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INTERNATIONAL STANDARD

colour inside

Information technology – Wireless beacon-enabled energy efficient mesh network (WiBEEM) for wireless home network services – Part 1: PHY layer

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INFORMATION TECHNOLOGY – WIRELESS BEACON-ENABLED ENERGY EFFICIENT MESH NETWORK (WIBEEM) FOR WIRELESS HOME NETWORK SERVICES –

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This International Standard has been approved by vote of the member bodies, and the voting results may be obtained from the address given on the second title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTRODUCTION

This International Standard specifies the WiBEEM (Wireless Beacon-enabled Energy Efficient Mesh network) protocol, which provides low-power-consuming mesh network functions by enabling the “beacon mode operation”. WiBEEM is based on the IEEE 802.15.4 standard with additional upper layer protocols and a specific usage of the MAC layer protocol. Through the novel use of beacons, WiBEEM technology achieves longer battery life, larger network support, quicker response, enhanced mobility and dynamic reconfiguration of the network topology compared with other protocols such as ZigBee.

In the beacon mode, beacon information propagates over the entire mesh network nodes during the BOP (Beacon-Only Period) of the superframe structure without any beacon conflicts by utilising a smart beacon scheduling technique in the BOP. It also provides location information about moving devices without spending extra time running a positioning and locating algorithm by using RSSI (Received Signal Strength Indication). These features allow the WiBEEM protocol to be widely used for wireless home network services in the ubiquitous network era.

One of the key features of the WiBEEM protocol is that it has a special time interval called BOP (Beacon-Only Period) in the superframe structure that allows more than two beacons to be transmitted. This unique time period is located at the beginning of the Superframe. Because the BOP does not use the CSMA/CA mechanism, the network will not work properly in the beacon mode unless an appropriate algorithm is applied. This algorithm needs to manage and control multiple beacons in a single superframe. The solution is the Beacon Scheduling method applied in the BOP to avoid collisions among beacons, providing synchronisation among all the nodes of the entire mesh network.

For the network layer, the NAA (Next Address Available) mechanism, which is a short address allocation algorithm, has been adopted to provide an efficient way of utilising the complete 16-bit address space. The NAA algorithm does not limit the maximum number of children nodes that a node of a mesh network can have. Since the number of children nodes is unlimited, the NAA mechanism allows the WiBEEM protocol to be used not only for home network services, but also for community services. WiBEEM can be used where high network expandability through efficient use of short address spaces, device mobility and end-to-end QoS are required.

This part of ISO/IEC 29145 specifies the Physical (PHY) layer for the WiBEEM protocol.

INFORMATION TECHNOLOGY – WIRELESS BEACON-ENABLED ENERGY EFFICIENT MESH NETWORK (WIBEEM) FOR WIRELESS HOME NETWORK SERVICES –

Part 1: PHY layer

1 Scope

This part of ISO/IEC 29145 specifies the physical (PHY) layer of WiBEEM (Wireless Beacon-enabled Energy Efficient Mesh network) protocol for wireless home network services that supports a low power-consuming wireless mesh network topology as well as device mobility and QoS.

2 Normative reference

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 29145-2, *Information technology – Wireless beacon-enabled energy efficient mesh network (WiBEEM) for wireless home network services – Part 2: MAC layer*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
access control list
table used by a device to determine which devices are authorised to perform a specific function

3.1.2
association
service used to establish the membership of a device in a wireless mesh network

3.1.3
authentication
service used to establish the identity of one device as a member of the set of devices authorised to communicate securely to other devices in the set

3.1.4
confidentiality
assurance that communicated data remain private to the parties for whom the data are intended

3.1.5
co-ordinator
wireless device configured to provide synchronisation services through the transmission of beacons

Note 1 to entry: If a co-ordinator is the principal controller of a wireless mesh network, it is called the WMC (WiBEEM Mesh Co-ordinator).

3.1.6
data integrity
assurance that the data have not been modified from their original form

3.1.7
device
entity containing an implementation of the WiBEEM applications, NWK, MAC and physical interface to the wireless medium

3.1.8
frame
data format of aggregated bits from a medium access control (MAC) layer entity transmitted in a specified sequence

3.1.9
packet
format of aggregated bits transmitted in a specified sequence across the physical medium

3.1.10
personal operating space
space of typically about 10 m around a person or object, no matter whether this peron or object is stationary or in motion

3.1.11
portable device
device that may be moved from location to location, but uses network communications only while at a fixed location

3.1.12
protocol data unit
unit of data exchanged between two peer entities

3.1.13
pseudo-random number generation
process of generating a deterministic sequence of bits from a given seed that has the statistical properties of a random sequence of bits when the seed is not known

3.1.14
service data unit
information delivered as a unit through a service access point (SAP)

3.1.15
WiBEEM end device
WiBEEM device acting as the leaf device of a mesh network

3.1.16
WiBEEM mesh co-ordinator
WiBEEM device acting as the principal controller of a mesh network

Note 1 to entry: A WiBEEM mesh network has exactly one WiBEEM mesh co-ordinator.

3.1.17
WiBEEM routable co-ordinator
WiBEEM device acting as the router of a mesh network

3.1.18
wireless medium
medium used to implement the transfer of protocol data units (PDUs) between peer physical layer (PHY) entities of a low-rate wireless mesh network

3.2 Abbreviations

The following acronyms and abbreviations are used in this standard. They are commonly used in other industry publications.

AES	Advanced Encryption Standard
BO	Beacon Order
BOP	Beacon Only Period
BOPL	Beacon Only Period Length
BPSK	Binary Phase-Shift Keying
CAP	Contention Access Period
CBC-MAC	Cipher Block Chaining Message Authentication Code
CCA	Clear Channel Assessment
CSMA-CA	Carrier Sense Multiple Access With Collision Avoidance
DSP	Deep Sleep Period
ED	Energy Detection
EIRP	Effective Isotropic Radiated Power
EVM	Error-Vector Magnitude
ID	Identifier
IFS	Interframe Space or Spacing
LLC	Logical Link Control
LQ	Link Quality
LQI	Link Quality Indication
LPDU	LLC Protocol Data Unit
LR-WPAN	Low-Rate Wireless Personal Area Network
LSB	Least Significant Bit
MAC	Medium Access Control
MIB	MAC Information Base
MLME	MAC Layer Management Entity
MLME-SAP	MAC Layer Management Entity-Service Access Point
MPDU	MAC Protocol Data Unit
MSB	Most Significant Bit
MSC	Message Sequence Chart
MSDU	MAC Service Data Unit
NAA	Next Address Available
NB	Number Of Backoff (periods)
O-QPSK	Offset Quadrature Phase-Shift Keying
PD-SAP	PHY Data Service Access Point
PDU	Protocol Data Unit
PER	Packet Error Rate
PHR	PHY Header

PHY	Physical Layer
PIB	PAN Information Base
PICS	Protocol Implementation Conformance Statement
PLME	Physical Layer Management Entity
PLME-SAP	Physical Layer Management Entity-Service Access Point
PN	Pseudo-Random Noise
POS	Personal Operating Space
PPDU	PHY Protocol Data Unit
PQP	Prioritised QoS Period
PSD	Power Spectral Density
PSDU	PHY Service Data Unit
QoS	Quality of Service
RF	Radio Frequency
RSSI	Received Signal Strength Indication
RX	Receive or Receiver
SAP	Service Access Point
SDL	Specification and Description Language
SDU	Service Data Unit
SFD	Start-of-Frame Delimiter
SHR	Synchronisation Header
TRX	Transceiver
TX	Transmit or Transmitter
WED	WiBEEM End Device
WiBEEM	Wireless Beacon-enabled Energy Efficient Mesh network
WLAN	Wireless Local Area Network
WM	Wireless Medium
WMC	WiBEEM Mesh Co-ordinator
WRC	WiBEEM Routable Co-ordinator

3.3 Conventions

All the italicised words used in this standard shall implement all the primitives that are specified in Clause 6 and represent relevant constants defined and stored in the MIB (Management Information Base) of each layer.

4 Conformance

A wireless device that claims conformance to this standard shall meet all the requirements specified in 6.2, and shall implement all the primitives specified in 6.3, the PPDU formats in 6.4, the PHY Constants and the PIB attributes in 6.5, the PHY specifications in 6.6 and the general radio specifications in 6.7. Each WiBEEM device shall be able to act as a WMC, a WRC or a WED. When operating in the role of a WMC, it shall act as specified in 5.3.2, when operating in the role of a WRC, it shall act as specified in 5.3.3, and when operating in the role of a WED, it shall act as specified in 5.3.3.

5 Overview of the WiBEEM technology

5.1 General description

WiBEEM (Wireless Beacon-enabled Energy Efficient Mesh network) is a low-power-consuming wireless communication protocol that allows mesh networking capability not only in the non-beacon mode but also in the beacon mode. It is well suited for collecting sensor data in ubiquitous harsh environments. One of the most unique features of the WiBEEM protocol is that even when multiple beacons are used, the mesh network operates properly without beacon collisions by utilising a smart-beacon scheduling algorithm. Mesh networking with beacon mode is an enhancement of the non-beacon mesh network. With beacons not only can sensor nodes within the RF range communicate, but nodes that are located outside the RF range, no matter how far away, can also reliably transfer data through a multi-hop communication mechanism without requiring all the intermediate routers to be always turned on. WiBEEM protocol is a low-power consuming wireless mesh networking technology that allows wireless connectivity between devices located in ubiquitous harsh environments.

WiBEEM technology that operates in the beacon mode has several advantages. First, the power efficiency increases by controlling the synchronisation between WMC (WiBEEM Mesh Co-ordinator) and WRC (WiBEEM Routable Co-ordinator) nodes in a superframe, because all the nodes can go to DSP (Deep Sleep Period) at the same time. In other words, when the network is in idle state, all the nodes within the mesh network can enter the DSP simultaneously, and when the network is awake, the nodes can start transferring data. This synchronisation mechanism enhances power efficiency, which is one of the most critical aspects in wireless sensor networks. The second major advantage of WiBEEM protocol is that mobility is supported. Supporting mobility means that a device can be detected anywhere in the network and is able to communicate reliably, providing a flexible communications network. The WiBEEM protocol supports not only peer-to-peer or star network topologies, but also a beacon-mode mesh network structure that enhances the reliability and flexibility of the entire mesh network while lowering overall power consumption.

Some of the characteristics of WiBEEM are listed below.

– Over-the-air data rates of minimum 31,25 kbit/s and maximum 250 kbit/s.
– Mesh network as well as star and peer-to-peer operation.
– Two addressing modes are supported: 16-bit short addresses that are allocated by the mesh network; or 64-bit extended addresses.
– Beacon scheduling method for the avoidance of beacon collisions.
– Carrier sense multiple access with collision avoidance (CSMA-CA) channel access.
– Fully acknowledged protocol for transfer reliability using ARQ protocol.
– Low power consumption for not only star but also mesh topologies.
– Energy detection (ED).
– Link quality indication (LQI).
– 16 channels in the 2 450 GHz band.

Some of the advantages that WiBEEM technology has are stated below.

– It allows multiple beacons to be transmitted in a single superframe, which enables synchronisation among nodes and thus consumes very little power even in the mesh network topology.
– It supports large size network expandability without increasing transmission power or receiver sensitivity.
– It improves data communication reliability using multiple communication paths.
– The network can be easily reconfigured.
– It prolongs battery life by reducing the number of data transmission.

A system conforming to this standard consists of several components. The most basic is the device. The first device to be generated in the network is a WiBEEM mesh co-ordinator (WMC). General devices that communicate with the WMC are called WiBEEM routable co-ordinators (WRCs). Also, devices that simply transmit the sensed data are called WiBEEM end devices (WEDs). Two or more devices within a POS (Personal Operating Space) communicating on the same physical channel constitute a mesh network. However, this mesh network shall include at least one WMC, operating as the mesh co-ordinator.

5.2 Functions and descriptions of device types

Functions and description of WiBEEM devices are presented in ISO/IEC 29145-2.

5.3 Functional overview of WiBEEM

5.3.1 General

A wireless networking protocol is fully characterised by a superframe structure and a data transfer model between devices in the MAC layer. The WiBEEM protocol utilises the superframe structure described in 5.3.2 and data transfer model between WiBEEM devices in the MAC layer described in 5.3.3.

5.3.2 Superframe structure of WiBEEM

WiBEEM protocol, when it operates in the beacon mode, utilises the superframe structure in the MAC layer as shown in Figure 1. The WMC determines this superframe structure, which consists of 5 distinct time slots. The first time slot of the superframe structure is BOP (beacon only period), where only beacons of all the WRC devices can be transmitted at the times predetermined by the smart beacon scheduling algorithm without performing CSMA-CA operation. During this time period, no devices are allowed to transmit any data except the WRC that was allowed to do so. The beacon payload transmitted by the WMC device propagates over the entire mesh network and the synchronisation between all the WiBEEM devices is maintained. Right after the BOP, PQP follows in which traffic with a certain level of priority is allowed to transmit data. If the WMC device decides not to have QoS support, it can reset the PQP such that the PQP length is zero. The PQP can also be set up by the request of any WiBEEM devices when WMC is asked to do so. During the CAP the data transfer can be carried out, where back-off times are determined based on the priority that the traffic has. Any device wishing to communicate during the CAP competes with other devices using a slotted CSMA-CA mechanism. A WiBEEM device that wants to provide parameterised QoS may use RAP (reservation-based access period), where devices that acquired the permission to send data from the WMC based on the reservation request can only use this period. Optionally, the superframe can have a DSP in which all the devices enter a low-power mode.

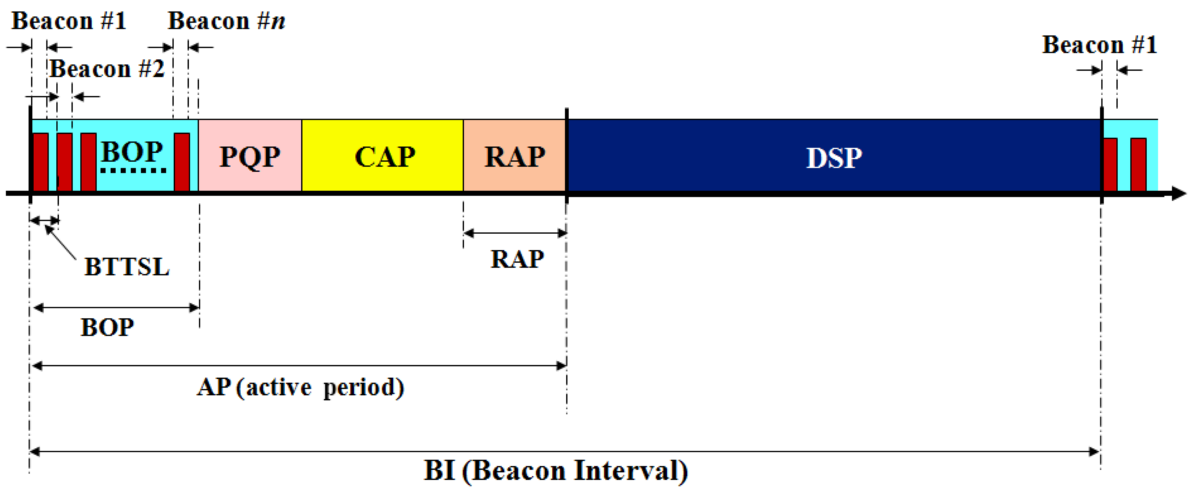

Figure 1 – Superframe structure of WiBEEM

5.3.3 Data transfer model

When a device wishes to transfer data to a co-ordinator in a beacon mode, it first listens to the network beacon. When the beacon is heard, the device synchronises to the superframe structure. At the appropriate time, the device transmits a data frame, using slotted CSMA/CA, to the co-ordinator. The co-ordinator may acknowledge the successful reception of the data by transmitting an optional acknowledgement frame. This sequence is summarised in Figure 2a. When a device wishes to transfer data in a non-beacon mode, it simply transmits a data frame, using unslotted CSMA-CA, to the co-ordinator. The co-ordinator acknowledges the successful reception of the data by transmitting an optional acknowledgement frame. The transaction is now complete. This sequence is summarised in Figure 2a. The procedure for a non-beacon mode is shown in Figure 2b.

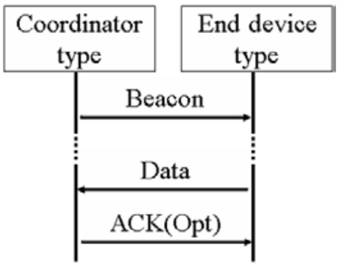

Figure 2a – Beacon mode

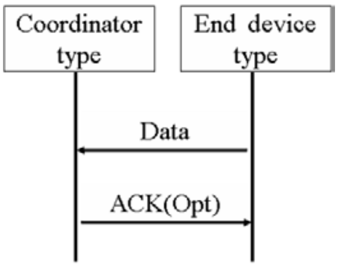

Figure 2b – Non-beacon mode

Figure 2 – Communication from an end device to a co-ordinator in a beacon and non-beacon mode

When the co-ordinator wishes to transfer data to a device in a beacon mode (as shown in Figur 3a), it indicates in the network beacon that the data message is pending. The device periodically listens to the network beacon and, if a message is pending, transmits a MAC command requesting the data, using slotted CSMA-CA. WMC or WRC acknowledges the successful reception of the data request by transmitting an acknowledgement frame. The pending data frame is then sent using slotted CSMA/CA or, if possible, immediately after the acknowledgement. The device may acknowledge the successful reception of the data by transmitting an optional acknowledgement frame. The transaction is now complete. Upon successful completion of the data transaction, the message is removed from the list of pending messages in the beacon. The procedure for a non-beacon mode is shown in Figur 3b.

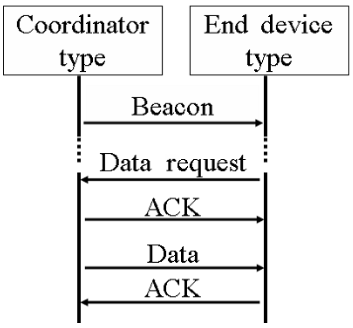

Figure 3a – Beacon mode Beacon mode

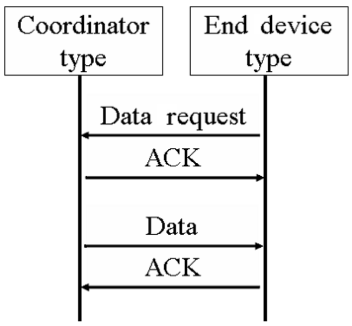

Figure 3b – Non-beacon mode

Figure 3 – Communication from a co-ordinator to an end device in a beacon and non-beacon mode

When the co-ordinator wishes to transfer data to another co-ordinator (as shown in Figure 4), it can send data without using beacons since the co-ordinators are always active.

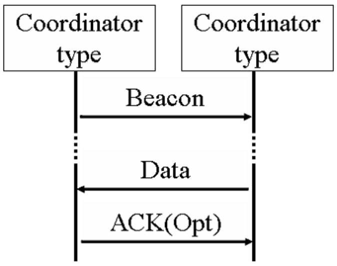

Figure 4a – Beacon mode

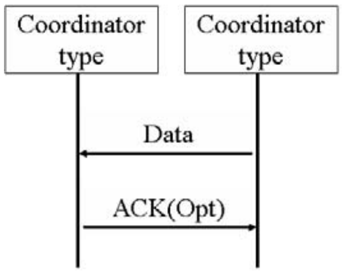

Figure 4b – Non-beacon mode

Figure 4 – Communications between co-ordinators in a beacon and non-beacon mode

End devices do not transmit beacons at any time. When an end device wishes to send data to another end device, it may communicate with other devices reachable via the build-in radio. In order to do this effectively, the devices wishing to communicate will need to either receive constantly or to synchronise with each other. In the former case, the device can simply transmit data using un-slotted CSMA-CA. In the latter case, other measures need to be taken in order to achieve synchronisation. End devices wishing to communicate shall send a frame to the target device notifying that it has data to send, and the receiver has to respond that it is ready to receive data, a shown in Figure 5. This kind of communication scheme is used in the power saving mode.

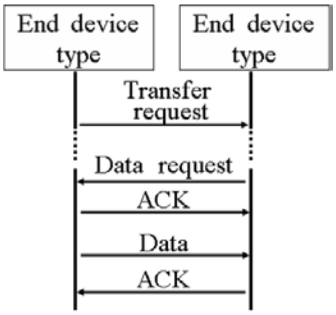

Figure 5 – Communications between end devices

6 PHY layer specifications

6.1 General

This clause specifies the physical layer (PHY) of the WiBEEM protocol. The PHY is responsible for the following tasks:

– activation and deactivation of the radio transceiver;

– energy detection within the current channel;

– link quality indication for received packets;

– clear channel assessment for CSMA/CA;

– channel frequency selection;

– data transmission and reception.

Constants and attributes that are specified and maintained by the PHY layer specification are written in the text of this clause in italics. Constants have a general prefix of “a”. Attributes have a general prefix of “phy”.

6.2 General requirements and definitions

6.2.1 General

This subclause specifies requirements that are common to both of the WiBEEM PHYs.

6.2.2 Operating frequency range

A compliant device shall operate in one or several frequency bands using the modulation and spreading formats summarised in Table 1.

NOTE The terms “chip rate” and “symbol rate” and corresponding units (chip/s and symbol/s) are used for spread spectrum code. The chip rate of a code is the number of pulses per second (chips per second) at which the code is transmitted (or received). The chip rate is larger than the symbol rate since one symbol is represented by multiple chips. The ratio is known as the spreading factor or processing gain.

Table 1 – Frequency bands and data rate

PHY MHz	**Frequency band** MHz	**Spreading parameters**		**Data parameters**		
		Chip rate kchip/s	**Modulation**	**Bit rate** kbit/s	**Symbol rate** ksymbol/s	**Symbol**
868/915	868 to 868,6	300	BPSK	20	20	Binary
	902 to 928	600	BPSK	40	40	Binary
2 450	2 400 to 2 483,5	2 000	O-QPSK	31,25	7,812 5	16-ary Orthogonal
			O-QPSK	62,50	15,625	16-ary Orthogonal
			O-QPSK	125	31,25	16-ary Orthogonal
			O-QPSK	250	62,5	16-ary Orthogonal

6.2.3 Channel assignments and numbering

A total of 27 channels, numbered 0 to 26, are available across the three frequency bands. 16 channels are available in the 2 450 MHz band, 10 in the 915 MHz band and one in the 868 MHz band. The centre frequency (F_c) of these channels is defined as follows:

F_c = 868,3 in MHz, for $k = 0$

$F_c = 906 + 2\,(k - 1)$ in megahertz, for $k = 1, 2, \ldots, 10$

and

$F_c = 2\,405 + 5\,(k - 11)$ in megahertz, for $k = 11, 12, \ldots, 26$

where k is the channel number.

For each PHY supported, a compliant device shall support all channels allowed by regulations for the region in which the device operates.

6.2.4 RF power measurement

Unless otherwise stated, all RF power measurements that either transmit or receive, shall be carried out at the appropriate transceiver to antenna connector. The measurements shall be carried out with equipment that is either matched to the impedance of the antenna connector or corrected for any mismatch. For devices without an antenna connector, the measurements shall be interpreted as effective isotropic radiated power (EIRP) (i.e., a 0 dBi gain antenna); and any radiated measurements shall be corrected to compensate for the antenna gain in the implementation.

6.2.5 Transmit power

The maximum transmit power shall conform to local regulations. A compliant device shall have its nominal transmit power level indicated by its PHY parameter.

6.2.6 Out-of-band spurious emission

The out-of-band spurious emissions shall conform to local regulations.

6.2.7 Receiver sensitivity definitions

The definitions in Table 2 are referenced by subclauses elsewhere in this standard regarding receiver sensitivity.

Table 2 – Receiver sensitivity definitions

Term	Definition of term	Conditions
Packet error rate (PER)	Average fraction of transmitted packets that are not detected correctly	– Average measured over random PSDU data
Receiver sensitivity	Threshold input signal power that yields a specific PER	– PSDU length = 160 octets – PER < 1 % – Power measured at antenna terminals – Interference not present

6.3 PHY service specifications

6.3.1 General

The PHY provides an interface between the MAC sublayer and the physical radio channel, via the RF firmware and RF hardware. The PHY conceptually includes a management entity called the PLME. This entity provides the layer management service interfaces through which layer management functions may be invoked. The PLME is also responsible for maintaining a database of managed objects pertaining to the PHY. This database is referred to as the PHY layer information base (PIB).

Figure 6 depicts the components and interfaces of the PHY.

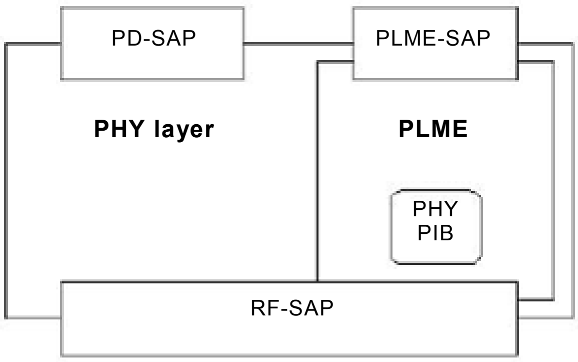

Figure 6 – PHY reference model

PHY provides two services, accessed through two SAPs: PHY data service, accessed through the PHY data SAP (PD-SAP), and PHY management service, accessed through the PLME's SAP (PLME-SAP).

6.3.2 PHY data service

6.3.2.1 Overview

The PD-SAP supports the transport of MPDUs between peer MAC layer entities. Table 3 lists the primitives supported by the PD-SAP. These primitives are discussed in the subclauses referenced in Table 3.

Table 3 – PD-SAP primitives

PD-SAP primitive	Request	Confirm	Indication
PD-DATA	6.3.2.2	6.3.2.3	6.3.2.4

6.3.2.2 PD-DATA.request

6.3.2.2.1 Function

The PD-DATA.request primitive requests the transfer of an MPDU (i.e., PSDU) from the MAC sublayer to the local PHY entity.

6.3.2.2.2 Semantics of the service primitive

The semantics of the PD-DATA.request primitive is as follows:

```
PD-DATA.request        (
                        psduLength,
                        psdu
                        )
```

Table 4 specifies the parameters for the PD-DATA.request primitive.

Table 4 – PD_Data.request parameters

Name	Type	Valid range	Description
psduLength	Unsigned integer	≤*aMaxPHYPacketSize*	The number of octets contained in the PSDU to be transmitted by the PHY entity
psdu	Set of octets	—	The set of octets forming the PSDU to be transmitted by the PHY entity.

6.3.2.2.3 When generated

The PD-DATA.request primitive is generated by a local MAC layer entity and issued to its PHY entity to request the transmission of an MPDU.

6.3.2.2.4 Effect on receipt

The receipt of the PD-DATA.request primitive by the PHY entity will cause the transmission of the supplied PSDU. Provided the transmitter is enabled (TX_ON state), the PHY will first construct a PPDU, containing the supplied PSDU and then transmit the PPDU. When the PHY entity has completed the transmission, it will issue the PD-DATA.confirm primitive with a status of SUCCESS.

If the PD-DATA.request primitive is received while the receiver is enabled (RX_ON state) or if the transceiver is disabled (TRX_OFF state), the PHY entity will issue the PD-DATA.confirm primitive with a status of RX_ON or TRX_OFF, respectively.

6.3.2.3 PD-DATA.confirm

6.3.2.3.1 Function

The PD-DATA.confirm primitive confirms the end of the transmission of an MPDU (i.e., PSDU) from a local MAC sublayer entity to a peer MAC sublayer entity.

6.3.2.3.2 Semantics of the service primitive

The semantics of the PD-DATA.confirm primitive is as follows:

```
PD-DATA.confirm        (
                        Status
                        )
```

Table 5 specifies the parameters for the PD-DATA.confirm primitive.

Table 5 – PD_DATA.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS,RX_ON, or TRX_OFF	The result of the request to transmit a packet

6.3.2.3.3 When generated

The PD-DATA.confirm primitive is generated by the PHY entity and issued to its MAC sublayer entity in response to a PD-DATA.request primitive. The PD-DATA.confirm primitive will return a status of either SUCCESS, indicating that the request to transmit was successful, or an error code of RX_ON or TRX_OFF. The reasons for these status values are fully described in 6.3.2.2.4.

6.3.2.3.4 Effect on receipt

On receipt of the PD-DATA.confirm primitive, the MAC sublayer entity is notified of the result of its request to transmit. If the transmission attempt was successful, the status parameter is set to SUCCESS. Otherwise, the status parameter will indicate the error.

6.3.2.4 PD-DATA.indication

6.3.2.4.1 Function

The PD-DATA.indication primitive indicates the transfer of an MPDU (i.e., PSDU) from the PHY to the local MAC sublayer entity.

6.3.2.4.2 Semantics of the service primitive

The semantics of the PD-DATA.indication primitive is as follows:

```
PD-DATA.indication   (
                      psduLength,
                      psdu,
                      ppduLinkQuality
                      )
```

Table 6 specifies the parameters for the PD-DATA.indication primitive.

Table 6 – PD_DATA.indication parameters

Name	Type	Valid range	Description
psduLength	Unsigned Integer	≤*aMaxPHYPacketSize*	The number of octets contained in the PSDU received by the PHY entity.
psdu	Set of octets	—	The set of octets forming the PSDU received by the PHY entity.
ppduLinkQuality	Integer	0x00 to 0xff	Link quality(LQ) value measured during reception of the PPDU (see 6.7.9).

6.3.2.4.3 When generated

The PD-DATA.indication primitive is generated by the PHY entity and issued to its MAC sublayer entity to transfer a received PSDU. This primitive will not be generated if the received psduLength field is zero or greater than *aMaxPHYPacketSize*.

6.3.2.4.4 Effect on receipt

On receipt of the PD-DATA.indication primitive, the MAC sublayer is notified of the arrival of an MPDU across the PHY data service.

6.3.3 PHY management service

6.3.3.1 Function

The PLME-SAP allows the transport of management commands between the MLME and the PLME. Table 7 lists the primitives supported by the PLME-SAP. These primitives are discussed in the clauses referenced in Table 7.

Table 7 – PLME-SAP primitives

PLME-SAP Primitive	Request	Confirm
PLME-CCA	6.3.3.2	6.3.3.3
PLME-ED	6.3.3.4	6.3.3.5
PLME-GET	6.3.3.6	6.3.3.7
PLME-SET-STATE	6.3.3.8	6.3.3.9
PLME-SET	6.3.3.10	6.3.3.11

6.3.3.2 PLME-CCA.request

6.3.3.2.1 Function

The PLME-CCA.request primitive requests that the PLME perform a CCA as defined in 6.7.10.

6.3.3.2.2 Semantics of the service primitive

The semantics of the PLME-CCA.request primitive is as follows:

```
PLME-CCA.request    (
                    )
```

There are no parameters associated with the PLME-CCA.request primitive.

6.3.3.2.3 When generated

The PLME-CCA.request primitive is generated by the MLME and issued to its PLME whenever the CSMACA algorithm requires an assessment of the channel.

6.3.3.2.4 Effect on receipt

If the receiver is enabled on receipt of the PLME-CCA.request primitive, the PLME will cause the PHY to perform a CCA. When the PHY has completed the CCA, the PLME will issue the PLME-CCA.confirm primitive with a status of either BUSY or IDLE, depending on the result of the CCA.

If the PLME-CCA.request primitive is received while the transceiver is disabled (TRX_OFF state) or if the transmitter is enabled (TX_ON state), the PLME will issue the PLME-CCA.confirm primitive with a status of TRX_OFF or TX_ON, respectively.

6.3.3.3 PLME-CCA.confirm

6.3.3.3.1 Function

The PLME-CCA.confirm primitive reports the results of a CCA.

6.3.3.3.2 Semantics of the service primitive

The semantics of the PLME-CCA.confirm primitive is as follows:

```
PLME-CCA.confirm        (
                        status
                        )
```

Table 8 specifies the parameters for the PLME-CCA.confirm primitive.

Table 8 – PLME-CCA confirm primitive

Name	Type	Valid range	Description
Status	Enumeration	TRX_OFF, TX_ON, BUSY, or IDLE	The result of the request to perform a CCA.

6.3.3.3.3 When generated

The PLME-CCA.confirm primitive is generated by the PLME and issued to its MLME in response to a PLME-CCA.request primitive. The PLME-CCA.confirm primitive will return a status of either BUSY or IDLE, indicating a successful CCA, or an error code of TRX_OFF or TX_ON. The reasons for these status values are fully described in 6.3.3.2.4.

6.3.3.3.4 Effect on receipt

On receipt of the PLME-CCA.confirm primitive, the MLME is notified of the results of the CCA. If the CCA attempt was successful, the status parameter is set to either BUSY or IDLE. Otherwise, the status parameter will indicate the error.

6.3.3.4 PLME-ED.request

6.3.3.4.1 Function

The PLME-ED.request primitive requests that the PLME perform an ED measurement (see 6.7.8).

6.3.3.4.2 Semantics of the service primitive

The semantics of the PLME-ED.request primitive is as follows:

```
PLME-ED.request    (
                   )
```

There are no parameters associated with the PLME-ED.request primitive.

6.3.3.4.3 When generated

The PLME-ED.request primitive is generated by the MLME and issued to its PLME to request an ED measurement.

6.3.3.4.4 Effect on receipt

If the receiver is enabled on receipt of the PLME-ED.request primitive, the PLME will cause the PHY to perform an ED measurement. When the PHY has completed the ED measurement, the PLME will issue the PLME-ED.confirm primitive with a status of SUCCESS.

If the PLME-ED.request primitive is received while the transceiver is disabled (TRX_OFF state) or if the transmitter is enabled (TX_ON state), the PLME will issue the PLME-ED.confirm primitive with a status of TRX_OFF or TX_ON, respectively.

6.3.3.5 PLME-ED.confirm

6.3.3.5.1 Function

The PLME-ED.confirm primitive reports the results of the ED measurement.

6.3.3.5.2 Semantics of the service primitive

The semantics of the PLME-ED.confirm primitive is as follows:

```
PLME-ED.confirm          (
                         status,
                         EnergyLevel
                         )
```

Table 9 specifies the parameters for the PLME-ED.confirm primitive.

Table 9 – PLME_ED.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	TRX_OFF, TX_ON, BUSY, or IDLE	The result of the request to perform a CCA.
EnergyLevel	Integer	0x00 to 0xff	ED level for the current channel.

6.3.3.5.3 When generated

The PLME-ED.confirm primitive is generated by the PLME and issued to its MLME in response to a PLME-ED.request primitive. The PLME-ED.confirm primitive will return a status of SUCCESS, indicating a successful ED measurement, or an error code of TRX_OFF or TX_ON. The reasons for these status values are fully described in 6.3.3.4.4.

6.3.3.5.4 Effect on receipt

On receipt of the PLME-ED.confirm primitive, the MLME is notified of the results of the ED measurement. If the ED measurement attempt was successful, the status parameter is set to SUCCESS. Otherwise, the status parameter will indicate the error.

6.3.3.6 PLME-GET.request

6.3.3.6.1 Function

The PLME-GET.request primitive requests information about a given PHY PIB attribute.

6.3.3.6.2 Semantics of the service primitive

The semantics of the PLME-GET.request primitive is as follows:

```
PLME-GET.request            (
                             PIBAttribute
                             )
```

Table 10 specifies the parameters for the PLME-GET.request primitive.

Table 10 – PLME_GET.request parameters

Name	Type	Valid range	Description
PIBAttribute	Enumeration	See Table 21	The identifier of the PHY attribute to get

6.3.3.6.3 When generated

The PLME-GET.request primitive is generated by the MLME and issued to its PLME to obtain information from the PHY PIB.

6.3.3.6.4 Effect on receipt

On receipt of the PLME-GET.request primitive, the PLME will attempt to retrieve the requested PHY PIB attribute from its database. If the identifier of the PIB attribute is not found in the database, the PLME will issue the PLME-GET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE.

If the requested PHY PIB attribute is successfully retrieved, the PLME will issue the PLME-GET.confirm primitive with a status of SUCCESS.

6.3.3.7 PLME-GET.confirm

6.3.3.7.1 Function

The PLME-GET.confirm primitive reports the results of an information request from the PHY PIB.

6.3.3.7.2 Semantics of the service primitive

The semantics of the PLME-GET.confirm primitive is as follows:

```
PLME-GET.confirm            (
                             status,
                             PIBAttribute,
                             PIBAttributeValue
                             )
```

Table 11 specifies the parameters for the PLME-GET.confirm primitive.

Table 11 – PLME_GET.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS or UNSUPPORTED_ATTRIBUTES	The result of the request for PHY PIB attributes information
PIBAttribute	Enumeration	0x00 to 0xff	The identifier of the PHY PIB attributes to get
PIBAttributeValue	Various	Attribute specific	The value of the indicated OHY PIB attribute to get

6.3.3.7.3 When generated

The PLME-GET.confirm primitive is generated by the PLME and issued to its MLME in response to a PLME-GET.request primitive. The PLME-GET.confirm primitive will return a status of either SUCCESS, indicating that the request to read a PHY PIB attribute was successful, or an error code of UNSUPPORTED_ATTRIBUTE. The reasons for these status values are fully described in 6.3.3.6.4.

6.3.3.7.4 Effect on receipt

On receipt of the PLME-GET.confirm primitive, the MLME is notified of the results of its request to read a PHY PIB attribute. If the request to read a PHY PIB attribute was successful, the status parameter is set to SUCCESS. Otherwise, the status parameter will indicate the error.

6.3.3.8 PLME-SET-TRX-STATE.request

6.3.3.8.1 Function

The PLME-SET-TRX-STATE.request primitive requests that the PHY entity change the internal operating state of the transceiver. The transceiver will have three main states:

– transceiver disabled (TRX_OFF);
– transmitter enabled (TX_ON);
– receiver enabled (RX_ON).

6.3.3.8.2 Semantics of the service primitive

The semantics of the PLME-SET-TRX-STATE.request primitive is as follows:

```
PLME-SET-TRX-STATE.request        (
                                   state
                                   rate
                                  )
```

Table 12 specifies the parameters for the PLME-SET-TRX-STATE.request primitive.

Table 12 – PLME-SET-TRX-STATE.request parameters

Name	Type	Valid range	Description
State	Enumeration	RX_ON, TRX_OFF, FORCE_TRX_OFF, or TX_ON	The net state in which to configure the transceiver
Rate	Enumeration	31.25K_ON, 62.50K_ON, 125 K_ON,	Multi-rate operation is configured

6.3.3.8.3 When generated

The PLME-SET-TRX-STATE.request primitive is generated by the MLME and issued to its PLME when the current operational state of the receiver needs to be changed.

6.3.3.8.4 Effect on receipt

On receipt of the PLME-SET-TRX-STATE.request primitive, the PLME will cause the PHY to change to the requested state. If the state change is accepted, the PHY will issue the PLME-SET-TRX-STATE.confirm primitive with a status of SUCCESS. If this primitive request a state that the transceiver is already configured, the PHY will issue the PLME-SET-TRX-STATE.confirm primitive with a status indicating the current state, i.e., RX_ON, TRX_OFF, or TX_ON. If this primitive is issued with RX_ON or TRX_OFF argument and the PHY is busy transmitting a PPDU, the PHY will issue the PLME-SET-TRX-STATE.confirm primitive with a status BUSY_TX and defer the state change till the end of transmission. If this primitive is issued with TX_ON or TRX_OFF argument and the PHY is in RX_ON state and has already received a valid SFD, the PHY will issue the PLME-SET-TRX-STATE.confirm primitive with a status BUSY_RX and defer the state change till the end of reception of the PPDU. If this primitive is issued with FORCE_TRX_OFF, the PHY will cause the PHY to go the TRX_OFF state irrespective of the state the PHY is in.

The rate value of 31.25K_ON, 62.50K_ON, 125K_ON, 250K_ON denotes the multi-rate physical channel operation. By the receipt of the rate, the physical channel is now re-configured to the newly designated rate.

6.3.3.9 PLME-SET-TRX-STATE.confirm

6.3.3.9.1 Function

The PLME-SET-TRX-STATE.confirm primitive reports the result of a request to change the internal operating state of the transceiver.

6.3.3.9.2 Semantics of the service primitive

The semantics of the PLME-SET-TRX-STATE.confirm primitive is as follows:

```
PLME-SET-TRX-STATE.confirm        (
                                  status
                                  rate
                                  )
```

Table 13 specifies the parameters for the PLME-SET-TRX-STATE.confirm primitive.

Table 13 – PLME-SET-TRX-STATE.confirm parameters

Name	Type	Valid range	Description
State	Enumeration	SUCCESS, RX_ON, TRX_OFF, TX_ON, BUSY_RX, or BUSY_TX	The result of the request to change the state of the transceiver.
Rate	Enumeration	31.25K_ON, 62.50K_ON, 125K_ON, 250K_ON	Multi-rate operation is confirmed

6.3.3.9.3 When generated

The PLME-SET-TRX-STATE.confirm primitive is generated by the PLME and issued to its MLME after attempting to change the internal operating state of the transceiver.

6.3.3.9.4 Effect on receipt

On receipt of the PLME-SET-TRX-STATE.confirm primitive, the MLME is notified of the result of its request to change the internal operating state of the transceiver. A status value of SUCCESS indicates that the internal operating state of the transceiver was accepted. A status value of RX_ON, TRX_OFF, or TX_ON indicates that the transceiver is already in the requested internal operating state. A status value of BUSY_TX is issued when the PHY is requested to change its state to RX_ON or TRX_OFF while transmitting. A status value of BUSY_RX is issued when the PHY is in RX_ON state, has already received a valid SFD and is requested to change its state to TX_ON or TRX_OFF.

Also, the MLME is notified the newly configured rate value by the primitive.

6.3.3.10 PLME-SET.request

6.3.3.10.1 Function

The PLME-SET.request primitive attempts to set the indicated PHY PIB attribute to the given value.

6.3.3.10.2 Semantics of the service primitive

The semantics of the PLME-SET.request primitive is as follows:

```
PLME-SET.request        (
                        PIBAttribute,
                        PIBAttributeValue
                        )
```

Table 14 specifies the parameters for the PLME-SET.request primitive.

Table 14 – PLME_SET.request parameters

Name	Type	Valid range	Description
PIBAttribute	Enumeration	RX_ON, TRX_OFF, FORCE_TRX_OFF, or TX_ON	The identifier of the PIB attribute to set.
PIBAttributeValue	Various	Attribute specific	The value of the indicated PIB attribute to set

6.3.3.10.3 When generated

The PLME-SET.request primitive is generated by the MLME and issued to its PLME to write the indicated PHY PIB attribute.

6.3.3.10.4 Effect on receipt

On receipt of the PLME-SET.request primitive, the PLME will attempt to write the given value to the indicated PHY PIB attribute in its database. If the PIBAttribute parameter specifies an attribute that is not found in the database (see Table 21), the PLME will issue the PLME-SET.confirm primitive with a status of UNSUPPORTED_ATTRIBUTE. If the PIBAttibuteValue parameter specifies a value that is out of the valid range for the given attribute, the PLME will issue the PLME-SET.confirm primitive with a status of INVALID_PARAMETER.

If the requested PHY PIB attribute is successfully written, the PLME will issue the PLME-SET.confirm primitive with a status of SUCCESS.

6.3.3.11 PLME-SET.confirm

6.3.3.11.1 Function

The PLME-SET.confirm primitive reports the results of the attempt to set a PIB attribute.

6.3.3.11.2 Semantics of the service primitive

The semantics of the PLME-SET.confirm primitive is as follows:

```
PLME-SET.confirm        (
                          status,
                          PIBAttribute
                          )
```

Table 15 specifies the parameters for the PLME-SET.confirm primitive.

Table 15 – PLME_SET.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS, UNSUPPORTED_ATTRIBUTE, Or INVALID_PARAMETER	The status of the attempt to set the request PIB attribute
PIBAttribute	Enumeration	See Table 21	The identifier of the PIB attribute being confirmed

6.3.3.11.3 When generated

The PLME-SET.confirm primitive is generated by the PLME and issued to its MLME in response to a PLME-SET.request primitive. The PLME-SET.confirm primitive will return a status of either SUCCESS, indicating that the requested value was written to the indicated PHY PIB attribute, or an error code of UNSUPPORTED_ATTRIBUTE or INVALID_PARAMETER. The reasons for these status values are fully described in 6.3.3.10.4.

6.3.3.11.4 Effect on receipt

On receipt of the PLME-SET.confirm primitive, the MLME is notified of the result of its request to set the value of a PHY PIB attribute. If the requested value was written to the indicated PHY PIB attribute, the status parameter is set to SUCCESS. Otherwise, the status parameter will indicate the error.

6.3.4 PHY enumerations description

Table 16 shows a description of the PHY enumeration values defined in the PHY specification.

Table 16 – PHY enumerations description

Enumeration	Value	Description
BUSY	0x00	The CCA attempt has detected a busy channel.
BUSY_RX	0x01	The transceiver is asked to change its state while receiving.
BUSY_TX	0x02	The transceiver is asked to change its state while transmitting.
FORCE_TRX_OFF	0x03	The transceiver is to be switched off.
IDLE	0x04	The CCA attempt has detected an idle channel.
INVALID_PARAMETER	0x05	A SET/GET request was issued with a parameter in the primitive that is out of the valid range.
RX_ON	0x06	The transceiver is in or is to be configured into the receiver enabled state.
SUCCESS	0x07	A SET/GET, an ED operation, or a transceiver state change was successful.
TRX_OFF	0x08	The transceiver is in or is to be configured into the transceiver disabled state.
TX_ON	0x09	The transceiver is in or is to be configured into the transmitter enabled state.
UNSUPPORTED_ATTRIBUTE	0x0a	A SET/GET request was issued with the identifier of an attribute that is not supported.

6.4 PPDU format

6.4.1 Function

This subclause specifies the format of the PPDU packet.

For convenience, the PPDU packet structure is presented so that the leftmost field as written in this standard shall be transmitted or received first. All multiple octet fields shall be transmitted or received least significant octet first and each octet shall be transmitted or received least significant bit (LSB) first. The same transmission order should apply to data fields transferred between the PHY and MAC sublayer.

Each PPDU packet consists of the following basic components:

– -SHR, which allows a receiving device to synchronise and lock onto the bit stream;
– -PHR, which contains frame length information;
– -variable length payload, which carries the MAC sub-layer frame.

6.4.2 General packet format

6.4.2.1 General

The PPDU packet structure shall be formatted as illustrated in Table 17.

Table 17 – Format of the PDU

Octets: 4	1	1		Variable
Preamble	SFD	Frame length	Reserved	PSDU
SHR		PHR		PHY payload

6.4.2.2 Preamble field

The preamble field is used by the transceiver to obtain chip and symbol synchronisation with an incoming message. The preamble field shall be composed of 32 binary zeros.

6.4.2.3 SFD field

The SFD is an 8 bit field indicating the end of the synchronisation (preamble) field and the start of the packet data. The basic format of 250 kbit/s is shown Table 18.

Table 18 – Format of the SFD field

Bits:0	1	2	3	4	5	6	7
1	1	1	0	0	1	0	1

However, if an adaptation is made to the SFD field, it can also be used for signalling of the different channel speeds. The problem arises when noticing that the SFD field shall be transmitted with the spreading sequence of the 250 kbit/s mode transmitted only once, which, of course, has a lower performance than the multi-repetition 125 kbit/s, 62,5 kbit/s and 31,25 kbit/s modes.

In order to tackle this problem, two different methods can be applied.

– For the lowest bit rate modes (125 kbit/s, 62,5 kbit/s and 31,25 kbit/s), the SFD field is transmitted two, four or eight times, respectively. This requires a change in the detector, because different detectors have to be involved in order to obtain the correct mode.
– For all modes, the SFD length remains constant. By permutation of all possible combinations of SFD fields, the best performing set is chosen and used for signalling.

6.4.2.4 Frame length field

The frame length field is 7 bit in length and specifies the total number of octets contained in the PSDU (i.e., PHY payload). It is a value between 0 and *aMaxPHYPacketSize* (see 6.3.2.2.2). Table 19 summarises the type of payload versus the frame length value.

Table 19 – Frame length values

Frame length value	Payload
0 to 4	Reserved
5	MPDU(Acknowledgement)
6 to 7	Reserved
8 to aMaxPHYPacketSize	MPDU

6.4.2.5 PSDU field

The PSDU field has a variable length and carries the data of the PHY packet. For all packet types of length five octets or greater than seven octets, the PSDU contains the MAC sublayer frame (i.e., MPDU).

6.5 PHY constants and PIB attributes

6.5.1 Function

This subclause specifies the constants and attributes required by the PHY.

6.5.2 PHY constants

The constants that define the characteristics of the PHY are presented in Table 20. These constants are hardware dependent and cannot be changed during operation.

Table 20 – PHY constants

Constant	Description	Value
aMaxPHYPacketSize	The maximum PSDU size(in octets) the PHY shall be able to receive.	127
aTurnaroundTime	RX-to-TX or TX-to-RX maximum turnaround time (see 6.7.2 and 6.7.3)	12 symbol periods

6.5.3 PHY PIB attributes

The PHY PIB comprises the attributes required to manage the PHY of a device. Each of these attributes can be read or written using the PLME-GET.request and PLME-SET.request primitives, respectively. The attributes contained in the PHY PIB are presented in Table 21.

Table 21 – PHY PIB attributes

Attribute	Identifier	Type	Range	Description
phyCurrentChannel	0x00	Integer	0 to 26	The RF channel to use for all following transmissions and receptions (see 6.2.3)
phyChannelsSupported	0x01	Bitmap	See description	The 5 most significant bits (MSBs)(b_{27},..,b_{37}) of phyChannlesSupported shall be reserved and set to 0, and the 27 LSBs(b_0,b_1,...b_{26}) shall indicate the status (1 = available,0 = unavailable) for each of the 27 valid channels(b shall indicate the status of channel k as in 6.2.3).
phyTranmitPower	0x02	Bitmap	0x00 to 0xbf	The 2 MSBs represent the tolerance on the transmit power 00 = ±1 dB 01 = ±3 dB 10 = ±6 dB The 6 LSBs represent a signed integer in two's complement format, corresponding to the nominal transmit power of the device in decibels relative to 1 mW. The lowest value of phyTransmitPower shall be interpreted as less than or equal to −32 dBm
PhyCCAMode	0x03	Integer	1 to 3	The CCA mode (see 6.7.10).

6.6 2 450 MHz PHY specifications

6.6.1 Requirements

The requirements for the 2 450 MHz PHY are specified in 6.6.2 through 6.6.3.

6.6.2 Data rate

The data rate of the WiBEEM (2 450 MHz) PHY shall be 31,25 kbit/s, 62,5 kbit/s, 125 kbit/s or 250 kbit/s.

6.6.3 Modulation and spreading

6.6.3.1 Overview

The 2 450 MHz PHY employs a 16-ary quasi-orthogonal modulation technique on the 31,25 kbit/s ~ 250 kbit/s. During each data symbol period, four information bits are used to select one of 16 nearly orthogonal pseudo-random noise (PN) sequences to be transmitted. The PN sequences for successive data symbols are concatenated, and the aggregate chip sequence is modulated onto the carrier using offset quadrature phase-shift keying (O-QPSK).

6.6.3.2 Reference modulator diagram

The functional block diagram in Figure 7 is provided as a reference for specifying the 2 450 MHz PHY modulation and spreading functions (for 31,25 kbit/s ~ 500 kbit/s). The number in each block refers to the subclause that describes that function.

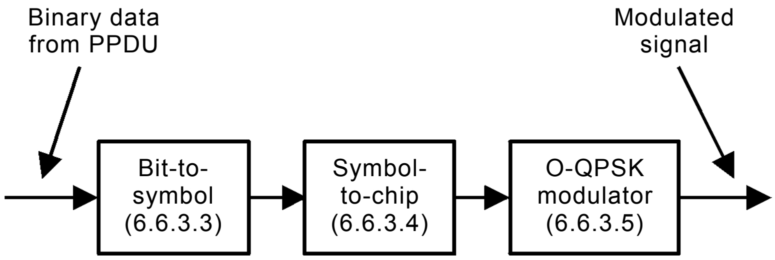

Figure 7 – Modulation and spreading functions

6.6.3.3 Bit-to-symbol mapping

For 31,25 kbit/s to 250 kbit/s, all binary data contained the PPDU shall be encoded using the modulation and spreading functions shown in Figure 7. This subclause describes how binary information is mapped into data symbols.

The 4 LSBs (b_0, b_1, b_2, b_3) of each octet shall map into one data symbol, and the 4 MSBs (b_4, b_5, b_6, b_7) of each octet shall map into the next data symbol. Each octet of the PPDU is processed through the modulation and spreading functions sequentially, beginning with the preamble field and ending with the last octet of the PSDU. Within each octet, the least significant symbol (b_0, b_1, b_2, b_3) is processed first and the most significant symbol (b_4, b_5, b_6, b_7) is processed second.

6.6.3.4 Symbol-to-chip mapping

Each data symbol shall be mapped into a 32-chip PN sequence.

For 250 kbit/s, the symbol-to-chip mapping sequence is shown in Figure 8.

Data symbol binary	Chip value (250 kbit/s)																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
0000	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0
0001	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0
0010	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0
0011	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1
0100	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1
0101	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0
0110	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1
0111	1	0	0	1	1	1	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1
1000	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1
1001	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1
1010	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1
1011	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0
1100	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0
1101	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0	1	0	0	1
1110	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	0
1111	1	1	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	0	0

Figure 8 – Symbol-to-chip mapping

For 125 kbit/s, 62,5 kbit/s and 31,25 kbit/s channel speeds, the chip sequence for 250 kbit/s is duplicated twice, four times and eight times.

6.6.3.5 O-QPSK modulation

The chip sequences representing each data symbol are modulated onto the carrier using O-QPSK with halfsine pulse shaping. Even-indexed chips are modulated onto the in-phase (I) carrier and odd-indexed chips are modulated onto the quadrature-phase (Q) carrier. Because each data symbol is represented by a 32-chip sequence, the chip rate (nominally 2,0 Mchip/s) is 32 times the symbol rate. To form the offset between I-phase and Q-phase chip modulation, the Q-phase chips shall be delayed by T_c with respect to the I-phase chips (see Figure 9), where T_c is the inverse of the chip rate.

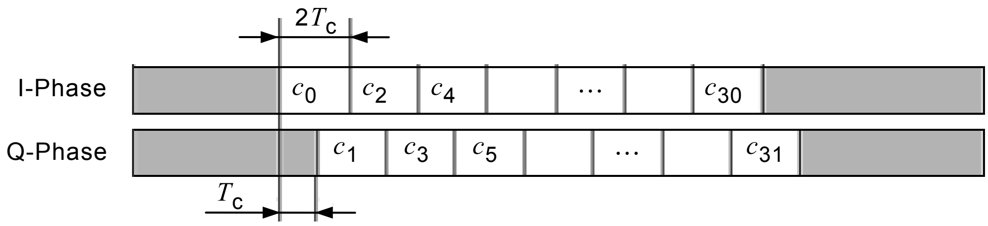

Figure 9 – O-QPSK chip offset

6.6.3.6 Pulse shape

The half-sine pulse shape used to represent each baseband chip is described by Equation (1).

$$p(t) = \begin{cases} \sin\left(\pi \dfrac{t}{2T_C}\right), & 0 \le t \le 2T_C \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

Figure 10 shows a sample baseband chip sequence with half-sine pulse shaping.

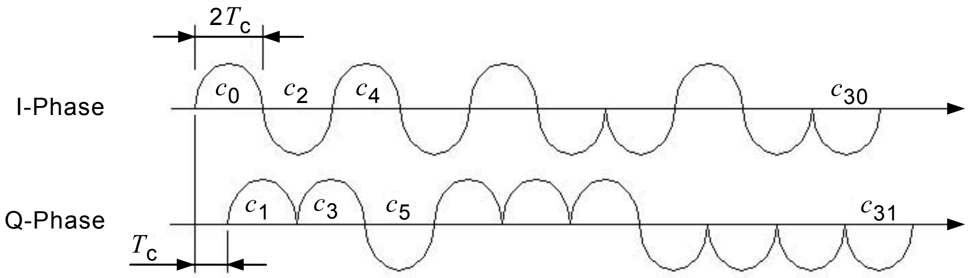

Figure 10 – Sample baseband chip sequences with pulse shaping

6.6.3.7 Chip transmission order

During each symbol period the least significant chip, c_0, is transmitted first and the most significant chip, c_{31}, is transmitted last.

6.6.3.8 2 450 MHz band radio specification

In addition to meeting regional regulatory requirements, devices operating in the 2 450 MHz band shall also meet the radio requirements.

6.6.3.9 Symbol rate

The 2 450 MHz PHY symbol rate shall be the given values as stated in Table 1, and for each data rate, the maximum offset is given as ±0,000 040.

6.6.3.10 Receiver sensitivity

Under the conditions specified in 6.2.7, a compliant device shall be capable of achieving a sensitivity of –85 dBm or better.

6.6.3.11 Receiver jamming resistance

The minimum jamming resistance levels are given in Table 22. The adjacent channel is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel is one more removed from the adjacent channel. For example, when channel 13 is the desired channel, channel 12 and channel 14 are the adjacent channels and channel 11 and channel 15 are the alternate channels.

Table 22 – Minimum receiver jamming resistance requirements for 2 450 MHz PHY

Adjacent channel rejection	Alternate channel rejection
0 dB	30 dB

The adjacent channel rejection shall be measured as follows. The desired signal shall be a compliant 2 450 MHz WiBEEM PHY signal of pseudo-random data. The desired signal is input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity.

In either the adjacent or the alternate channel, a WiBEEM PHY signal is input at the relative level specified in Table 22. The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 6.2.7 under these conditions.

6.7 General radio specifications

6.7.1 Application of specifications

The specifications in 6.7.2 through 6.7.10 apply to either or both the 2 450 MHz PHY and the 868/915 MHz PHY.

6.7.2 TX-to-RX turnaround time

The TX-to-RX turnaround time shall be less than *aTurnaroundTime*.

The TX-to-RX turnaround time shall be measured at the air interface from the trailing edge of the last transmitted symbol until the receiver is ready to begin the reception of the next PHY packet.

6.7.3 RX-to-TX turnaround time

The RX-to-TX turnaround time shall be less than *aTurnaroundTime*.

The RX-to-TX turnaround time shall be measured at the air interface from the trailing edge of the last chip (of the last symbol) of a received packet until the transmitter is ready to begin transmission of the resulting acknowledgement. Actual transmission start times are specified by the MAC sublayer.

6.7.4 Error-vector magnitude (EVM) definition

6.7.4.1 General

The modulation accuracy of a WiBEEM transmitter is determined with an EVM measurement. In order to calculate the EVM measurement, a time record of N received complex chip values $(\tilde{I}_j, \tilde{Q}_j)$ is captured. For each received complex chip, a decision is made about which complex chip value was transmitted. The ideal position of the chosen complex chip (the centre of the decision box) is represented by the vector (I_j, Q_j). The error vector $(\delta I_j, \delta Q_j)$ is defined as the distance from this ideal position to the actual position of the received point (see Figure 11).

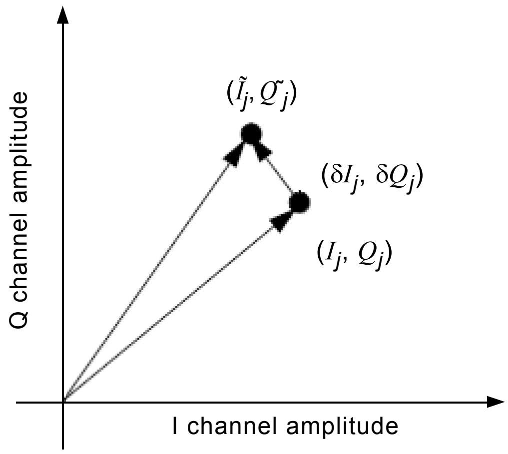

Figure 11 – Error vector calculation

Thus, the received vector is the sum of the ideal vector and the error vector as shown in Equation (2):

$$(\tilde{I}_j, \tilde{Q}_j) = (I_j, Q_j) + (\delta I_j, \delta Q_j) \quad (2)$$

The EVM for WiBEEM PHY is defined as

$$EVM \equiv \sqrt{\frac{\frac{1}{N}\sum_{j=1}^{N}\delta I_j^2 + \delta Q_j^2}{S^2}} \times 100\,\%$$

where

S is the magnitude of the vector to the ideal constellation point, and

$(\delta I_j, \delta Q_j)$ is the error vector.

6.7.4.2 EVM calculated values

A WiBEEM PHY transmitter shall have EVM values of less than 35 % when measured for 1 000 chips. The error-vector measurement shall be made on baseband I and Q chips after recovery through a reference receiver system. The reference receiver shall perform carrier lock, symbol timing recovery and amplitude adjustment while making the measurements.

6.7.5 Transmit centre frequency tolerance

The transmitted centre frequency tolerance shall be ±0,000 040 maximum.

6.7.6 Transmit power

A WiBEEM transmitter shall be capable of transmitting at least –3 dBm. Devices should transmit lower power when possible in order to reduce interference to other devices and systems.

The maximum transmit power is limited by local regulatory bodies.

6.7.7 Receiver maximum input level of desired signal

The receiver maximum input level is the maximum power level of the desired signal, in decibels relative to 1 mW, present at the input of the receiver for which the error rate criterion in 6.2.7 is met. A WiBEEM receiver shall have a receiver maximum input level greater than or equal to –20 dBm.

6.7.8 Receiver ED

The receiver ED measurement is intended for use by a network layer as part of a channel selection algorithm. It is an estimate of the received signal power within the bandwidth of a WiBEEM channel. No attempt is made to identify or decode signals on the channel. The ED time shall be equal to 8 symbol periods for 250 kbit/s channel speed.

The ED result shall be reported to the MLME using PLME-ED.confirm (see 6.3.3.5) as an 8-bit integer ranging from 0x00 to 0xff. The minimum ED value (0) shall indicate received power less than 10 dB above the specified receiver sensitivity, and the range of received power spanned by the ED values shall be at least 40 dB. Within this range, the mapping from the received power in decibels to ED value shall be linear with an accuracy of ±6 dB.

6.7.9 LQI

The LQI measurement is a characterisation of the strength and/or quality of a received packet. The measurement may be implemented using receiver ED, a signal-to-noise ratio estimation, or a combination of these methods. The use of the LQI result by the network or application layers is not specified in this standard.

The LQI measurement shall be performed for each received packet, and the result shall be reported to the MAC sublayer using PD-DATA.indication (see 6.3.2.4) as an integer ranging from 0x00 to 0xff. The minimum and maximum LQI values (0x00 and 0xff) should be associated with the lowest and highest quality WiBEEM signals detectable by the receiver, and LQ values in between should be uniformly distributed between these two limits. At least eight unique values of LQ shall be used.

6.7.10 CCA

The WiBEEM PHY shall provide the capability to perform CCA according to at least one of the following three methods.

– CCA Mode 1: Energy above threshold. CCA shall report a busy medium upon detecting any energy above the ED threshold.
– CCA Mode 2: Carrier sense only. CCA shall report a busy medium only upon the detection of a signal with the modulation and spreading characteristics of WiBEEM. This signal may be above or below the ED threshold.
– CCA Mode 3: Carrier sense with energy above threshold. CCA shall report a busy medium only upon the detection of a signal with the modulation and spreading characteristics of WiBEEM with energy above the ED threshold.

For any of the CCA modes, if the PLME-CCA.request primitive (see 6.3.3.2) is received by the PHY Layer during reception of a PPDU, CCA shall report a busy medium. PPDU reception is considered to be in progress following detection of the SFD, and it remains in progress until the number of octets specified by the decoded PHR has been received.

A busy channel shall be indicated by the PLME-CCA.confirm primitive (6.3.3.3) with a status of BUSY. A clear channel shall be indicated by the PLME-CCA.confirm primitive (6.3.3.3) with a status of IDLE.

The PHY PIB attribute *phyCCAMode* (see 6.5) shall indicate the appropriate operation mode. The CCA parameters are subject to the following criteria.

a) The ED threshold shall be at most 10 dB above the specified receiver sensitivity.
b) The CCA detection time shall be equal to 8 symbol periods.

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