade"* state shall run the new firmware during a time period specified in FU_EXEC_REQ.SafetyTimer.

If it does not receive any confirmation at all before this timer expires, the Service Node discards the new FW, reboots with the old version and switches to *"Exception"* state with "Safety time expired" code.

In case the SN receives a FU_KILL_REQ message it will discard the new FW, reboot with the old version and switch to "Idle" state.

6.3.5.2.6 Exception

A Service Node can enter in exception state from any other state upon an event related to the Firmware Upgrade that shall be notified to the Base Node as an exception.

In case the SN receives a FU_KILL_REQ in "Exception" state it shall discard any ongoing FW upgrade progress and switch to "idle" state. On any other event the SN will take no action and respond a FU_STATE_RSP to any request with the code describing the specific exception. Exception state has a code, that shall have information that can give more information on the exception happened. This code shall set the "temporary" flag in case restarting the same Firmware Upgrade process could turn in success.

There is a field up to the manufacturer of one byte for additional information about the exception, the format of this field is out of the scope of this specification.

6.3.5.3 Control packets

6.3.5.3.1 FU_INIT_REQ

The Base Node sends this packet in order to configure a Service Node for the Firmware Upgrade. If the Service Node is in *"Idle"* state, it will change its state from *"Idle"* to *"Receiving"* and will answer with FU_STATE_RSP. In any other case it will just answer sending FU_STATE_RSP.

The content of FU_INIT_REQ is shown below.

Table 116 - Fields of FU_INIT_REQ

Field	Length	Description
Type	4 bits	0 = FU_INIT_REQ.
Version	2 bits	0 for this version of the protocol.
PageSize	2 bits	0 for a PageSize=32; 1 for a PageSize=64; 2 for a PageSize=128; 3 for a PageSize=192.
ImageSize	32 bits	Size of the signed firmware in bytes.

Field	Length	Description
CRC	32 bits	CRC of the signed firmware. The input polynomial M(x) is formed as a polynomial whose coefficients are bits of the data being checked (the first bit to check is the highest order coefficient and the last bit to check is the coefficient of order zero). The Generator polynomial for the CRC is $G(x)=x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^7+x^5+x^4+x^2+x+1$. The remainder R(x) is calculated as the remainder from the division of $M(x)\cdot x^{32}$ by G(x). The coefficients of the remainder will then be the resulting CRC.
Signature algorithm	4 bits	0 – no signature (not recommended to use in field, for testing purposes only) 1 – RSA 3072 + SHA-256 2 – ECDSA 256 + SHA-256 3-15 – Reserved for future use
Reserved	4 bits	Shall be 0 for this version of the document. Reserved for future use.
Signature length	8 bits	Length of the signature part of the signed firmware in bytes.

6.3.5.3.2 FU_EXEC_REQ

This packet is used by the Base Node to command a Service Node in "*Complete*" state to restart using the new firmware, once the complete image has been received by the Service Node. FU_EXEC_REQ specifies when the Service Node has to restart and how long the "safety" period shall be, as explained in 6.3.5.2.5. Additionally, FU_EXEC_REQ can be used in "*Countdown*" state to reset the restart and the safety timers.

Depending on the value of *RestartTimer*, a Service Node in *"Complete"* state may change either to *"Countdown"* or to *"Upgrade"* state. In any case, the Service Node answers with FU_STATE_RSP.

In "*Countdown*" state, the Base Node can reset *RestartTimer* and *SafetyTimer* with a FU_EXEC_REQ message (both timers must be specified in the message because both will be overwritten).

The content of this packet is described below.

Table 117 - Fields of FU_EXEC_REQ

Field	Length	Description
Type	4 bits	1 = FU_EXEC_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0 .
RestartTimer	16 bits	0..65536 seconds; time before restarting with new FW.

Field	Length	Description
SafetyTimer	16 bits	0..65536 seconds; time to test the new FW. It starts when the "*Upgrade*"state is entered.

6.3.5.3.3 FU_CONFIRM_REQ

This packet is sent by the Base Node to a Service Node in *"Upgrade"* state to confirm the current FW. If the Service Node receives this message, it discards the old FW version and switches to *"Idle"* state. The Service Node answers with FU_STATE_RSP when receiving this message.

In any other state, the Service Node answers with FU_STATE_RSP without performing any additional actions.

This packet contains the fields described below.

Table 118 - Fields of FU_CONFIRM_REQ

Field	Length	Description
Type	4 bits	2 = FU_CONFIRM_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.

6.3.5.3.4 FU_STATE_REQ

This packet is sent by the Base Node in order to get the Firmware Upgrade state of a Service Node. The Service Node will answer with FU_STATE_RSP.

This packet contains the fields described below.

Table 119 - Fields of FU_STATE_REQ

Field	Length	Description
Type	4 bits	3 = FU_STATE_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.

6.3.5.3.5 FU_KILL_REQ

The Base Node sends this message to terminate the Firmware Upgrade process. A Service Node receiving this message will automatically switch to *"Idle"* state and optionally delete the downloaded data. The Service Node replies sending FU_STATE_RSP.

The content of this packet is described below.

Table 120 - Fields of FU_KILL_REQ

Field	Length	Description
Type	4 bits	4 = FU_KILL_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.

6.3.5.3.6 FU_STATE_RSP

6.3.5.3.6.1 General

This packet is sent by the Service Node as an answer to FU_STATE_REQ, FU_KILL_REQ, FU_EXEC_REQ, FU_CONFIRM_REQ or FU_INIT_REQ messages received through the unicast connection. It is used to notify the Firmware Upgrade state in a Service Node.

Additionally, FU_STATE_RSP is used as default response to all events that happen in states where they are not foreseen (e.g. FU_EXEC_REQ in "*Receiving*" state, FU_INIT_REQ in "*Upgrade*"...).

This packet contains the fields described below.

Table 121 - Fields of FU_STATE_RSP

Field	Length	Description
Type	4 bits	5 = FU_STATE_RSP.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
State	4 bits	0 for Idle; 1 for Receiving; 2 for Complete; 3 for Countdown; 4 for Upgrade; 5 for Exception 6 to 15 reserved for future use.
Reserved	4 bits	0.
CRC	32 bits	CRC as the one received in the CRC field of FU_INIT_REQ.
Received	32 bits	Number of received pages (this field should only be present if State is Receiving).

Field	Length	Description
Exception code	16 bits	Exception code describing the exception ocurred (this field shall only be present if State is Exception) This field is described with detail in section 6.3.5.3.6.2

6.3.5.3.6.2 Exception code

The exception code has a number of fields that give more information to the Base Node about the exception that have happened during the Firmware Upgrade process.

Table 122 – Fields of Exception code

Field	Length	Description
Permanent	1 bit	Flag used to inform if a retry on the firmware upgrade will not success, because the exception being permanent. 0 if the exception is temporary 1 if the exception is permanent
Code	7 bits	Code describing the type of exception that happened **0 – General**: for an exception that do not fit any of the other codes **1 – Protocol:** Page number out of bounds, page length mismatch from FU_INIT_REQ... **2 – CRC verification fail:** If the CRC verification failed **3 – Invalid image:** If the image was not a firmware image or not for the device **4 – Signature verification fail:** the signature verification failed. **5 – Safety time expired**: the safety time in ”upgrade” state expires
Manufacturer code	8 bits	Field that provides additional detail about the exception. This code is up to the manufacturer.

6.3.5.3.7 FU_DATA

This packet is sent by the Base Node to transfer a page of the signed firmware to a Service Node. No answer is expected by the Base Node.

This packet contains the fields described below.

Table 123 - Fields of FU_DATA

Field	Length	Description
Type	4 bits	6 = FU_DATA.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
PageIndex	32 bits	Index of the page being transmitted.
Reserved	8 bits	Padding byte for 16-bit devices. Set to 0 by default.
Data	*Variable*	Data of the page. The length of this data is PageSize (32, 64, 128 or 192) bytes for every page, except the last one that will have the remaining bytes of the image.

6.3.5.3.8 FU_MISS_REQ

This packet is sent by the Base Node to a Service Node to request information about the pages that are still to be received.

If the Service Node is in "*Receiving*" state it will answer with a FU_MISS_BITMAP or FU_MISS_LIST message. If the Service Node is in any other state it will answer with a FU_STATE_RSP.

This packet contains the fields described below.

Table 124 - Fields of FU_MISS_REQ

Field	Length	Description
Type	4 bits	7 = FU_MISS_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
PageIndex	32 bits	Starting point to gather information about missing pages.

6.3.5.3.9 FU_MISS_BITMAP

This packet is sent by the Service Node as an answer to a FU_MISS_REQ. It carries the information about the pages that are still to be received.

This packet will contain the fields described below.

Table 125 - Fields of FU_MISS_BITMAP

Field	Length	Description
Type	4 bits	8 = FU_MISS_BITMAP.

Field	Length	Description
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
Received	32bits	Number of received pages.
PageIndex	32 bits	Page index of the page represented by the first bit of the bitmap. It should be the same as the *PageIndex* field in FU_MISS_REQ messages, or a posterior one. If it is posterior, it means that the pages in between are already received. In this case, if all pages after the *PageIndex* specified in FU_MISS_REQ have been received, the Service Node shall start looking from the beginning (*PageIndex* = 0).
Bitmap	*Variable*	This bitmap contains the information about the status of each page. The first bit (most significant bit of the first byte) represents the status of the page specified by *PageIndex.* The next bit represents the status of the *PageIndex+1* and so on. A '1' represents that a page is missing, a '0' represents that the page is already received. After the bit that represents the last page in the image, it is allowed to overflow including bits that represent the missing status of the page with index zero. The maximum length of this field is *PageSize* bytes.

It is up to the Service Node to decide to send this type of packet or a FU_MISS_LIST message. It is usually more efficient to transmit this kind of packets when the number of missing packets is not very low. But it is up to the implementation to transmit one type of packet or the other. The Base Node should understand both.

In case a Service Node receives a FU_MISS_REQ during CRC calculation, it shall respond either with an empty FU_MISS_BITMAP or an empty FU_MISS_LIST.

6.3.5.3.10 FU_MISS_LIST

This packet is sent by the Service Node as an answer to a FU_MISS_REQ. It carries the information about the pages that are still to be received.

This packet will contain the fields described below.

Table 126 - Fields of FU_MISS_LIST

Field	Length	Description
Type	4 bits	9 = FU_MISS_LIST.

Field	Length	Description
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
Received	32 bits	Number of received pages.
PageIndexList	Variable	List of pages that are still to be received. Each page is represented by its PageIndex, coded as a 32 bit integer. These pages should be sorted in ascending order (low to high), being possible to overflow to the *PageIndex* equal to zero to continue from the beginning. The first page index should be the same as the *PageIndex* field in FU_MISS_REQ, or a posterior one. If it is posterior, it means that the pages in between are already received (by posterior it is allowed to overflow to the page index zero, to continue from the beginning). The maximum length of this field is *PageSize* bytes.

It is up to the Service Node to decide to transmit this packet type or a FU_MISS_BITMAP message. It is usually more efficient to transmit this kind of packets when the missing packets are very sparse, but it is implementation-dependent to transmit one type of packet or the other. The Base Node should understand both.

In case a Service Node receives a FU_MISS_REQ during CRC calculation, it shall respond either with an empty FU_MISS_BITMAP or an empty FU_MISS_LIST.

6.3.5.3.11 FU_INFO_REQ

This packet is sent by a Base Node to request information from a Service Node, such as manufacturer, device model, firmware version and other parameters specified by the manufacturer. The Service Node will answer with one or more FU_INFO_RSP packets.

This packet contains the fields described below.

Table 127 - Fields of FU_INFO_REQ

Field	Length	Description
Type	4 bits	10 = FU_INFO_REQ.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
InfoIdList	Variable	List of identifiers with the information to retrieve. Each identifier is 1 byte long.

Field	Length	Description
		The maximum length of this field is 32 bytes.

The following identifiers are defined:

Table 128 - InfoId possible values

InfoId	Name	Description
0	Manufacturer	Universal Identifier of the Manufacturer.
1	Model	Model of the product working as Service Node.
2	Firmware	Current firmware version being executed.
128-255	*Manufacturer specific*	Range of values that are manufacturer specific.

6.3.5.3.12 FU_INFO_RSP

This packet is sent by a Service Node as a response to a FU_INFO_REQ message from the Base Node. A Service Node may have to send more than one FU_INFO_RSP when replying to a information request by the Base Node.

This packet contains the fields described below.

Table 129 - Fields of FU_INFO_RSP

Field	Length	Description
Type	4 bits	11 = FU_INFO_RSP.
Version	2 bits	0 for this version of the protocol.
Reserved	2 bits	0.
InfoData	0 – 192 bytes	Data with the information requested by the Base Node. It may contain several entries (one for each requested identifier), each entry has a maximum size of 32 bytes. The maximum size of this field is 192 bytes (6 entries).

The InfoData field can contain several entries, the format of each entry is specified below.

Table 130 - Fields of each entry of InfoData in FU_INFO_RSP

Field	Length	Description
InfoId	8 bits	Identifier of the information as specified in 6.3.5.3.11.
Reserved	3 bits	0.
Length	5 bits	Length of the Data field (If Length is 0 it means that the specified InfoId is not supported by the specified device).
Data	0 – 30 bytes	Data with the information provided by the Service Node. Its content may depend on the meaning of the InfoId field. No value may be longer than 30 bytes.

6.3.5.4 Firmware integrity and authentication

6.3.5.4.1 General

The firmware integrity and authentication is ensured by two means: the firmware CRC and the firmware signature. Both CRC and signature verifications are performed in the state "Receiving", on the complete image after the receiving completion.

6.3.5.4.2 Image CRC

The role of the firmware upgrade CRC is to check the integrity of the image received from the Base Node, over the link Base Node – Service Node.

The Base node, before initiating the firmware upgrade process, calculates a 32 bits CRC on the complete image, using the Generator polynomial G(x)=x32+x26+x23+x22+x16+x12+x11+x10+x8+x7+x5+x4+x2+x+1, and appends the result at the end of the firmware upgrade payload.

After the receiving completion, the Service Node must verify the integrity of the whole image by the CRC recalculation. The firmware upgrade is deemed valid only when this CRC recalculation is successful.

6.3.5.4.3 Image signature

The role of the signature is to verify the integrity and the authenticity of the image as generated by the manufacturer. Indeed the firmware image, as generated by the image originator (the chip manufacturer) is provided to the Base Node via several different means. The firmware image signature provides evidence that the firmware image was not altered or substituted along all these transportation means and locations, and evidence that the concerned manufacturer is the originator.

The signature is generated by the originator of the firmware image, on the whole image using asymmetric key cryptography, and then included in the signed firmware to be delivered. The algorithm used for this purpose, how to equip the Service Nodes with the public key, and the infrastructure for certificate management are the scope of the firmware image generator. The algorithm used must comply with FIPS 186-4 standard, http://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.186-4.pdf, preferably ECDSA 256 bits or RSA 3072 bits as an alternate solution.

Firmware image originators are strongly recommended for equipping the entities having in charge the spreading of the firmware image with tools allowing them to process to the verification before the deployment.

After receiving the signed firmware the Service node must verify the firmware image signature. The image is deemed valid only when the verification is successful.

6.3.6 Examples

The figures below are an example of the traffic generated between the Base Node and the Service Node during the Firmware Upgrade process.

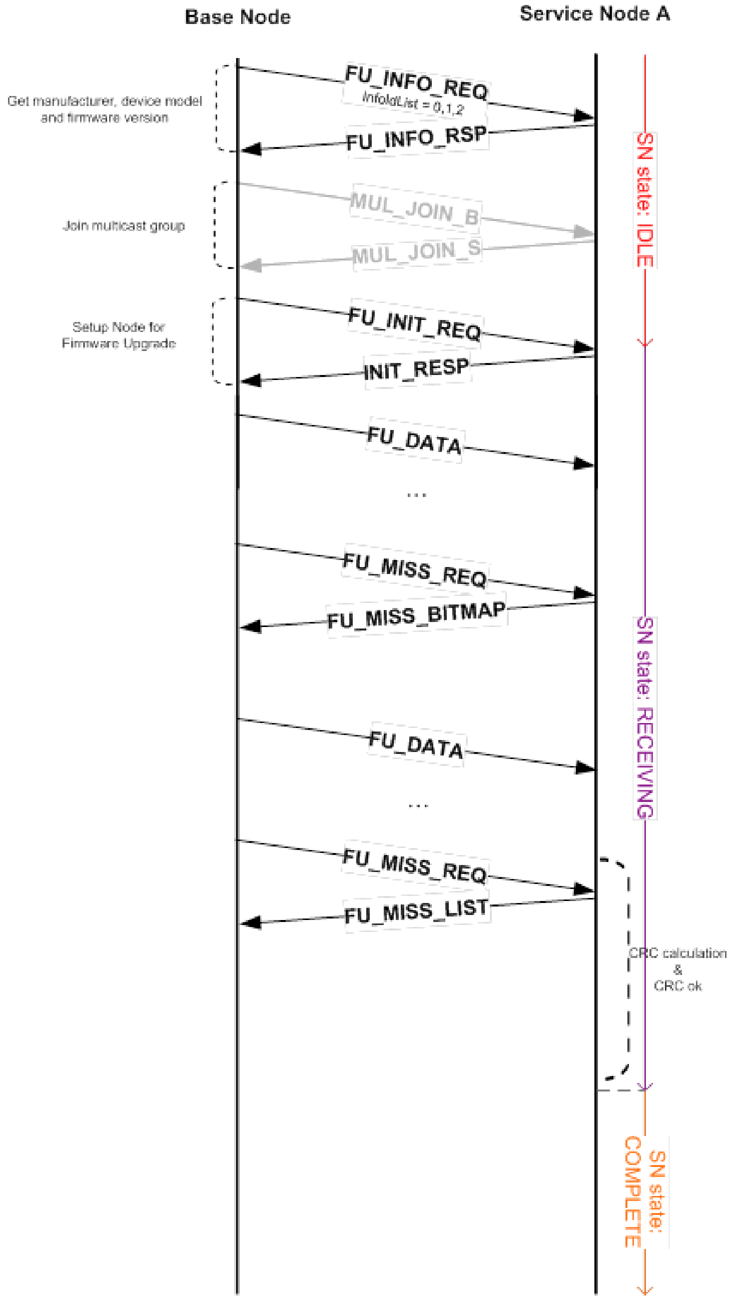

Figure 140 - Init Service Node and complete FW image

Figure 140 shows the initialization of the process, the FW download and the integrity check of the image. In the example above, the downloaded FW image is supposed to be complete before sending the last FU_MISS_REQ. The Base Node sends it to verify its bitmap. In this example, FU_MISS_LIST has an empty *PageIndexList* field, which means that the FW image is complete.

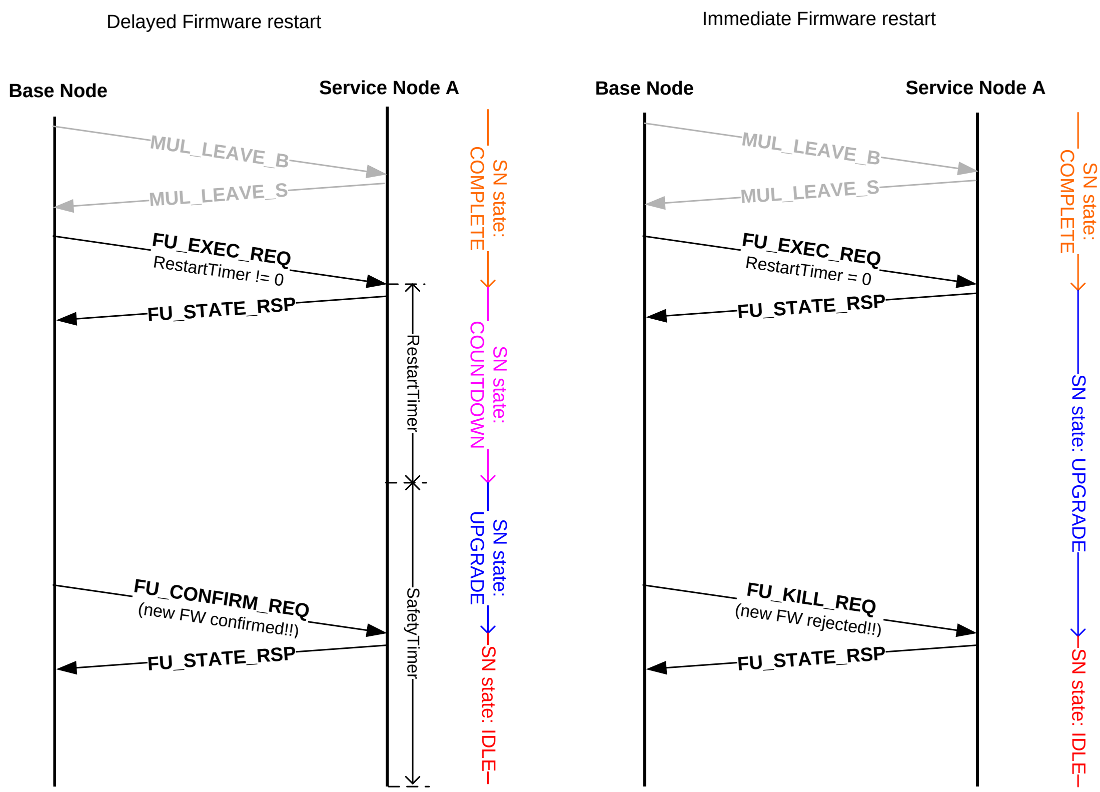

Figure 141 - Execute upgrade and confirm/reject new FW version

Above it is shown how to proceed after completing the FW download. The Base Node commands the Service Node to reboot either immediately ("Immediate Firmware Start", *RestartTimer* = 0) or after a defined period of time ("Delayed Firmware start", *RestartTimer* != 0). After reboot, the Base Node can either confirm the recently downloaded message sending a FU_CONFIRM_REQ or reject it (sending a FU_KILL_REQ or letting the safety period expire doing nothing).

6.4 Management interface description

6.4.1 General

Management functions defined in earlier sections shall be available over an abstract management interface specified in this section. The management interface can be accessed over diverse media. Each physical media shall specify its own management plane communication profile over which management information is exchanged. It is mandatory for implementations to support PRIME management plane communication profile. All other "management plane communication profiles" are optional and maybe mandated by certain "application profiles" to use in specific cases.

The present version of specifications describes two communication profiles, one of which is over this specification NULL SSCS and other over serial link.

With these two communication profiles, it shall be possible to address the following use-cases:

- Remote access of management interface over NULL SSCS. This shall enable Base Node's use as a supervisory gateway for all devices in a Subnetwork
- Local access of management interface (over peripherals like RS232, USBSerial etc) in a Service Node. Local access shall fulfill cases where a coprocessor exists for supervisory control of processor or when manual access is required over local physical interface for maintenance.

Management data comprises of a 2 bytes header followed by payload information corresponding to the type of information carried in message. The header comprises of a 10 bit length field and 6 bit message_id field.

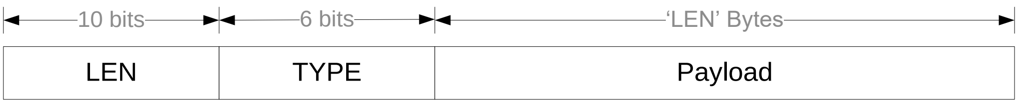

Figure 142 – Management data frame

Table 131 - Management data frame fields

Name	Length	Description
MGMT.LEN	10 bits	Length of payload data following the 2 byte header. LEN=0 implies there is no payload data following this header and the TYPE field contains all required information to perform appropriate action. NOTE: The length field maybe redundant in some communication profiles (e.g. When transmitted over PRIME), but is required in others. Therefore for the sake of uniformity, it is always included in management data.
MGMT.TYPE	6 bits	Type of management information carried in corresponding data. Some message_id have standard semantics which should be respected by all PRIME compliant devices while others are reserved for local use by vendors. 0x00 – Get PIB attribute query; 0x01 – Get PIB attribute response; 0x02 – Set PIB attribute command; 0x03 – Reset all PIB statistics attributes; 0x04 – Reboot destination device; 0x05 – Firmware upgrade protocol message; 0x06 – Enhanced PIB Query 0x07 – Enhances PIB Response 0x08 to 0x0F: Reserved for future use. Vendors should not use these values for local purpose; 0x10 – 0x3F : Reserved for vendor specific use.

6.4.2 Payload format of management information

6.4.2.1 Get PIB attribute query

This query is issued by a remote management entity that is interested in knowing values of PIB attributes maintained on a compliant device with this specification.

The payload may comprise of a query on either a single PIB attribute or multiple attributes. For reasons of efficiency queries on multiple PIB attributes maybe aggregated in one single command. Given that the length of a PIB attribute identifier is constant, the number of attributes requested in a single command is derived from the overall MGMT.LEN field in header.

The format of payload information is shown in the following figure.

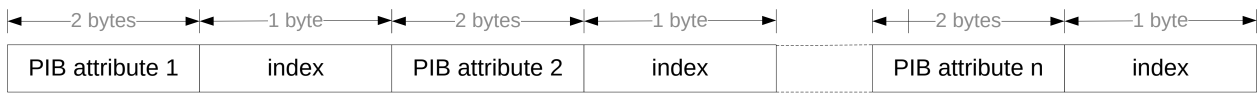

Figure 143 – Get PIB Attribute query. Payload

Fields of a GET request are summarized in table below:

Table 132 - GET PIB Atribubute request fields

Name	Length	Description
PIB Attribute id	2 bytes	16 bit PIB attribute identifier
Index	1 byte	Index of entry to be returned for corresponding PIB Attribute id. This field is only of relevance while returning PIB list attributes. Index = 0; if PIB Attribute is not a list; Index = 1 to 255; Return list record at given index.

6.4.2.2 Get PIB attribute response

This data is sent out from a compliant device of this specification in response to a query of one or more PIB attributes. If a certain queried PIB attribute is not maintained on the device, it shall still respond to the query with value field containing all '1s' in the response.

The format of payload is shown in the following figure.

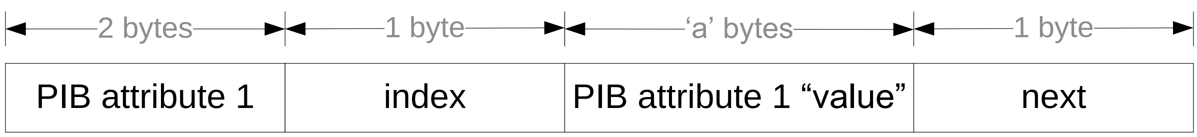

Figure 144 - Get PIB Attribute response. Payload

Fields of a GET request are summarized in table below:

Table 133 - GET PIB Attribute response fields

Name	Length	Description
PIB Attribute id	2 bytes	16 bit PIB attribute identifier.
Index	1 byte	Index of entry returned for corresponding PIB Attribute id. This field is only of relevance while returning PIB list attributes. index = 0; if PIB Attribute is not a list. index = 1 to 255; Returned list record is at given index.
PIB Attribute value	'a' bytes	Values of requested PIB attribute. In case of a list attribute, value shall comprise of entire record corresponding to given index of PIB attribute
Next	1 byte	Index of next entry returned for corresponding PIB Attribute id. This field is only of relevance while returning PIB list attributes. next = 0; if PIB Attribute is not a list or if no records follow the one being returned for a list PIB attribute i.e. given record is last entry in list. next = 1 to 255; index of next record in list maintained for given PIB attribute.

Response to PIB attribute query can span across several MAC GPDUs. This shall always be the case when an aggregated (comprising of several PIB attributes) PIB query's response if longer than the maximum segment size allowed to be carried over the NULL SCSS.

6.4.2.3 Set PIB attribute

This management data shall be used to set specific PIB attributes. Such management payload comprises of a 2 byte PIB attribute identifier, followed by the relevant length of PIB attribute information corresponding to that identifier. For reasons of efficiency, it shall be possible to aggregate SET command on several PIB attributes in one GPDU. The format of such an aggregated payload is shown in figure below:

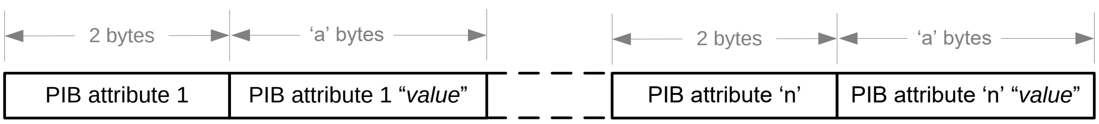

Figure 145 – Set PIB attribute. Aggregated payload

For cases where the corresponding PIB attribute is only a trigger (all ACTION PIB attributes), there shall be no associated value and the request data format shall be as shown below.

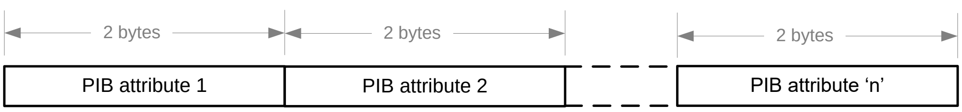

Figure 146 – Set PIB Attribute. ACTION PIB attributes

It is assumed that the management entity sending out this information has already determined if the corresponding attributes are supported at target device. This may be achieved by a previous query and its response.

6.4.2.4 Reset statistics

This command has optional payload. In case there is no associated payload, the receiving device shall reset all of its PIB statistical attributes.

For cases when a remote management entity only intends to perform reset of selective PIB statistical attributes, the payload shall contain a list of attributes that need to be reset. The format shall be the same as shown in Section 6.4.2.1.

Since there is no confirmation message going back from the device complying with this specification, the management entity needs to send a follow-up PIB attribute query, in case it wants to confirm successful completion of appropriate action.

6.4.2.5 Reboot device

There is no corresponding payload associated with this command. The command is complete in itself. The receiving compliant device with this specification shall reboot itself on receipt of this message.

It is mandatory for all implementations compliant with this specification to support this command and its corresponding action.

6.4.2.6 Firmware upgrade

The payload in this case shall comprise of firmware upgrade commands and responses described in section 6.2.3.2 of the specification.

6.4.2.7 Enhanced PIB query

6.4.2.7.1 General

This command let perform a variety of queries grouped in one. At the moment there is one query type that can be performed, more queries will be added in future releases of the specification.
The format of this command is shown in the Figure 147.

0x06	Query 1	Query 2	…	Query n

Figure 147 – Enhanced PIB query format

1 bit	7 bits	8 bits
0	Iterator of 15 bits	

Figure 148 – Iterator short format

1 bit	7 bits	*n* bytes
1	Iterator length (*n*)	Iterator of *n* bytes

Figure 149 – Iterator long format

The available queries are the ones listed in the Table 131.

6.4.2.7.2 PIB list query

This query is used to request the next elements in a collection of elements on a PIB element. Such as node list or connection list.

The format of this query is listed in Table 134

Table 134 – PIB List query format

Element	Size(bytes)	Description
0x0E	1	Code for the PIB list query operation
Attribute ID	2	Attribute ID of the PIB
Number	1	Maximum number of records to retrieve
Iterator	*	Iterator returned in the last item if the PIB list response message, the response will start in the next element after that one. The constant value "0x0000" in this field will retrieve the first element

6.4.2.8 Enhanced PIB response

6.4.2.8.1 General

This command let respond to a variety of queries requested in Enhanced PIB query. At the moment there is one response type, more response types will be added in future releases of the specification.

The format of this command is shown in the Figure 150.

0x07	Response 1	Response 2	…	Response n

Figure 150 – Enhanced PIB response format

The available responses are listed in the Table 131.

6.4.2.8.2 PIB list response

This response is used to send information on lists of PIB collection elements, such as node list or connection list.

The format of this command is shown in the Table 135.

Table 135 – PIB list response format

Element	Size(bytes)	Description
0x0F	1	Code for the PIB list response operation
Attribute ID	2	Attribute ID of the PIB
Number	1	Number of records contained in this message

Element	Size(bytes)	Description
End of List	1	It defines if the end of the list has been reached (1) or not (0)
Length	1	Length of each record
Iterator 1	*	Iterator of the record #1
Value 1	*	Value of the record #1
…..	….	….
Iterator n	*	Iterator of the record #n
Value n	*	Value of the record #n

The iterator has the same format as the ones described in section 6.4.2.7.2

6.4.3 NULL SSCS communication profile

This communication profile enables exchange of management information described in previous sections over the NULL SSCS.

The management entities at both transmitting and receiving ends are applications making use of the NULL SSCS enumerated in Section 0 of this specs. Data is therefore exchanged as MAC Generic PDUs.

6.4.4 Serial communication profile

6.4.4.1 Physical layer

The PHY layer maybe any serial link (e.g. RS232, USB Serial). The serial link is required to work 8N1 configuration at one of the following data rates:

9600 bps, 19200 bps, 38400 bps, 57600 bps.

6.4.4.2 Data encapsulation for management messages

In order ensure robustness, the stream of data is encapsulated in HDLC-type frames which include a 2 byte header and 4 byte CRC. All data is encapsulated between a starting flag-byte 0x7E and ending flag-byte 0x7E as shown in Figure below:

Figure 151 – Data encapsulations for management messages

If any of the intermediate data characters has the value 0x7E, it is preceded by an escape byte 0x7D, followed by a byte derived from XORing the original character with byte 0x20. The same is done if there is a 0x7D within the character stream. An example of such case is shown here:

```
Msg to Tx:          0x01 0x02 0x7E      0x03 0x04 0x7D      0x05 0x06
Actual Tx sequence: 0x01 0x02 0x7D 0x5E 0x03 0x04 0x7D 0x5D 0x05 0x06
                              Escape              Escape
                              sequence            sequence
```

The 32 bit CRC at end of the frame covers both *'Header'* and *'Payload'* fields. The CRC is calculated over the original data to be transmitted i.e. before byte stuffing of escape sequences described above is performed. CRC calculation is

The input polynomial M(x) is formed as a polynomial whose coefficients are bits of the data being checked (the first bit to check is the highest order coefficient and the last bit to check is the coefficient of order zero). The Generator polynomial for the CRC is G(x)=x32+x26+x23+x22+x16+x12+x11+x10+x8+x7+x5+x4+x2+x+1. The remainder R(x) is calculated as the remainder from the division of M(x)·x32 by G(x). The coefficients of the remainder will then be the resulting CRC.

6.4.5 TCP communication profile

This communication profile enables exchange of management information described in previous sections over a TCP socket. The socket number will be defined by the manufacturer and the device will have the role of a TCP server.

Management messages as described in Figure 142 are used in sequence with no extra header in this profile. The message boundaries will be described with the length field of the management message.

6.5 List of mandatory PIB attributes

6.5.1 General

PIB attributes listed in this section shall be supported by all implementations. PIB attributes that are not listed in this section are optional and vendors may implement them at their choice. In addition to the PIB attributes, the management command to reboot a certain device (as specified in 6.4.2.5) shall also be universally supported.

6.5.2 Mandatory PIB attributes common to all device types

6.5.2.1 PHY PIB attribute

(See Table 101)

Table 136 - PHY PIB common mandatory attributes

Attribute Name	Id
phyStatsRxTotalCount	0x00A4

Attribute Name	Id
phyStatsBlkAvgEvm	0x00A5
phyEmaSmoothing	0x00A8
phyRFStatsRxTotalCount	0x101D

6.5.2.2 MAC PIB attributes

(See Table 105, Table 107 and Table 108)

Table 137 - MAC PIB comon mandatory attributes

Attribute Name	Id
macEMASmoothing	0x0019
macCSMAR1 (non-Robust Modes only)	0x0034
macCSMAR2 (non-Robust Modes only)	0x0035
macCSMAR1Robust (Robust Modes supported)	0x003B
macCSMAR2Robust (Robust Modes supported)	0x003C

Attribute Name	Id
MacCapabilities	0x002C

List Attribute Name	Id
macListPhyComm	0x0059

6.5.2.3 Application PIB attributes

(See Table 113)

Table 138 - Applications PIB common mandotory attributes

Attribute Name	Id
AppFwVersion	0x0075
AppVendorId	0x0076
AppProductId	0x0077

6.5.3 Mandatory Base Node attributes

6.5.3.1 MAC PIB attributes

(See Table 105 and Table 109)

Table 139 - MAC PIB Base Node mandatory attributes

Attribute Name	Id
macBeaconsPerFrame	0x0013

List Attribute Name	Id
macListRegDevices	0x0050
macListActiveConn	0x0051

6.5.4 Mandatory Service Node attributes

6.5.4.1 MAC PIB attributes

(See Table 107, Table 109 and Table 112)

Table 140 - MAC PIB Service Node mandatory attributes

Attribute Name	Id
macLNID	0x0020
MacLSID	0x0021
MacSID	0x0022
MacSNA	0x0023
MacState	0x0024
MacSCPLength	0x0025
MacNodeHierarchyLevel	0x0026
MacBeaconSlotCount	0x0027
macBeaconRxSlot	0x0028
MacBeaconTxSlot	0x0029
MacBeaconRxFrequency	0x002A
MacBeaconTxFrequency	0x002B

List Attribute Name	Id
macListSwitchTable	0x0053
macListAvailableSwitches	0x0056

Attribute Name	Id
MACActionTxData	0x0060
MACActionConnClose	0x0061
MACActionRegReject	0x0062
MACActionProReject	0x0063
MACActionUnregister	0x0064
macSecDUK	0x005B

6.5.4.2 Application PIB attributes

(See Table 114)

Table 141 - APP PIB Service Node mandatory attributes

Attribute Name	Id
AppFwdlRunning	0x0070
AppFwdlRxPktCount	0x0071

Annex A
(informative)
Examples of CRC

CRC-8 Example

The table below gives the CRC-8 examples (see section 3.3.2.3) calculated for several specified strings

Table 142 – Examples of CRC-8 calculated for various ASCII strings

String	CRC-8
‘T’	0xab
“THE”	0xa0
0x03, 0x73	0x61
0x01, 0x3f	0xa8
“123456789”	0xf4

CRC-32 Example

The table below gives the CRC-32 example (see section 3.3.2.3)

Table 143 – Example of CRC-32

String	CRC-32
0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37 0x38 0x39 0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37 0x38 0x39 0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37 0x38 0x39 0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37 0x38 0x39 0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37 0x38 0x39	0x24a56cf5

Annex B
(normative)
EVM calculation

This annex describes calculation of the EVM by a reference receiver, assuming accurate synchronization and FFT window placement. Let

- r_k^i denotes the FFT output for symbol *i* and *k* are the indices of data subcarriers.
- $\Delta b_k \in \{0,1,..,P-1\}$ represents the decision on the received information symbol coded in the phase increment.
- *P* = 2, 4, or 8 in the case of DBPSK, DQPSK or D8PSK, respectively.

The EVM definition is then given by;

$$EVM = \frac{\sum_{i=1}^{L} \sum_{k \in \{\text{data subcarriers}\}} \left(abs\left(r_k^i - r_{k-1}^i e^{-(j*2*\pi/P)\times\Delta b_{k-1}}\right)\right)^2}{\sum_{i=1}^{L} \sum_{k \in \{\text{data subcarriers}\}} \left(abs\left(r_k^i\right)\right)^2}$$

In the above, abs(.) refers to the magnitude of a complex number. L is the number of OFDM symbols in the most recently received PPDU, over which the EVM is calculated.

The noise can be estimated as the numerator of the EVM. The RSSI can be estimated as the denominator of the EVM. The SNR can be estimated as the reciprocal of the EVM above plus 3dB due to differential decoding.

Annex C
(informative)
Interleaving matrixes (N_{CH} = 1)

Table 144 - Header interleaving matrix.

12	11	10	9	8	7	6	5	4	3	2	1
24	23	22	21	20	19	18	17	16	15	14	13
36	35	34	33	32	31	30	29	28	27	26	25
48	47	46	45	44	43	42	41	40	39	38	37
60	59	58	57	56	55	54	53	52	51	50	49
72	71	70	69	68	67	66	65	64	63	62	61
84	83	82	81	80	79	78	77	76	75	74	73

Table 145 - DBPSK(FEC ON) interleaving matrix.

12	11	10	9	8	7	6	5	4	3	2	1
24	23	22	21	20	19	18	17	16	15	14	13
36	35	34	33	32	31	30	29	28	27	26	25
48	47	46	45	44	43	42	41	40	39	38	37
60	59	58	57	56	55	54	53	52	51	50	49
72	71	70	69	68	67	66	65	64	63	62	61
84	83	82	81	80	79	78	77	76	75	74	73
96	95	94	93	92	91	90	89	88	87	86	85

Table 146 - DQPSK(FEC ON) interleaving matrix.

12	11	10	9	8	7	6	5	4	3	2	1
24	23	22	21	20	19	18	17	16	15	14	13
36	35	34	33	32	31	30	29	28	27	26	25
48	47	46	45	44	43	42	41	40	39	38	37
60	59	58	57	56	55	54	53	52	51	50	49
72	71	70	69	68	67	66	65	64	63	62	61
84	83	82	81	80	79	78	77	76	75	74	73
96	95	94	93	92	91	90	89	88	87	86	85
108	107	106	105	104	103	102	101	100	99	98	97
120	119	118	117	116	115	114	113	112	111	110	109
132	131	130	129	128	127	126	125	124	123	122	121
144	143	142	141	140	139	138	137	136	135	134	133
156	155	154	153	152	151	150	149	148	147	146	145
168	167	166	165	164	163	162	161	160	159	158	157
180	179	178	177	176	175	174	173	172	171	170	169
192	191	190	189	188	187	186	185	184	183	182	181

Table 147 - D8PSK(FEC ON) interleaving matrix.

18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19
54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37
72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55
90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74	73
108	107	106	105	104	103	102	101	100	99	98	97	96	95	94	93	92	91
126	125	124	123	122	121	120	119	118	117	116	115	114	113	112	111	110	109
144	143	142	141	140	139	138	137	136	135	134	133	132	131	130	129	128	127
162	161	160	159	158	157	156	155	154	153	152	151	150	149	148	147	146	145
180	179	178	177	176	175	174	173	172	171	170	169	168	167	166	165	164	163
198	197	196	195	194	193	192	191	190	189	188	187	186	185	184	183	182	181
216	215	214	213	212	211	210	209	208	207	206	205	204	203	202	201	200	199
234	233	232	231	230	229	228	227	226	225	224	223	222	221	220	219	218	217
252	251	250	249	248	247	246	245	244	243	242	241	240	239	238	237	236	235
270	269	268	267	266	265	264	263	262	261	260	259	258	257	256	255	254	253
288	287	286	285	284	283	282	281	280	279	278	277	276	275	274	273	272	271

Annex D
(normative)
MAC layer constants

This section defines all the MAC layer constants.

Table 148 - Table of MAC constants

Constant	Value	Description
MACBeaconLength1	5 symbols	Length of beacon in symbols. Type A frame and DBPSK_CC modulation
MACBeaconLength2	16 symbols	Length of beacon in symbols. Type B frame and DQPSK_RC modulation
MACBeaconLength3	24 symbols	Length of beacon in symbols. Type B frame and DBPSK_RC modulation
MACBeaconLength4	19 symbols	Length of beacon in symbols. Type BC frame and DQPSK_R modulation
MACBeaconLength5	27 symbols	Length of beacon in symbols. Type BC frame and DBPSK_R modulation
MACMinSCPLength	64 symbols	Minimum length of SCP.
MACPriorityLevels	4	Number of levels of priority supported by the system.
MACMinRobustnessLevel	DBPSK_CC	Weakest modulation scheme
MACCtrlPktPriority	1	MAC Priority used to transmit all the Control Packets except ALV Control Packets
MACALVCtrlTketPriority	0	MAC Priority used to transmit ALV control Packets
MACSuperFrameLength	32	Number of frames that defines the superframe
MACRandSeqChgTime	32767 seconds (approx 9 hours)	Maximum duration of time after which the Base Node should circulate a new random sequence to the Subnetwork for encryption functions.
MACMaxPRNIgnore	3	Maximum number of Promotion-Needed messages a Terminal can ignore.
MACConcurrentAliveProcedure	2	The number of Alive procedure a Service Node shall support at any given time

Constant	Value	Description
$N_{miss\text{-}beacon}$	5	Number of superframes a Service Node does not receive an expected beacon before considering its Switch Node as unavailable.
ARQMaxTxCount	32	Maximum allowed retransmission count before an ARQ connection must be closed
ARQCongClrTime	10 sec	When the receiver has indicated congestion, this time must be waited before retransmitting the data.
ARQMaxCongInd	7	After ARQMaxCongInd consecutive transmissions which failed due to congestion, the connection should be declared permanently dead.
ARQMaxAckHoldTime	7 sec	Time the receiver may delay sending an ACK in order to allow consolidated ACKs or piggyback the ACK with a data packet.
aUnitBackOffPeriod	Equal to PHY PIB attributes aTurnaroundTime + phyCCADuration	The number of symbols forming the basic time period used by the RF CSMA-CA algorithm.

Annex E
(normative)
Convergence layer constants

The following TYPE values are defined for use by Convergence layers from chapter 5.

Table 149 - TYPE value assignments

TYPE Symbolic Name	Value
TYPE_CL_IPv4_AR	1
TYPE_CL_IPv4_UNICAST	2
TYPE_CL_432	3
TYPE_CL_MGMT	4
TYPE_CL_IPv6_AR	5
TYPE_CL_IPv6_DATA	6

The following LCID values apply for broadcast connections defined by Convergence layers from chapter 5.

Table 150 - LCID value assignments

LCID Symbolic Name	Value	MAC Scope
LCI_CL_IPv4_BROADCAST	1	Broadcast.
LCI_CL_432_BROADCAST	2	Broadcast.

The following Result values are defined for Convergence layer primitives.

Table 151 - Result values for Convergence layer primitives

Result	Description
Success = 0	The SSCS service was successfully performed.
Reject = 1	The SSCS service failed because it was rejected by the base node.
Timeout = 2	A timed out occurs during the SSCS service processing
Not Registered = 6	The service node is not currently registered to a Subnetwork.
Unsupported SP = 14	Device doesn’t support SP > 0 but asked for an encrypted connection establishment

Annex F
(normative)
Profiles

Given the different applications which are foreseen for this specification compliant products, it is necessary to define different profiles. Profiles cover the functionalities that represent the respective feature set. They need to be implemented as written in order to assure interoperability.

This specification has a number of options, which, if exercised in different ways by different vendors, will hamper both compliance testing activities and future product interoperability. The profiles further restrict those options so as to promote interoperability and testability.

A specific profile will dictate which capabilities a Node negotiates through the Registering and Promotion processes.

F.1 Smart Metering Profile

The following options will be either mandatory or optional for Smart Metering Nodes.

REG.CAP_SW:

- Base Node: Set to 1.
- Service Node: Set to 1.

REG.CAP_PA:

- Base Node: optional.
- Service Node: optional.

REG.CAP_CFP:

- Base Node: optional.
- Service Node: optional.

REG.CAP_DC

- Base Node: optional.
- Service Node: optional.

REG.CAP_MC

- Base Node: Set to 1.
- Service Node: optional.

REG.CAP_RM

- Base Node: Set to 1.
- Service Node: Set to 1.

REG.CAP_ARQ

- Base Node: optional.
- Service Node: optional.

PRO.SWC_DC

- Service Node: optional.

PRO.SWC_MC

- Service Node: optional.

PRO.SWC_RM

- Service Node: Set to 1.

PRO.SWC_ARQ

- Service Node: optional.

Annex G
(informative)
List of frequencies used

The tables below give the exact center frequencies (in Hz) for the 97 subcarriers of the OFDM signal, channel by channel.

Note that a guard period of 15 subcarriers is kept between any two consecutive channels.

Table 152 – Channel 1: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
86	41992.18750	111	54199.21875	136	66406.25000	161	78613.28125
87	42480.46875	112	54687.50000	137	66894.53125	162	79101.56250
88	42968.75000	113	55175.78125	138	67382.81250	163	79589.84375
89	43457.03125	114	55664.06250	139	67871.09375	164	80078.12500
90	43945.31250	115	56152.34375	140	68359.37500	165	80566.40625
91	44433.59375	116	56640.62500	141	68847.65625	166	81054.68750
92	44921.87500	117	57128.90625	142	69335.93750	167	81542.96875
93	45410.15625	118	57617.18750	143	69824.21875	168	82031.25000
94	45898.43750	119	58105.46875	144	70312.50000	169	82519.53125
95	46386.71875	120	58593.75000	145	70800.78125	170	83007.81250
96	46875.00000	121	59082.03125	146	71289.06250	171	83496.09375
97	47363.28125	122	59570.31250	147	71777.34375	172	83984.37500
98	47851.56250	123	60058.59375	148	72265.62500	173	84472.65625
99	48339.84375	124	60546.87500	149	72753.90625	174	84960.93750
100	48828.12500	125	61035.15625	150	73242.18750	175	85449.21875
101	49316.40625	126	61523.43750	151	73730.46875	176	85937.50000
102	49804.68750	127	62011.71875	152	74218.75000	177	86425.78125
103	50292.96875	128	62500.00000	153	74707.03125	178	86914.06250
104	50781.25000	129	62988.28125	154	75195.31250	179	87402.34375
105	51269.53125	130	63476.56250	155	75683.59375	180	87890.62500

#	Frequency	#	Frequency	#	Frequency	#	Frequency
106	51757.81250	131	63964.84375	156	76171.87500	181	88378.90625
107	52246.09375	132	64453.12500	157	76660.15625	182	88867.18750
108	52734.37500	133	64941.40625	158	77148.43750		
109	53222.65625	134	65429.68750	159	77636.71875		
110	53710.93750	135	65917.96875	160	78125.00000		

Table 153 – Channel 2: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
198	96679.68750	223	108886.71875	248	121093.75000	273	133300.78125
199	97167.96875	224	109375.00000	249	121582.03125	274	133789.06250
200	97656.25000	225	109863.28125	250	122070.31250	275	134277.34375
201	98144.53125	226	110351.56250	251	122558.59375	276	134765.62500
202	98632.81250	227	110839.84375	252	123046.87500	277	135253.90625
203	99121.09375	228	111328.12500	253	123535.15625	278	135742.18750
204	99609.37500	229	111816.40625	254	124023.43750	279	136230.46875
205	100097.65625	230	112304.68750	255	124511.71875	280	136718.75000
206	100585.93750	231	112792.96875	256	125000.00000	281	137207.03125
207	101074.21875	232	113281.25000	257	125488.28125	282	137695.31250
208	101562.50000	233	113769.53125	258	125976.56250	283	138183.59375
209	102050.78125	234	114257.81250	259	126464.84375	284	138671.87500
210	102539.06250	235	114746.09375	260	126953.12500	285	139160.15625
211	103027.34375	236	115234.37500	261	127441.40625	286	139648.43750
212	103515.62500	237	115722.65625	262	127929.68750	287	140136.71875
213	104003.90625	238	116210.93750	263	128417.96875	288	140625.00000
214	104492.18750	239	116699.21875	264	128906.25000	289	141113.28125
215	104980.46875	240	117187.50000	265	129394.53125	290	141601.56250

#	Frequency	#	Frequency	#	Frequency	#	Frequency
216	105468.75000	241	117675.78125	266	129882.81250	291	142089.84375
217	105957.03125	242	118164.06250	267	130371.09375	292	142578.12500
218	106445.31250	243	118652.34375	268	130859.37500	293	143066.40625
219	106933.59375	244	119140.62500	269	131347.65625	294	143554.68750
220	107421.87500	245	119628.90625	270	131835.93750		
221	107910.15625	246	120117.18750	271	132324.21875		
222	108398.43750	247	120605.46875	272	132812.50000		

Table 154 – Channel 3: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
310	151367.18750	335	163574.21875	360	175781.25000	385	187988.28125
311	151855.46875	336	164062.50000	361	176269.53125	386	188476.56250
312	152343.75000	337	164550.78125	362	176757.81250	387	188964.84375
313	152832.03125	338	165039.06250	363	177246.09375	388	189453.12500
314	153320.31250	339	165527.34375	364	177734.37500	389	189941.40625
315	153808.59375	340	166015.62500	365	178222.65625	390	190429.68750
316	154296.87500	341	166503.90625	366	178710.93750	391	190917.96875
317	154785.15625	342	166992.18750	367	179199.21875	392	191406.25000
318	155273.43750	343	167480.46875	368	179687.50000	393	191894.53125
319	155761.71875	344	167968.75000	369	180175.78125	394	192382.81250
320	156250.00000	345	168457.03125	370	180664.06250	395	192871.09375
321	156738.28125	346	168945.31250	371	181152.34375	396	193359.37500
322	157226.56250	347	169433.59375	372	181640.62500	397	193847.65625
323	157714.84375	348	169921.87500	373	182128.90625	398	194335.93750
324	158203.12500	349	170410.15625	374	182617.18750	399	194824.21875
325	158691.40625	350	170898.43750	375	183105.46875	400	195312.50000

#	Frequency	#	Frequency	#	Frequency	#	Frequency
326	159179.68750	351	171386.71875	376	183593.75000	401	195800.78125
327	159667.96875	352	171875.00000	377	184082.03125	402	196289.06250
328	160156.25000	353	172363.28125	378	184570.31250	403	196777.34375
329	160644.53125	354	172851.56250	379	185058.59375	404	197265.62500
330	161132.81250	355	173339.84375	380	185546.87500	405	197753.90625
331	161621.09375	356	173828.12500	381	186035.15625	406	198242.18750
332	162109.37500	357	174316.40625	382	186523.43750		
333	162597.65625	358	174804.68750	383	187011.71875		
334	163085.93750	359	175292.96875	384	187500.00000		

Table 155 – Channel 4: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
422	206054.68750	447	218261.71875	472	230468.75000	497	242675.78125
423	206542.96875	448	218750.00000	473	230957.03125	498	243164.06250
424	207031.25000	449	219238.28125	474	231445.31250	499	243652.34375
425	207519.53125	450	219726.56250	475	231933.59375	500	244140.62500
426	208007.81250	451	220214.84375	476	232421.87500	501	244628.90625
427	208496.09375	452	220703.12500	477	232910.15625	502	245117.18750
428	208984.37500	453	221191.40625	478	233398.43750	503	245605.46875
429	209472.65625	454	221679.68750	479	233886.71875	504	246093.75000
430	209960.93750	455	222167.96875	480	234375.00000	505	246582.03125
431	210449.21875	456	222656.25000	481	234863.28125	506	247070.31250
432	210937.50000	457	223144.53125	482	235351.56250	507	247558.59375
433	211425.78125	458	223632.81250	483	235839.84375	508	248046.87500
434	211914.06250	459	224121.09375	484	236328.12500	509	248535.15625
435	212402.34375	460	224609.37500	485	236816.40625	510	249023.43750

#	Frequency	#	Frequency	#	Frequency	#	Frequency
436	212890.62500	461	225097.65625	486	237304.68750	511	249511.71875
437	213378.90625	462	225585.93750	487	237792.96875	512	250000.00000
438	213867.18750	463	226074.21875	488	238281.25000	513	250488.28125
439	214355.46875	464	226562.50000	489	238769.53125	514	250976.56250
440	214843.75000	465	227050.78125	490	239257.81250	515	251464.84375
441	215332.03125	466	227539.06250	491	239746.09375	516	251953.12500
442	215820.31250	467	228027.34375	492	240234.37500	517	252441.40625
443	216308.59375	468	228515.62500	493	240722.65625	518	252929.68750
444	216796.87500	469	229003.90625	494	241210.93750		
445	217285.15625	470	229492.18750	495	241699.21875		
446	217773.43750	471	229980.46875	496	242187.50000		

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5762 **Table 156 – Channel 5: List of frequencies used**

#	Frequency	#	Frequency	#	Frequency	#	Frequency
534	260742.18750	559	272949.21875	584	285156.25000	609	297363.28125
535	261230.46875	560	273437.50000	585	285644.53125	610	297851.56250
536	261718.75000	561	273925.78125	586	286132.81250	611	298339.84375
537	262207.03125	562	274414.06250	587	286621.09375	612	298828.12500
538	262695.31250	563	274902.34375	588	287109.37500	613	299316.40625
539	263183.59375	564	275390.62500	589	287597.65625	614	299804.68750
540	263671.87500	565	275878.90625	590	288085.93750	615	300292.96875
541	264160.15625	566	276367.18750	591	288574.21875	616	300781.25000
542	264648.43750	567	276855.46875	592	289062.50000	617	301269.53125
543	265136.71875	568	277343.75000	593	289550.78125	618	301757.81250
544	265625.00000	569	277832.03125	594	290039.06250	619	302246.09375
545	266113.28125	570	278320.31250	595	290527.34375	620	302734.37500

#	Frequency	#	Frequency	#	Frequency	#	Frequency
546	266601.56250	571	278808.59375	596	291015.62500	621	303222.65625
547	267089.84375	572	279296.87500	597	291503.90625	622	303710.93750
548	267578.12500	573	279785.15625	598	291992.18750	623	304199.21875
549	268066.40625	574	280273.43750	599	292480.46875	624	304687.50000
550	268554.68750	575	280761.71875	600	292968.75000	625	305175.78125
551	269042.96875	576	281250.00000	601	293457.03125	626	305664.06250
552	269531.25000	577	281738.28125	602	293945.31250	627	306152.34375
553	270019.53125	578	282226.56250	603	294433.59375	628	306640.62500
554	270507.81250	579	282714.84375	604	294921.87500	629	307128.90625
555	270996.09375	580	283203.12500	605	295410.15625	630	307617.18750
556	271484.37500	581	283691.40625	606	295898.43750		
557	271972.65625	582	284179.68750	607	296386.71875		
558	272460.93750	583	284667.96875	608	296875.00000		

Table 157 – Channel 6: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
646	315429.68750	671	327636.71875	696	339843.75000	721	352050.78125
647	315917.96875	672	328125.00000	697	340332.03125	722	352539.06250
648	316406.25000	673	328613.28125	698	340820.31250	723	353027.34375
649	316894.53125	674	329101.56250	699	341308.59375	724	353515.62500
650	317382.81250	675	329589.84375	700	341796.87500	725	354003.90625
651	317871.09375	676	330078.12500	701	342285.15625	726	354492.18750
652	318359.37500	677	330566.40625	702	342773.43750	727	354980.46875
653	318847.65625	678	331054.68750	703	343261.71875	728	355468.75000
654	319335.93750	679	331542.96875	704	343750.00000	729	355957.03125
655	319824.21875	680	332031.25000	705	344238.28125	730	356445.31250

#	Frequency	#	Frequency	#	Frequency	#	Frequency
656	320312.50000	681	332519.53125	706	344726.56250	731	356933.59375
657	320800.78125	682	333007.81250	707	345214.84375	732	357421.87500
658	321289.06250	683	333496.09375	708	345703.12500	733	357910.15625
659	321777.34375	684	333984.37500	709	346191.40625	734	358398.43750
660	322265.62500	685	334472.65625	710	346679.68750	735	358886.71875
661	322753.90625	686	334960.93750	711	347167.96875	736	359375.00000
662	323242.18750	687	335449.21875	712	347656.25000	737	359863.28125
663	323730.46875	688	335937.50000	713	348144.53125	738	360351.56250
664	324218.75000	689	336425.78125	714	348632.81250	739	360839.84375
665	324707.03125	690	336914.06250	715	349121.09375	740	361328.12500
666	325195.31250	691	337402.34375	716	349609.37500	741	361816.40625
667	325683.59375	692	337890.62500	717	350097.65625	742	362304.68750
668	326171.87500	693	338378.90625	718	350585.93750		
669	326660.15625	694	338867.18750	719	351074.21875		
670	327148.43750	695	339355.46875	720	351562.50000		

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5766 **Table 158 – Channel 7: List of frequencies used**

#	Frequency	#	Frequency	#	Frequency	#	Frequency
758	370117.18750	783	382324.21875	808	394531.25000	833	406738.28125
759	370605.46875	784	382812.50000	809	395019.53125	834	407226.56250
760	371093.75000	785	383300.78125	810	395507.81250	835	407714.84375
761	371582.03125	786	383789.06250	811	395996.09375	836	408203.12500
762	372070.31250	787	384277.34375	812	396484.37500	837	408691.40625
763	372558.59375	788	384765.62500	813	396972.65625	838	409179.68750
764	373046.87500	789	385253.90625	814	397460.93750	839	409667.96875
765	373535.15625	790	385742.18750	815	397949.21875	840	410156.25000

#	Frequency	#	Frequency	#	Frequency	#	Frequency
766	374023.43750	791	386230.46875	816	398437.50000	841	410644.53125
767	374511.71875	792	386718.75000	817	398925.78125	842	411132.81250
768	375000.00000	793	387207.03125	818	399414.06250	843	411621.09375
769	375488.28125	794	387695.31250	819	399902.34375	844	412109.37500
770	375976.56250	795	388183.59375	820	400390.62500	845	412597.65625
771	376464.84375	796	388671.87500	821	400878.90625	846	413085.93750
772	376953.12500	797	389160.15625	822	401367.18750	847	413574.21875
773	377441.40625	798	389648.43750	823	401855.46875	848	414062.50000
774	377929.68750	799	390136.71875	824	402343.75000	849	414550.78125
775	378417.96875	800	390625.00000	825	402832.03125	850	415039.06250
776	378906.25000	801	391113.28125	826	403320.31250	851	415527.34375
777	379394.53125	802	391601.56250	827	403808.59375	852	416015.62500
778	379882.81250	803	392089.84375	828	404296.87500	853	416503.90625
779	380371.09375	804	392578.12500	829	404785.15625	854	416992.18750
780	380859.37500	805	393066.40625	830	405273.43750		
781	381347.65625	806	393554.68750	831	405761.71875		
782	381835.93750	807	394042.96875	832	406250.00000		

Table 159 – Channel 8: List of frequencies used

#	Frequency	#	Frequency	#	Frequency	#	Frequency
870	424804.68750	895	437011.71875	920	449218.75000	945	461425.78125
871	425292.96875	896	437500.00000	921	449707.03125	946	461914.06250
872	425781.25000	897	437988.28125	922	450195.31250	947	462402.34375
873	426269.53125	898	438476.56250	923	450683.59375	948	462890.62500
874	426757.81250	899	438964.84375	924	451171.87500	949	463378.90625
875	427246.09375	900	439453.12500	925	451660.15625	950	463867.18750

#	Frequency	#	Frequency	#	Frequency	#	Frequency
876	427734.37500	901	439941.40625	926	452148.43750	951	464355.46875
877	428222.65625	902	440429.68750	927	452636.71875	952	464843.75000
878	428710.93750	903	440917.96875	928	453125.00000	953	465332.03125
879	429199.21875	904	441406.25000	929	453613.28125	954	465820.31250
880	429687.50000	905	441894.53125	930	454101.56250	955	466308.59375
881	430175.78125	906	442382.81250	931	454589.84375	956	466796.87500
882	430664.06250	907	442871.09375	932	455078.12500	957	467285.15625
883	431152.34375	908	443359.37500	933	455566.40625	958	467773.43750
884	431640.62500	909	443847.65625	934	456054.68750	959	468261.71875
885	432128.90625	910	444335.93750	935	456542.96875	960	468750.00000
886	432617.18750	911	444824.21875	936	457031.25000	961	469238.28125
887	433105.46875	912	445312.50000	937	457519.53125	962	469726.56250
888	433593.75000	913	445800.78125	938	458007.81250	963	470214.84375
889	434082.03125	914	446289.06250	939	458496.09375	964	470703.12500
890	434570.31250	915	446777.34375	940	458984.37500	965	471191.40625
891	435058.59375	916	447265.62500	941	459472.65625	966	471679.68750
892	435546.87500	917	447753.90625	942	459960.93750		
893	436035.15625	918	448242.18750	943	460449.21875		
894	436523.43750	919	448730.46875	944	460937.50000		

Annex H
(informative)
Informative

H.1 Data exchange between to IP communication peers

This example shows the primitive exchange between a service node (192.168.0.100/24) and a base node when the former wants to exchange IP packets with a third service node (192.168.0.101/24) whose IP address is in the same IP Subnetwork.

This example makes the following assumptions:

- Service node (192.168.0.100) IPv4 SSCS does not exist so it needs to start a IPv4 SSCS and register its IP address in the base node prior to the exchange of IP packets.
- Service node (192.168.0.101) has already registered its IP Address in the base node.

The steps illustrated in next page are:

1. The IPv4 layer of the service node (192.168.0.100) invokes the CL_IPv4_ESTABLISH.request primitive. To establish IPv4 SSCS, it is required,

   a. To establish a connection with the base node so all address resolution messages can be exchanged over it.

   b. To inform the service node MAC layer that IPv4 SSCS is ready to receive all IPv4 broadcasts packets. Note the difference between broadcast and multicast. To join a multicast group, the service node will need to inform the base node of the group it wants to join. This is illustrated in section A.2

2. The IPv4_ layer, once the IPv4 SSCS is established, needs to register its IP address in the base node. To do so, it will use the already established connection.

3. Whenever the IPv4_ needs to deliver an IPv4 packet to a new destination IP address, the following two steps are to be done (in this example, the destination IP address is 192.168.0.101).

   a. As the IPv4 destination address is new, the IPv4 SSCS needs to request the EUI-48 associated to that IPv4 address. To do so, a lookup request message is sent to the base node.

   b. Upon the reception of the EUI-48, a new connection (type = TYPE_CL_IPv4_UNICAST) is established so that all IP packets to be exchanged between 192.168.0.100 and 192.168.0.101 will use that connection.

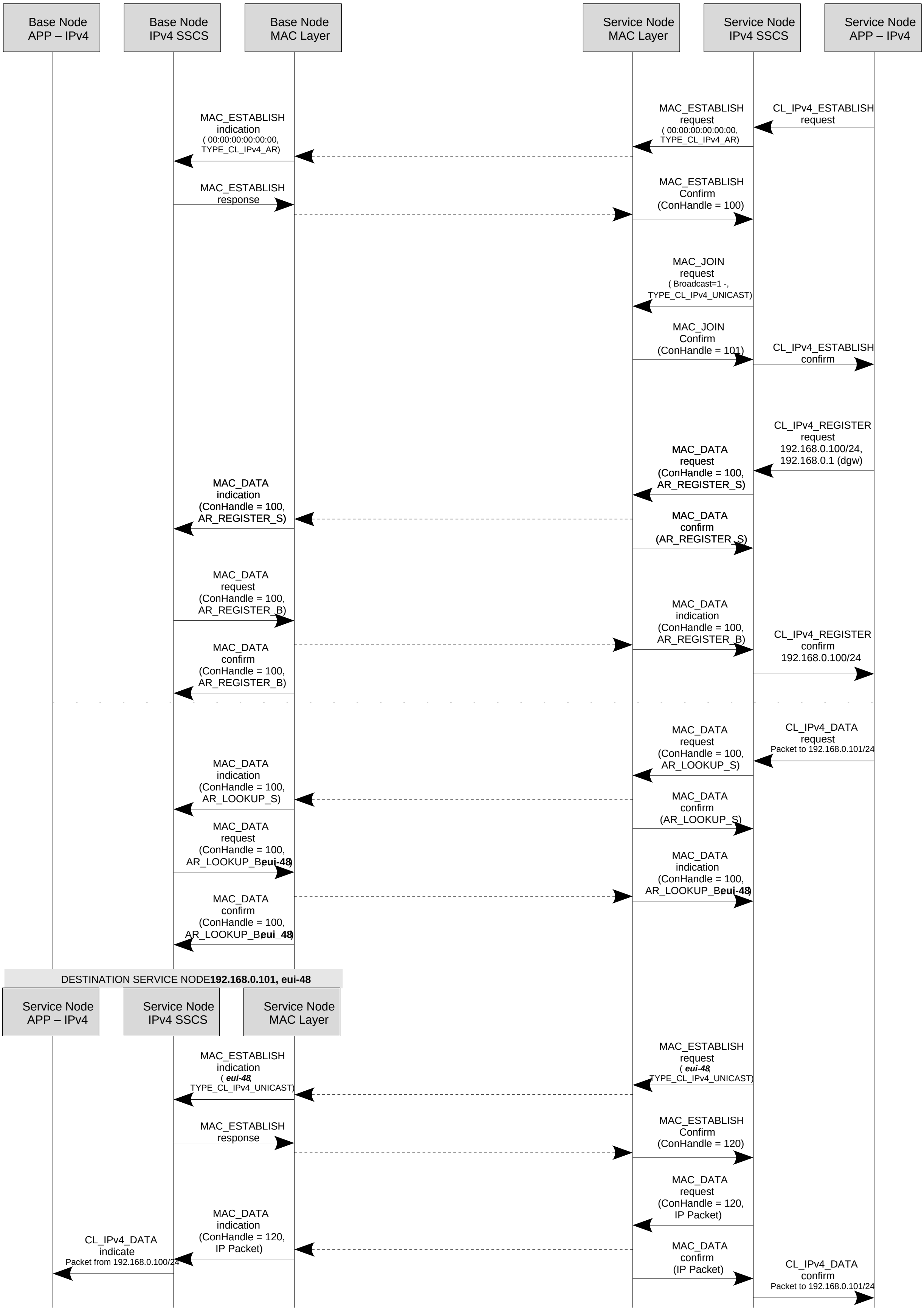


Figure H 1 - MSC of IPv4 SSCS services

H.2 Joining a multicast group

The figure below illustrates how a service node joins a multicast group. As mentioned before, main difference between multicast and broadcast is related to the messages exchanged. For broadcast, the MAC layer will immediately issue a MAC_JOIN.confirm primitive since it does not need to perform any end-to-end operation. For multicast, the MAC_JOIN.confirm is only sent once the Control Packet transaction between the service node and base node is complete.

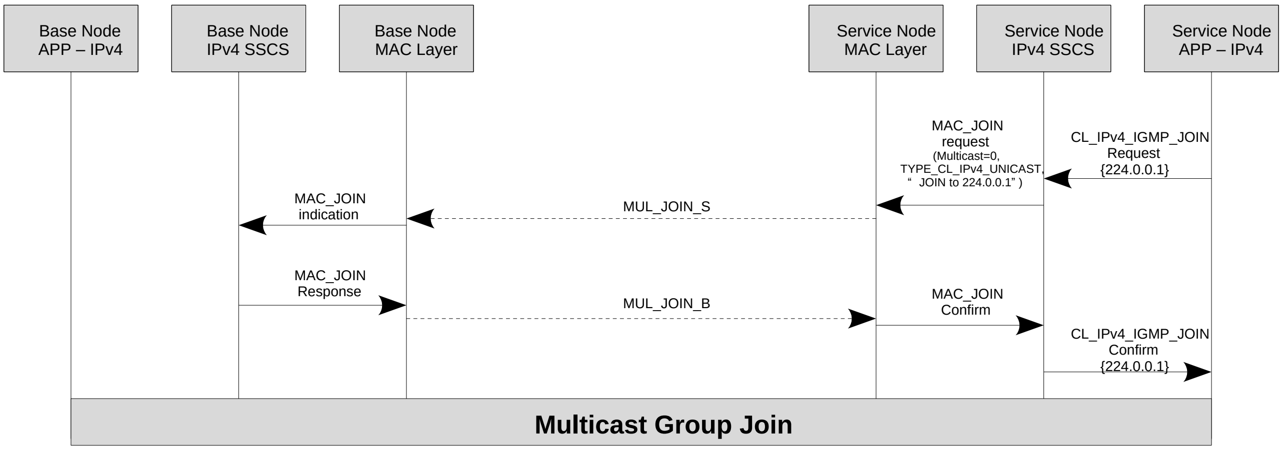


Figure H 2-Joining MS

The MSC below shows the 432 connection establishment and release. 432 SSCS is connection oriented. Before any 432_Data service can take place a connection establishment has to take place. The service node upper layer request a connexction establishment to thez 432 SSCS by providing to it the device identifier as parameter for the CL_432_Establish.request. With the help od the MAC layer services, the service node 432 SSCS request a connection establishment to the base node. This last one when the connection establishment is successful, notifies to the upper layers that a service node has joined the network with the help of the CL_432_Join.indication primitive and provides to the concerned service node a SSCS destination address in addition to its own SSCS address with the help of the MAC_Establish.response which crries out these parameters.

The CL_432_release service ends the connection. It is requested by the service node upper layer to the 432 SSCS which perform it with the help of MAC layer primitives. At the base node side the 432 SSCS notifies the end of the connection to the upper layer by a CL_432_Leave.indication.

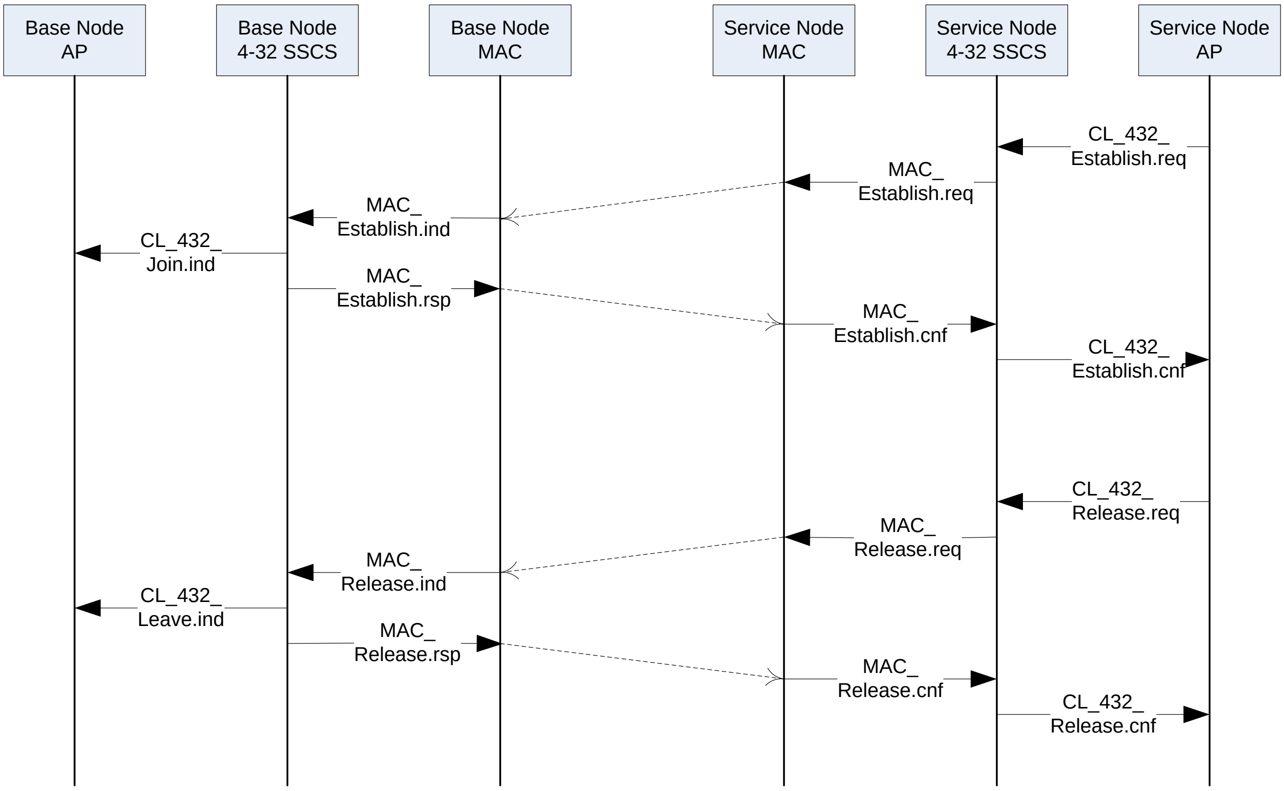


Figure H 3 - MSC 432 SSCS services

Annex I
(informative)
ARQ algorithm

The algorithm described here is just a recommendation with good performance and aims to better describe how ARQ works. However manufacturers could use a different algorithm as long as it complies with the specification.

When a packet is received the packet ID should be checked. If it is the expected ID and contains data, it shall be processed normally. If the packet does not contain data, it can be discarded. If the ID does not match with the one expected, it is from the future and fits in the input window, then for all the packets not received with ID from the last one received to this one, we can assume that they are lost. If the packet contains data, save that data to pass it to the CL once all the packets before have been received and processed by CL.

If the packet ID does not fit in the input window, we can assume that it is a retransmission that has been delayed, and may be ignored.

If there is any NACK all the packets with PKTID lower than the first NACK in the list have been correctly received, and they can be removed from the transmitting window. If there is not any NACK and there is an ACK, the packets before the received ACK have been received and can be removed from the transmission window. All the packets in the NACK list should be retransmitted as soon as possible.

These are some situations for the transmitter to set the flush bit that may improve the average performance:

- When the window of either the transmitter or the receiver is filled;
- When explicitly requested by the CL;
- After a period of time as a timeout.

The receiver has no responsibility over the ACK send process other than sending them when the transmitter sets the flush bit. Although it has some control over the flow control by the window field. On the other hand the receiver is able to send an ACK if it improves the ARQ performance in a given scenario. One example of this, applicable in most cases, could be making the receiver send an ACK if a period of time has been passed since the last sent ACK, to improve the bandwidth usage (and omit the timeout flush in the transmitter). In those situations the transmitter still has the responsibility to interoperate with the simplest receiver (that does not send it by itself).

It is recommended that the ARQ packet sender maintains a timer for every unacknowledged packet. If the packet cannot get successfully acknowledged when the timer expires, the packet will be retransmitted. This kind of timeout retry works independently with the NACK-initiated retries. After a pre-defined maximum number of timeout retries, it is strongly recommended to tear down the connection. This timeout and connection-teardown mechanism is to prevent the Node retry the ARQ packet forever. The exact number of the timeout values and the timeout retries are left for vendor's own choice.

Annex J
(normative)
PHY backwards compatibility mechanism with PRIME v1.3.6

PRIME specification version V1.4 is an extension of version V1.3.6. The inclusion of new features, such as additional robust modes and a new frame type (Type B), implies that PRIME v1.4 compliant devices shall be able to support the following scenarios:

1. Homogeneous networks which do not implement neither the new frame type (Type B) defined in Section 3.3.2 nor the additional robust modes (Robust DBPSK, Robust DQPSK).
2. Homogeneous networks which implement the new frame type (Type B) defined in Section 3.3.2 as well as the additional robust modes (Robust DBPSK, Robust DQPSK).
3. Mixed networks, composed of a combination of devices described in points (1) and (2) above.

Cases (1) and (2) are trivial since the networks are homogeneous and all devices implement the same features. However, case (3) “Mixed networks” requires a specific mechanism that provides compatibility between PRIME compliant devices using different feature sets. Please note that compatibility between case (1) and case (2) devices could be trivially achieved forcing those devices with an extended set of features to ignore them and to use a more limited configuration (e.g., frame Type A and no robust modes). Nonetheless, the aim of this Annex is to define a backwards compatibility mechanism for mixed networks that allows devices with different feature sets to be part of the same network.

Taking the PHY frame types into account, a backwards compatible frame (“BC frame”) is defined, as shown in Figure 152:

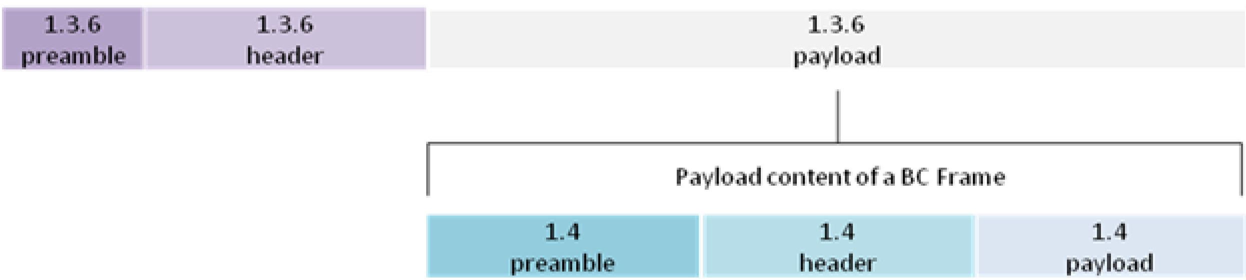


Figure 152 - Backwards Compatible PHY frame

The BC frame is compatible with PRIME v1.3.6 frame at PHY level, since it is just a v1.3.6 PPDU (corresponding to a v1.4 Type A PPDU) encapsulating a v1.4 Type B PPDU.

BC frame predefined content is described below in Figure 153:

a. PPDU content
    - Protocol [3:0]: Default transmission scheme, equal to DBPSK_CC
    - LEN[5:0]: Type A payload length (number of symbols in Type B header and Type B payload + 4)
b. PNPDU content

- HDR.HT[1:0]: default PNPDU value, equal to “1”
- Reserved[3:0]: predefined sequence, equal to “1010”
- PNH.SNA[47:0]: predefined value, "7A:2B:CB:CF:AB:AA”

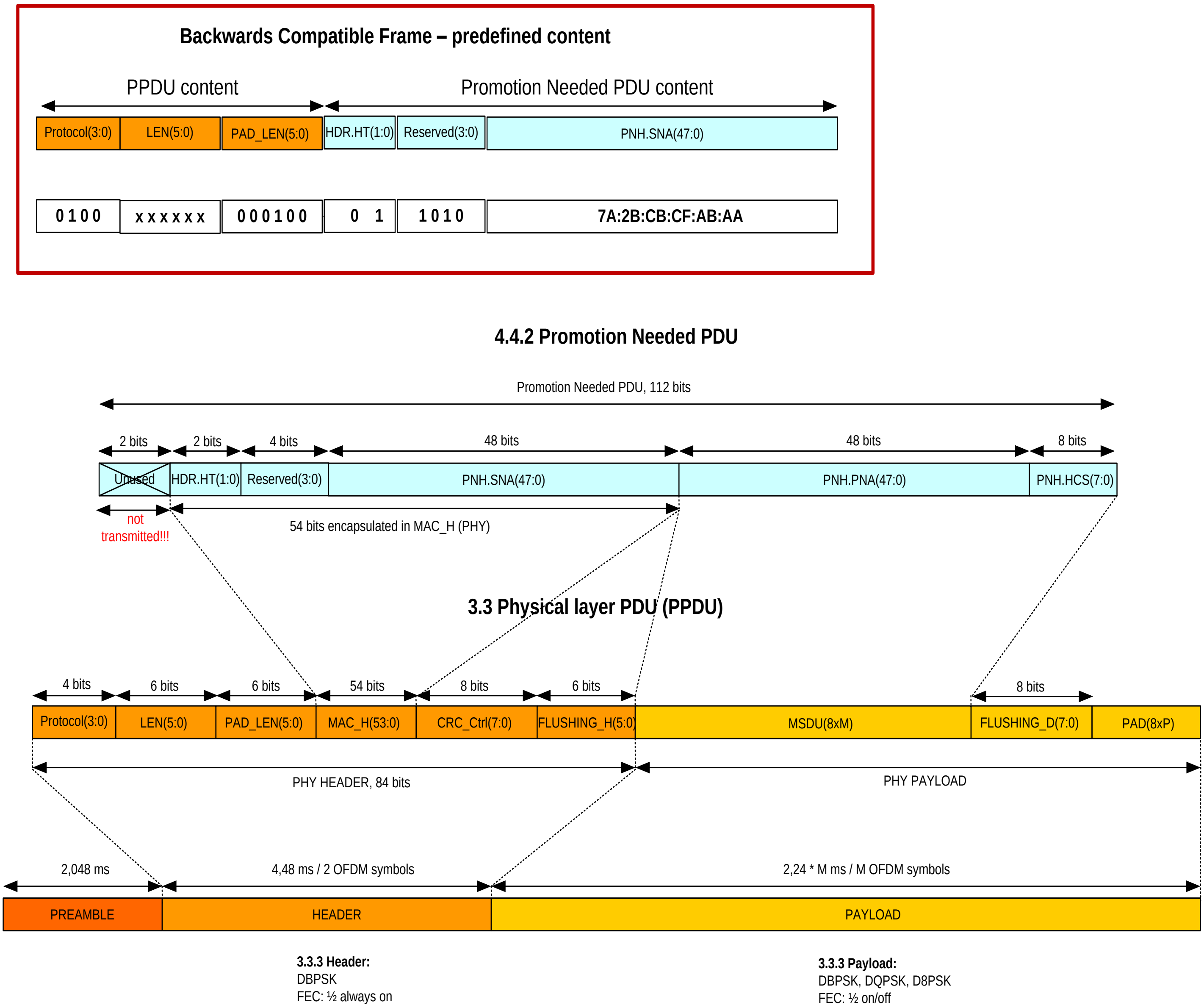


Figure 153 - BC frame predefined content

In mixed networks, the behavior of v1.4 and v1.3.6 devices upon reception of a BC frame will be different:

1. v1.3.6 devices detect preamble and header. The content of the v1.3.6 header in a BC frame is a predefined value (see Figure 153). The MAC of v1.3.6 devices will automatically discard the BC frame, but it will not provoke any collisions while the frame is being transmitted (Figure 154).

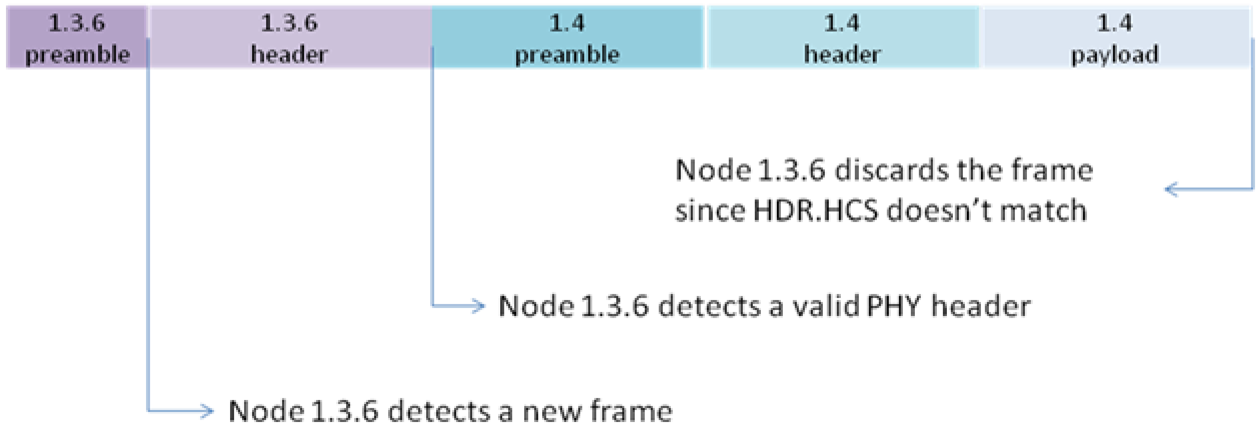


Figure 154 - PHY BC frame detected by v1.3.6 devices

2. 1.4 devices will detect the v1.3.6 preamble and immediately after that the predefined MAC_H configuration described above. Consequently, a v1.4 device will identify that a BC frame has been received and shall start searching the v1.4 preamble and header (Figure 155):

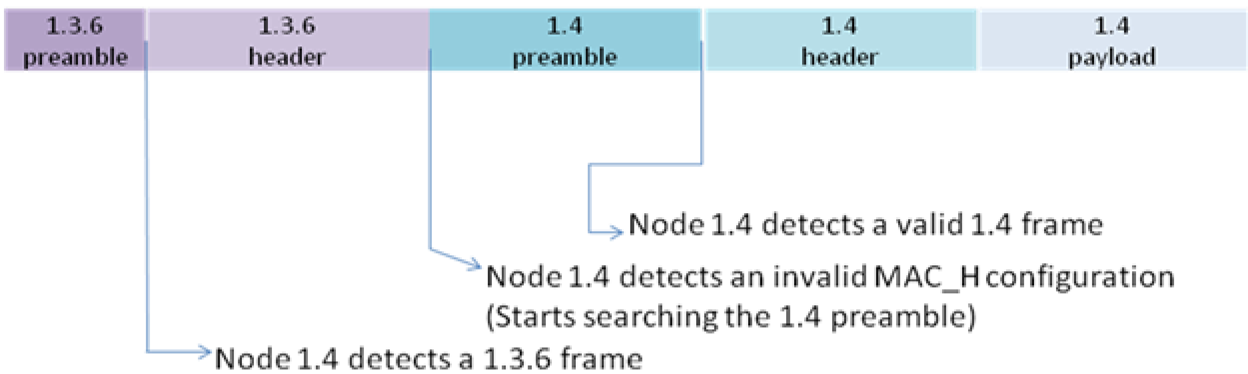


Figure 155 - BC PHY frame detected by v1.4 devices

Two additional use cases have been added to this Annex for the sake of clarification:

1. 1.3.6 frame received by a v1.4 node (Figure 156):

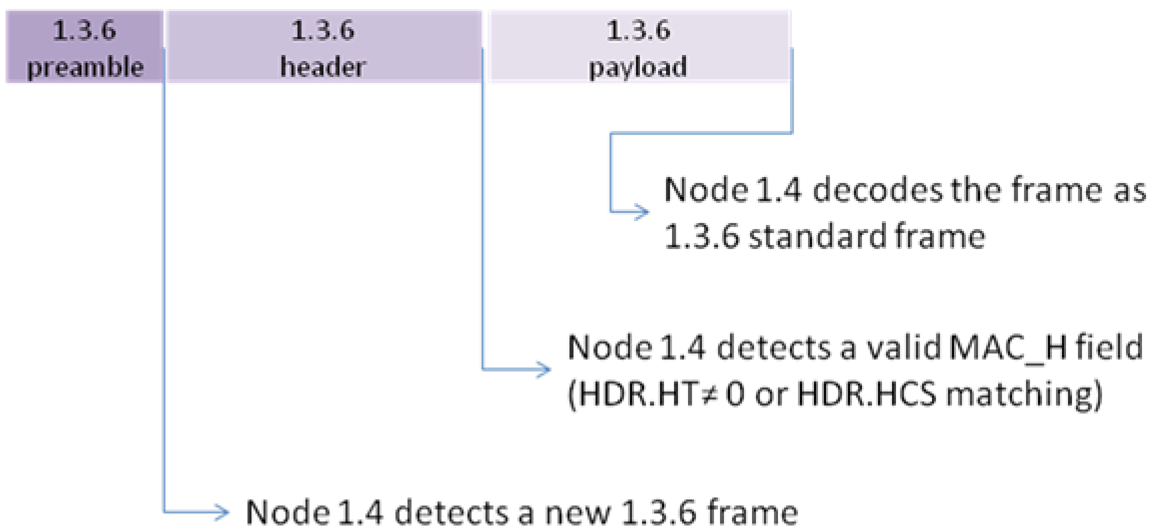


Figure 156 - v1.3.6 frame received by a v1.4 node

2. BC frame received by a v1.4 node in a very hard environment (Figure 157):

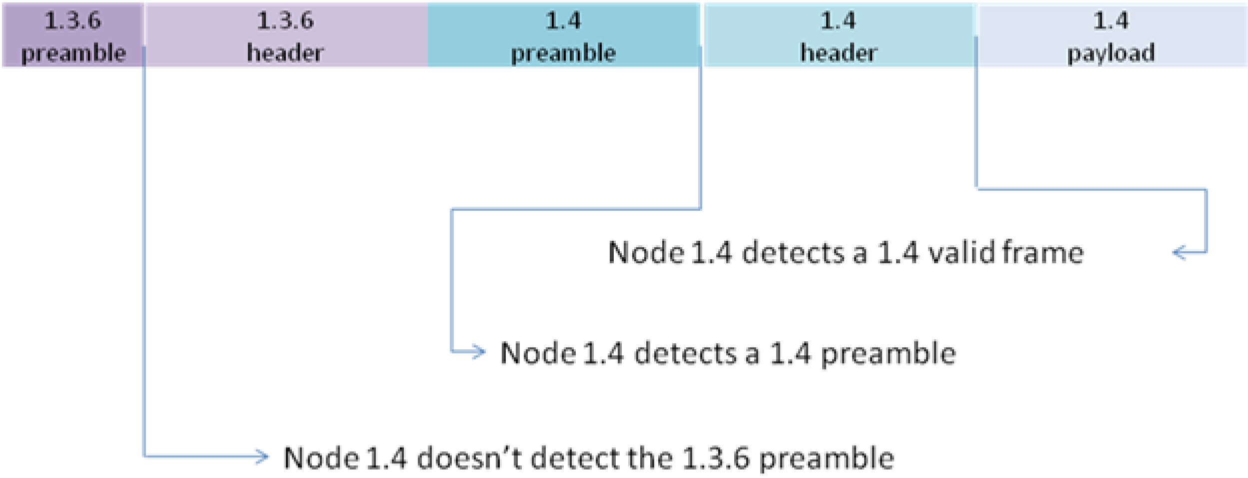


Figure 157 - BC PHY frame in noisy environment

Annex K
(normative)
MAC Backward Compatibility PDUs and Procedures

K.1 MAC PDU format

K.1.1 Generic MAC PDU

In a network running in PRIME compatibility mode, all nodes shall use the standard Generic Mac header, as enumerated in Section 4.4.2.2, and the compatibility packet header (CPKT). The compatibility packet header is 6 bytes in length and its composition is shown in Figure 158. Table 160 enumerates the description of each field.

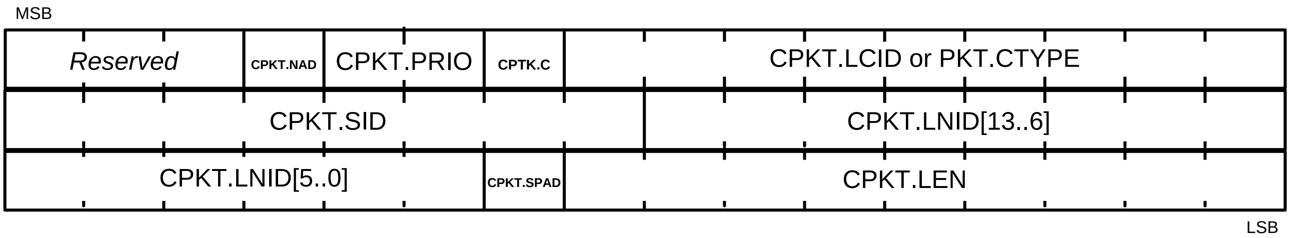


Figure 158 – Compatibility Packet Header

Table 160 – Compatibility packet header fields

Name	**Length**	**Description**
Reserved	3 bits	Always 0 for this version of the specification. Reserved for future use.
CPKT.NAD	1 bit	No Aggregation at Destination • If CPKT.NAD=0 the packet may be aggregated with other packets at destination. • If CPKT.NAD=1 the packet may not be aggregated with other packets at destination.
CPKT.PRIO	2 bits	Indicates packet priority between 0 and 3.
CPKT.C	1 bits	Control • If CPKT.C=0 it is a data packet. • If CPKT.C=1 it is a control packet.
CPKT.LCID / CPKT.CTYPE	9 bits	Local Connection Identifier or Control Type • If CPKT.C=0, CPKT.LCID represents the Local Connection Identifier of data packet. • If CPKT.C=1, CPKT.CTYPE represents the type of the control packet.

Name	Length	Description
CPKT.SID	8 bits	Switch identifier • If HDR.DO=0, CPKT.SID represents the SID of the packet source. • If HDR.DO=1,C PKT.SID represents the SID of the packet destination.
CPKT.LNID	14 bits	Local Node identifier. • If HDR.DO=0, CPKT.LNID represents the LNID of the packet source • If HDR.DO=1, CPKT.LNID represents the LNID of the packet destination.
CPKT.SPAD	1bit	Indicates if padding is inserted while encrypting payload. Note that this bit is only of relevance when Security Profile 1 (see 4.3.8.2.2) is used.
CPKT.LEN	9 bits	Length of the packet payload in bytes.

K.1.1.1 MAC control packets

The CPKT.CTYPE field follows the same enumeration as the PKT.CTYPE field (see Table 20). Control packet retransmission shall follow the mechanisms described in Section 4.4.2.6.2.

K.1.1.1.1 Compatibility REG control packet (CREG, CPKT.CTYPE=1)

The CREG control packet shall be used for registration requests (REG_REQ) in any case.

REG and CREG control packets are distinguished based on the packet length. If the payload length is 8 or 40 bytes, the payload is in CREG format; otherwise it is in REG format.

The description of data fields of this control packet is described in Table 161 and Figure 159. The meaning of the packets differs depending on the direction of the packet. This packet interpretation is explained in Table 162. These packets are used during the registration and unregistration processes in a compatibility mode network, as explained in Annex K.2.1 and K.2.2.

The PKT.SID field is used in this control packet as the Switch where the Service Node is registering. The PKT.LNID field is used in this control packet as the Local Node Identifier being assigned to the Service Node during the registration process negotiation.

The CREG.CAP_PA field is used to indicate the packet aggregation capability as discussed in Section 4.3.7. In the uplink direction, this field is an indication from the registering Terminal Node about its own capabilities. For the Downlink response, the Base Node evaluates whether or not all the devices in the cascaded chain from itself to this Terminal Node have packet-aggregation capability. If they do, the Base Node shall set CREG.CAP_PA=1; otherwise CREG.CAP_PA=0.

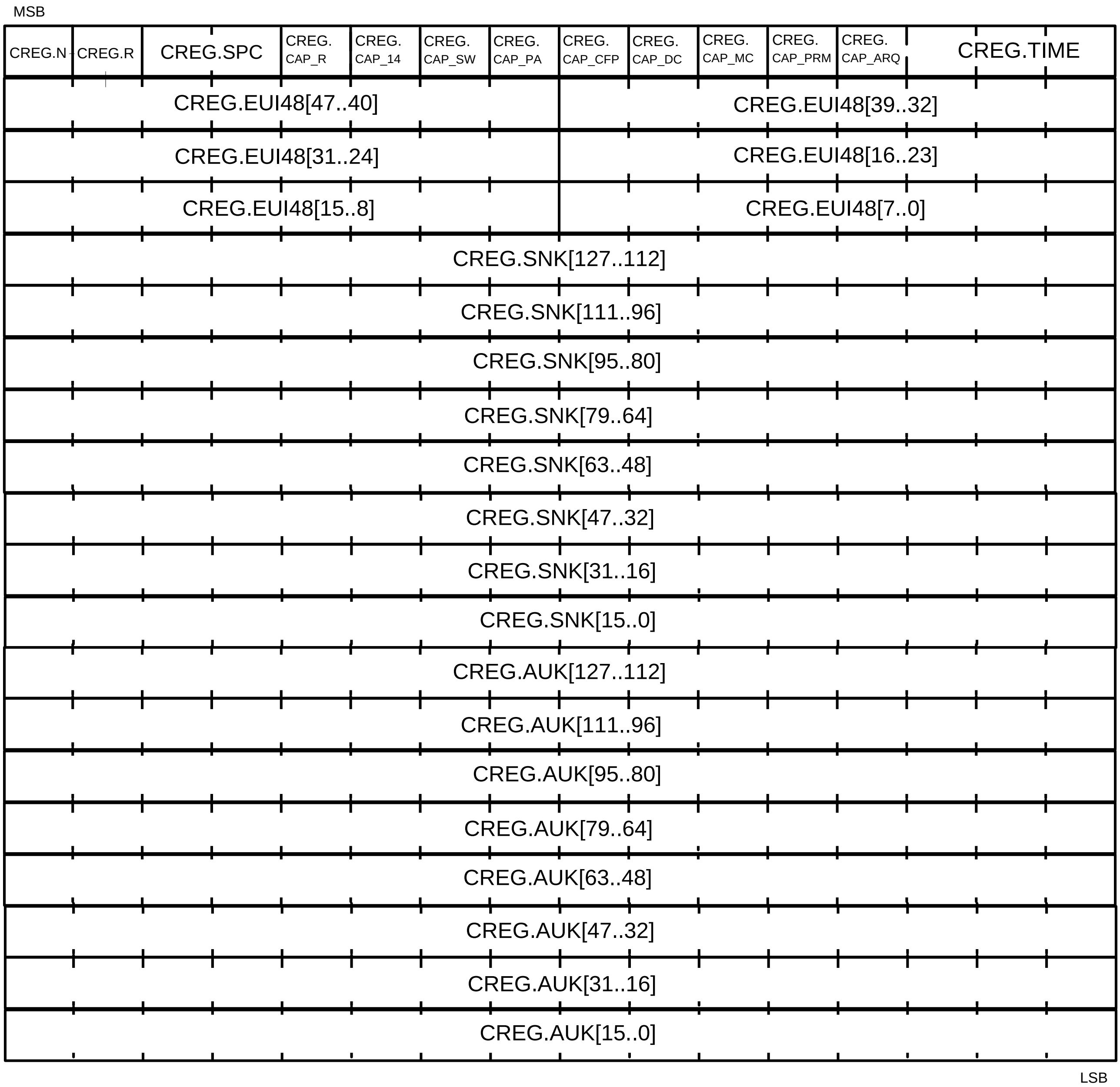


Figure 159 - CREG control packet structure

Table 161 - CREG control packet fields

Name	Length	Description
CREG.N	1 bit	Negative • CREG.N=1 for the negative register; • CREG.N=0 for the positive register. (see Table 162)

Name	Length	Description
CREG.R	1 bit	Roaming • CREG.R=1 if Node already registered and wants to perform roaming to another Switch; • CREG.R=0 if Node not yet registered and wants to perform a clear registration process.
CREG.SPC	2 bits	Security Profile Capability for Data PDUs: • CREG.SPC=0 No encryption capability; • CREG.SPC=1 Security profile 1 capable device; • CREG.SPC=2 Security profile 2 capable device); • CREG.SPC=3 Security profile 3 capable device (not yet specified).
CREG.CAP_R	1 bit	Robust Mode CREG REQ 1 if the node is using a robust link to join the network; 0 if the node is using a non-robust link to join the network CREG RSP the value is set to the same as CREG REQ frame CREG ACK the value is set to the same as CREG REQ frame
CREG.CAP_14	1 bit	PRIME v1.4 Backward Compatibility Mode Capable 1 (uplink) if the device is capable of using PRIME v1.4 backwards compatibility mode (i.e. this value is 1 for all PRIME v1.4 devices sending this message). 1 (downlink) if the base node is acting in 1.4 backwards compatibility mode. 0 if the device is a PRIME v1.3.6 device.
CREG.CAP_SW	1 bit	Switch Capable 1 if the device is able to behave as a Switch Node; 0 if the device is not.

Name	Length	Description
CREG.CAP_PA	1 bit	Packet Aggregation Capability 1 if the device has packet aggregation capability (uplink) if the data transit path to the device has packet aggregation capability (Downlink) 0 otherwise.
CREG.CAP_CFP	1 bit	Contention Free Period Capability 1 if the device is able to perform the negotiation of the CFP; 0 if the device cannot use the Contention Free Period in a negotiated way.
CREG.CAP_DC	1 bit	Direct Connection Capability 1 if the device is able to perform direct connections; 0 if the device is not able to perform direct connections.
CREG.CAP_MC	1 bit	Multicast Capability 1 if the device is able to use multicast for its own communications; 0 if the device is not able to use multicast for its own communications.
CREG.CAP_PRM	1 bit	PHY Robustness Management Capable 1 if the device is able to perform PHY Robustness Management; 0 if the device is not able to perform PHY Robustness Management.
CREG.CAP_ARQ	1 bit	ARQ Capable 1 if the device is able to establish ARQ connections; 0 if the device is not able to establish ARQ connections.
CREG.TIME	3 bits	Time to wait for an ALV_B messages before assuming the Service Node has been unregistered by the Base Node. For all messages except REG_RSP this field should be set to 0. For REG_RSP its value means: CALV.TIME = 0 => 32 seconds; CALV.TIME = 1 => 64 seconds; CALV.TIME = 2 => 128 seconds ~ 2.1 minutes; CALV.TIME = 3 => 256 seconds ~ 4.2 minutes; CALV.TIME = 4 => 512 seconds ~ 8.5 minutes; CALV.TIME = 5 => 1024 seconds ~ 17.1 minutes; CALV.TIME = 6 => 2048 seconds ~ 34.1 minutes; CALV.TIME = 7 => 4096 seconds ~ 68.3 minutes.
CREG.EUI-48	48 bit	EUI-48 of the Node EUI-48 of the Node requesting the Registration.

Name	Length	Description
CREG.SNK	128 bits	Encrypted Subnetwork key that shall be used to derive the Subnetwork working key
CREG.AUK	128 bits	Encrypted authentication key. This is a random sequence meant to act as authentication mechanism.

Table 162 - CREG control packet types

Name	HDR.DO	CPKT.LNID	CREG.N	CREG.R	Description
REG_REQ	0	0x3FFF	0	R	Registration request • If R=0 any previous connection from this Node should be lost; • If R=1 any previous connection from this Node should be maintained.
REG_RSP	1	< 0x3FFF	0	R	Registration response. This packet assigns the CPCK.LNID to the Service Node.
REG_ACK	0	< 0x3FFF	0	R	Registration acknowledged by the Service Node.
REG_REJ	1	0x3FFF	1	0	Registration rejected by the Base Node.
REG_UNR_S	0	< 0x3FFF	1	0	• After a REG_UNR_B: Unregistration acknowledge; • Alone: Unregistration request initiated by the Node.
REG_UNR_B	1	< 0x3FFF	1	0	• After a REG_UNR_S: Unregistration acknowledge; • Alone: Unregistration request initiated by the Base Node

Fields CREG.SNK and CREG.AUK are of significance only for REG_RSP and REG_ACK messages with Security Profile 1 (CREG.SCP=1). For all other message-exchange variants using the CREG control packet, these fields shall not be present reducing the length of payload.

In REG_RSP message, the CREG.SNK and CREG.AUK shall always be inserted encrypted with WK0.

In the REG_ACK message, the CREG.SNK field shall be set to zero. The contents of the CREG.AUK field shall be derived by decrypting the received REG_RSP message with WK0 and re-encrypting the decrypted CREG.AUK field with SWK derived from the decrypted CREG.SNK and random sequence previously received in SEC control packets.

K.1.1.1.2 Compatibility PRO control packet (CPRO, CPKT.CTYPE = 3)

The compatibility promotion (CPRO) control packet is used by the base node and all service nodes to promote a Service Node from Terminal function to Switch function. The description of the fields of this packet is given in Table 163 and Figure 160. The meaning of the packet differs depending on the direction of the packet and on the values of the different types. Table 164 shows the different interpretation of the packets. The promotion process in backward compatibility mode is explained in more detail in Annex K.2.3 and K.2.3.1.

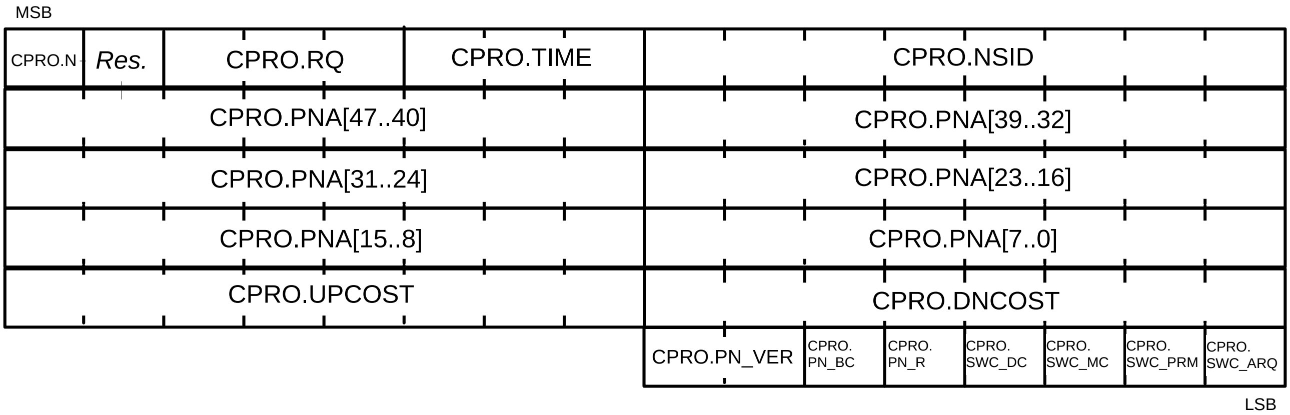


Figure 160 - CPRO_REQ_S control packet structure

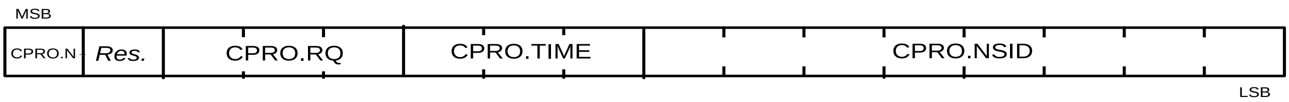


Figure 161 - CPRO control packet structure

Note that Figure 160 includes all fields as used by a CPRO_REQ_S message. All other messages are much smaller, containing only CPRO.N, CPRO.RC, CPRO.TIME and CPRO.NSID as shown in Figure 161.

Table 163 - CPRO control packet fields

Name	Length	Description
CPRO.N	1 bit	Negative CPRO.N=1 for the negative promotion CPRO.N=0 for the positive promotion
Reserved	1 bit	Reserved for future version of this protocol This shall be 0 for this version of the protocol.
CPRO.RQ	3 bits	Receive quality of the PNPDU message received from the Service Node requesting the Terminal to promote.
CPRO.TIME	3 bits	The ALV.TIME which is being used by the terminal which will become a switch. On a reception of this time in a PRO_REQ_B the Service Node should reset the Keep-Alive timer in the same way as receiving an ALV_B.

Name	Length	Description
CPRO.NSID	8 bits	New Switch Identifier. This is the assigned Switch identifier of the Node whose promotion is being managed with this packet. This is not the same as the PKT.SID of the packet header, which must be the SID of the Switch this Node is connected to, as a Terminal Node.
CPRO.PNA	0 or 48 bits	Promotion Need Address contains the EUI-48 of the Terminal requesting the Service Node promotes to become a Switch. This field is only included in the PRO_REQ_S message.
CPRO.UPCOST	0 or 8 bits	Total uplink cost from the Terminal Node to the Base Node. This value is calculated in the same way a Switch Node calculates the value it places into its own Beacon PDU. This field is only included in the PRO_REQ_S message.
CPRO.DNCOST	0 or 8 bits	Total Downlink cost from the Base Node to the Terminal Node. This value is calculated in the same way a Switch Node calculates the value it places into its own Beacon PDU. This field is only included in the PRO_REQ_S message.
CPRO.PN_VER	2 bits	Protocol version (PNH.VER) of the node represented by PRO.PNA. (This field is always zero for PRIME v1.3.6 nodes)
CPRO.PN_BC	1 bit	Backwards Compatibility mode of the node represented by PRO.PNA. 1 if the device is backwards compatible with 1.3.6 PRIME 0 if it is not. (This field is always zero for PRIME v1.3.6 nodes)
CPRO.PN_R	1 bit	Robust mode compatibility of the node represented by PRO.PNA. 1 if the device supports robust mode 0 if it is not (This field is always zero for PRIME v1.3.6 nodes)
CPRO.SWC_DC	1 bit	Direct Connection Switching Capability 1 if the device is able to behave as Direct Switch in direct connections. 0 otherwise

Name	Length	Description
CPRO.SWC_MC	1 bit	Multicast Switching Capability 1 if the device is able to manage the multicast traffic when behaving as a Switch. 0 otherwise
CPRO.SWC_PRM	1 bit	PHY Robustness Management Switching Capability 1 if the device is able to perform PRM for the Terminal Nodes when behaving as a Switch. 0 if the device is not able to perform PRM when behaving as a Switch.
CPRO.SWC_ARQ	1 bit	ARQ Buffering Switching Capability 1 if the device is able to perform buffering for ARQ connections while switching. 0 if the device is not able to perform buffering for ARQ connections while switching.

Table 164 - CPRO control packet types

Name	HDR.DO	CPRO.N	CPRO.NSID	Description
PRO_REQ_S	0	0	0xFF	Promotion request initiated by the Service Node.
PRO_REQ_B	1	0	< 0xFF	The Base Node will consider that the Service Node has promoted with the identifier CPRO.NSID. • After a PRO_REQ: Promotion accepted; • Alone: Promotion request initiated by the Base Node.
PRO_ACK	0	0	< 0xFF	Promotion acknowledge
PRO_REJ	1	1	0xFF	The Base Node will consider that the Service Node is demoted. It is sent after a PRO_REQ to reject it.
PRO_DEM_S	0	1	< 0xFF	The Service Node considers that it is demoted: • After a PRO_DEM_B: Demotion accepted; • After a PRO_REQ_B: Promotion rejected; • Alone: Demotion request.

Name	HDR.DO	CPRO.N	CPRO.NSID	Description
PRO_DEM_B	1	1	< 0xFF	The Base Node considers that the Service Node is demoted. • After a PRO_DEM_S: Demotion accepted; • Alone: Demotion request.

K.1.1.1.3 Compatibility BSI control packet (CBSI, CPKT.CTYPE = 4)

The Compatibility Beacon Slot Information (CBSI) control packet is only used by the Base Node and Switch Nodes. It is used to exchange information that is further used by a Switch Node to transmit its beacon. The description of the fields of this packet is given in Table 165 and Figure 162. The meaning of the packet differs depending on the direction of the packet and on the values of the different types. Table 166 represents the different interpretation of the packets. The promotion process is explained in more detail in 4.6.3.

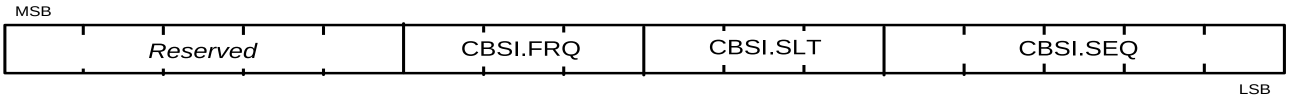


Figure 162 - CBSI control packet structure

Table 165 - CBSI control packet fields

Name	Length	Description
Reserved	5 bits	*Reserved for future version of this protocol. In this version, this field should be initialized to 0.*
CBSI.FRQ	3 bits	Transmission frequency of Beacon Slot, encoded as: FRQ = 0 => 1 beacon every frame FRQ = 1 => 1 beacon every 2 frames FRQ = 2 => 1 beacon every 4 frames FRQ = 3 => 1 beacon every 8 frames FRQ = 4 => 1 beacon every 16 frames FRQ = 5 => 1 beacon every 32 frames FRQ = 6 => *Reserved* FRQ = 7 => *Reserved*
CBSI.SLT	3 bits	Beacon Slot to be used by target Switch 0 – 4: non-robust mode beacon slot 5 – 6: robust mode beacon slot
CBSI.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.

Table 166 - CBSI control message types

Name	HDR.DO	Description
BSI_ACK	0	Acknowledgement of receipt of BSI control message

Name	HDR.DO	Description
BSI_IND	1	Beacon-slot change command

K.1.1.1.4 Compatibility FRA control packet (CFRA, CPKT.CTYPE = 5)

This control packet is broadcast from the Base Node and relayed by all Switch Nodes to the entire Subnetwork. It is used by switches transmitting CBCN compatibility beacons, and the terminal nodes directly attached to them, to learn about upcoming frame changes. The description of fields of this packet is given in Table 167 and Figure 163. Table 168 shows the different interpretations of the packets.

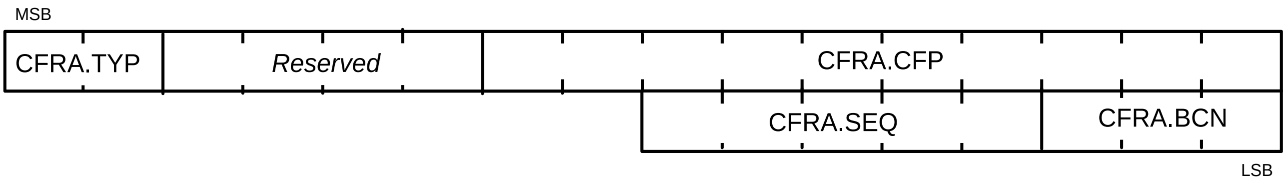


Figure 163 - CFRA control packet structure

Table 167 - CFRA control packet fields

Name	Length	Description
CFRA.TYP	2 bits	0: Beacon count change 1: CFP duration change 2: Reserved for PRIME v1.4 FRA message (see Section 4.4.2.6.5.1)
Reserved	4 bits	Reserved for future version of this protocol. In this version, this field should be initialized to 0.
CFRA.CFP	10 bits	Offset of CFP from start of frame
CFRA.SEQ	5 bits	The Beacon Sequence number when the specified change takes effect.
CFRA.BCN	3 bits	Number of beacons in a frame

Table 168 - CFRA control packet types

Name	CFRA.TYP	Description
FRA_BCN_IND	0	Indicates changes to frame structure due to change in beacon-slot count
FRA_CFP_IND	1	Indicates changes to frame structure due to change in CFP duration as a result of grant of CFP or end of CFP period for any requesting Service Node in the Subnetwork.

K.1.1.1.5 Compatibility ALV control packet (CALV, CPKT.CTYPE = 7)

In a compatibility mode network, the CALV control message is used exclusively for Keep-Alive signaling between a Service Node, the Service Nodes above it and the Base Node. The message exchange is bidirectional, that is, a message is periodically exchanged in each direction. The structure of these messages is shown in Figure 164 and Table 169. The different Keep-Alive message types are shown in Table 170. The compatibility keep-alive process is shown in Annex K.2.5.

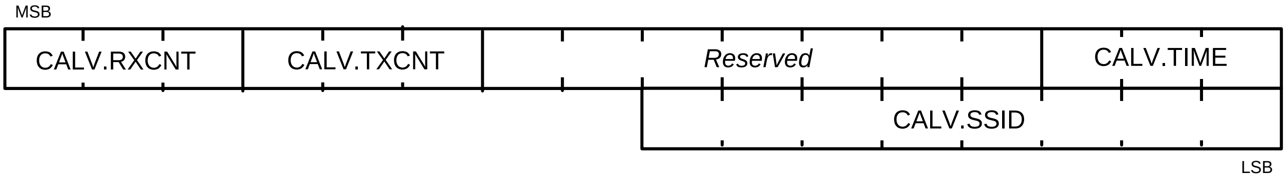


Figure 164 - CALV Control packet structure

Table 169 - CALV control message fields

Name	**Length**	**Description**
CALV.RXCNT	3 bits	Modulo 8 counter to indicate number of received CALV messages.
CALV.TXCNT	3 bits	Modulo 8 counter to indicate number of transmitted CALV messages.
Reserved	7 bits	Should always be encoded as 0 in this version of the specification.
CALV.TIME	3 bits	Time to wait for an ALV_B messages before assuming the Service Node has been unregistered by the Base Node. CALV.TIME = 0 => 32 seconds; CALV.TIME = 1 => 64 seconds; CALV.TIME = 2 => 128 seconds ~ 2.1 minutes; CALV.TIME = 3 => 256 seconds ~ 4.2 minutes; CALV.TIME = 4 => 512 seconds ~ 8.5 minutes; CALV.TIME = 5 => 1024 seconds ~ 17.1 minutes; CALV.TIME = 6 => 2048 seconds ~ 34.1 minutes; CALV.TIME = 7 => 4096 seconds ~ 68.3 minutes.
CALV.SSID	8 bits	For a Terminal, this should be 0xFF. For a Switch, this is its Switch Identifier.

Table 170 – Keep-Alive control packet types

Name	**HDR.DO**	**Description**
ALV_S	0	Keep-Alive message from a Service Node
ALV_B	1	Keep-Alive message from the Base Node

K.1.2 Compatibility Beacon PDU (CBCN)

In a compatibility mode network, the compatibility beacon PDU (CBCN) is transmitted by the base node and some of the Switch devices on the Subnetwork (see table in section 4.9.3.2).

Figure 165 below shows contents of a CBCN beacon.

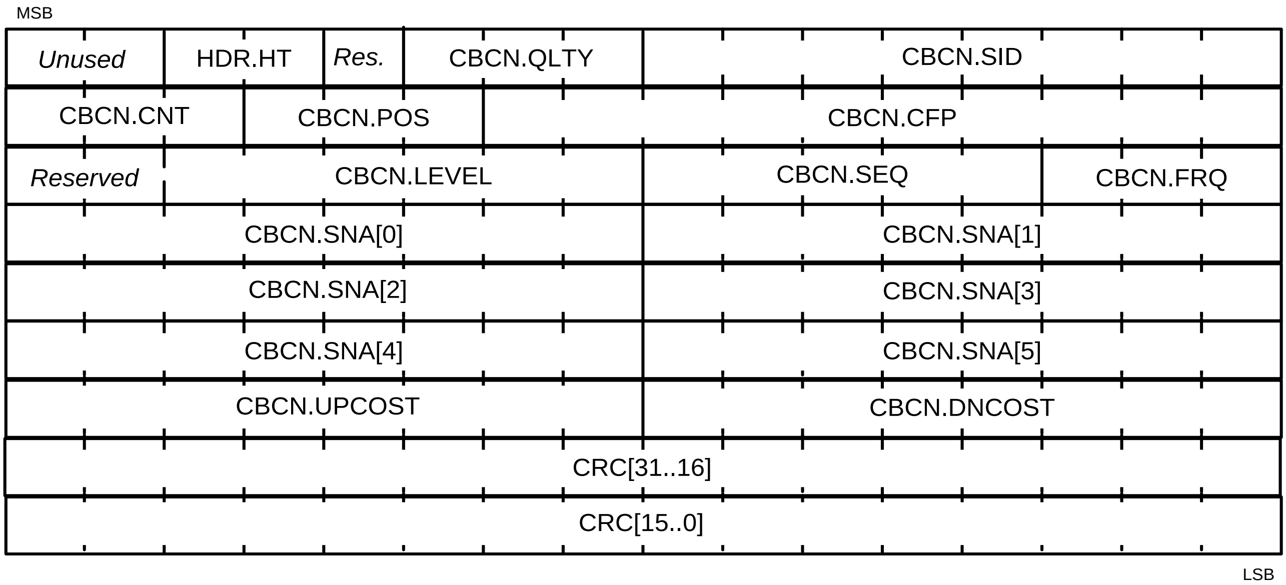


Figure 165 – Beacon PDU structure

Table 171 shows the CBCN PDU fields.

Table 171 - Beacon PDU fields

Name	Length	Description
Unused	2 bits	Unused bits which are always 0; included for alignment with MAC_H field in PPDU header (Fig 7, Section 3.3.3).
HDR.HT	2 bits	Header Type HDR.HT = 2 for Beacon PDU
Reserved	1 bit	Always 0 for this version of the specification. Reserved for future use.
CBCN.QLTY	3 bits	Quality of round-trip connectivity from this Switch Node to the Base Node. CBCN.QLTY=7 for best quality (Base Node or very good Switch Node), CBCN.QLTY=0 for worst quality (Switch having unstable connection to Subnetwork)
CBCN.SID	8 bits	Switch identifier of transmitting Switch
CBCN.CNT	3 bits	Number of beacon-slots in this frame
CBCN.SLT	3 bits	Beacon-slot in which this BPDU is transmitted CBCN.SLT=0 is reserved for the Base Node
CBCN.CFP	10 bits	Offset of CFP from start of frame CBCN.CFP=0 indicates absence of CFP in a frame. (CBCN. CFP includes robust beacon slots)

Name	Length	Description
Reserved	1 bit	Always 0 for this version of the specification. Reserved for future use.
CBCN.LEVEL	6 bits	Hierarchy of transmitting Switch in Subnetwork
CBCN.SEQ	5 bits	Sequence number of this BPDU in super frame. Incremented for every beacon the Base Node sends and is propagated by Switch through its BPDU such that entire Subnetwork has the same notion of sequence number at a given time.
CBCN.FRQ	3 bits	Transmission frequency of this BPDU. Values are interpreted as follows: 0 = 1 beacon every frame 1 = 1 beacon every 2 frames 2 = 1 beacon every 4 frames 3 = 1 beacon every 8 frames 4 = 1 beacon every 16 frames 5 = 1 beacon every 32 frames 6 = Reserved 7 = Reserved
CBCN.SNA	48 bits	Subnetwork identifier in which the Switch transmitting this BPDU is located
CBCN.UPCOST	8 bits	Total uplink cost from the transmitting Switch Node to the Base Node. The cost of a single hop is calculated based on modulation scheme used on that hop in uplink direction. Values are derived as follows: 8PSK = 0 QPSK = 1 BPSK = 2 8PSK_F = 1 QPSK_F = 2 BPSK_F = 4 The Base Node will transmit in its beacon a CBCN.UPCOST of 0. A Switch Node will transmit in its beacon the value of CBCN.UPCOST received from its upstream Switch Node, plus the cost of the upstream uplink hop to its upstream Switch. When this value is larger than what can be held in CBCN.UPCOST the maximum value of CBCN.UPCOST should be used.

Name	Length	Description
CBCN.DNCOST	8 bits	Total Downlink cost from the Base Node to the transmitting Switch Node. The cost of a single hop is calculated based on modulation scheme used on that hop in Downlink direction. Values are derived as follows: 8PSK 0 QPSK 1 BPSK 2 8PSK_F 1 QPSK_F 2 BPSK_F 4 The Base Node will transmit in its beacon a CBCN.DNCOST of 0. A Switch Node will transmit in its beacon the value of CBCN.DNCOST received from its upstream Switch Node, plus the cost of the upstream Downlink hop from its upstream Switch. When this value is larger than what can be held in CBCN.DNCOST the maximum value of CBCN.DNCOST should be used.
CRC	32 bits	The CRC shall be calculated with the same algorithm as the one defined for the CRC field of the MAC PDU (see section 0 for details). This CRC shall be calculated over the complete BPDU except for the CRC field itself.

The CBCN BPDU is also used to detect when the uplink Switch is no longer available either by a change in the characteristics of the medium or because of failure etc. The rules in section 4.4.4 apply.

K.2 MAC procedures

K.2.1 Registration process

The initial Service Node start-up (4.3.1) is followed by a Registration process. A Service Node in a *Disconnected* functional state shall transmit a registration control packet to the Base Node in order to get itself included in the Subnetwork.

All beacons shall be sent in CBCN format.

Since no LNID or SID is allocated to a Service Node at this stage, the CPKT.LNID field shall be set to all 1s and the CPKT.SID field shall contain the SID of the Switch Node through which it seeks attachment to the Subnetwork.

Base Nodes may use a Registration request as an authentication mechanism. However this specification does not recommend or forbid any specific authentication mechanism and leaves this choice to implementations.

For all successfully accepted Registration requests, the Base Node shall allocate an LNID that is unique within the domain of the Switch Node through which the attachment is realized. This LNID shall be indicated in the PKT.LNID field of response (REG_RSP). The assigned LNID, in combination with the SID of the Switch Node through which the Service Node is registered, would form the NID of the registering Node.

Based on the flag CBNC.CAP_14 a service node knows whether it is registered to a PRIME v1.4 (standard or compatibility mode) or a PRIME v1.3.6 network. Registration is a three-way process. The REG_RSP shall be acknowledged by the receiving Service Node with a REG_ACK message. The same format is used for the REG_RSP as for the REG_REQ.

Figure 166 represents a successful Registration process and Figure 167 shows a Registration request that is rejected by the Base Node. Details on specific fields that distinguish one Registration message from the other are given in Table 22 and Table 162.

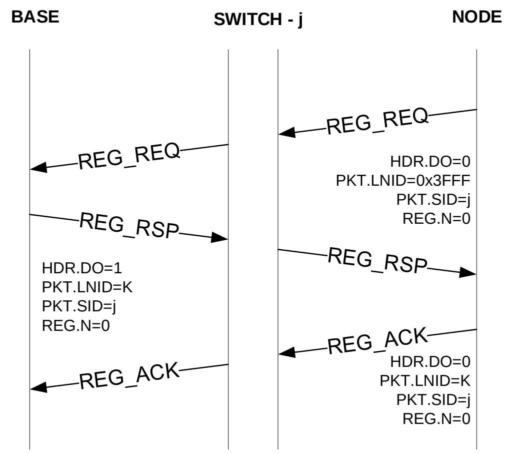


Figure 166 – Registration process accepted

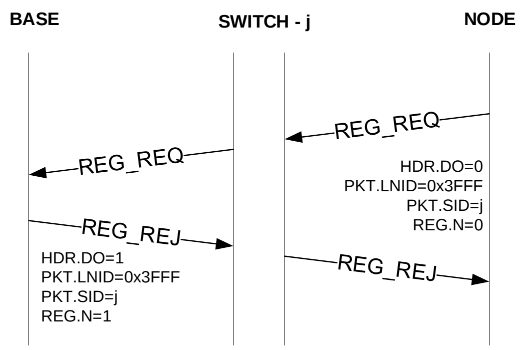


Figure 167 – Registration process rejected

When assigning an LNID, the Base Node shall not reuse an LNID released by an unregister process until after (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds, to ensure that all retransmit packets have left the Subnetwork. Similarly, the Base Node shall not reuse an LNID freed by the Keep-Alive process until T_{keep_alive} seconds have passed, using the last known acknowledged T_{keep_alive} value, or if larger, the last unacknowledged $T_{keep\_alive,}$ for the Service Node using the LNID.

During network startup where the whole network is powered on at once, there will be considerable contention for the medium. It is recommended, but optional, that randomness is added to the first transmission of REQ_REQ and all subsequent retransmissions. A random delay of maximum duration of 10% of *macMinCtlReTxTimer* may be imposed before the first REG_REQ message, and a similar random delay of up to 10% of *macMinCtlReTxTimer* may be added to each retransmission.

K.2.2 Unregistering process

The unregistering process follows the description in Section 4.6.2. All nodes use compatibility mode unregistration packets (CREG).

K.2.3 Promotion process

A Node that cannot reach any existing Switch may send promotion-needed frames so that a Terminal can be promoted and begin to switch. During this process, a Node that cannot reach any existing Switch may send PNPDUs so that a nearby Terminal can be promoted and begin to act as a Switch. During this process, a Terminal will receive PNPDUs and at its discretion, generate compatibility mode PRO_REQ control packets to the Base Node. In a compatibility mode network no standard PRO messages are used but only CPRO and CBSI messages.

The Base Node examines the promotion requests during a period of time. It may use the address of the new Terminal, provided in the promotion-request packet, to decide whether or not to accept the promotion. It will decide which Node shall be promoted, if any, sending a promotion response. The other Nodes will not receive any answer to the promotion request to avoid Subnetwork saturation. Eventually, the Base Node may send a rejection if any special situation occurs. If the Subnetwork is specially preconfigured, the Base Node may send Terminal Node promotion requests directly to a Terminal Node.

When a Terminal Node requests promotion, the CPRO.NSID field in the PRO_REQ_S message shall be set to all 1s. The PRO.NSID field shall contain an LSID allocated to the promoted Node in the PRO_REQ_B message. The acknowledging Switch Node shall set the CPRO.NSID field in its PRO_ACK to the newly allocated LSID. This final PRO_ACK shall be used by intermediate Switch Nodes to update their switching tables as described in 4.3.5.2.

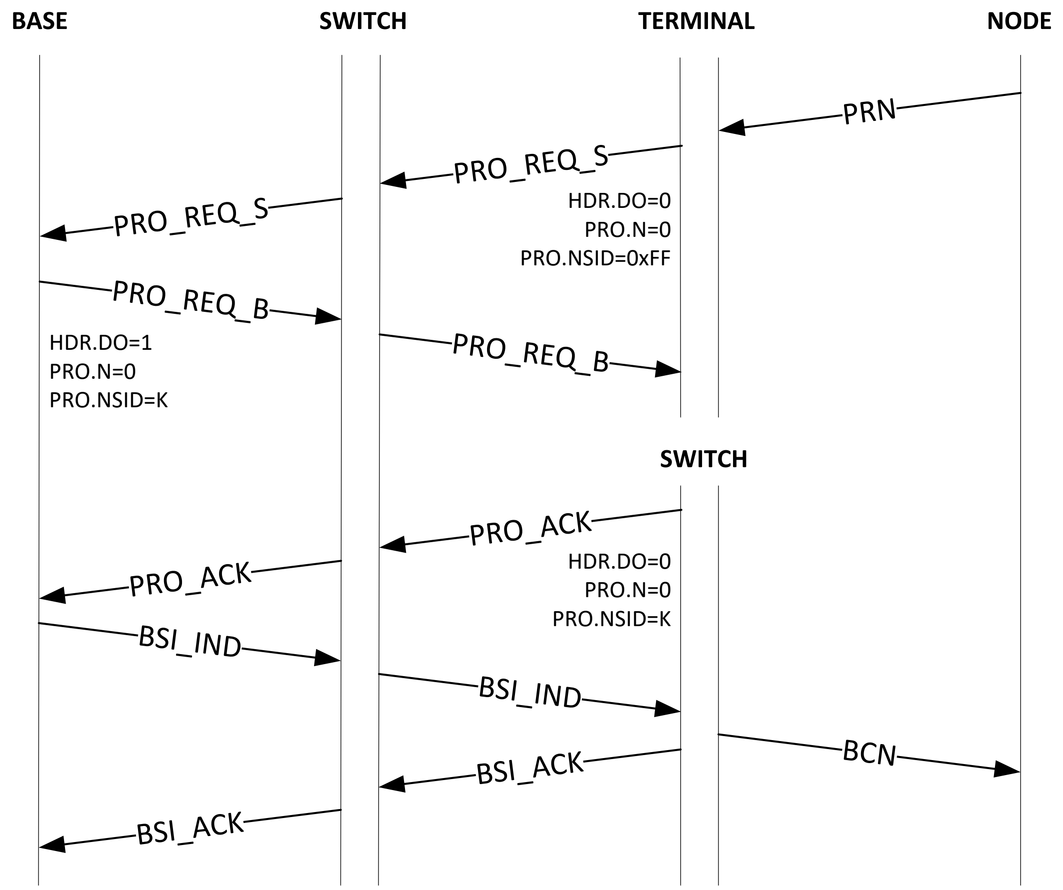
When reusing LSIDs that have been released by a demotion process, the Base Node should not allocate the LSID until after (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds to ensure all retransmit packets that might use that LSID have left the Subnetwork. Similarly, the Base Node shall not reuse an LNID freed by the Keep-Alive process until T_{keep_alive} seconds have passed, using the last known acknowledged T_{keep_alive} value, or if larger, the last unacknowledged $T_{keep\_alive,}$ for the Service Node using the LNID.

After the base node receives the PRO_ACK, the Base Node sends a BSI_IND to the service node. The encoding of the Beacon is decided using the beacon slot, if the beacon slot is 5 or 6, the encoding shall be DBPSK_R. The service node shall respond with the corresponding BSI_ACK.

The base node can use BSI_IND with two purposes:

- Change the allocation of the transmitted beacon. Only if the robustness of the beacon does not change.
- Start double switching by sending a second beacon in the other modulation.
- After a switch is double switching the next BSI_IND shall change the transmission properties of the robust beacon if slot is 5 or 6 and of the non-robust beacon otherwise.

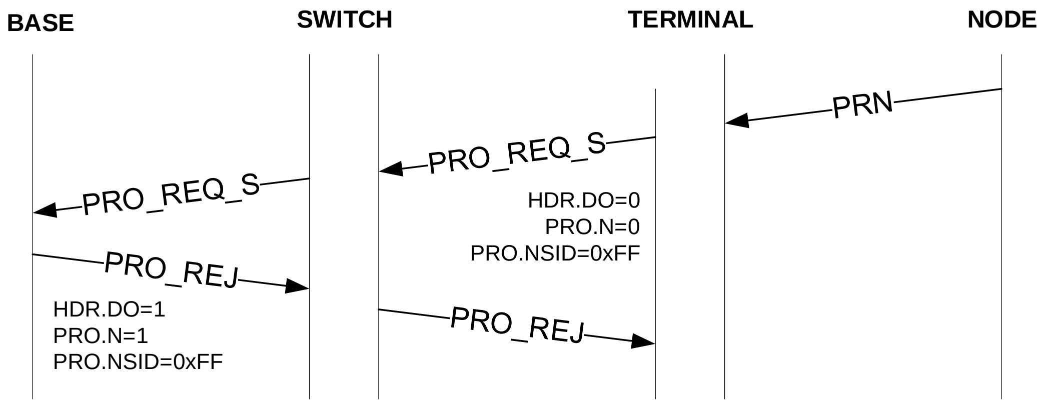
6096



6097

6098 **Figure 168 – Promotion process initiated by a Service Node**

6099



6100

6101 **Figure 169 – Promotion process rejected by the Base Node**

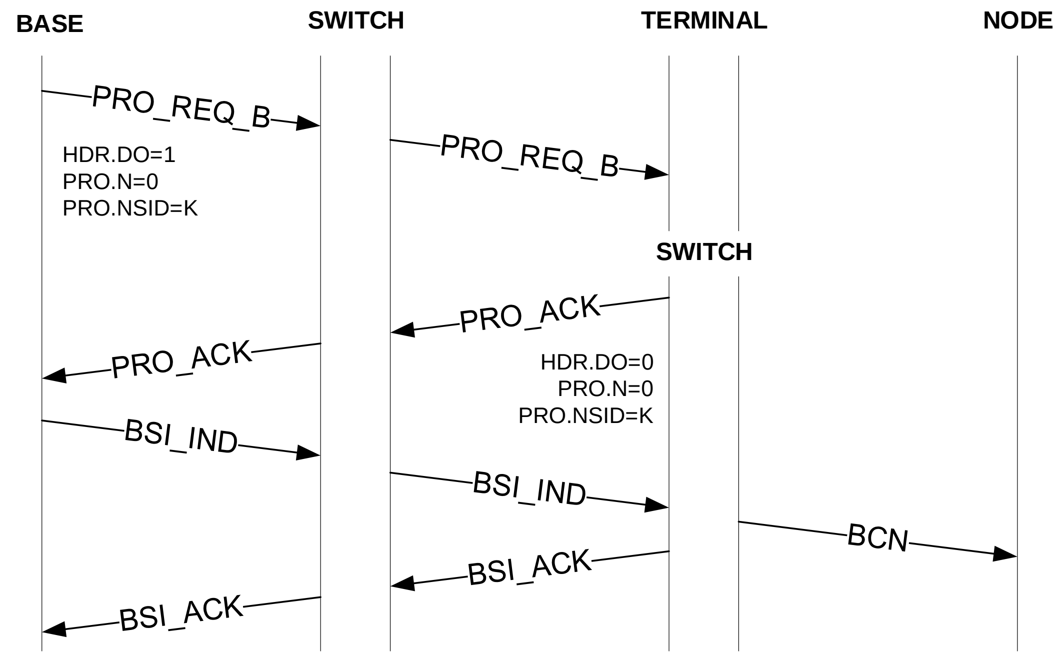


Figure 170 – Promotion process initiated by the Base Node

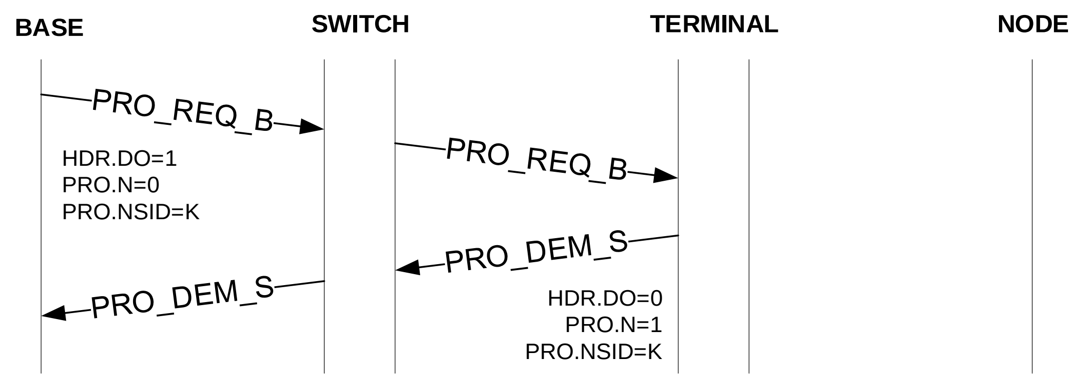


Figure 171 – Promotion process rejected by a Service Node

K.2.3.1 Double switching

Every time a Base Node promotes a node to act as robust switch, it shall start two BSI procedures to promote the Service Node so it has two beacon slots assigned, one robust and one non-robust.

One of the BSI_IND shall have a beacon slot in the range 0-4 for the non-robust beacon (DBPSK_CC) and the other one shall send the beacon slot in the range 5-6 for the robust beacon (DBPSK_R). For future changes of the BSI information the rule to separate the robust and non-robust beacons shall be the range of the beacon slot

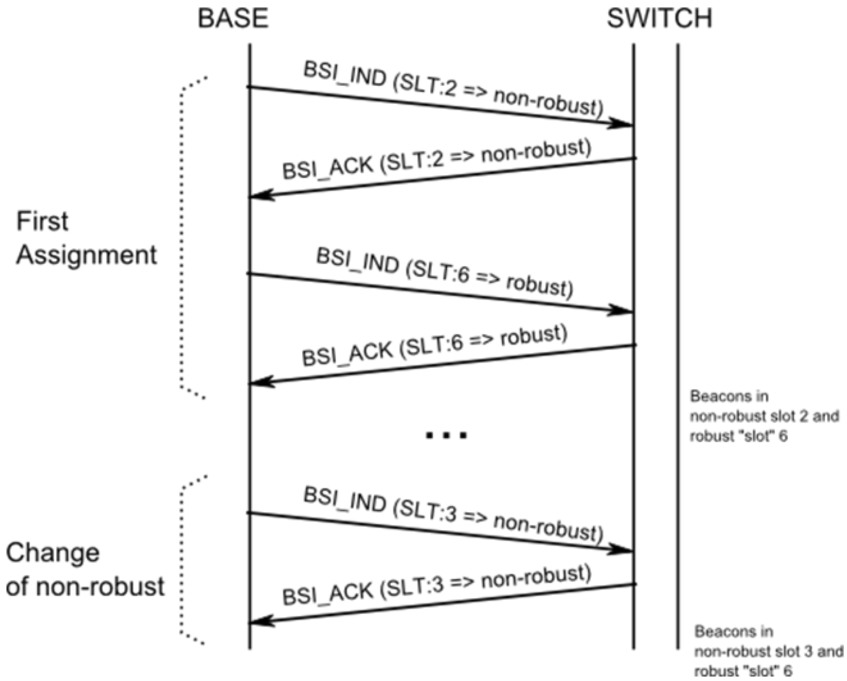


Figure 172 - Double switching BSI message exchange

K.2.4 Demotion process

The Base Node or a Switch Node may decide to discontinue a switching function at anytime. The demotion process provides for such a mechanism. In a compatibility mode network, only CPRO control packets are used for all demotion transactions.

The CPRO.NSID field shall contain the SID of the Switch Node that is being demoted as part of the demotion transaction. The PRO.PNA field is not used in any demotion process transaction and its contents are not interpreted at either end.

Following the successful completion of a demotion process, a Switch Node shall immediately stop the transmission of beacons and change from a *Switch* functional state to a *Terminal* functional state. The Base Node may reallocate the LSID and Beacon Slot used by the demoted Switch after (*macCtrlMsgFailTime* + *macMinCtlReTxTimer*) seconds to other Terminal Nodes requesting promotion.

The present version of this specification does not specify any explicit message to reject a demotion requested by a peer at the other end.

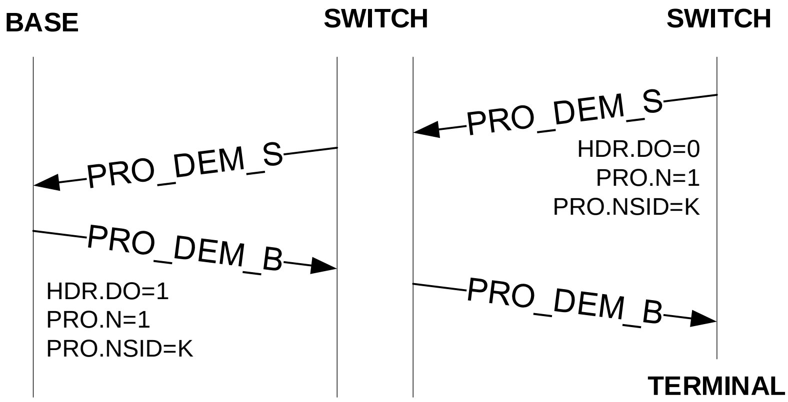


Figure 173 – Demotion process initiated by a Service Node

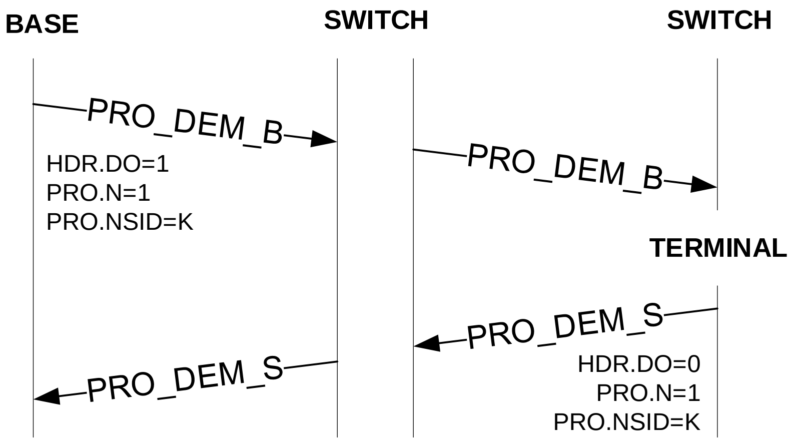


Figure 174 – Demotion process initiated by the Base Node

K.2.5 Keep-Alive process

The Keep-Alive process in a compatibility mode network is fundamentally different from the Keep-Alive process used in a standard PRIME v1.4 network. It is based on the PRIME v1.3.6 end-to-end process. The Keep-Alive process is used to detect when a Service Node has left the Subnetwork because of changes to the network configuration or because of fatal errors it cannot recover from.

When the Service Node receives the REG_RSP packet it uses the REG.TIME/CREG.TIME field to start a timer T_{keep_alive}. For every ALV_B it receives, it restarts this timer using the value from CALV.TIME. The encoding of CALV.TIME is specified in Table 169. It should also send an ALV_S to the Base Node. If the timer ever expires, the Service Node assumes it has been unregistered by the Base Node. The message PRO_REQ does also reset the Keep-Alive timer to the CPRO.TIME value.

Each switch along the path of a ALV_B message takes should keep a copy of the CPRO.TIME and then CALV.TIME for each Switch Node below it in the tree. When the switch does not receive an ALV_S message from a Service Node below it for T_{keep_alive} as defined in CPRO.TIME and CALV.TIME it should remove the Switch Node entry from its switch table. See section 4.3.5.2 for more information on the switching table. Additionally a Switch Node may use the REG.TIME/CREG.TIME and CALV.TIME to consider also every Service Node Registration status and take it into account for the switching table.

For every ALV_S or ALV_B message sent by the Base Node or Service Node, the counter CALV.TXCNT should be incremented before the message is sent. This counter is expected to wrap around. For every ALV_B or

ALV_S message received by the Service Node or the Base Node the counter CALV.RXCNT should be incremented. This counter is also expected to wrap around. These two counters are placed into the ALV_S and ALV_B messages. The Base Node should keep a CALV.TXCNT and CALV.RXCNT separated counter for each Service Node. These counters are reset to zero in the Registration process.

The algorithm used by the Base Node to determine when to send ALV_B messages to registered Service Nodes and how to determine the value CALV.TIME and REG.TIME/CREG.TIME is not specified here.

K.2.6 Connection management

The processes follow the standard processes described in section 4.3

K.2.7 Multicast group management

The processes follow the standard processes described in section 4.6.7. The base node shall not send any MUL_SW_LEAVE_B to PRIME v1.3.6 service nodes, as the PRIME v1.3.6 switches implement a different mechanism for multicast group tracking.

K.2.8 Robustness Management

Robustness management is not performed between devices running legacy version of protocol.

K.2.9 Channel allocation and deallocation

The process follows the description in Section 4.6.9. The Base Node shall send a CFRA broadcast packet.

Annex L
(informative)
Type A, Type B PHY frames and Robust modes

The following is a recommendation about how to combine the two PHY frame formats defined by PRIME with the available payload transmission schemes. As a general guideline, preamble and header shall be at least as robust as the payload.

Type A and Type B PRIME PHY frames specify different Preamble lengths and Header formats:

- TYPE A PHY frames, as described in Figure 3, comprise a "Preamble A" lasting 2.048 ms and a "Header A" with a length equal to two OFDM symbols (2 x 2.24 ms).
- TYPE B PHY frames, as described in Figure 4, **achieve higher robustness** by means of a "Preamble B" lasting 8.192 ms and a "Header B" with a length equal to four OFDM symbols (4 x 2.24 ms)

Table 172 shows all possible combinations, recommendations [OK / NOK] are based on the fact that preamble and header shall be at least as robust as the payload.

Table 172 - PHY frame types and Payload transmission schemes

HEADER and PREAMBLE	PAYLOAD							
	Robust DBPSK	Robust DQPSK	DBPSK_CC	DBPSK	DQPSK_CC	DQPSK	D8PSK_CC	D8PSK
Type A (short preamble, short header)	NOK	NOK	OK	OK	OK	OK	OK	OK
Type B (long preamble, long header)	OK	OK	OK	OK	OK	OK	OK	OK

Annex M
(informative)
Channel Hopping examples

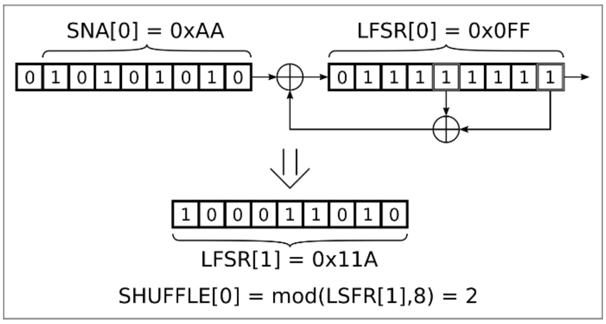
M.1 Channel sequence generation examples

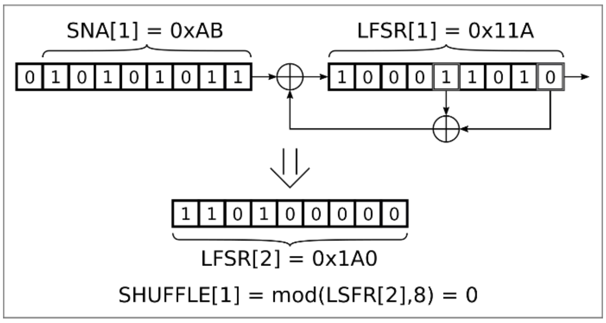
In this section examples are reported for the generation of the main hopping sequence. For the sake of simplicity and to make easier the understanding, the examples use a contained number of channels. Moreover, note that the examples are also applicable to understand the generation of the beacon hopping sequence (with the due changes, e.g. macHoppingSequenceLength => macHoppingBCNSequenceLength, macHoppingInitialChannelList => macHoppingBCNInitialChannelList).

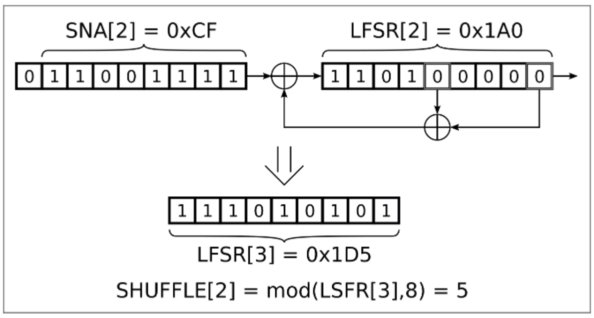
M.1.1 First example

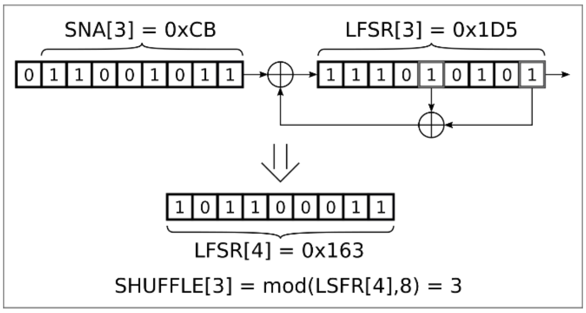
For this example we will be generating the channel sequence of a RF medium with macHoppingInitialChannelList = 0x00FF, hence macHoppingSequenceLength equal to 8, and a SNA with value 7A:2B:CB:CF:AB:AA.

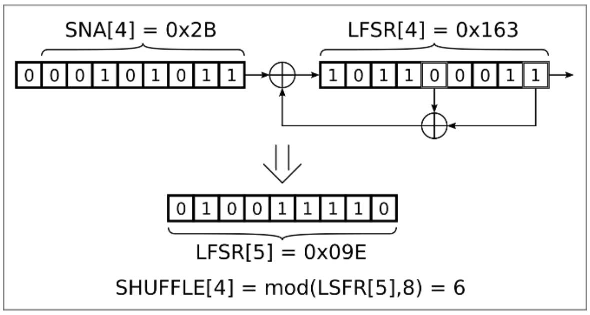
The first step is to obtain the SHUFFLE array values:

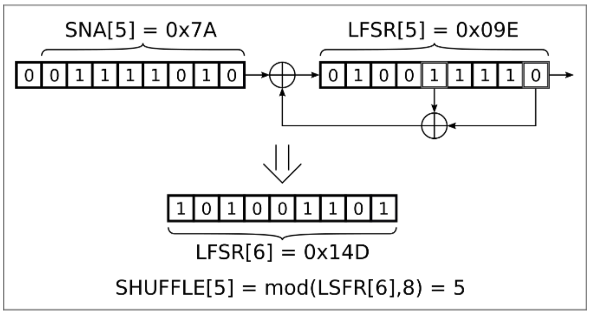


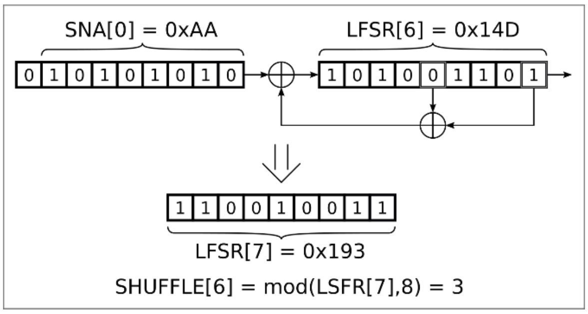


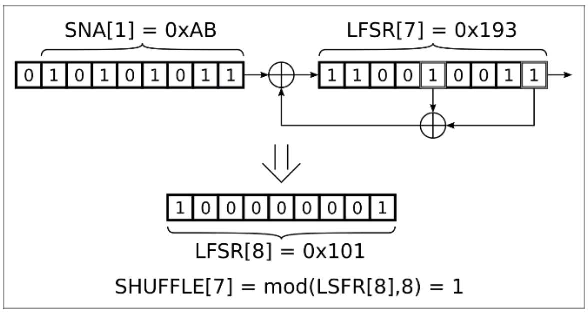












Then apply the shuffling algorithm to the CHANNELS array:

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 0, 1, 2, 3, 4, 5, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 0, 1, 2, 3, 4, 5, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 2, 1, 0, 3, 4, 5, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 0, 3, 4, 5, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 5, 3, 4, 0, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 5, 3, 4, 0, 6, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 5, 3, 6, 0, 4, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 5, 3, 6, 0, 4, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 2, 5, 4, 6, 0, 3, 7 }
```

```
SHUFFLE[] = { 2, 0, 5, 3, 6, 5, 3, 1 }
CHANNELS[] = { 1, 7, 5, 4, 6, 0, 3, 2 }
```

This resulting CHANNELS array will be the channel sequence shared by the network.

M.1.2 Second example

In this section the example of M.1.1 is largely reused.

Now, let’s consider the case where macHoppingInitialChannelList = 0x03ED, hence again macHoppingSequenceLength = 8, and a SNA with value 7A:2B:CB:CF:AB:AA. Compared to example of M.1.1, macHoppingInitialChannelList is different, i.e. different channels are selected for hopping. Repeating the same procedure reported in M.1.1**¡Error! No se encuentra el origen de la referencia.**, and summarizing the key steps, before shuffling we have

SHUFFLE = {2, 0, 5, 3, 6, 5, 3, 1}

CHANNELS = {0, 2, 3, 5, 6, 7, 8, 9}

and after shuffling

SHUFFLE = {2, 0, 5, 3, 6, 5, 3, 1}

CHANNELS = {2, 9, 7, 6, 8, 0, 5, 3}

M.2 Channel transitions with different frame and CFP/SCP lengths: examples

Two examples are shown: one with frame length equal to 276 symbols (see Figure 175) and one with frame length equal to 552 symbols (see Figure 176). For clarity, on both examples, two consecutive frames are reported.

Each example is subdivided into three parts: on the top row, the case where the CFP is smaller than 138 symbols, on the middle row, the case where the CFP is exactly 138 symbols, on the bottom row the case where the CFP is greater than 138 symbols.

According to section 4.6.10, the dwell time for the main sequence is 138 symbols, while the dwell time for the beacon sequence is equal to the frame length. Guard-times are reported in grey in the figures: they also allows identifying a RF channel change.

In the examples, for ease of drawing, for the main sequence “Main Pos” is an abbreviation to avoid writing macHoppingSequencePosition (and neglecting the formula that includes modulo macHoppingSequenceLength). Similarly, for the beacon sequence, “FrameSeq” is the value incremented for the beacon sequence (and neglecting the formula with BCN.SEQ modulo macHoppingBCNSequenceLength).

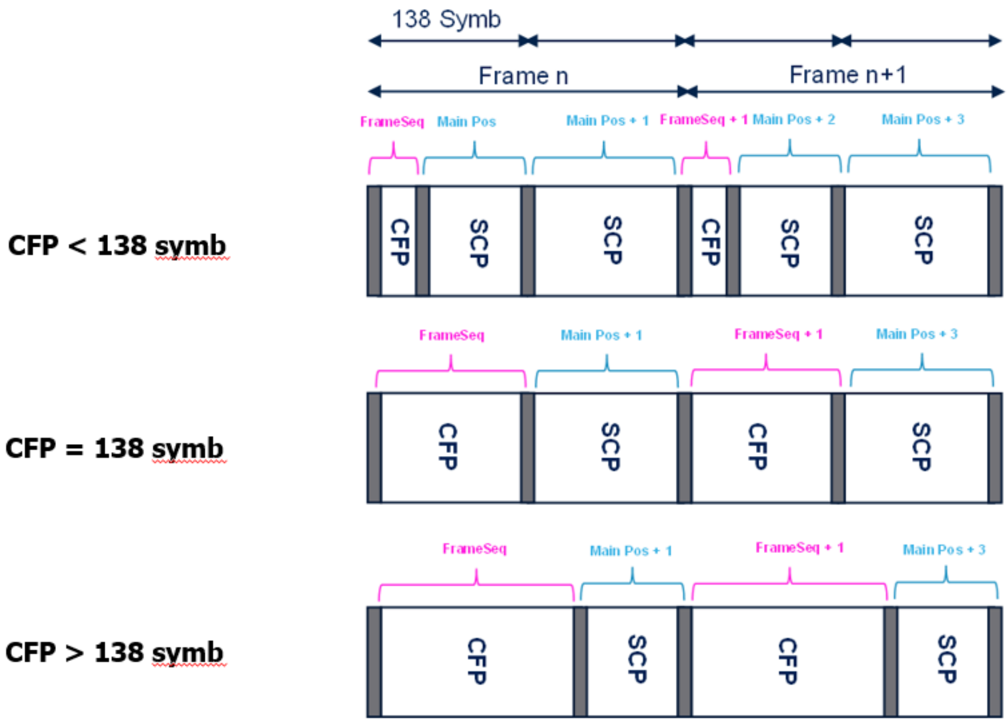


Figure 175 - Example with FrameLength = 276 symbols

Figure 176 - Example with FrameLength = 552 symbols

As it can be seen, RF channel changes occur in these events:

- a transition between SCP and CFP (at the start of a new frame, at the first CFP symbol, swapping from the main channel sequence to the beacon channel sequence)
- a transition between CFP and SCP (at the last CFP symbol, swapping from the beacon channel sequence to the main channel sequence)
- after each dwell time during the SCP (channel changes in the main channel sequence)

Annex N
(normative)
Management Information Base for PRIME Nodes

The purpose of this annex is to describe the Management Information Base (MIB) required for every PRIME PLC-only Base Node. The objects defined in this MIB will be requested by a Network Management System which will generate alarms and reports used for network operation purposes.

A part of MIB objects can be directly mapped to some existing PIB attributes. The value of the rest of MIB objects can be computed based on already defined PIB and List attributes.

N.1 Basic requirements for Base Nodes

N.1.1 Instantaneous Objects

The following objects should be available as instantaneous values to be consulted at any time:

<table>
<tr><th>Object Name</th><th>Type</th><th>Description</th></tr>
<tr><td>Network Uptime (ms)</td><td>Integer32</td><td>Time from last network reset.

Network reset time is when the BN started to send beacons</td></tr>
<tr><td>Number of Terminals in the subnetwork</td><td>Integer16</td><td>Number of registered SN in terminal state</td></tr>
<tr><td>Number of Switches in the subnetwork</td><td>Integer16</td><td>Number of registered SN in switch state</td></tr>
<tr><td>Number of Beacons Allocated</td><td>Integer16</td><td>Allocated beacons in a superframe, calculated as the sum of all beacons transmitted in the Subnetwork during a superframe. The number of beacons transmitted by a device in a superframe depends on the transmission frequency (BCN.FRQ) associated to BPDU</td></tr>
<tr><td>Number of Switching levels</td><td>Integer16</td><td>Number of logical levels in the subnetwork</td></tr>
<tr><td>Number of Elements per level</td><td>Table</td><td>This object is a table with up to 63 rows (only 8 rows are required) and two columns.<table><tr><th>Entry Element</th><th>Type</th></tr></table></td></tr>
</table>

<table>
<tr><td></td><td></td><td><table><tr><td>Number of Switches</td><td>Integer16</td></tr><tr><td>Number of Terminals</td><td>Integer16</td></tr></table></td></tr>
<tr><td>Total Number of Unicast Active Connections</td><td>Integer16</td><td>The number of unicast non direct connections</td></tr>
<tr><td>Detail of Active Connections</td><td>Table</td><td>Number of active connections per each type of connection implemented in the Base Node and defined in Annex E of PRIME specification. If the BN does not implement a type of connection, it will answer with the message “No Such Object Available” for this object. If there are no active connections of a particular type, the associated Number of Active Connections will be zero. The minimum required objects are the ones associated to TYPE_CL_432 and TYPE_CL_MGMT<table><tr><td>Entry Element</td><td>Type</td></tr><tr><td>Connection Type</td><td>Integer8</td></tr><tr><td>Number of Active Connections</td><td>Integer16</td></tr></table></td></tr>
<tr><td>Total Number of Multicast Connections</td><td>Integer16</td><td>Number of active multicast connections</td></tr>
<tr><td>Detail of Devices Registered in a Multicast Connection</td><td>Table</td><td>Number of nodes per active multicast connection<table><tr><td>Entry Element</td><td>Type</td></tr><tr><td>Multicast Connection ID</td><td>Integer16</td></tr><tr><td>Number of Devices per Multicast connection</td><td>Integer16</td></tr></table></td></tr>
</table>

N.1.2 Periodic Objects

The periodic objects’ values should be integrated per a period equal to 1 minute. The Base Node should be able to keep the information for 60 periods. Apart from these periods, the Base Node should save the accumulated value for each object since the last network reset. The first row is the accumulated value, the second is the last period, the third is the period before that and so on.

The following objects should be available with the conditions described in the previous paragraph. Therefore, it is a table with 61 rows and 7 columns.

Object Name	Type	Description
Number of Topology Changes	4x Integer32	- Promotions - Demotions - Registrations - Unregistrations
Overall Coverage	Integer16	It reflects the overall network reachability.
Average Availability	Integer32	The accumulated value (first value of the table) is calculated as the average availability of the different nodes registered (at least once in the period) in the subnetwork. The accumulated value (first row) will take into account every meters registered since the last reset. The formulas to calculate these values are the following. For the accumulated value: $Availability = \frac{\sum_{i=1}^{n} Treg_i}{n\,Tuptime}$ where: Treg: is the time that a particular node is registered in the subnetwork since the last reset n: is the number of different nodes registered at least once since the last reset Tuptime: is the time since the last reset. For each of the 60 values corresponding to each period:

		$$Availability = \frac{\sum_{i=1}^{n} Treg_i}{n\,T}$$ where: Treg: is the time that a particular node is registered in the subnetwork during the corresponding period n: is the number of different nodes registered at least once in the corresponding period T: is the period value.
Number of Nodes used in the Availability calculation	Integer16	The Number of Nodes (n) associated to Average Availability

N.2 Advanced Requirements for Base Nodes

N.2.1 Topology

The following object is a table including the list with the instantaneous “image” of the subnetwork topology. The last three values, are calculated since the last reset of the base node.

List of registered nodes with the following information of each of them:

<table>
<tr><th>Object Name</th><th>Description</th></tr>
<tr><td>Topology</td><td>
<table>
<tr><th>Entry Element</th><th>Type</th></tr>
<tr><td>MAC</td><td>EUI48</td></tr>
<tr><td>State</td><td>Integer8 (0:Disconnected;1:Terminal;2:Switch;3:Base)</td></tr>
<tr><td>LNID</td><td>Integer16</td></tr>
<tr><td>SID</td><td>Integer8 (if not directly connected to the BN)</td></tr>
<tr><td>LSID</td><td>Integer8 (if it is a switch)</td></tr>
<tr><td>Availability</td><td>Integer32 (Total Time, in seconds, in which the Service Node is in registered state)</td></tr>
<tr><td>Disconnections</td><td>Integer32</td></tr>
<tr><td>Coverage</td><td>Integer16</td></tr>
</table>
</td></tr>
</table>

N.2.2 Traffic Sniffer and Topology Logging

Apart from these read-only objects, the node should provide a method to activate the sniffer option. For this purpose, the following objects would be available for read-write operations.

<table>
<tr><th>Object Name</th><th colspan="2">Description</th></tr>
<tr><td rowspan="6">Sniffer</td><td>Entry Element</td><td>Type</td></tr>
<tr><td>Enable Sniffer</td><td>Integer8 (0 or 1)</td></tr>
<tr><td>Enable Sniffer Optional Fields</td><td>Integer8 (0 or 1)</td></tr>
<tr><td>Enable Topology</td><td>Integer8 (0 or 1)</td></tr>
<tr><td>Destination Address</td><td>IPAddress (128 bits, supporting IPv4 and IPv6 addressing)</td></tr>
<tr><td>Destination Port</td><td>Integer32</td></tr>
</table>

When the node receives a “1” value for the Enable Sniffer object, it should activate the sniffer option sending every MAC PDU encapsulated in TCP to the destination address- port indicated by the corresponding objects. If Enable Sniffer Optional Fields object is also set to 1, the information will include optional fileds.

When the node receives a “1” value for the Enable Topology object, it should activate the topology logging function sending every topology change encapsulated in TCP to the destination address-port indicated by the corresponding objects.

Annex O
(informative)
Traffic Sniffer and Topology Logging Protocol Definition

The protocol described here is just a recommendation to better describe sniffer and topology custom messages. However manufacturers could use a different protocols as long as it complies with the specification.

The protocol used to transmit the sniffed traffic is a simple binary protocol encoded in big endian. The protocol encapsulates messages just having a fixed message format that could allow carrying other information in the future.

When Topology, Sniffer or both are enabled, the device will open the socket. The basic message has the following format:

4 bytes	1 byte	'Length' bytes
Length	Type	Payload

Length: is the length of the payload, the messages are encoded sequentially and multiplexed using this length.

Type: is the type of the message, currently there are just 2 type of messages: MAC PDU reception and transmission.

The message types that can be carried now are the following:

Message type	**Identifier**
MAC_TX	0
MAC_RX	1
Topology	2

O.1 MAC_TX and MAC_RX

For the messages MAC_TX and MAC_RX the payload will have the following format:

4	5	2	2	Len	-
Time Counter	Date and Time	PHY INFO	Len	PDU	Optional fields

Time Counter: is a time counter of 10 microseconds that overflows every 12hours approximately.

Date and Time: Number of seconds since 00:00 (midnight) 1 January, 1970 GMT.

PHY Info:

Bits	type	Description

15	OptionalFields	1 if optional fields are present, 0 otherwise.
14	Interface	1 if PLC, 0 other. If 0, SNR, Power and Encodingare not valid
10-13	reserved	
7-9	Encoding	The encoding of the PDU: 0 – DBPSK 1 – DQPSK 2 – D8PSK 3 – DBPSK_CC 4 – DQPSK_CC 5 – D8PSK_CC 6 – DBPSK_R 7 – DQPSK_R
4-6	SNR	Signal to Noise ratio in which this message was received (only reception) as defined in PRIME standard: 0: ≤ 0 dB 1: ≤ 3 dB 2: ≤ 6 dB … 7: > 18 dB
0-3	Power	For RX: Reception power in which this messages was received (only reception) PRIME: 0: ≥ 70 dBuV 1: ≥ 72 dBuV 2: ≥ 74 dBuV … 15: > 98 dBuV For TX: 0: Maximal output level (MOL) 1: MOL -3 dB 2: MOL -6 dB … 7: MOL -21 dB

6309 Len: the length of the PDU payload.

6310 PDU: the MAC PDU buffer.

6311 Optional fields: Optional information of each MAC PDU; this field can contain several fields with the following
6312 format.

1	1	Field length

Field id	Field length	Data

Some pre-defined optional fields are the following:

Field id	length	type			Description
0	4	PHY RX details	SNR	2 bytes	Signal to Noise ratio in which this message was received in 0.1 dB steps.
			RX Power	2 bytes	Reception power in which this messages was received (only reception) in 0.1 dBuV steps
1	*	IFACE			Text representation of the interface this messages was received/transmitted: e.g: plc1, plc3
2	6	EUI-48			MAC Address of the service node origin of the PDU if uplink and destination if downlink.
3	4	Duration			The duration of the PDU in 10s of microseconds.
255	*	Vendor Specific			Content of this field is vendor specific, two first bytes in data shall contain the AppVendorId. It is recommended that vendors follow similar field structure with Field Id, Length and Data inside the Vendor Specific field.

O.2 Topology

For the Topology messages, the payload will have the following format:

4	5	6	1	2	1	1
Time Counter	Date and Time	EUI-48	SID	LNID	STATE	SSID

Time Counter: is a time counter of 10 microseconds that overflows every 12 hours approximately.

Date and Time: Number of seconds since 00:00 (midnight) 1 January, 1970 GMT.

EUI-48: MAC Address of the service node.

SID: Switch Identifier of the parent. 0 if directly connected to the Base Node.

LNID: LNID of the service node.

STATE: State of the service node as defined in PRIME Specification (0:Disconnected, 1:Terminal, 2:Switch, 3:Base)

SSID: Switch Identifier if the service node is in Switch State

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