

**IEEE Standard for
Local and metropolitan area networks—**

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 3: Physical Layer (PHY) Specifications for Low- Data-Rate, Wireless, Smart Metering Utility Networks

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

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(Amendment to
IEEE Std 802.15.4™-2011)

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Abstract: In this amendment to IEEE Std 802.15.4-2011, outdoor low-data-rate, wireless, smart metering utility network requirements are addressed. Alternate PHYs are defined as well as only those MAC modifications needed to support their implementation.

Keywords: ad hoc network, IEEE 802.15.4, IEEE 802.15.4g, low data rate, low power, LR-WPAN, mobility, PAN, personal area network, radio frequency, RF, short range, smart metering utility networks, SUN, wireless, wireless personal area network, WPAN

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This amendment specifies alternate PHYs in addition to those of IEEE Std 802.15.4-2011. In addition to the new PHYs, the amendment also defines those MAC modifications needed to support their implementation.

The alternate PHYs support principally outdoor, low-data-rate, wireless, smart metering utility network (SUN) applications under multiple regulatory domains. The SUN PHYs are as follows:

- Multi-rate and multi-regional frequency shift keying (MR-FSK) PHY
- Multi-rate and multi-regional orthogonal frequency division multiplexing (MR-OFDM) PHY
- Multi-rate and multi-regional offset quadrature phase-shift keying (MR-O-QPSK) PHY

The SUN PHYs support multiple data rates in bands ranging from 169 MHz to 2450 MHz.

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IEEE Standard for Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 3: Physical Layer (PHY) Specifications for Low- Data-Rate, Wireless, Smart Metering Utility Networks

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NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strike through~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.¹

¹Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

2. Normative references

Insert the following new reference alphabetically into Clause 2:

ANSI X3.66-1979, Advanced Data Communication Control Procedures.²

²ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Insert the following definitions alphabetically into 3.1:

BT: shaping parameter for filtered FSK modulation, where B is the 3 dB bandwidth of the shaping filter, and T is the FSK symbol period.

common signaling mode (CSM): a common physical layer (PHY) mode used between smart metering utility network (SUN) devices implementing the multi-PHY management (MPM) scheme.

designated channel: a communication channel or conterminal aggregation of communication channels.

duty cycle: the ratio of the sum of the durations of all transmissions in a given period of continuous operation, to the duration of the given period of continuous operation.

multi-physical layer (PHY) layer management (MPM): A scheme that facilitates interoperability and negotiation among potential coordinators with different PHYs by permitting a potential coordinator to detect an operating network during its discovery phase using the common signaling mode (CSM) appropriate to the band being used.

physical layer (PHY) mode: a set of parameters that fully describe the characteristics of a transmitted signal, such that two devices implementing this set of parameters may successfully exchange packets.

smart metering utility network (SUN): a principally outdoor, low data rate wireless network that supports two-way communications among sensing, measurement, and control devices in the smart grid.

smart metering utility network (SUN) device: an entity containing an implementation of the medium access control (MAC) sublayer specified in this standard and the multi-rate and multi-regional frequency shift keying (MR-FSK) physical layer (PHY), and optionally the multi-rate and multi-regional orthogonal frequency division multiplexing (MR-OFDM) or the multi-rate and multi-regional offset quadrature phase-shift keying (MR-O-QPSK) PHY.

3.2 Acronyms and abbreviations

Insert the following acronyms alphabetically into 3.2:

BCH	Bose Chaudhuri Hocquenghem
BDE	bit differential encoding
CP	cyclic prefix
CSM	common signaling mode
DFT	discrete Fourier transform
EB	enhanced beacon
EBI	enhanced beacon interval
EBR	enhanced beacon request
FSK	frequency shift keying
HCS	header check sequence
IDFT	inverse discrete Fourier transform
IE	information element
ISR	interference-to-signal ratio

LTF	long training field
MCS	modulation and coding scheme
MDSSS	multiplexed direct sequence spread spectrum
MPM	multi-PHY layer management
MR-FSK	multi-rate and multi-regional frequency shift keying
MR-OFDM	multi-rate and multi-regional orthogonal frequency division multiplexing
MR-O-QPSK	multi-rate and multi-regional offset quadrature phase-shift keying
NBPAN	nonbeacon-enabled personal area network
NRNSC	nonrecursive and nonsystematic code
OTD	offset time duration
PAD	pad bits
PC	parity check
QAM	quadrature amplitude modulation
RSC	recursive and systematic code
SPC	single parity check
STF	short training field
SUN	smart metering utility network
TAIL	PPDU tail bit field
TPC	turbo product code

4. General description

Insert the following new subclause (4.1a) after 4.1:

4.1a Introduction to smart metering utility network (SUN)

SUNs enable multiple applications to operate over shared network resources, providing monitoring and control of a utility system. SUN devices are designed to operate in very large-scale, low-power wireless applications and often require using the maximum power available under applicable regulations, in order to provide long-range, point-to-point connections. Frequently, SUNs are required to cover geographically widespread areas containing a large number of outdoor devices. In these cases, SUN devices may employ mesh or peer-to-peer multihop techniques to communicate with an access point.

Three alternative PHYs are provided for SUN devices. The multi-rate and multi-regional frequency shift keying (MR-FSK) PHY provides good transmit power efficiency due to the constant envelope of the transmit signal. The multi-rate and multi-regional offset quadrature phase-shift keying (MR-O-QPSK) PHY shares the characteristics of the IEEE 802.15.4-2011 O-QPSK PHY, making multi-mode systems more cost effective and easier to design. The multi-rate and multi-regional orthogonal frequency division multiplexing (MR-OFDM) PHY provides higher data rates at higher spectral efficiency.

Insert the following two new subclauses (4.2a–4.2c) after 4.2:

4.2a MR-FSK Generic PHY mechanism

The MR-FSK Generic PHY mechanism provides a means to describe additional PHY modes in a standardized format. For SUN devices capable of supporting the MR-FSK Generic PHY mechanism, this enables:

- The flexibility to use a standard-defined mechanism to interface to previously deployed devices
- The flexibility to extend the existing IEEE Std 802.15.4, in order to take advantage of technology advances or to react to regulatory changes.

4.2b Mode switch mechanism

The mode switch mechanism enables a device using the MR-FSK PHY to change its symbol rate and/or modulation scheme on a packet-by-packet basis. This is done as a PHY layer operation, requiring minimal involvement from the MAC layer. A specific mode switch PPDU is used to inform the receiver of the mode switch and specifies the new PHY mode of the following PPDU.

Using the mode switch mechanism, the current PHY mode (i.e., symbol rate or modulation scheme) can be overridden for a single packet. For example, the mode switch mechanism can be invoked by a device that is configured to operate at the MR-FSK mode with a lower data rate (e.g., 50 kb/s) to enable higher data rate communications when needed. This might be used to facilitate a common communication PHY mode, while enabling higher data rate communications for those devices that are already established in the network. Also, this mechanism permits two devices using the FSK PHY to establish the communication in a different PHY mode.

To take advantage of this mechanism, the system implementer would typically configure devices with identical mode switch parameters. However, a source device wishing to use the mode switch mechanism would typically request SUN PHY capability information (including the mode switch parameter entries) from the destination device(s) to ensure that the mode switch mechanism, with the identical parameters, is supported by the destination device(s).

4.2c Multi-PHY management (MPM) of the SUN WPAN

Multiple, different SUN PHYs can operate in the same location and within the same frequency band. In order to mitigate interference, a multi-PHY management (MPM) scheme is specified for SUNs to facilitate inter-PHY coexistence. For this purpose, the MPM scheme facilitates interoperability and negotiation among potential coordinators with different PHYs by permitting a potential coordinator to detect an operating network during its discovery phase using the common signaling mode (CSM) appropriate to the band being used, as defined in Table 69a. The MPM procedure can be used in conjunction with the clear channel assessment (CCA) mechanism to provide coexistence.

5. MAC protocol

5.1 MAC functional description

Insert the following new paragraph before the last paragraph of 5.1:

For the MR-FSK PHY, the symbol duration used for MAC and PHY timing parameters, shown in Table 0, shall be the symbol duration of operating mode #1 specified in Table 134 and Table 135. For the MR-OFDM PHY, the symbol duration used for MAC timing parameters (*macLIFSPeriod* and *macSIFSPeriod*) shall be the symbol duration of MR-FSK operating mode #1 specified in Table 134 and Table 135, and the PHY symbol duration is defined in 18.2 and is to be used for *aTurnaroundTime*, *macAckWaitDuration*, and *aCCATime*. For the MR-O-QPSK PHY, the meaning of a symbol duration is described in 18.3.2.14.

Table 0—MR-FSK symbol duration used for MAC and PHY timing parameters

Frequency band (MHz)	MR-FSK symbol duration used for MAC and PHY timing parameters (μs)
169.400–169.475 (Europe)	208+1/3
450–470 (US FCC Part 22/90)	104+1/6
470–510 (China)	20
779–787 (China)	20
863–870 (Europe)	20
896–901 (US FCC Part 90)	100
901–902 (US FCC Part 24)	100
902–928 (US ISM)	20
917–923.5 (Korea)	20
928–960 (US FCC Part 22/24/90/101)	100
920–928 (Japan)	20
950–958 (Japan)	20
1427–1518 (US FCC Part 90)/(Canada SRSP 301.4)	100
2400–2483.5 (Worldwide)	20

5.1.1 Channel access

Insert the following new subclause (5.1.1.2a) after 5.1.1.2:

5.1.1.2a Enhanced beacon (EB) timing for MPM procedure

In a beacon-enabled PAN, a SUN device operating as a coordinator transmits an enhanced beacon (EB) containing a Coexistence Specification information element (IE) at fixed intervals, in addition to the usual periodic beacons. Figure 9a shows the EB timing for beacon-enabled PANs.

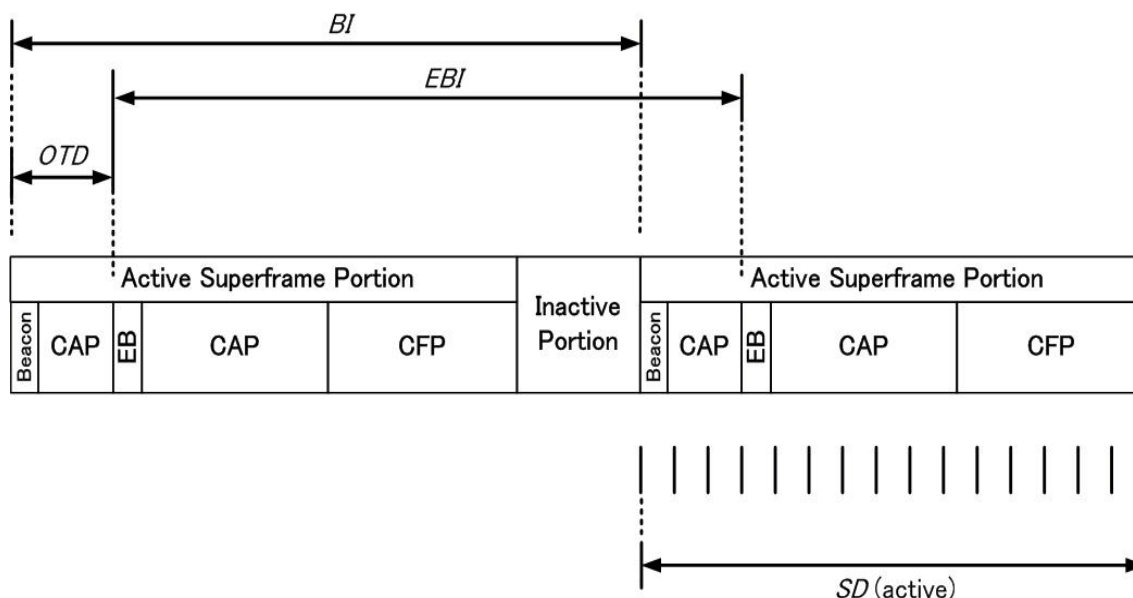


Figure 9a—Timing information for EB frames

The MAC PIB attribute *macEnhancedBeaconOrder* describes the interval at which the coordinator shall start transmissions of its EB frames. The values of *macEnhancedBeaconOrder* and the enhanced beacon interval (EBI) are related as follows:

$$EBI = aBaseSuperframeDuration \times 2^{\text{macEnhancedBeaconOrder}} \text{ symbols}$$

The value of *macEnhancedBeaconOrder* should not be larger than the value of *macBeaconOrder*.

The time offset between the start of the periodic beacon transmission and the start of the following EB transmission is described by the MAC PIB attribute *macOffsetTimeSlot*. The values of *macOffsetTimeSlot* and offset time duration (OTD) are related as follows:

$$OTD = aBaseSlotDuration \times \text{macOffsetTimeSlot} \text{ symbols}$$

In a nonbeacon-enabled PAN (NBPAN), the time offset between the starts of two EB frames is described by the NBPAN order, *macNBPANEnhancedBeaconOrder*. The resolution of time shall be *aBaseSlotDuration*. The values of *macNBPANEnhancedBeaconOrder* and the NBPAN EBI (EBI_{NBPAN}) are related as follows:

$$EBI_{NBPAN} = aBaseSlotDuration \times \text{macNBPANEnhancedBeaconOrder} \text{ symbols}$$

5.1.2 Starting and maintaining PANs

5.1.2.3 Starting and realigning a PAN

5.1.2.3.1 Starting a PAN

Change the first paragraph of 5.1.2.3.1 as indicated:

A PAN should be started by an FFD only after having first performed a MAC sublayer reset, by issuing the MLME-RESET.request primitive, as described in 6.2.8.1, with the SetDefaultPIB parameter set to TRUE, an active channel scan, and a suitable PAN identifier selection. If the device is a SUN device operating as a coordinator, a passive scan for an EB Coexistence Specification IE, as described in 5.1.13, should take place prior to the active channel scan. The algorithm for selecting a suitable PAN identifier from the list of PAN descriptors returned from the active channel scan procedure is out of the scope of this standard. In addition, an FFD should set *macShortAddress* to a value less than 0xffff.

5.1.6 Transmission, reception, and acknowledgment

5.1.6.4 Use of acknowledgments and retransmissions

5.1.6.4.2 Acknowledgment

Insert the following new paragraph after the first paragraph of 5.1.6.4.2:

A SUN device may set the Enhanced Acknowledgment bit in the SUN PHY Capabilities IE, as described in 5.2.4.20b, to indicate that it supports enhanced acknowledgment frames.

Insert the following new subclause (5.1.13) after 5.1.12.5:

5.1.13 MPM procedure for inter-PHY coexistence

To facilitate interference avoidance among multiple SUNs utilizing different PHYs in the same location, all SUN coordinators operating at a duty cycle of more than 1% shall support the MPM procedures. In the MPM scheme, EBs are sent using the CSM, as defined in Table 69a. EBs used in the MPM procedures described here are EBs containing a Coexistence Specification IE.

The transmission of EBs should take place in all the channels defined for CSM, as described in Table 69a, that overlap with the channel(s) in operation. The scanning for EBs and the transmission of enhanced beacon requests (EBRs) should take place in all the channels defined for CSM that overlap with the channel of interest or at least two channels for PHY modes where the CSM requires frequency hopping.

In a beacon-enabled PAN, an existing coordinator³ shall transmit an EB at a fixed interval by using CSM. Any intending coordinator⁴ shall first scan for an EB until the expiration of the EBI or until an EB is detected, whichever occurs first. If an intending coordinator detects an EB, it shall either occupy another channel, achieve synchronization with the existing PAN, or stop communication. While specific mechanisms to achieve synchronization between two PANs utilizing different PHY modes are implementation-dependent, the timing information applicable for synchronization purposes is specified in the EB. Figure 34u illustrates the MPM procedure.

³An existing coordinator is a coordinator currently operating a network.

⁴An intending coordinator is a coordinator intending to start a separate network.

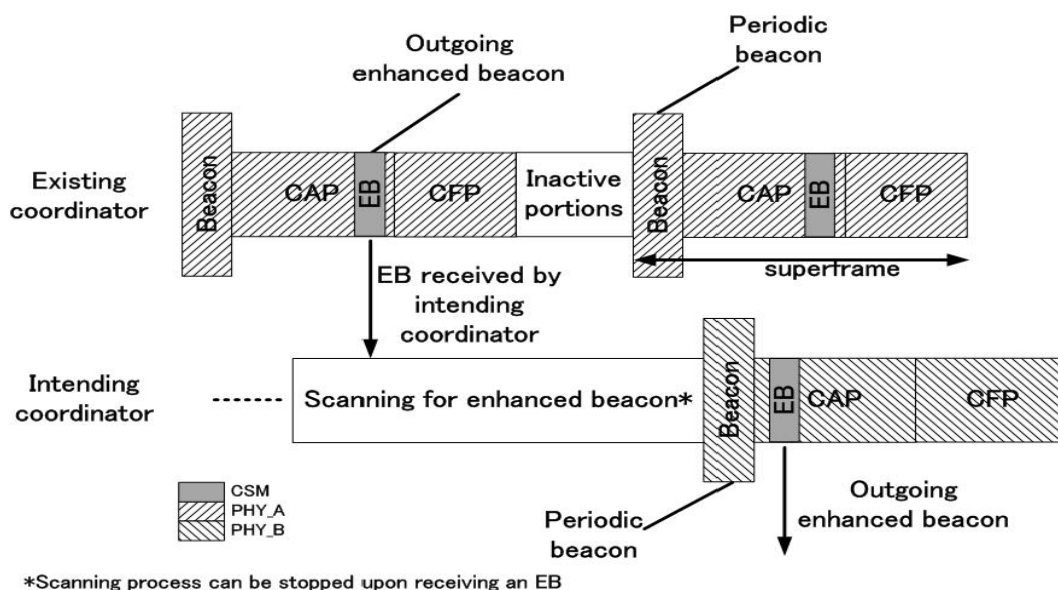


Figure 34u—Inter-PHY mode coexistence in a beacon-enabled PAN

The EB shall only be sent in the CAP.

In a nonbeacon-enabled PAN, an existing coordinator should transmit an EB periodically using the CSM. Any intending coordinator shall first scan for an EB until the expiration of $EBI_{NB PAN}$ or until an EB is detected, whichever occurs first. The illustration of the procedure is given in Figure 34v.

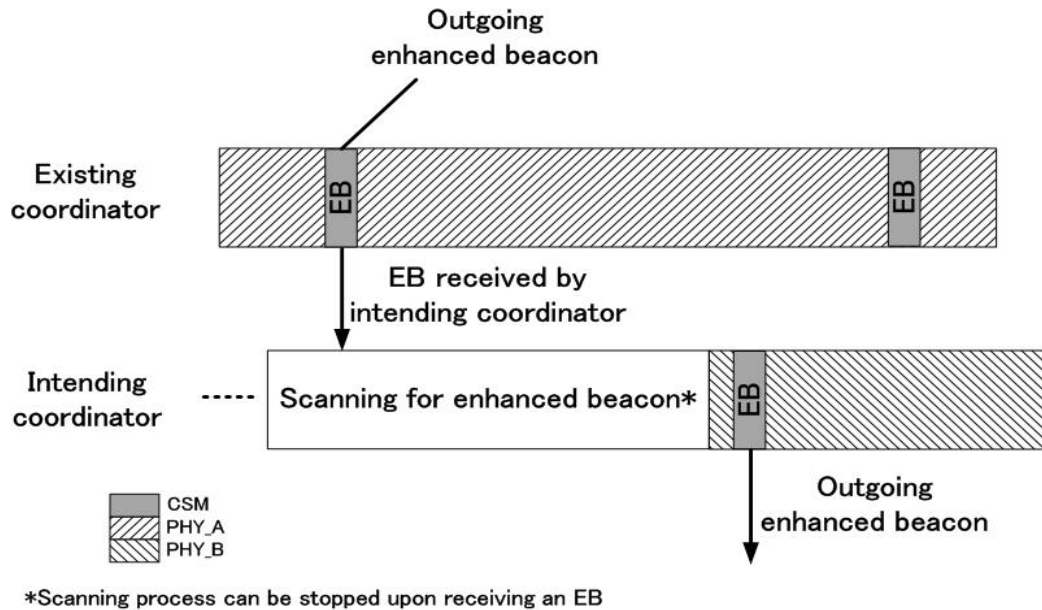


Figure 34v—Inter-PHY mode coexistence in a nonbeacon-enabled PAN

Alternatively, an EB may be obtained in an on-demand manner. In this case, an EBR containing the ID of the Coexistence Specification IE in the list of IE IDs is sent by the intending coordinator requesting an EB from the existing coordinator. Upon receiving an enhanced beacon request (EBR), the existing coordinator (or any other device within the same area that is capable of receiving and transmitting an EBR/EB using the CSM) may respond by sending an EB to the intending coordinator. The intending coordinator should transmit an EBR at least once every $EBI_{NB PAN}$. To increase the probability of receiving an EBR, the existing coordinator may periodically allocate a fraction of the CAP time to scan for the EBR in CSM. The illustration of the procedure is given in Figure 34w.

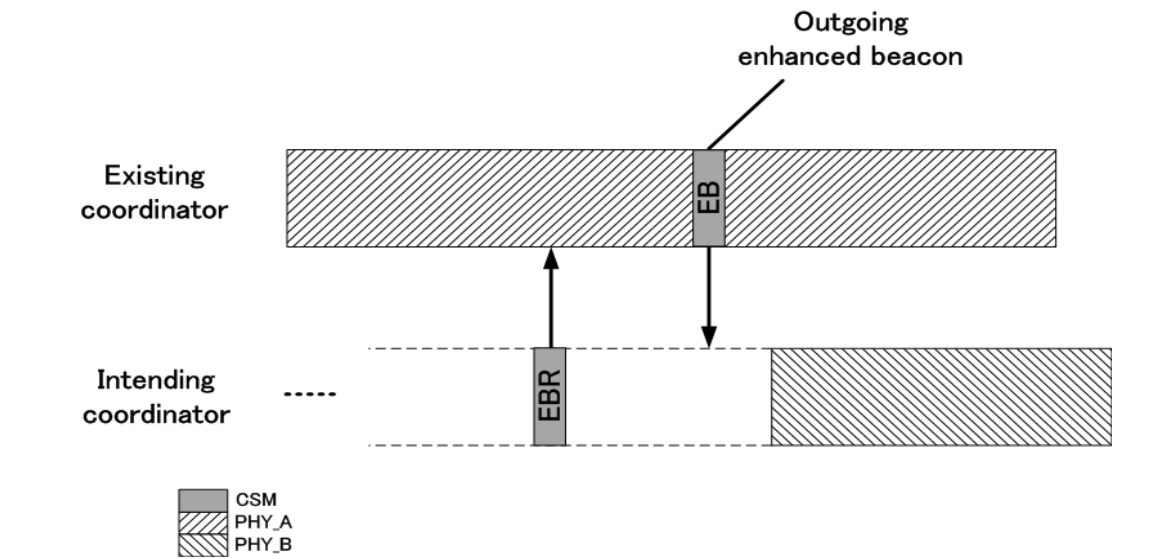


Figure 34w—Alternative method for inter-PHY mode coexistence in a nonbeacon-enabled PAN

5.2 MAC frame formats

5.2.1 General MAC frame format

Replace Figure 35 with the following figure:

Octets: 1/2	0/1	0/2	0/1/2/8	0/2	0/1/2/8	0/1/5/6/ 10/14	variable		variable	2/4
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Information Elements		Frame Payload	FCS
		Addressing fields					Header IEs	Payload IEs		
MHR							MAC Payload		MFR	

Figure 35—General MAC frame format

5.2.1.9 FCS field*Change the first paragraph of 5.2.1.9 as indicated:*

The FCS field contains a 16-bit ITU-T CRC or a 32-bit CRC equivalent to ANSI X3.66-1979. The FCS is calculated over the MHR and MAC payload parts of the frame; these parts together are referred to as the calculation field. Only devices compliant with one or more of the SUN PHYs shall implement the 4-octet FCS. For these devices, the default FCS length shall be 4 octets.

Change the second paragraph of 5.2.1.9 as indicated:

The 2-octet FCS shall be calculated using the following standard generator polynomial of degree 16:

Change the third paragraph of 5.2.1.9 as indicated:

The 2-octet FCS shall be calculated for transmission using the following algorithm:

Change the sixth paragraph of 5.2.1.9 as indicated:

The 2-octet FCS for this case would be the following:

*Change the caption of Figure 37 as indicated:***Figure 37—Typical 2-octet FCS implementation***Insert the following paragraphs at the end of 5.2.1.9:*

The 4-octet FCS is calculated using the following standard generator polynomial of degree 32:

$$G_{32}(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$$

The 4-octet FCS is the one's complement of the (modulo 2) sum of the two remainders in a) and b):

- The remainder resulting from $[(x^k \times (x^{31} + x^{30} + \dots)]$ divided (modulo 2) by $G_{32}(x)$, where the value k is the number of bits in the calculation field.
- The remainder resulting from the calculation field contents, treated as a polynomial, is multiplied by x^{32} and then divided by $G_{32}(x)$.

At the transmitter, the initial remainder of the division shall be preset to all ones and then modified via division of the calculation field by the generator polynomial $G_{32}(x)$. The one's complement of this remainder is the 4-octet FCS field. The FCS field is transmitted commencing with the coefficient of the highest order term.

At the receiver, the initial remainder shall be preset to all ones. The serial incoming bits of the calculation field and FCS, when divided by $G_{32}(x)$ in the absence of transmission errors, result in a unique nonzero remainder value. The unique remainder value is the polynomial shown:

$$x^{31} + x^{30} + x^{26} + x^{25} + x^{24} + x^{18} + x^{15} + x^{14} + x^{12} + x^{11} + x^{10} + x^8 + x^6 + x^5 + x^4 + x^3 + x + 1$$

Upon transmission, if the length of the calculation field is less than 4 octets, the FCS computation shall assume padding the calculation field by appending zero value octets to the most significant bits to make the

calculation field length exactly 4 octets; however, these pad bits shall not be transmitted. Upon reception, if the length of the calculation field is less than 4 octets, the received calculation field shall be appended with zero value octets to the most significant bits to make the calculation field length exactly 4 octets prior to computing the FCS for validation.

As an example, consider an acknowledgment frame with no payload and the following 3-byte MHR:

0100 0000 0000 0000 0101 0110
b₀.....b₂₃

[leftmost bit (b₀) transmitted first in time]

Prior to FCS computation, the zero padded calculation field is given as follows:

0100 0000 0000 0000 0101 0110 0000 0000
b₀.....b₃₁

The 4-octet FCS for this case would be the following:

0101 1101 0010 1001 1111 1010 0010 1000
r₀.....r₃₁

[leftmost bit (r₀) transmitted first in time]

5.2.2 Format of individual frame types

5.2.2.1 Beacon frame format

Replace Figure 38 and Figure 40a with the following figures:

Octets: 2	1	4/10	0/5/6/ 10/14	2	variable	variable	variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Superframe Specification	GTS fields	Pending address fields	Beacon Payload	FCS
MHR				MAC Payload				MFR

Figure 38—Beacon frame format

Octets: 1/2	0/1	variable	0/1/5/6/10/14	variable		variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Information Elements		Beacon Payload	FCS
				Header IEs	Payload IEs		
MHR					MAC Payload		MFR

Figure 40a—Enhanced beacon frame format

5.2.2.2 Data frame format

Replace Figure 46 with the following figure:

Octets: 2	0/1	variable	0/1/5/6/10/14	variable		variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Information Elements		Data Payload	FCS
				Header IEs	Payload IEs		
MHR				MAC Payload			MFR

Figure 46—Data frame format

5.2.2.3 Acknowledgment frame format

Replace Figure 47 and Figure 47a with the following figures:

Octets: 2	1	2/4
Frame Control	Sequence Number	FCS
MHR		MFR

Figure 47—Acknowledgment frame format

Octets: 1/2	0/1	0/2	0/1/2/8	0/2	0/1/2/8	0/1/5/6/10/14	variable		variable	2/4
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Information Elements		Payload	FCS
		Addressing fields					Header IEs	Payload IEs		
MHR							MAC Payload		MFR	

Figure 47a—Enhanced Acknowledgment frame format

5.2.2.4 MAC command frame format

Replace Figure 48 with the following figure:

Octets: 2	0/1	variable	0/1/5/6/10/14	variable		1	variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Information Elements		Command Frame Identifier	Command Payload	FCS
				Header IEs	Payload IEs			
MHR					MAC Payload			MFR

Figure 48—MAC command frame format

5.2.4 Information element

5.2.4.5 MLME Information Elements

Insert the following new entries into Table 4d:

Table 4d—Sub-ID allocation for short form

Sub-ID value	Content length	Name	Description
0x21	9	Coexistence Specification	Conveys the parameters that define the EB
0x22	Variable	SUN PHY Capabilities	Declares the PHY Capabilities of the device
0x23	16	MR-FSK Generic PHY Descriptor	Declares one MR-FSK Generic PHY Descriptor
0x24	3	Mode Switch Parameter Entry	Declares one Mode Switch Parameter Entry
0x25–0x3f	—	Reserved	—

Insert the following new subclauses (5.2.4.20a–5.2.4.20d) after 5.2.4.20:

5.2.4.20a Coexistence Specification IE

The Coexistence Specification IE shall be formatted as illustrated in Figure 4800. The leftmost seven octets are information for a beacon-enabled network, and the rightmost six octets are information for a nonbeacon-enabled network.

The Beacon Order field, Superframe Order field, and Final CAP Slot field are as specified in 5.2.2.1.2.

The Enhanced Beacon Order field specifies the transmission interval of the EB frames. See 5.1.1.2a for an explanation of the relationship between EB order and EBI.

The Offset Time Slot field specifies the time offset between the periodic beacon and the following EB, as described in 5.1.1.2a.

The CAP Backoff Offset field specifies the actual slot position in which the EB is transmitted due to the backoff procedure in the CAP.

Bit #: 0–3	4–7	8–11	12–15	16–19	20–23	24–55	56–71
Beacon Order	Superframe Order	Final CAP Slot	Enhanced Beacon Order	Offset Time Slot	CAP Backoff Offset	Channel Page	NBPAN Enhanced Beacon Order

Figure 48oo—Format of the Coexistence Specification IE

The NBPAN Enhanced Beacon Order field specifies the transmission interval between consecutive EBs in the nonbeacon-enabled mode. The valid range for this field shall be 0–16383.

The Channel Page field shall contain a valid channel page value as defined in 8.1.2.10.

If the Beacon Order field is set to 15, the Superframe Order, Final CAP Slot, and Offset Time Slot fields shall be set to zero upon transmission and ignored upon reception. When generated in response to an EBR that contained a list of requested IEs, the content of the EB shall include the IEs corresponding to the requested IE IDs, as shown in Table 4j.

Table 4j— EBR IE per enabled attribute

PIB attribute	IE type	IEs to include
<i>macMPMIE</i>	MLME payload	Coexistence Specification IE (as defined in 5.2.4.20a)

5.2.4.20b SUN device capabilities IE

The SUN device capabilities IE, shown in Figure 48pp, declares which SUN features a device supports.

Octets: 1	2	Variable
SUN Features	Frequency Bands Supported	PHY Type Descriptor(s)

Figure 48pp—SUN device capabilities IE format

The SUN Features field is encoded as a bitmap in the first octet of the IE Content field, as illustrated in Figure 48pp with a detailed description in Figure 48qq. A bit set to one indicates the feature is supported. Otherwise, the feature is not supported.

The bits of the SUN Features field are defined as follows:

- Bit 0 indicates support for enhanced acknowledgment frames, as described in 5.1.6.4.2.
- Bit 1 indicates support for data whitening, as described in 18.1.3.
- Bit 2 indicates support for interleaving, as described in 18.1.2.5.

Octets: 1							
Bit #: 0	1	2	3	4	5	6	7
Enhanced ACK	Data Whitening	Interleaving	SFD G1	NRNSC FEC	RSCFEC	Mode Switch	Reserved

Figure 48qq—SUN Features field format

- Bit 3 indicates support for start-of-frame delimiter (SFD) Group 1, as described in 18.1.1.2.
- Bit 4 indicates support for nonrecursive and nonsystematic code (NRNSC) forward error correction (FEC), as described in 18.1.2.4.
- Bit 5 indicates support for recursive and systematic code (RSC) forward error correction (FEC), as described in 18.1.2.4.
- Bit 6 indicates support for the mode switch mechanism, as described in 18.1.4.

The Frequency Bands Supported field is a bitmap indexed by the frequency band identifier values given in Table 68f. The least significant bit of the bitmap corresponds to frequency band identifier zero. A bit set to one indicates that the device supports operation in that frequency band; otherwise, it does not.

The PHY Type Descriptor field is shown in Figure 48rr.

Octets: 2			2
Bit #: 0–3	4	5–15	0–15
PHY Type	All Frequency Bands	PHY Modes Supported (PHY Mode ID bitmap: $b_0 \dots b_{10}$)	Specific Frequency Bands (only present if All Frequency Bands = 0)

Figure 48rr—PHY Type Descriptor field format

The PHY Type field contains an unsigned integer whose value identifies a PHY Type defined in Table 4k.

The All Frequency Bands field indicates whether the optional Specific Frequency Bands field is present. If the All Frequency Bands field is set to one, the optional Specific Frequency Bands field is absent and the PHY Type is supported in all frequency bands declared in the Frequency Bands Supported field of the SUN device capabilities IE. If the All Frequency Bands field is set to zero, the optional Specific Frequency Bands field is present and the PHY Type is only supported in the frequency bands declared in the Specific Frequency Bands field of this PHY Type Descriptor.

The PHY Modes Supported field is a bitmap indicating which PHY modes are supported for the PHY Type. The PHY modes for each possible PHY Type are defined in Table 4l, Table 4m, Table 4n, Table 4o, Table 4p, and Table 4q. A bit set to one in bit b_n of the PHY Mode ID bitmap indicates that the PHY Mode with ID n in the table of PHY Modes corresponding to the PHY Type is supported; otherwise, it is not supported.

The optional Specific Frequency Bands field is encoded in the same manner as the Frequency Bands Supported field of the SUN device capabilities IE.

Table 4k—Modulation scheme encoding

PHY type	Modulation scheme
0	Filtered FSK-A
1	Filtered FSK-B
2	O-QPSK-A
3	O-QPSK-B
4	O-QPSK-C
5	OFDM Option 1
6	OFDM Option 2
7	OFDM Option 3
8	OFDM Option 4
9–15	Reserved

Filtered FSK PHY modes are defined in Table 4l and Table 4m. For additional information on Filtered FSK,

Table 4l—Filtered FSK-A PHY mode encoding

PHY Mode ID	Narrowband FSK PHY mode
0	4.8 kb/s; Filtered 2FSK; mod index = 1.0; channel spacing = 12.5 kHz
1	9.6 kb/s; Filtered 4FSK; mod index = 0.33; channel spacing = 12.5 kHz
2	10 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 12.5 kHz
3	20 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 12.5 kHz
4	40 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 12.5 kHz
5	4.8 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 12.5 kHz
6	2.4 kb/s; Filtered 2FSK; mod index = 2.0; channel spacing = 12.5 kHz
7	9.6 kb/s; Filtered 4FSK; mod index = 0.33; channel spacing = 12.5 kHz
8–10	Reserved

see 18.1.2.

O-QPSK PHY modes are defined in Table 4n, Table 4o, and Table 4p.

For each OFDM option, the supported MCSs are defined in Table 4q.

In each encoding of PHY modes in the PHY Type Descriptor field, a bit set to one in a bit position corresponding to a given modulation scheme in Table 4l, Table 4m, Table 4n, Table 4o, Table 4p, and Table 4q indicates the PHY mode for that modulation scheme is supported. A value of zero similarly indicates that the PHY mode is not supported.

Table 4m—Filtered FSK-B PHY mode encoding

PHY Mode ID	FSK PHY mode
0	50 kb/s; Filtered 2FSK; mod index = 1.0; channel spacing = 200 kHz
1	100 kb/s; Filtered 2FSK; mod index = 1.0; channel spacing = 400 kHz
2	150 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 400 kHz
3	200 kb/s; Filtered 2FSK; mod index = 0.5; channel spacing = 400 kHz
4	200 kb/s; Filtered 4FSK; mod index = 0.33; channel spacing = 400 kHz
5	200 kb/s; Filtered 2FSK; mod index = 1.0; channel spacing = 600 kHz
6	400 kb/s; Filtered 4FSK; mod index = 0.33; channel spacing = 600 kHz
7–10	Reserved

Table 4n—O-QPSK-A PHY mode encoding

PHY Mode ID	Narrowband O-QPSK PHY mode
0	chip rate = 100 kchip/s; SpreadingMode = DSSS; RateMode = 0; data rate = 6.25 kb/s
1	chip rate = 100 kchip/s; SpreadingMode = DSSS; RateMode = 1; data rate = 12.5 kb/s
2	chip rate = 100 kchip/s; SpreadingMode = DSSS; RateMode = 2; data rate = 25 kb/s
3	chip rate = 100 kchip/s; SpreadingMode = DSSS; RateMode = 3; data rate = 50 kb/s
4–10	Reserved

Table 4o—O-QPSK-B PHY mode encoding

PHY Mode ID	O-QPSK PHY mode
0	chip rate = 1000 kchip/s; SpreadingMode = DSSS; RateMode = 0; data rate = 31.25 kb/s
1	chip rate = 1000 kchip/s; SpreadingMode = DSSS; RateMode = 1; data rate = 125 kb/s
2	chip rate = 1000 kchip/s; SpreadingMode = DSSS; RateMode = 2; data rate = 250 kb/s
3	chip rate = 1000 kchip/s; SpreadingMode = DSSS; RateMode = 3; data rate = 500 kb/s
4	chip rate = 1000 kchip/s; SpreadingMode = MDSSS; RateMode = 0; data rate = 62.5 kb/s
5	chip rate = 1000 kchip/s; SpreadingMode = MDSSS; RateMode = 1; data rate = 125 kb/s
6	chip rate = 1000 kchip/s; SpreadingMode = MDSSS; RateMode = 2; data rate = 250 kb/s
7	chip rate = 1000 kchip/s; SpreadingMode = MDSSS; RateMode = 3; data rate = 500 kb/s
8–10	Reserved

The value of the SUN PHY Capabilities IE length field is computed as follows:

$$Length = 1 + 2 + 2 \times NumPHYTypeAllFreq1 + 4 \times NumPHYTypeAllFreq0$$

Table 4p—O-QPSK-C PHY mode encoding

PHY Mode ID	O-QPSK PHY mode
0	chip rate = 2000 kchip/s; SpreadingMode = DSSS; RateMode = 0; data rate = 31.25 kb/s
1	chip rate = 2000 kchip/s; SpreadingMode = DSSS; RateMode = 1; data rate = 125 kb/s
2	chip rate = 2000 kchip/s; SpreadingMode = DSSS; RateMode = 2; data rate = 250 kb/s
3	chip rate = 2000 kchip/s; SpreadingMode = DSSS; RateMode = 3; data rate = 500 kb/s
4	chip rate = 2000 kchip/s; SpreadingMode = MDSSS; RateMode = 0; data rate = 62.5 kb/s
5	chip rate = 2000 kchip/s; SpreadingMode = MDSSS; RateMode = 1; data rate = 125 kb/s
6	chip rate = 2000 kchip/s; SpreadingMode = MDSSS; RateMode = 2; data rate = 250 kb/s
7	chip rate = 2000 kchip/s; SpreadingMode = MDSSS; RateMode = 3; data rate = 500 kb/s
8–10	Reserved

Table 4q—OFDM PHY mode encoding

PHY Mode ID	OFDM PHY modes (Option 1,2,3,4)
0	MCS0 supported
1	MCS1 supported
2	MCS2 supported
3	MCS3 supported
4	MCS4 supported
5	MCS5 supported
6	MCS6 supported
7–10	Reserved

where

$NumPHYTypeAllFreq1$ is the number of PHY Type Descriptor fields that have the All Frequency Bands field set to one

$NumPHYTypeAllFreq0$ is the number of PHY Type Descriptor fields that have the All Frequency Bands field set to zero

5.2.4.20c MR-FSK Generic PHY Descriptor IE

The Generic PHY Descriptor IE is encoded as shown in Figure 48ss.

The Modulation Order, Modulation Scheme, and MR-FSK Generic PHY Descriptor ID fields all contain unsigned integers, as defined in Table 71a.

The Modulation Index field is encoded as an unsigned integer with permissible values in the range 0–45. Values in the range 46–63 are undefined. The value of the modulation index (MI) for filtered 2FSK is computed using the value of the Modulation Index field in the following way:

Octets: 1			1		4	2	4	4
Bit #: 0–1	2–3	4–7	Bit #: 0–5	6–7	1 st Channel Center Frequency	Number of Channels	Channel Spacing	Symbol Rate
Modulation Order	Modulation Scheme	MR-FSK Generic PHY Descriptor ID	Modulation Index	BT				

Figure 48ss—MR-FSK Generic PHY Descriptor IE format

$$MI = 0.25 + \text{Modulation Index} \times 0.05$$

The *MI* for filtered 4FSK shall be one third of the value computed for filtered 2FSK.

The BT field is encoded as an unsigned integer, as defined in Table 4r.

Table 4r—BT Encoding

BT field	BT
0	0.5
1	1.0
2–3	Reserved

The 1st Channel Center Frequency field contains an unsigned integer whose value is the center frequency of the first channel in hertz.

The Number of Channels field contains an unsigned integer whose value is the number of channels for the Generic PHY.

The Channel Spacing field contains an unsigned integer whose value is the difference between adjacent channel center frequencies in hertz.

The Symbol Rate field contains an unsigned integer whose value is the number of symbols transmitted per second.

5.2.4.20d Mode Switch Parameter Entry IE

The Mode Switch Parameter Entry IE is encoded as shown in Table 48tt.

The Secondary FSK SFD field value is set to one if a secondary SFD is present; otherwise, it is set to zero, as described in Table 71b.

The Target Mode field contains an unsigned integer indicating the PHY Mode of the new mode PPDU. The values are as defined in Table 4k.

The Source Mode field contains the mode that is used to transmit the mode switch PPDU. It is set to zero for 2FSK or to one for 4FSK.

Octets: 1				1	1
Bit #: 0	1–4	5	6–7	Settling Delay	Secondary FSK Preamble Length
Secondary FSK SFD	Target Mode	Source Mode	Mode Switch Parameter Entry Index		

Figure 48tt—Mode Switch Parameter Entry IE format

The Mode Switch Parameter Entry Index field contains an unsigned integer whose value is the index into the *phyModeSwitchParameterEntries* PIB attribute array containing the Mode Switch Parameter Entry.

The Settling Delay field contains an unsigned integer whose value times two is the settling delay in microseconds (0–510 μ sec), as described in Table 71b.

The Secondary FSK Preamble Length field contains an unsigned integer whose value is the number of preamble repetitions for the secondary preamble when the new mode is MR-FSK, as described in Table 71b.

6. MAC services

6.2 MAC management service

6.2.4 Communications notification primitives

6.2.4.1 MLME-BEACON-NOTIFY.indication

Insert the following new parameter at the end of the list in 6.2.4.1 (before the closing parenthesis):

CoexSpecification

Insert the following new row at the end of Table 16:

Table 16—MLME-BEACON-NOTIFY.indication parameters

Name	Type	Valid Range	Description
CoexSpecification	Set of octets	As defined in 5.2.4.20a	The information on the multi-PHY management (MPM)

6.2.10 Primitives for channel scanning

6.2.10.1 MLME-SCAN.request

Insert the following new parameters at the end of the list in 6.2.10.1 (before the closing parenthesis):

MPMScanDurationBPAN,
MPMScanDurationNBPAN,
MPMScan,
MPMScanType

Insert the following new rows at the end of Table 30:

6.2.12 Primitives for updating the superframe configuration

6.2.12.1 MLME-START.request

Insert the following new parameters at the end of the list in 6.2.12.1 (before the closing parenthesis)

IEID,
EnhancedBeaconOrder,
OffsetTimeSlot,
NBPANEnhancedBeaconOrder

Change Table 34 (the entire table is not shown) as indicated. The description of the parameter BeaconOrder is reproduced here to assist the reader. No changes are made to this description.

Table 30—MLME-SCAN.request parameters

Name	Type	Valid range	Description
MPMScanDurationBPAN	Integer	0–14	The maximum time spent scanning for an EB in a beacon-enabled PAN on the channel is $[aBaseSuperframeDuration * 2^n]$ symbols, where symbol refers to the symbol time in the current PHY, and n is equal to MPMScanDurationBPAN. See 5.1.1.2a.
MPMScanDurationNBPAN	Integer	1–16383	The maximum time spent scanning for an EB in a nonbeacon-enabled PAN on the channel is $[aBaseSlotDuration * n]$ symbols, where symbol refers to the symbol time in the current PHY, and n is equal to MPMScanDurationNBPAN. See 5.1.1.2a.
MPMScan	Boolean	TRUE or FALSE	This parameter is only valid for SUN devices. When set to TRUE, an MPM scan is invoked and the ScanDuration parameter shall be ignored. When set to FALSE, the scan duration shall be set according to the ScanDuration parameter; the MPMScanType, MPMScanDurationBPAN, and MPMScanDurationNBPAN parameters shall be ignored.
MPMScanType	Enumeration	BPAN or NBPAN	This parameter is only valid for SUN devices. When the MPMScan parameter is set to TRUE and the MPMScanType parameter is set to BPAN, the scan duration shall be set according to the MPMScanDurationBPAN parameter. When the MPMScan parameter is set to TRUE and the MPMScanType parameter is set to NBPAN, the scan duration shall be set according to the MPMScanDurationNBPAN parameter.

Insert the following new paragraphs before the last paragraph of 6.2.12.1:

In a beacon-enabled PAN (BeaconOrder < 15), the MLME examines the OffsetTimeOrder parameter to determine the time to begin transmitting the EB following the periodic beacon. EB intervals are determined by the value of the EnhancedBeaconOrder parameter.

In a nonbeacon-enabled PAN (BeaconOrder = 15), the MLME examines the NBPANEnhancedBeaconOrder parameter to determine the interval between the start of two EBs.

See 5.1.1.2a for the description of EB timing.

Table 34—MLME-START.request primitives

Name	Type	Valid range	Description
BeaconOrder	Integer	0–15	Indicates the frequency with which the beacon is transmitted, as defined in 5.1.1.1.
<u>IEID</u>	<u>List of IEs</u>	<u>See Table 4d</u>	<u>Determines which IEs are sent in the EB.</u>
<u>EnhancedBeaconOrder</u>	<u>Integer</u>	<u>0–15</u>	<u>Indicates how often the EB is to be transmitted in a beacon-enabled PAN. A value of 15 indicates that no EB will be transmitted. See 5.1.1.2a.</u>
<u>OffsetTimeSlot</u>	<u>Integer</u>	<u>1–15</u>	<u>Indicates the time difference between the EB and the preceding periodic beacon. See 5.1.1.2a.</u>
<u>NBPANEnhancedBeaconOrder</u>	<u>Integer</u>	<u>0–16383</u>	<u>Indicates how often the EB is to be transmitted in a nonbeacon-enabled PAN (i.e., <i>macBeaconOrder</i> = 15). A value of 16383 indicates that no EB will be transmitted. See 5.1.1.2a.</u>

6.3 MAC data service

6.3.1 MCPS-DATA.request

Insert the following new parameters at the end of the list in 6.3.1 (before the closing parenthesis):

ModeSwitch,
NewModeSUNPage,
ModeSwitchParameterEntry

Change Table 46 (the entire table is not shown) as indicated:

Table 46—MCPS-DATA.request parameters

Name	Type	Valid range	Description
DataRate	Integer	0–48	Indicates the data rate. For CSS PHYs, a value of one indicates 250 kb/s, while a value of two indicates 1 Mb/s. For UWB PHYs, values 1–4 are valid and are defined in 14.2.6.1. For the MR-OFDM PHY, values 1–7 are valid; <u>each data rate value corresponds to the variable MCS{(data rate value)–1}, as described in Table 148. For the MR-O-QPSK PHY with SpreadingMode set to DSSS, values 1–4 are valid; each data rate value corresponds to the RateMode parameter plus one, as described in Table 166. For the MR-O-QPSK PHY with SpreadingMode set to MDSSS, values 5–8 are valid; each data rate value corresponds to the RateMode parameter plus five, as described in Table 167. For all other PHYs, the parameter is set to zero.</u>
ModeSwitch	Boolean	TRUE or FALSE	A value of TRUE instructs the PHY entity to <u>send a mode switch PPDU first and then a following PPDU that contains the PSDU using the associated mode switch parameters. The mode switch PPDU is transmitted using the PHY mode specified by phyCurrentSUNPageEntry. The PPDU containing the PSDU is transmitted using the PHY mode specified by NewModeSUNPageEntry.</u> A value of FALSE instructs the PHY to <u>send the PSDU in a single PPDU using the PHY mode specified by phyCurrentSUNPageEntry on phyCurrentChannel.</u> <u>This parameter is only valid for MR-FSK PHY, as described in 18.1.1.4 and 18.1.4.</u>
NewModeSUNPageEntry	Bitmap	0x00000000–0xffffffff	<u>The modulation scheme and particular PHY mode for the new mode as defined by the channel page structure. The type and valid range are the same as defined for phyCurrentSUNPageEntry. This parameter is only valid if ModeSwitch = TRUE.</u>
ModeSwitchParameterEntry	Integer	0x00–0x03	<u>The mode switch parameter entry specifies the index in the phyModeSwitchParameterEntries array for the ModeSwitchDescriptor to be used for this PHY mode switch. This parameter is only valid if ModeSwitch = TRUE.</u>

6.3.3 MCPS-DATA.indication

Insert the following new parameter at the end of the list in 6.3.3 (before the closing parenthesis):

ModeSwitchPacketReceived

Insert the following new row at the end of Table 48:

Table 48—MCPS-DATA.indication parameters

Name	Type	Valid range	Description
ModeSwitchPacketReceived	Boolean	TRUE or FALSE	TRUE if a PHY mode switch packet is received.

6.4 MAC constants and PIB attributes

6.4.1 MAC constants

Change Table 51 (the entire table is not shown) as indicated. The descriptions of the constants $aBaseSlotDuration$, $aBaseSuperframeDuration$, and $aNumSuperframeSlots$ are reproduced here to assist the reader. No changes are made to these descriptions.

Table 51—MAC sublayer constants

Constant	Description	Value
$aBaseSlotDuration$	The number of symbols forming a superframe slot when the superframe order is equal to zero, as described in 5.1.1.1.	60
$aBaseSuperframeDuration$	The number of symbols forming a superframe when the superframe order is equal to zero.	$aBaseSlotDuration \times aNumSuperframeSlots$
$aNumSuperframeSlots$	The number of slots contained in any superframe.	16
$aUnitBackoffPeriod$	The number of symbols forming the basic time period used by the CSMA-CA algorithm.	~~20~~ For all PHYs except SUN PHYs operating in the 920 MHz band and the 950 MHz band, $aTurnaroundTime + aCCATime$. For SUN PHYs operating in the 920 MHz band or the 950 MHz band, $aTurnaroundTime + phyCCADuration$.

6.4.2 MAC PIB attributes*Change Table 52 (the entire table is not shown) as indicated:***Table 52—MAC PIB attributes**

Attribute	Type	Range	Description	Default
<i>macSyncSymbolOffset</i> [†]	Integer	0x000–0x100 for the 2.4 GHz band 0x000–0x400 for the 868 MHz and 915 MHz bands, and the MR-FSK and MR-OFDM PHYs	The offset, measured in symbols, between the symbol boundary at which the MLME captures the timestamp of each transmitted or received frame, and the onset of the first symbol past the SFD, namely, the first symbol of the Length field.	Implementation specific
<i>macEnhancedBeaconOrder</i>	Integer	0–15	<u>Specification of how often the coordinator transmits an EB. If <i>macEnhancedBeaconOrder</i> = 15, no periodic EB will be transmitted.</u>	0
<i>macMPMIE</i>	Boolean	TRUE, FALSE	<u>An indication of whether the Coexistence Specification IE is to be included in the EB. If this value is TRUE, the EB will include the Coexistence Specification IE. If this value is FALSE, the EB will not include the Coexistence Specification IE. See Table 4j.</u>	FALSE
<i>macNBPANEnhancedBeaconOrder</i>	Integer	0–16383	<u>Specification of how often the coordinator transmits an EB in a nonbeacon-enabled PAN (i.e., <i>macBeaconOrder</i> = 15). If <i>macNBPANEnhancedBeaconOrder</i> = 16383, no EB will be transmitted.</u>	16383
<i>macOffsetTimeSlot</i>	Integer	1–15	<u>The offset between the start of the periodic beacon transmission and the start of the following EB transmission expressed in superframe time slots.</u>	15
<i>macFCSType</i>	Integer	0–1	<u>The type of the FCS. A value of zero indicates a 4-octet FCS, as specified in 5.2.1.9. A value of one indicates a 2-octet FCS, as specified in 5.2.1.9.</u> <u>This attribute is only valid for SUN PHYs.</u>	0

6.4.3 Calculating PHY dependent MAC PIB values

Change the first paragraph of 6.4.3 as indicated:

The read-only attribute *macAckWaitDuration* is dependent on a combination of constants and PHY PIB attributes. The PHY PIB attributes are listed in Table 71. The formula for relating the constants and attributes for all PHYs except the SUN PHYs is:

$$\begin{aligned} \text{macAckWaitDuration} = \\ aUnitBackoffPeriod + aTurnaroundTime + \text{phySHRDuration} + \text{ceiling}(6 \times \text{phySymbolsPerOctet}) \end{aligned}$$

Insert the following new paragraphs after the first paragraph of 6.4.3:

The formula for relating the constants and attributes for the MR-FSK PHY is:

$$\begin{aligned} \text{macAckWaitDuration} = \\ aUnitBackoffPeriod + aTurnaroundTime + \text{phySHRDuration} + \text{ceiling}(9 \times \text{phySymbolsPerOctet}) \end{aligned}$$

The formula for relating the constants and attributes for the MR-OFDM PHY is:

$$\begin{aligned} \text{macAckWaitDuration} = \\ aUnitBackoffPeriod + aTurnaroundTime + \text{phySHRDuration} + \text{phyPHRDuration} + \text{ceiling}(6 \times \text{phySymbolsPerOctet}) \end{aligned}$$

The formula for relating the constants and attributes for the MR-O-QPSK PHY is:

$$\begin{aligned} \text{macAckWaitDuration} = \\ aUnitBackoffPeriod + aTurnaroundTime + \text{phySHRDuration} + \text{phyPHRDuration} + \text{phyPSDUDuration}(\text{LENGTH}) \end{aligned}$$

where LENGTH is the length, in octets, of the acknowledgment frame, and *phyPSDUDuration*(LENGTH) is given in 18.3.2.14.

8. General PHY requirements

8.1 General requirements and definitions

Insert the following items at the end of the second bulleted list in 8.1:

- **MR-FSK PHY:** multi-rate and multi-regional frequency shift keying (MR-FSK) PHY operating in multiple over-the-air data rates in support of SUN applications, as defined in 18.1.
- **MR-OFDM PHY:** multi-rate and multi-regional orthogonal frequency division multiplexing (MR-OFDM) PHY operating in multiple over-the-air data rates in support of SUN applications, as defined in 18.2.
- **MR-O-QPSK PHY:** multi-rate and multi-regional offset quadrature phase-shift keying (MR-O-QPSK) PHY operating in multiple over-the-air data rates in support of SUN applications, as defined in 18.3.

8.1.1 Operating frequency range

Insert the following new rows at the end of Table 66, and add the footnotes to the table as indicated:

Table 66—Frequency bands and data rates^a

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation ^b	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
169	169.400–169.475	—	Filtered 2FSK	4.8	4.8	Binary
			Filtered 2FSK	2.4	2.4	
			Filtered 4FSK	9.6	4.8	4-ary
450	450–470	—	Filtered 2FSK	4.8	4.8	Binary
			Filtered 4FSK	9.6	4.8	4-ary
470	470–510	—	Filtered 2FSK	50	50	Binary
				100	100	
			Filtered 4FSK	200	100	4-ary
		—	OFDM	As defined in 18.2		
		100	O-QPSK	6.25–50 (as defined in 18.3)	3.125	—
780	779–787	—	Filtered 2FSK	50	50	Binary
				100	100	
			Filtered 4FSK	200	100	4-ary
		—	OFDM	As defined in 18.2		
		1000	O-QPSK	31.25–500 (as defined in 18.3)	15.625	—

Table 66—Frequency bands and data rates^a (continued)

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation ^b	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
863	863–870	—	Filtered 2FSK	50	50	Binary
				100	100	
			Filtered 4FSK	200	100	4-ary
		—	OFDM	As defined in 18.2		
868	868–870	100	O-QPSK	6.25–50 (as defined in 18.3)	3.125	—
896	896–901	—	Filtered 2FSK	10	10	Binary
				20	20	
				40	40	
901	901–902	—	Filtered 2FSK	10	10	Binary
				20	20	
				40	40	
915	902–928	—	Filtered 2FSK	50	50	Binary
			Filtered 2FSK	150	150	
			Filtered 2FSK	200	200	
		—	OFDM	As defined in 18.2		
		1000	O-QPSK	31.25–500 (as defined in 18.3)	15.625	—
917	917–923.5	—	Filtered 2FSK	50	50	Binary
			Filtered 2FSK	150	150	
			Filtered 2FSK	200	200	
		—	OFDM	As defined in 18.2		
		1000	O-QPSK	31.25–500 (as defined in 18.3)	15.625	—
920	920–928	—	Filtered 2FSK	50	50	Binary
			Filtered 2FSK	100	100	
			Filtered 2FSK	200	200	
			Filtered 4FSK	400		
		OFDM	As defined in 18.2			
		100	O-QPSK	6.25-50 (as defined in 18.3)	3.125	

Table 66—Frequency bands and data rates^a (continued)

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation ^b	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
928	928–960 ^c	—	Filtered 2FSK	10	10	Binary
				20	20	
				40	40	
950	950–958	—	Filtered 2FSK	50	50	Binary
			Filtered 2FSK	100	100	
			Filtered 2FSK	200	200	
			Filtered 4FSK	400		4-ary
		—	OFDM	As defined in 18.2		
		100	O-QPSK	6.25–50 (as defined in 18.3)	3.125	—
1427	1427–1518 ^c	—	Filtered 2FSK	10	10	Binary
				20	20	
				40	40	
2450	2400–2483.5	—	Filtered 2FSK	50	50	Binary
			Filtered 2FSK	150	150	
			Filtered 2FSK	200	200	
		—	OFDM	As defined in 18.2		
		2000	O-QPSK	31.25–500 (as defined in 18.3)	15.625	—

^aData rates shown are over-the-air data rates.^bSee 18.1.2 for more information on filtered FSK.^cNoncontiguous.

8.1.2 Channel assignments

Insert the following new paragraphs after the last paragraph of 8.1.2:

The addition of the SUN PHY specifications requires a greater channel numbering capability. To address this issue, the definitions of channel pages nine and ten have been modified for the SUN PHYs to accommodate the larger number of channels, while maintaining consistency with the existing channel assignment schemes. See 8.1.2.10 for more information.

When *phyCurrentPage* is equal to nine or ten, *phyCurrentSUNPageEntry* shall specify the current frequency band, modulation scheme, and PHY mode of operation. The PIB attribute *phyNumSUNPageEntriesSupported* shall contain the number of SUN channel page entries supported, and *phySUNPageEntriesSupported* shall contain a complete list of the SUN channel page entries supported. The PHY PIB attributes are defined in 9.3.

8.1.2.1 Channel numbering for 780 MHz band

Insert the following new paragraph before the first paragraph of 8.1.2.1:

This subclause does not apply to the SUN PHY specifications. See 8.1.2.9 for an explanation of channel numbering for the SUN PHYs.

8.1.2.2 Channel numbering for 868 MHz, 915 MHz, and 2450 MHz bands

Insert the following new paragraph before the first paragraph of 8.1.2.2:

This subclause does not apply to the SUN PHY specifications. See 8.1.2.9 for an explanation of channel numbering for the SUN PHYs.

8.1.2.3 Channel numbering for 950 MHz PHYs

Insert the following new paragraph before the first paragraph of 8.1.2.3:

This subclause does not apply to the SUN PHY specifications. See 8.1.2.9 for an explanation of channel numbering for the SUN PHYs.

Insert the following new subclauses (8.1.2.9–8.1.2.10.2) after 8.1.2.8:

8.1.2.9 Channel numbering for SUN PHYs

The channel center frequency $ChanCenterFreq$ for all SUN PHYs, except the MR-O-QPSK PHY operating in the 868–870 MHz band, shall be derived as follows:

$$ChanCenterFreq = ChanCenterFreq_0 + NumChan \times ChanSpacing$$

where $ChanCenterFreq_0$ is the first channel center frequency in MHz, $ChanSpacing$ is the separation between adjacent channels in MHz, $NumChan$ is the channel number from 0 to $TotalNumChan-1$, and $TotalNumChan$ is the total number of channels for the available frequency band. The parameters $ChanSpacing$, $TotalNumChan$, and $ChanCenterFreq_0$ for different frequency bands and modulation schemes are specified in Table 68d.

Three channels are available for the MR-O-QPSK PHY operating in the 868–870 MHz band. The channel center frequency for each of these channels is shown in Table 68e.

8.1.2.10 Channel pages for SUN PHYs

Channel page nine is used to specify the standard-defined PHY operating modes, and channel page ten is used to specify the MR-FSK Generic-PHY-defined PHY modes. A device that implements more than one PHY operating mode, as described by channel page nine, may have multiple channel page nine entries in the *phySUNPageEntriesSupported* table. The channels are defined by *phySUNChannelsSupported*. The PHY PIB attributes are defined in 9.3.

The structures of channel pages nine and ten are shown in Figure 64a.

8.1.2.10.1 Channel page structure for standard-defined PHY modes

Channel page nine specifies each standard-defined SUN PHY operating mode supported by the device.