IEEE P802.15
Wireless Personal Area Networks

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Abstract	
Purpose	For reference and future consideration as draft text.
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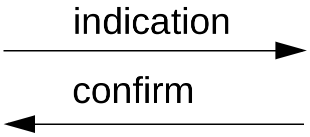
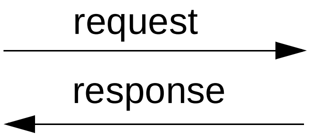
Note: in this text the following conventions have been used:

MLME-SET



MLME-GET



The PHY related text in this contribution has been derived from contribution 15-03-0268-02-003a.

~~IEEE Standard for~~
~~Information technology —~~
~~Telecommunications and information~~
~~exchange between systems —~~
~~Local and metropolitan area networks —~~
~~Specific requirements~~

~~Draft Amendment to Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher Speed Physical Layer Extension for the High Rate Wireless Personal Area Networks (WPAN)~~

1. Overview

Wireless personal area networks (WPANs) are used to convey information over relatively short distances among a relatively few participants. Unlike wireless local area networks (WLANs), connections effected via WPANs involve little or no infrastructure. This allows small, power efficient, inexpensive solutions to be implemented for a wide range of devices.

The term WPAN in this document refers specifically to a wireless personal area network as defined by this document. The terms “wireless personal area network,” “WPAN,” and “802.15.3a WPAN” in this document are synonymous.

1.1 Scope

This standard defines an alternate PHY specification, in conjunction with the 802.15.3 MAC, for high data rate wireless connectivity with fixed, portable and moving devices within or entering a personal operating space. A goal of this standard will be to achieve a level of interoperability or coexistence with other 802.15™ standards. It is also the intent of this standard to work toward a level of coexistence with other wireless devices in conjunction with coexistence task groups such as 802.15.2™.

Based on the previous calls for applications collected for 802.15.3a, there remained a significant group of applications that could not be addressed by 802.15.3™. High data rates are required for time dependent and large file transfer applications such as video or digital still imaging without sacrificing the requirements of low complexity, low cost and low power consumption with 110 Mb/s being proposed as the lowest rate for these types of data.

It is possible, for example, that several data rates would be supported for different consumer applications. Consequently, the notions of cost, frequency band, performance, power and data rate scalability were addressed in the development of this standard. A personal operating space is a space about a person or object that typically extends up to 10 m in all directions and envelops the person whether stationary or in motion. Personal operating space use models permit more freedom over the design of the radio than in medical or enterprise LAN applications where the primary goal is link robustness at long range. In an area covered by a WLAN, it is expected that a robust link would be established anywhere within the coverage area without any special action on the part of the user. Link robustness is equally important for a WPAN but it is acceptable to take an action like moving closer to establish it. Consequently, WPAN standards are able to focus on other priorities, such as cost, size, power consumption and data rate.

1.2 Purpose

The purpose of this standard is to provide for low complexity, low cost, low power consumption (comparable to the goals of 802.15.1) and high data rate wireless connectivity among devices within or entering the personal operating space. The data rate is high enough, 20 Mb/s or more, to satisfy a set of consumer multimedia industry needs for WPAN communications. This standard also addresses the quality of service capabilities required to support multimedia data types.

2. References

NOTE—The IEEE standards referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

3. Definitions

4. Acronyms and abbreviations

6. Layer Management

6.3 MLME SAP interface

Table 1—Addition to table in clause 6.3

Name	Request	Indication	Response	Confirm
MLME-RANGE	6.3.23.1	6.3.23.2	6.3.23.3	6.3.23.4
MLME-FET	6.3.24.1	6.3.24.3	6.3.24.2	6.3.24.4
MLME-InterferNoiseTemp	6.3.25.1	6.3.25.2	6.3.25.3	6.3.25.4

6.3.23 Ranging

This mechanism supports range determination between two DEVs. The primitive's parameters are defined in Table 2.

Table 2—MLME-RANGE primitive parameters

Name	Type	Valid Range	Description
SrcID	Integer	Any valid DEVID as defined in 7.2.3	The device ID of the source
DestID	Integer	Any valid DEVID as defined in 7.2.3	The device ID of the destination
Timeout	Integer	As defined in 6.3.23.4.2	The time limit for the reception of the returned range token #2 as shown in clause TBD
Reason Code	Integer	As defined in 6.3.23.4.2	Indicates the result of the command

6.3.23.1 MLME-RANGE.request

This primitive is used to request that the range between two devices be mesured. The semantics of the primitive are as follows:

MLME-RANGE.request (DestID, SrcID, Timeout)

The parameters are defined in Table 2.

6.3.23.1.1 When generated

This primitive is generated by the source DME to request a range measurement.

6.3.23.1.2 Effect of receipt

When a DEV MLME receives this primitive from its DME, it will generate a RANGE command, which it will send to the Destination PNID. The Destination PNID, upon receiving the RANGE command, will generate an MLME-RANGE.indication.

6.3.23.2 MLME-RANGE.indication

This primitive is used to indicate a received RANGE command. The semantics of the primitive are as follows:

MLME-RANGE.indication (DestID, SrcID, Timeout)

The parameters are defined in Table 2.

6.3.23.2.1 When generated

This primitive is sent by the non-initiating MLME to its DME upon receiving a RANGE command.

6.3.23.2.2 Effect upon receipt

When the Destination DME receives this primitive, it will determine whether to accept or reject the source DEV request for a range measurement. The Destination DME will then send a MLME-RANGE.response with appropriate parameter values to its MLME via the MLME-SAP.

6.3.23.3 MLME-RANGE.response

This primitive is used to initiate a response to an MLME-RANGE.indication. The semantics of the primitive are as follows:

MLME-RANGE.response (DestID, SrcID, ReasonCode)

The parameters are defined in Table 2.

6.3.23.3.1 When generated

This primitive is generated by the Destination DME upon receiving an MLME-RANGE.indication.

6.3.23.3.2 Effect upon receipt

When the destination MLME receives this primitive from its DME, it will either initialize the ranging state machine in anticipation of exchanging ranging tokens or it will reject the ranging request with a ReasonCode indicating the reason for the request being denied.

6.3.23.4 MLME-RANGE.confirm

This primitive is used to inform the initiating source DME whether the requested ranging token exchange will commence or was the ranging request rejected. The semantics of the primitive are as follows:

MLME-RANGE.confirm (DestID, SrcID, ReasonCode)

The parameters are defined in Table 2.

6.3.23.4.1 When generated

The initiating source MLME sends this primitive to its DME to confirm whether a ranging token exchange is pending.

6.3.23.4.2 Effect upon receipt

When the initiating source MLME receives a ReasonCode = ExchangeTokens it shall initiate the ranging token exchange as per clause 7.5.11. When the ReasonCode = DoNotExchangeTokens the source MLME shall terminate the ranging token exchange procedure and perhaps attempt ranging later. When the ReasonCode = RangingNotSupported the source MLME shall terminate the ranging token exchange and shall not initiate another range measurement with that particular destination DEV. If the second token is not received by the source DEV within the time specified by parameter "Timeout" then the ReasonCode shall be set to ReasonCode=TimeoutFailure.

6.3.24 Frequency Exclusion Table (FET)

These primitives are used by the MAC and DME (see clause 6.1) to management the FET; that is, to “get” and “set” the FET. The parameters used for these primtives are defined in Table 3.

Table 3—MLME-FET primitive parameters

Name	Type	Valid Range	Description
DestID	Integer	Any valid DEVID as defined in 7.2.3	The device ID of the source
SrcID	Integer	Any valid DEVID as defined in 7.2.3	The device ID of the destination
FET	Integer Vector	As defined in 7.5.11	The time limit for the reception of the returned range token #2 as shown in clause TBD
ERR_FET	Enumeration	Successful, Unsuccessful	Indicates the result of the MLME request

6.3.24.1 MLME-FET.request

This primitive is used by the management entity to get the FET; that is, the requesting managment identity desires a copy of the local FET table. The semantics of this primtive are

MLME-FET.request (DestID, SrcID)

6.3.24.1.1 When generated

This primitive is sent by the management entity (DME or MAC) as a request to the MLME to suppy the FET to the requesting DEV.

6.3.24.1.2 Effect of receipt

The target MLME, upon receiving an MLME-FET.request, sends the FET table via a MLME-FET.response primitive.

6.3.24.2 MLME-FET.response

This primitive is used by the MLME to suppy a copy of the stored FET to the requesting management entity. The semantics of this primtive are

MLME-FET.response (DestID, SrcID, FET, ERR_FET)

6.3.24.2.1 When generated

This primitive is sent by the target MLME to the requesting management, in response to an MLME-FET.request, along with a copy of the FET.

6.3.24.2.2 Effect of receipt

The MLME copies the FET and sends it to the DEV specified in the OrigID, along with the appropriate error message.

6.3.24.3 MLME-FET.indication

This primitive is used by the management entity to set the FET. The semantics of this primtive are

MLME-FET.indication (DestID, SrcID, FET)

6.3.24.3.1 When generated

This primitive is sent from the management entity (DME or MAC) to the MLME to send a new FET to the indicated DEV. The DEV can be either local or remote.

6.3.24.3.2 Effect of receipt

The MLME, upon receiving this primitve from the management entity, will store the FET and send an error message to the orginating DEV via an MLME-FET.confirm.

6.3.24.4 MLME-FET.confirm

This primitive is used by the MLME to confirm that a copy of the FET has been stored in the MLME. An error message shall be sent back to the originating ID. The semantics of this primtive are

MLME-FET.confirm (DestID, SrcID, ERR_FET)

6.3.24.4.1 When generated

This primitive is sent by the target MLME to the originating management entity in response to an MLME-FET.indication.

6.3.24.4.2 Effect of receipt

The management entity reads to the error code to ascertain if the command was executed correctly.

6.3.25 Interference Noise Temperature

These primitives are used by the MAC and DME (see clause 6.1) to manage the transmitted power on a per OFDM frequency bin basis in compliance with the concept of interference noise temperature. They are used to adjust the transmit PSD over the UWB bandwidth based upon noise temperture estimates generated by the receive function. The specification of the algorithms for generting the noise temperature estimates is outside of the scope of this standard. The NoiTempTxVector is a local primitive that is not shared over the network. The parameters used for these primtives are defined in Table 3.

Table 4—MLME-NoiTempTxVector primitive parameters

Name	Type	Valid Range	Description
NoiTempTxVector	Integer Vector	1818 octets	There are 1818 4.125 MHz wide frequency bins over the UWB band from 3.1 GHz to 10.6 GHz. Each TX frequency bin has an associated octet weighting. The default value is decimal 1.0.
ERR_NoiTempTxVector	Enumeration	Successful, Unsuccessful	Indicates the result of the MLME request

6.3.25.1 NoiTempTxVector.request

This primitive is used by the management entity when requesting a copy of the NoiTempTxVector. The semantics of this primtive are

MLME-NoiTempTxVector.request ()

The target is always the local MLME. The NoiTempTxVector is not transported across the wireless link.

6.3.25.1.1 When generated

This primitive is generated whenever the management entity needs a copy of the NoiTempTxVector in order to properly weight each of the OFDM sub-carriers prior to a packet transmission.

6.3.25.1.2 Effect of receipt

The MLME shall send the NoiTempTxVector via the NoiTempTxVector response.

6.3.25.2 NoiTempTxVector.indication

This primitive is used by the management entity to indicate that a new NoiTempTxVector is being sent to the MLME for storage. The semantics of this primtive are

MLME-NoiTempTxVector.indication (NoiTempTxVector)

The target is always the local MLME. The NoiTempTxVector is not transported across the wireless link.

6.3.25.2.1 When generated

This primitive is generated whenever the management entity has a new NoiTempTxVector that needs to be copied into the local MLME.

6.3.25.2.2 Effect of receipt

The local MLME, when receiving the indication shall store the NoiTemTxVector and return a confirm message with the proper error message.

6.3.25.3 NoiTempTxVector.response

This primitive is used by the MLME to send a copy of the NoiTempTxVector to the requesting management entity. The semantics of this primtive are

MLME-NoiTempTxVector.response (NoiTempTxVector, ERR_NoiTempTxVector)

The target is always the local management entity. The NoiTempTxVector is not transported across the wireless link.

6.3.25.3.1 When generated

This primitive is generated by the local MLME to send a copy of the NoiTempTxVector for use in setting the OFDM sub-carrier levels prior to a packet transmission. The error codes are given in Table 4.

6.3.25.3.2 Effect of receipt

The local management entity shall check the ERR_NoiTempTxVector parameter prior to using the NoiTemTxVector to make sure it is valid.

6.3.25.4 NoiTempTxVector.confirm

This primitive is used by the MLME to send a confirmation message to the local management entity to indicate the reception of a new NoiTempTxVector. The semantics of this primtive are

MLME-NoiTempTxVector.response (NoiTempTxVector, ERR_NoiTempTxVector)

The target is always the local management entity. The NoiTempTxVector is not transported across the wireless link. The ERR_NoiTempTxVector is defined in Table 4.

6.3.25.4.1 When generated

This primitive is generated in response to an indication to confirm that the NoiTempTxVector was successfully received.

6.3.25.4.2 Effect of receipt

The local management entity reads the ERR_NoiTempTxVector parameter to ascertain that the NoiTempTxVector was successfully loaded into the MLME.

7. MAC Frame Formats

7.5 MAC command types

Table 5—Addition to table of clause 7.5

Command type hex value b15-b0	Command name	Sub-clause	Associated	Secure membership (if requred)
0x001D	Ranging	7.5.10	X	
0x001E	FET request	7.5.11.1	X	
0x001F	FET response	7.5.11.2	X	

7.5.10 Ranging

The ranging command is used to initiate a ranging token exchange between two devices. The issuance of a ranging command shall result in the following activity between DEV A and DEV B:

1) DEV A sends a ranging token to DEV B
2) DEV B holds onto the token for a time t and then sends the token back to DEV A
3) Next DEV A sends a second ranging token to DEV B
4) DEV B holds onto the token for a time 2t and then sends the token back to DEV A
5) DEV A calculates the ranging information as discussed above

The source device calculates the ranging information. If the destination device wants range information it will have to send a ranging command in the reverse direction. The command structure is shown below.

Table 6—Ranging Command

Octets 2	2	2	2	1	1
Command Type	Length	Source PNID	Destination PNID	Timeout uS	Reason Code

The Timeout field has the resolution of uS and is used to timeout the ranging process.

The reason code field has the following values:

ExchangeTokens = 0x01
DoNotExchangeTokens = 0x02
RangingNotSupported = 0x03
TimeoutFailure = 0x04

The definition of the reason codes is presented in clause 6.3.23.4.2.

7.5.11 Frequency Exclusion Table

The Frequency Exclusion Table shall be formatted as illustrated in Figure 1. This table is used to communicate which OFDM sub-carriers the responding DEV wants to avoid using for data information. These OFDM sub-carriers carriers may or may not actually be transmitted depending upon local regulatory requirements.

octets: 0-3072	1
FET Vector	Length(=0-3072)

Figure 1—Frequency Exclusion Table (FET) format

There are 1818 frequency bins between 3.1 GHz and 10.6 GHz, each 4.125 MHz wide. A particular frequency bin can be indexed by a 3 octet hex number. Each FET vector numerically represents an indexing of the possible OFDM sub-carriers where an FET vector of value 0x000 represents the subcarrier starting at 3.1 GHz and an FET vector of value 0x71A represents the subcarrier ending at 10.59925 GHz. The maximum number of excluded OFDM frequency bins is 1024.

7.5.11.1 FET request

The FET request command shall be formatted as illustrated in Figure 2. This command may be sent by any DEV in the piconet to any other DEV in the piconet, including the PNC, to request the current channel condition as experienced at the target DEV.

octets: 2	2
Length (=0)	Command type

Figure 2—FET request command format

7.5.11.2 FET response

The FET response command shall be formatted as illustrated in Figure 3. This command is sent by the target DEV in response to the originating DEV’s request for a copy of the FET table. The FET table is defined in Figure 1.

octets: 1-3073	2
FET Table	Command type

Figure 3—FET response command format

8. MAC Functional Description

8.11.3 Frequency Exclusion Table (FET)

The FET can be used either for compliance to regulatory domain requirements or as a method of dealing with interference. The UWB OFDM band may be thought of as consisting of 4.125 MHz wide OFDM frequency bins evenly spaced from the bottom to the top of the UWB frequency band. The actual width of the UWB frequency band is regulatory region dependent and each regulatory region may have “keep out” bands where insignificant UWB energy is not allowed to be transmitted. (Note that the fundamental 500 MHz frequency block required in the United States may not be common to all regulatory domains). This necessitates being able to shape the frequency spectrum as per regulatory domain requirements. In addition, in those cases where the UWB DEV can determine that operation on a particular OFDM frequency bin is subject to interference, or may result in interference, that DEV may desire to not utilize that particular frequency bin. The frequency exclusion table can be used to determine which OFDM subcarriers within the 7.5 GHz UWB frequency band are actually carrying information. The subcarriers that are not carrying information may either be modulated with a random sequence or may be turned or phased off.

The FET tabular information is stored in the MLME and can be set or read by the DME or MAC. In addition, a command can be issued to read a remotes FET in order to determine the remote DEV’s OFDM frequency bin status. Two DEVs may match the OFDM tone usage by comparing FET tables and generating common masks. Note that the allocation of bits to active tones is beyond the scope of this standard. One common method is to FEC across the OFDM frequency bins to avoid water pouring bit loading algorithms. The FET tables can be used to assist in FEC decoding by indicating where erasures should be inserted.

8.11.3.1 FET MSC

Of interest is the case where a local DEV requests the transmission of the FET from another remote DEV. The local DEV sends an FET request (7.5.11.1) which solicits an FET response (7.5.11.2) as shown in Figure 4.

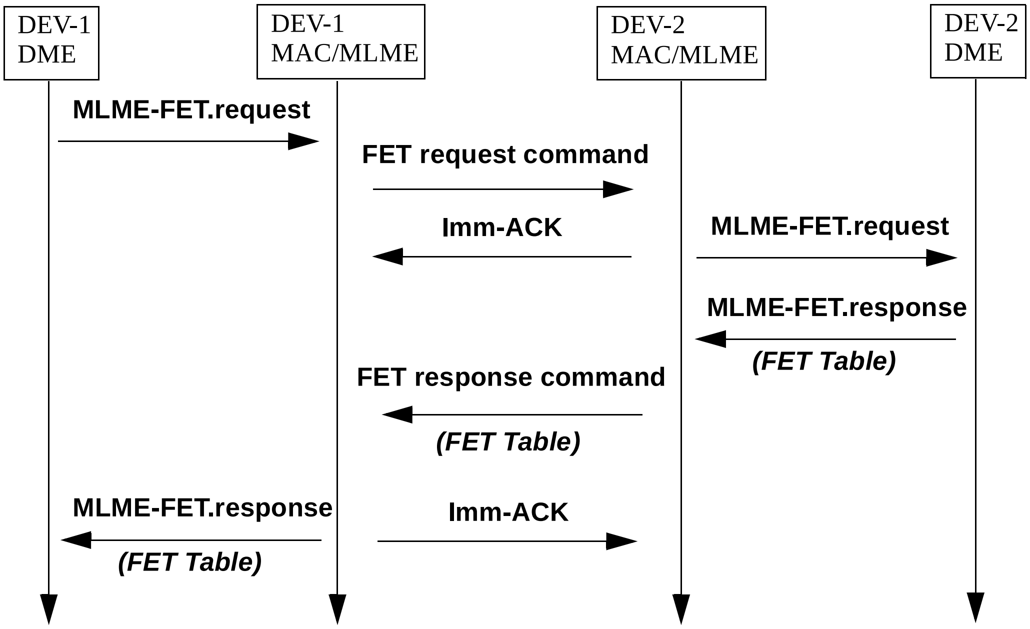


Figure 4—FET Request MSC

8.16 Ranging and Ranging Token Exchange

Figure 1 illustrates the message sequence involved when requesting a range measurement. The ranging command initiates the precise exchange of a ranging token between the source DEV and the destination DEV as shown in the message sequence chart below.

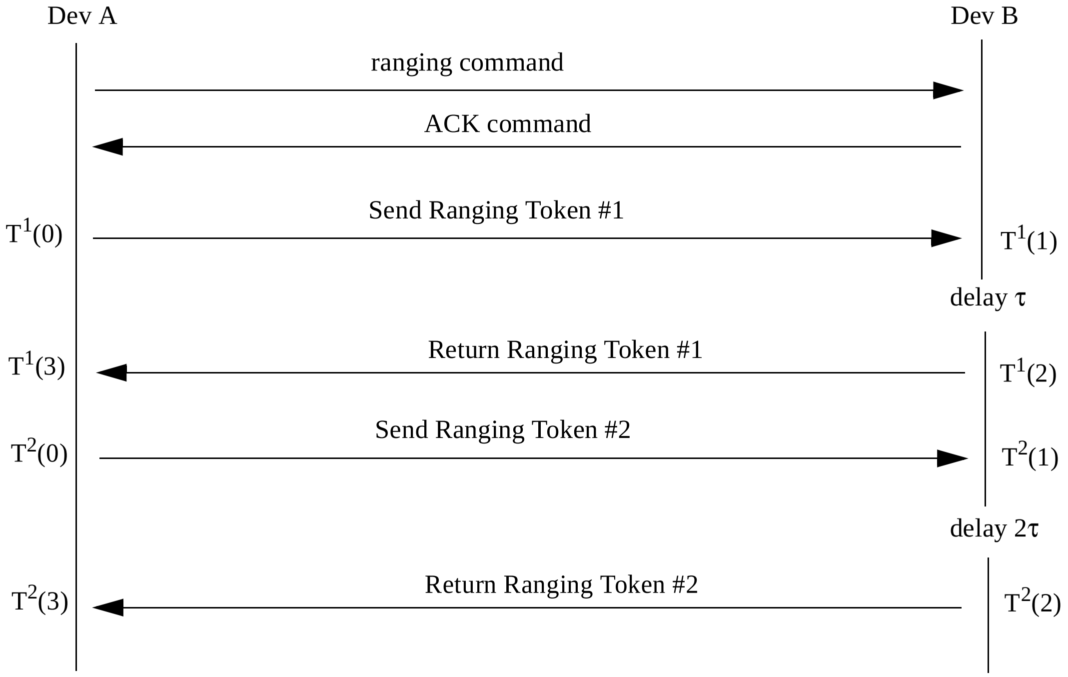


Figure 5—MSC for ranging token exchange

Device A must receive the second token from device B within the amount of time indicated in the command Timout field. The ranging token itself is PHY dependent and is described in clause 12.x. The time of flight between the two devices is then calculated as

$$T_{flight} = \{T^1(3)- T^1(0)\} - [\{T^2(3)- T^2(0)\}/2]$$

where the time epochs are defined in Figure 1. The calculated range is then stored as PHY Management object PHYPIB_Range (clause 12.x.x).

12. UWB Physical Layer

12.1 Introduction

This clause specifies the PHY entity for a UWB system that utilizes the unlicensed 3.1 - 10.6 GHz UWB band, as regulated in the United States by the Code of Federal Regulations, Title 47, Section 15. The UWB system provides a wireless PAN with data payload communication capabilities of 55, 80, 110, 160, 200, 320, and 480 Mb/s. The support of transmitting and receiving at data rates of 55, 110, and 200 Mb/s is mandatory. The proposed UWB system employs orthogonal frequency division multiplexing (OFDM). The system uses a total of 122 sub-carriers that are modulated using quadrature phase shift keying (QPSK). Forward error correction coding (convolutional coding) is used with a coding rate of 11/32, ½, 5/8, and ¾. The proposed UWB system also supports multiple modes of operations: a mandatory 3-band mode (Mode 1), and an optional 7-band mode (Mode 2).

12.1.1 Overview of the proposed UWB system description

12.1.1.1 Mathematical description of the signal

The transmitted signals can be described using a complex baseband signal notation. The actual RF transmitted signal is related to the complex baseband signal as follows:

$$r_{RF}(t) = \mathrm{Re}\left\{ \sum_{k=0}^{N-1} r_k(t - kT_{SYM}) \exp(j2\pi f_k t) \right\}$$

where Re( ) represents the real part of a complex variable, $r_k(t)$ is the complex baseband signal of the kth OFDM symbol and is nonzero over the interval from 0 to T_{SYM}, N is the number of OFDM symbols, T_{SYM} is the symbol interval, and f_k is the center frequency for the kth band. The exact structure of the kth OFDM symbol depends on its location within the packet:

$$r_k(t) = \begin{cases} r_{preamble,k}(t) & 0 \le k < N_{preamble} \\ r_{header,k-N_{preamble}}(t) & N_{preamble} \le k < N_{header} \\ r_{data,k-N_{preamble}}(t) & N_{header} \le k < N_{data} \end{cases}$$

The structure of each component of $r_k(t)$ as well as the offsets $N_{preamble}$, N_{header}, and N_{data} will be described in more detail in the following sections.

All of the OFDM symbols $r_k(t)$ can be constructed using an inverse Fourier transform with a certain set of coefficient *Cn*, where the coefficients are defined as either data, pilots, or training symbols:

$$r_k(t) = \begin{cases} 0 & t \in [0, T_{CP}] \\ \displaystyle\sum_{n=-N_{ST}/2}^{N_{ST}/2} C_n \exp(j2\pi n\Delta_f)(t - T_{CP}) & t \in [T_{CP}, T_{FFT} + T_{CP}] \\ 0 & t \in [T_{FFT} + T_{CP}, T_{FFT} + T_{CP} + T_{GI}] \end{cases}$$

The parameters Δ_f and N_{ST} are defined as the subcarrier frequency spacing and the number of total subcarriers used, respectively. The resulting waveform has a duration of $T_{FFT} = 1/\Delta_f$. Shifting the time by T_{CP} creates the "circular prefix" which is used in OFDM to mitigate the effects of multipath. The parameter T_{GI} is the guard interval duration.

12.1.1.2 Discrete-time implementation considerations

The following description of the discrete time implementation is informational. The common way to implement the inverse Fourier transform is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used, the coefficients 1 to 61 are mapped to the same numbered IFFT inputs, while the coefficients -61 to -1 are copied into IFFT inputs 67 to 127. The rest of the inputs, 62 to 66 and the 0 (DC) input, are set to zero. This mapping is illustrated in Figure 1. After performing the IFFT, a zero-padded prefix of length 32 is pre-appended to the IFFT output and a guard interval is added at the end of the IFFT output to generate an output with the desired length of 165 samples.

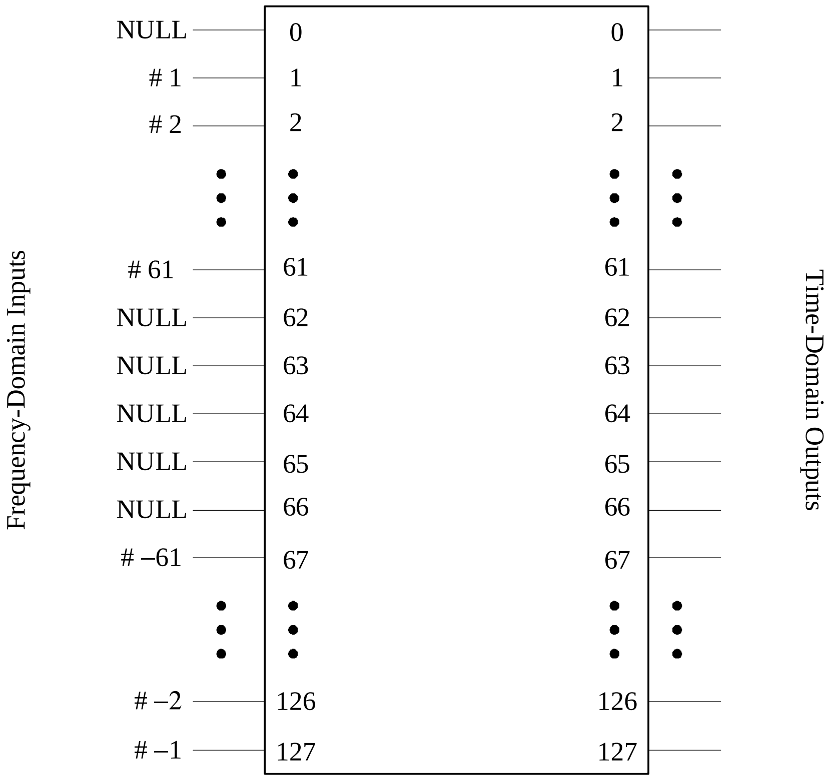


Figure 6—Input and outputs of IFFT

12.1.2 Scope

This subclause describes the PHY services provided to the IEEE 802.15.3 wireless PAN MAC. The OFDM PHY layer consists of two protocol functions, as follows:

a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defined a method of mapping the IEEE 802.15 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.

b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the OFDM system.

12.1.3 UWB PHY function

The UWB PHY contains three functional entities: the PMD function, the PHY convergence function, and the layer management function. The UWB PHY service is provided to the MAC through the PHY service primitives.

12.1.3.1 PLCP sublayer

In order to allow the IEEE 802.15.3 MAC to operate with minimum dependence on the PMD sublayer, a PHY convergence sublayer is defined. This function simplifies the PHY service interface to the IEEE 802.15.3 MAC services.

12.1.3.2 PMD sublayer

The PMD sublayer provides a means to send and receive data between two or more stations.

12.1.3.3 PHY management entity (PLME)

The PLME performs management of the local PHY functions in conjunction with the MAC management entity.

12.2 UWB PHY specific service parameter list

12.2.1 Introduction

Some PHY implementations require medium management state machines running in the MAC sublayer in order to meet certain PMD requirements. This PHY-dependent MAC state machines reside in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY services primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the PHY specification for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the OFDM PHY.

12.2.2 TXVECTOR parameters

The parameters in Table 1 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service primitive.

Table 7—TXVECTOR parameters

Parameter	Associate Primitive	Value
LENGTH	PHY-STXSTART.request (TXVECTOR)	1-4095
DATARATE	PHY-TXSTART.request (TXVECTOR)	55, 80, 110, 160, 200, 320 and 480 (Support for 55, 110 and 200 Mbps data rates is mandatory.)
SCRAMBLER_INIT	PHY-TXSTART.request (TXVECTOR)	Scrambler initialization: 2 null bits
TXPWR_LEVEL	PHY-TXSTART.request (TXVECTOR)	1-8

12.2.2.1 TXVECTOR LENGTH

The allowed values for the LENGTH parameter are in the range 1-4095. This parameter is used to indicate the number of octets in the frame payload (which does not include the FCS), which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octets transfers that will occur between the MAC and the PHY after receiving a request to start the transmission.

12.2.2.2 TXVECTOR DATARATE

The DATARATE parameter describes the bit rate at which the PLCP shall transmit the PSDU. Its value can be any of the rates defined in Table 1. Data rates of 55, 110, and 200 Mb/s shall be supported; other rates may also be supported.

12.2.2.3

The SCRAMBLER_INIT parameter consists of 2 null bits used for the scrambler initialization.

12.2.2.4 TXVECTOR TXPWR_LEVEL

The allowed values for the TXPWR_LEVEL parameter are in the range from 1-8. This parameter is used to indicate which of the available TxPowerLevel attributes defined in the MIB shall be used for the current transmission.

12.2.3 RXVECTOR parameters

The parameters in Table 2 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive.

12.2.3.1 RXVECTOR LENGTH

The allowed values for the LENGTH parameter are in the range 1-4095. This parameter is used to indicate the value contained in the LENGTH field that the PLCP has received in the PLCP header. The MAC and the PLCP will use this value to determine the number of octet transfers that will occur between the two sublayers during the transfer of the received PSDU.

Table 8—RXVECTOR parameters

Parameter	Associate Primitive	Value
LENGTH	PHY-RXSTART.indicate (RXVECTOR)	1-4096
RSSI	PHY-RXSTART.indicate (RXVECTOR)	0-RSSI maximum
DATARATE	PHY-RXSTART.indicate (RXVECTOR)	55, 80, 110, 160, 200, 320 and 480

12.2.3.2 RXVECTOR RSSI

The allowed values for the receive signal strength indicator (RSSI) parameter are in the range from 0 through RSSI maximum. This parameter is a measure by the PHY sublayer of the energy observed at the antenna used to receive the current PSDU. RSSI shall be measured during the reception of the PLCP preamble. RSSI is to be used in a relative manner, and it shall be a monotonically increasing function of the received power.

12.2.3.3 RXVECTOR DATARATE

DATARATE shall represent the data rate at which the current PPDU was received. The allowed values of the DATARATE are 55, 80, 110, 160, 200, 320, or 480.

12.3 UWB PLCP sublayer

12.3.1 Introduction

This subclause provides a method for converting the PSDUs to PPDUs. During the transmission, the PSDU shall be provided with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation, decoding, and delivery of the PSDU.

12.3.2 PLCP frame format

Figure 2 shows the format for the PHY frame including the PLCP preamble, PLCP header (PHY header, MAC header, header check sequence, tail bits, and pad bits), MAC frame body (frame payload plus FCS), tail bits, and pad bits. Additionally, an optional band extension sequence will be included after the PLCP header when frame payload is transmitted using Mode 2.

The PHY layer first pre-appends the PHY header plus the tail bits to the MAC header and then calculates the HCS over the combined headers and tail bits. The tail bits are added after the PHY header in order to return the convolutional encoder to the "zero state". The resulting HCS is appended to the end of the MAC header along with an additional set of tail bits. Pad bits are also added after the tail bits in order to align the data stream on an OFDM symbol boundary.

Tail bits are also added to the MAC frame body (i.e., the frame payload plus FCS) in order to return the convolutional encoder to the "zero state". If the size of the MAC frame body plus tail bits are not an integer multiple of the bits/OFDM symbol, then pad bits (PD) are added to the end of the tail bits in order to align the data stream on the OFDM symbol boundaries.

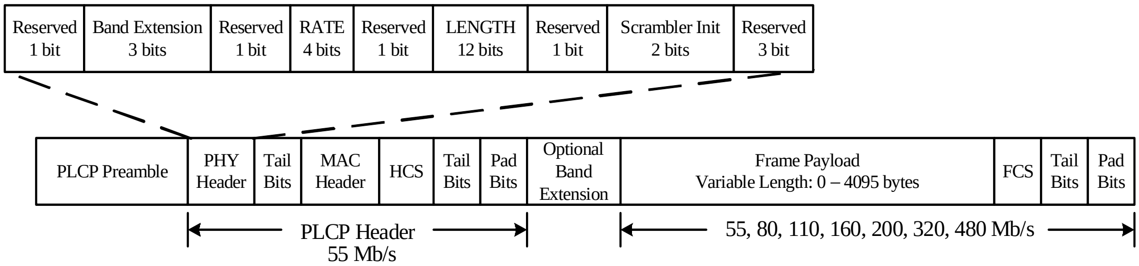


Figure 7—PLCP frame format for a Mode 1 device

The PLCP preamble is sent first, followed by the PLCP header, followed by an optional band extension sequence, followed by the frame payload, the FCS, the tail bits, and finally the pad bits. As shown in Figure 2, the PLCP header is always sent at an information data rate of 55 Mb/s. The PLCP header is always transmitted using Mode 1. The remainder of the PLCP frame (frame payload, FCS, tail bits, and pad bits) is sent at the desired information data rate of 55, 80, 110, 160, 200, 320, or 480 Mb/s using either Mode 1 or Mode 2.

12.3.2.1 RATE-dependent parameters

The data rate dependent modulation parameters are listed in Table 3.

Table 9—Rate-dependent parameters

Data Rate (Mb/s)	Modulation	Coding Rate (R)	Conjugate Symmetric Input to FFT	Time Spreading	Overall Spreading Gain	Coded bits per OFDM symbol (N_{CBPS})
55	QPSK	11/32	Yes	Yes	4	100
80	QPSK	1/2	Yes	Yes	4	100
110	QPSK	11/32	No	Yes	2	200
160	QPSK	1/2	No	Yes	2	200
200	QPSK	5/8	No	Yes	2	200
320	QPSK	1/2	No	No	1	200
480	QPSK	3/4	No	No	1	200

12.3.2.2 Timing-related parameters

A list of the timing parameters associated with the OFDM PHY is listed in Table 4.

12.3.3 PLCP preamble

A standard PLCP preamble shall be added prior to the PLCP header to aid receiver algorithms related to synchronization, carrier-offset recovery, and channel estimation. The standard PLCP preamble, which is shown

Table 10—Timing-related parameters

Parameter	Value
N_{SD}: Number of data subcarriers	100
N_{SDP}: Number of defined pilot carriers	12
N_{SG}: Number of total subcarriers used	10
N_{ST}: Number of total subcarriers used	122 (=N_{SD} + N_{SDP} + N_{SG})
Δ_F: Subcarrier frequency spacing	4.125 MHz (=528 MHz/128)
T_{FFT}: IFFT/FFT period	242.42 ns (1/Δ_F)
T_{CP}: Cyclic prefix duration	60.61 ns (=32/528 MHz)
T_{GI}: Guard interval duration	9.47 ns (=5/528 MHz)
T_{SYM}: Symbol interval	312.5 ns (T_{CP} + T_{FFT} + T_{GI})

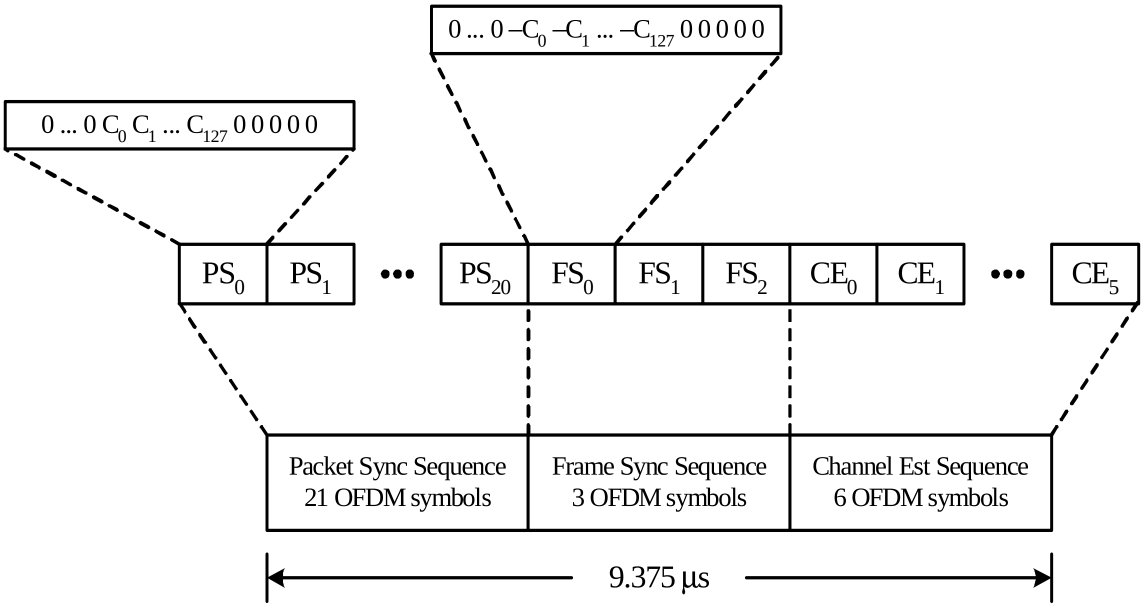
in Figure 3, consists of three distinct portions: packet synchronization sequence, frame synchronization sequence, and the channel estimation sequence. The packet synchronization sequence shall be constructed by successively appending 21 periods, denoted as $\{PS_0, PS_1, \ldots, PS_{20}\}$, of a time-domain sequence. Each piconet will use a distinct time-domain sequence. These time-domain sequences are defined in Table 5 through Table 8. Each period of the timing synchronization sequence shall be constructed by pre-appending 32 "zero samples" and by appending a guard interval of 5 "zero samples" to the sequences defined in Table 5 through Table 8. This portion of the preamble can be used for packet detection and acquisition, coarse carrier frequency estimation, and coarse symbol timing.

Similarly, the frame synchronization sequence shall be constructed by successively appending 3 periods, denoted as $\{FS_0, FS_1, FS_2\}$, of an 180 degree rotated version of the time-domain sequence specified in Table 5 through Table 8. Again, each period of the frame synchronization sequence shall be constructed by pre-appending 32 "zero samples" and by appending a guard interval of 5 "zero samples" to the sequences defined in Table 5 through Table 8. This portion of the preamble can be used to synchronize the receiver algorithm within the preamble.

Figure 8—Standard PLCP preamble format

Finally, the channel estimation sequence shall be constructed by successively appending 6 periods, denoted as $\{CE_0, CE_1, \ldots, CE_5\}$, of the OFDM training symbol. This training symbol is generated by passing the frequency-domain sequence, defined in Table 9, though the IFFT, and pre-appending the output with 32 "zero samples" and appending and a guard interval consisting of 5 "zero samples" to the resulting time-domain output. This portion of the preamble can be used to estimate the channel frequency response, for fine carrier frequency estimation, and fine symbol timing.

Note: The time domain sequences in Tables 5-8 should be normalized appropriately in order to have the same average power as the signals which are defined in the frequency domain (and are thus passed through an IFFT operation), such as the channel estimation sequence defined in Table 9, and the payload samples.



In addition to a standard PLCP preamble, a streaming-mode PLCP preamble is also defined in this section. In the streaming packet mode, the first packet shall use the standard PLCP preamble, while the remaining packets (second packet and on), which are separated by a MIFS time, shall use the streaming-mode PLCP preamble instead of the standard PLCP preamble. The streaming-mode PLCP preamble, which is shown in Figure 4, consists of three distinct portions: packet synchronization sequence, frame synchronization sequence, and the channel estimation sequence. The packet synchronization sequence shall be constructed by successively appending 6 periods, denoted as $\{PS_0, PS_1, \ldots, PS_5\}$, of a time-domain sequence. Each piconet will use a distinct time-domain sequence. These time-domain sequences are defined in Table 5 through Table 8. Each period of the timing synchronization sequence shall be constructed by pre-appending 32 "zero samples" and by appending a guard interval of 5 "zero samples" to the sequences defined in Table 5 through Table 8. This portion of the preamble can be used for packet detection and acquisition, coarse carrier frequency estimation, and coarse symbol timing.

Similarly, the frame synchronization sequence shall be constructed by successively appending 3 periods, denoted as $\{FS_0, FS_1, FS_2\}$, of an 180 degree rotated version of the time-domain sequence specified in Table 5 through Table 8. Again, each period of the frame synchronization sequence shall be constructed by pre-appending 32 "zero samples" and by appending a guard interval of 5 "zero samples" to the sequences defined in Table 5 through Table 8. This portion of the preamble can be used to synchronize the receiver algorithm within the preamble.

Finally, the channel estimation sequence shall be constructed by successively appending 6 periods, denoted as $\{CE_0, CE_1, \ldots, CE_5\}$, of the OFDM training symbol. This training symbol is generated by passing the frequency-domain sequence, defined in Table 9, though the IFFT, and pre-appending the output with 32 "zero samples" and appending and a guard interval consisting of 5 "zero samples" to the resulting time-domain output. This portion of the preamble can be used to estimate the channel frequency response, for fine carrier frequency estimation, and fine symbol timing.

Figure 9—Streaming-mode PLCP preamble format for a Mode 1 device

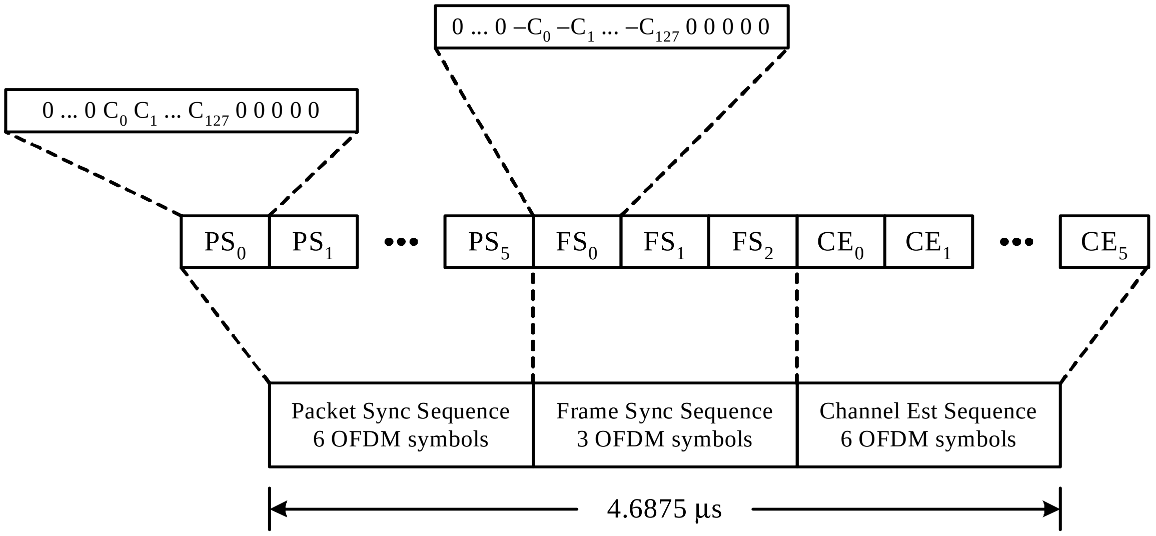


Table 11—Time-domain packet synchronization sequence for Preamble Pattern 1

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_0	0.6564	C_{32}	-0.0844	C_{64}	-0.2095	C_{96}	0.4232
C_1	-1.3671	C_{33}	1.1974	C_{65}	1.1640	C_{97}	-1.2684
C_2	-0.9958	C_{34}	1.2261	C_{66}	1.2334	C_{98}	-1.8151
C_3	-1.3981	C_{35}	1.4401	C_{67}	1.5338	C_{99}	-1.4829
C_4	0.8481	C_{36}	-0.5988	C_{68}	-0.8844	C_{100}	1.0302
C_5	1.0892	C_{37}	-0.4675	C_{69}	-0.3857	C_{101}	0.9419
C_6	-0.8621	C_{38}	0.8520	C_{70}	0.7730	C_{102}	-1.1472
C_7	1.1512	C_{39}	-0.8922	C_{71}	-0.9754	C_{103}	1.4858
C_8	0.9602	C_{40}	-0.5603	C_{72}	-0.2315	C_{104}	-0.6794
C_9	-1.3581	C_{41}	1.1886	C_{73}	0.5579	C_{105}	0.9573
C_{10}	-0.8354	C_{42}	1.1128	C_{74}	0.4035	C_{106}	1.0807
C_{11}	-1.3249	C_{43}	1.0833	C_{75}	0.4248	C_{107}	1.1445
C_{12}	1.0964	C_{44}	-0.9073	C_{76}	-0.3359	C_{108}	-1.2312
C_{13}	1.3334	C_{45}	-1.6227	C_{77}	-0.9914	C_{109}	-0.6643
C_{14}	-0.7378	C_{46}	1.0013	C_{78}	0.5975	C_{110}	0.3836
C_{15}	1.3565	C_{47}	-1.6067	C_{79}	-0.8408	C_{111}	-1.1482
C_{16}	0.9361	C_{48}	0.3360	C_{80}	0.3587	C_{112}	-0.0353
C_{17}	-0.8212	C_{49}	-1.3136	C_{81}	-0.9604	C_{113}	-0.6747
C_{18}	-0.2662	C_{50}	-1.4448	C_{82}	-1.0002	C_{114}	-1.1653
C_{19}	-0.6866	C_{51}	-1.7238	C_{83}	-1.1636	C_{115}	-0.8896
C_{20}	0.8437	C_{52}	1.0287	C_{84}	0.9590	C_{116}	0.2414

Table 11—Time-domain packet synchronization sequence for Preamble Pattern 1

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{21}	1.1237	C_{53}	0.6100	C_{85}	0.7137	C_{117}	0.1160
C_{22}	-0.3265	C_{54}	-0.9237	C_{86}	-0.6776	C_{118}	-0.6987
C_{23}	1.0511	C_{55}	1.2618	C_{87}	0.9824	C_{119}	0.4781
C_{24}	0.7927	C_{56}	0.5974	C_{88}	-0.5454	C_{120}	0.1821
C_{25}	-0.3363	C_{57}	-1.0976	C_{89}	1.1022	C_{121}	-1.0672
C_{26}	-0.1342	C_{58}	-0.9776	C_{90}	1.6485	C_{122}	-0.9676
C_{27}	-0.1546	C_{59}	-0.9982	C_{91}	1.3307	C_{123}	-1.2321
C_{28}	0.6955	C_{60}	0.8967	C_{92}	-1.2852	C_{124}	0.5003
C_{29}	1.0608	C_{61}	1.7640	C_{93}	-1.2659	C_{125}	0.7419
C_{30}	-0.1600	C_{62}	-1.0211	C_{94}	0.9435	C_{126}	-0.8934
C_{31}	0.9442	C_{63}	1.6913	C_{95}	-1.6809	C_{127}	0.8391

Table 12—Time-domain packet synchronization sequence for Preamble Pattern 2

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{0}	0.9679	C_{32}	-1.2905	C_{64}	1.5280	C_{96}	0.5193
C_{1}	-1.0186	C_{33}	1.1040	C_{65}	-0.9193	C_{97}	-0.3439
C_{2}	0.4883	C_{34}	-1.2408	C_{66}	1.1246	C_{98}	0.1428
C_{3}	0.5432	C_{35}	-0.8062	C_{67}	1.2622	C_{99}	0.6251
C_{4}	-1.4702	C_{36}	1.5425	C_{68}	-1.4406	C_{100}	-1.0468
C_{5}	-1.4507	C_{37}	1.0955	C_{69}	-1.4929	C_{101}	-0.5798
C_{6}	-1.1752	C_{38}	1.4284	C_{70}	-1.1508	C_{102}	-0.8237
C_{7}	-0.0730	C_{39}	-0.4593	C_{71}	0.4126	C_{103}	0.2667
C_{8}	-1.2445	C_{40}	-1.0408	C_{72}	-1.0462	C_{104}	-0.9563
C_{9}	0.3143	C_{41}	1.0542	C_{73}	0.7232	C_{105}	0.6016
C_{10}	-1.3951	C_{42}	-0.4446	C_{74}	-1.1574	C_{106}	-0.9964
C_{11}	-0.9694	C_{43}	-0.7929	C_{75}	-0.7102	C_{107}	-0.3541
C_{12}	0.4563	C_{44}	1.6733	C_{76}	0.8502	C_{108}	0.3965
C_{13}	0.3073	C_{45}	1.7568	C_{77}	0.6260	C_{109}	0.5201
C_{14}	0.6408	C_{46}	1.3273	C_{78}	0.9530	C_{110}	0.4733
C_{15}	-0.9798	C_{47}	-0.2465	C_{79}	-0.4971	C_{111}	-0.2362
C_{16}	-1.4116	C_{48}	1.6850	C_{80}	-0.8633	C_{112}	-0.6892

Table 12—Time-domain packet synchronization sequence for Preamble Pattern 2

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{17}	0.6038	C_{49}	-0.7091	C_{81}	0.6910	C_{113}	0.4787
C_{18}	-1.3860	C_{50}	1.1396	C_{82}	-0.3639	C_{114}	-0.2605
C_{19}	-1.0888	C_{51}	1.5114	C_{83}	-0.8874	C_{115}	-0.5887
C_{20}	1.1036	C_{52}	-1.4343	C_{84}	1.5311	C_{116}	0.9411
C_{21}	0.7067	C_{53}	-1.5005	C_{85}	1.1546	C_{117}	0.7364
C_{22}	1.1667	C_{54}	-1.2572	C_{86}	1.1935	C_{118}	0.6714
C_{23}	-1.0225	C_{55}	0.8274	C_{87}	-0.2930	C_{119}	-0.1746
C_{24}	-1.2471	C_{56}	-1.5140	C_{88}	1.3285	C_{120}	1.1776
C_{25}	0.7788	C_{57}	1.1421	C_{89}	-0.7231	C_{121}	-0.8803
C_{26}	-1.2716	C_{58}	-1.0135	C_{90}	1.2832	C_{122}	1.2542
C_{27}	-0.8745	C_{59}	-1.0657	C_{91}	0.7878	C_{123}	0.5111
C_{28}	1.2175	C_{60}	1.4073	C_{92}	-0.8095	C_{124}	-0.8209
C_{29}	0.8419	C_{61}	1.8196	C_{93}	-0.7463	C_{125}	-0.8975
C_{30}	1.2881	C_{62}	1.1679	C_{94}	-0.8973	C_{126}	-0.9091
C_{31}	-0.8210	C_{63}	-0.4131	C_{95}	0.5560	C_{127}	0.2562

Table 13—Time-domain packet synchronization sequence for Preamble Pattern 3

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{0}	0.4047	C_{32}	-0.9671	C_{64}	-0.7298	C_{96}	0.2424
C_{1}	0.5799	C_{33}	-0.9819	C_{65}	-0.9662	C_{97}	0.5703
C_{2}	-0.3407	C_{34}	0.7980	C_{66}	0.9694	C_{98}	-0.6381
C_{3}	0.4343	C_{35}	-0.8158	C_{67}	-0.8053	C_{99}	0.7861
C_{4}	0.0973	C_{36}	-0.9188	C_{68}	-0.9052	C_{100}	0.9175
C_{5}	-0.7637	C_{37}	1.5146	C_{69}	1.5933	C_{101}	-0.4595
C_{6}	-0.6181	C_{38}	0.8138	C_{70}	0.8418	C_{102}	-0.2201
C_{7}	-0.6539	C_{39}	1.3773	C_{71}	1.5363	C_{103}	-0.7755
C_{8}	0.3768	C_{40}	0.2108	C_{72}	0.3085	C_{104}	-0.2965
C_{9}	0.7241	C_{41}	0.9245	C_{73}	1.3016	C_{105}	-1.1220
C_{10}	-1.2095	C_{42}	-1.2138	C_{74}	-1.5546	C_{106}	1.7152
C_{11}	0.6027	C_{43}	1.1252	C_{75}	1.5347	C_{107}	-1.2756
C_{12}	0.4587	C_{44}	0.9663	C_{76}	1.0935	C_{108}	-0.7731

Table 13—Time-domain packet synchronization sequence for Preamble Pattern 3

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{13}	-1.3879	C_{45}	-0.8418	C_{77}	-0.8978	C_{109}	1.0724
C_{14}	-1.0592	C_{46}	-0.6811	C_{78}	-0.9712	C_{110}	1.1733
C_{15}	-1.4052	C_{47}	-1.3003	C_{79}	-1.3763	C_{111}	1.4711
C_{16}	-0.8439	C_{48}	-0.3397	C_{80}	-0.6360	C_{112}	0.4881
C_{17}	-1.5992	C_{49}	-1.1051	C_{81}	-1.2947	C_{113}	0.7528
C_{18}	1.1975	C_{50}	1.2400	C_{82}	1.6436	C_{114}	-0.6417
C_{19}	-1.9525	C_{51}	-1.3975	C_{83}	-1.6564	C_{115}	1.0363
C_{20}	-1.5141	C_{52}	-0.7467	C_{84}	-1.1981	C_{116}	0.8002
C_{21}	0.7219	C_{53}	0.2706	C_{85}	0.8719	C_{117}	-0.0077
C_{22}	0.6982	C_{54}	0.7294	C_{86}	0.9992	C_{118}	-0.2336
C_{23}	1.2924	C_{55}	0.7444	C_{87}	1.4872	C_{119}	-0.4653
C_{24}	-0.9460	C_{56}	-0.3970	C_{88}	-0.4586	C_{120}	0.6862
C_{25}	-1.2407	C_{57}	-1.0718	C_{89}	-0.8404	C_{121}	1.2716
C_{26}	0.4572	C_{58}	0.6646	C_{90}	0.6982	C_{122}	-0.8880
C_{27}	-1.2151	C_{59}	-1.1037	C_{91}	-0.7959	C_{123}	1.4011
C_{28}	-0.9869	C_{60}	-0.5716	C_{92}	-0.5692	C_{124}	0.9531
C_{29}	1.2792	C_{61}	0.9001	C_{93}	1.3528	C_{125}	-1.1210
C_{30}	0.6882	C_{62}	0.7317	C_{94}	0.9536	C_{126}	-0.9489
C_{31}	1.2586	C_{63}	0.9846	C_{95}	1.1784	C_{127}	-1.2566

12.3.4 PLCP header

The OFDM training symbols shall be followed by the PHY header, which contains the BAND EXTENSION field, the RATE of the MAC frame body, the length of the frame payload (which does not include the FCS), and the seed identifier for the data scrambler. The BAND EXTENSION field specifies the mode of transmission for the frame payload. The RATE field conveys the information about the type of modulation, the coding rate, and the spreading factor used to transmit the MAC frame body.

The PLCP header field shall be composed of 28 bits, as illustrated in Figure 5. Bit 0 shall be reserved for future use. The next three bits 1 to 3 shall encode the BAND EXTENSION field. Bit 4 shall be reserved for future use. Bits 5-8 shall encode the RATE. Bit 9 shall be reserved for future use. Bits 10-21 shall encode the LENGTH field, with the least significant bit (LSB) being transmitted first. Bit 22 shall be reserved for future

Table 14—Time-domain packet synchronization sequence for Preamble Pattern 4

Sequence Element	Value	Sequence Element	Value	Sequence Element	Value	Sequence Element	Value
C_{0}	1.1549	C_{32}	-1.2385	C_{64}	1.3095	C_{96}	-1.0094
C_{1}	1.0079	C_{33}	-0.7883	C_{65}	0.6675	C_{97}	-0.7598
C_{2}	0.7356	C_{34}	-0.7954	C_{66}	1.2587	C_{98}	-1.0786
C_{3}	-0.7434	C_{35}	1.0874	C_{67}	-0.9993	C_{99}	0.6699
C_{4}	-1.3930	C_{36}	1.1491	C_{68}	-1.0052	C_{100}	0.9813
C_{5}	1.2818	C_{37}	-1.4780	C_{69}	0.6601	C_{101}	-0.5563
C_{6}	-1.1033	C_{38}	0.8870	C_{70}	-1.0228	C_{102}	1.0548
C_{7}	-0.2523	C_{39}	0.4694	C_{71}	-0.7489	C_{103}	0.8925
C_{8}	-0.7905	C_{40}	1.5066	C_{72}	0.5086	C_{104}	-1.3656
C_{9}	-0.4261	C_{41}	1.1266	C_{73}	0.1563	C_{105}	-0.8472
C_{10}	-0.9390	C_{42}	0.9935	C_{74}	0.0673	C_{106}	-1.3110
C_{11}	0.4345	C_{43}	-1.2462	C_{75}	-0.8375	C_{107}	1.1897
C_{12}	0.4433	C_{44}	-1.7869	C_{76}	-1.0746	C_{108}	1.5127
C_{13}	-0.3076	C_{45}	1.7462	C_{77}	0.4454	C_{109}	-0.7474
C_{14}	0.5644	C_{46}	-1.4881	C_{78}	-0.7831	C_{110}	1.4678
C_{15}	0.2571	C_{47}	-0.4090	C_{79}	-0.3623	C_{111}	1.0295
C_{16}	-1.0030	C_{48}	-1.4694	C_{80}	-1.3658	C_{112}	-0.9210
C_{17}	-0.7820	C_{49}	-0.7923	C_{81}	-1.0854	C_{113}	-0.4784
C_{18}	-0.4064	C_{50}	-1.4607	C_{82}	-1.4923	C_{114}	-0.5022
C_{19}	0.9034	C_{51}	0.9113	C_{83}	0.4233	C_{115}	1.2153
C_{20}	1.5406	C_{52}	0.8454	C_{84}	0.6741	C_{116}	1.5783
C_{21}	-1.4613	C_{53}	-0.8866	C_{85}	-1.0157	C_{117}	-0.7718
C_{22}	1.2745	C_{54}	0.8852	C_{86}	0.8304	C_{118}	1.2384
C_{23}	0.3715	C_{55}	0.4918	C_{87}	0.4878	C_{119}	0.6695
C_{24}	1.8134	C_{56}	-0.6096	C_{88}	-1.4992	C_{120}	0.8821
C_{25}	0.9438	C_{57}	-0.4321	C_{89}	-1.1884	C_{121}	0.7807
C_{26}	1.3130	C_{58}	-0.1327	C_{90}	-1.4008	C_{122}	1.0537
C_{27}	-1.3070	C_{59}	0.4953	C_{91}	0.7795	C_{123}	-0.0791
C_{28}	-1.3462	C_{60}	0.9702	C_{92}	1.2926	C_{124}	-0.2845
C_{29}	1.6868	C_{61}	-0.8667	C_{93}	-1.2049	C_{125}	0.5790
C_{30}	-1.2153	C_{62}	0.6803	C_{94}	1.2934	C_{126}	-0.4664
C_{31}	-0.6778	C_{63}	-0.0244	C_{95}	0.8123	C_{127}	-0.1097

Table 15—Frequency-domain OFDM training sequence

Tone Number	Value	Tone Number	(1-j)/sqrt(2)	Tone Number	Value	Tone Number	Value
-56	(1-j)/sqrt(2)	-28	(1-j)/sqrt(2)	1	(1+j)/sqrt(2)	29	(1+j)/sqrt(2)
-55	(-1+j)/sqrt(2)	-27	(1-j)/sqrt(2)	2	(-1-j)/sqrt(2)	30	(-1-j)/sqrt(2)
-54	(-1+j)/sqrt(2)	-26	(-1+j)/sqrt(2)	3	(1+j)/sqrt(2)	31	(-1-j)/sqrt(2)
-53	(1-j)/sqrt(2)	-25	(-1+j)/sqrt(2)	4	(-1-j)/sqrt(2)	32	(1+j)/sqrt(2)
-52	(1-j)/sqrt(2)	-24	(-1+j)/sqrt(2)	5	(-1-j)/sqrt(2)	33	(-1-j)/sqrt(2)
-51	(1-j)/sqrt(2)	-23	(1-j)/sqrt(2)	6	(-1-j)/sqrt(2)	34	(-1-j)/sqrt(2)
-50	(-1+j)/sqrt(2)	-22	(-1+j)/sqrt(2)	7	(-1-j)/sqrt(2)	35	(-1-j)/sqrt(2)
-49	(1-j)/sqrt(2)	-21	(-1+j)/sqrt(2)	8	(-1-j)/sqrt(2)	36	(-1-j)/sqrt(2)
-48	(-1+j)/sqrt(2)	-20	(1-j)/sqrt(2)	9	(1+j)/sqrt(2)	37	(1+j)/sqrt(2)
-47	(-1+j)/sqrt(2)	-19	(-1+j)/sqrt(2)	10	(1+j)/sqrt(2)	38	(1+j)/sqrt(2)
-46	(-1+j)/sqrt(2)	-18	(-1+j)/sqrt(2)	11	(1+j)/sqrt(2)	39	(-1-j)/sqrt(2)
-45	(1-j)/sqrt(2)	-17	(-1+j)/sqrt(2)	12	(-1-j)/sqrt(2)	40	(-1-j)/sqrt(2)
-44	(-1+j)/sqrt(2)	-16	(-1+j)/sqrt(2)	13	(1+j)/sqrt(2)	41	(-1-j)/sqrt(2)
-43	(-1+j)/sqrt(2)	-15	(1-j)/sqrt(2)	14	(-1-j)/sqrt(2)	42	(-1-j)/sqrt(2)
-42	(-1+j)/sqrt(2)	-14	(-1+j)/sqrt(2)	15	(1+j)/sqrt(2)	43	(-1-j)/sqrt(2)
-41	(-1+j)/sqrt(2)	-13	(1-j)/sqrt(2)	16	(-1-j)/sqrt(2)	44	(-1-j)/sqrt(2)
-40	(-1+j)/sqrt(2)	-12	(-1+j)/sqrt(2)	17	(-1-j)/sqrt(2)	45	(1+j)/sqrt(2)
-39	(-1+j)/sqrt(2)	-11	(1-j)/sqrt(2)	18	(-1-j)/sqrt(2)	46	(-1-j)/sqrt(2)
-38	(1-j)/sqrt(2)	-10	(1-j)/sqrt(2)	19	-(1-j)/sqrt(2)	47	(-1-j)/sqrt(2)
-37	(-1+j)/sqrt(2)	-9	(1-j)/sqrt(2)	20	(1+j)/sqrt(2)	48	(-1-j)/sqrt(2)
-36	(1-j)/sqrt(2)	-8	(-1+j)/sqrt(2)	21	(-1-j)/sqrt(2)	49	(1+j)/sqrt(2)
-35	(-1+j)/sqrt(2)	-7	(-1+j)/sqrt(2)	22	(-1-j)/sqrt(2)	50	(-1-j)/sqrt(2)
-34	(-1+j)/sqrt(2)	-6	(-1+j)/sqrt(2)	23	(1+j)/sqrt(2)	51	(1+j)/sqrt(2)
-33	(-1+j)/sqrt(2)	-5	(-1+j)/sqrt(2)	24	(-1-j)/sqrt(2)	52	(1+j)/sqrt(2)
-32	(1-j)/sqrt(2)	-4	(-1+j)/sqrt(2)	25	(-1-j)/sqrt(2)	53	(1+j)/sqrt(2)
-31	(-1+j)/sqrt(2)	-3	(1-j)/sqrt(2)	26	(-1-j)/sqrt(2)	54	(-1-j)/sqrt(2)
-30	(-1+j)/sqrt(2)	-2	(-1+j)/sqrt(2)	27	(1+j)/sqrt(2)	55	(-1-j)/sqrt(2)
-29	(1-j)/sqrt(2)	-1	(1-j)/sqrt(2)	28	(1+j)/sqrt(2)	56	(1+j)/sqrt(2)

use. Bits 23-24 shall encode the initial state of the scrambler, which is used to synchronize the descrambler of the receiver. Bits 25-27 shall be reserved for future use.

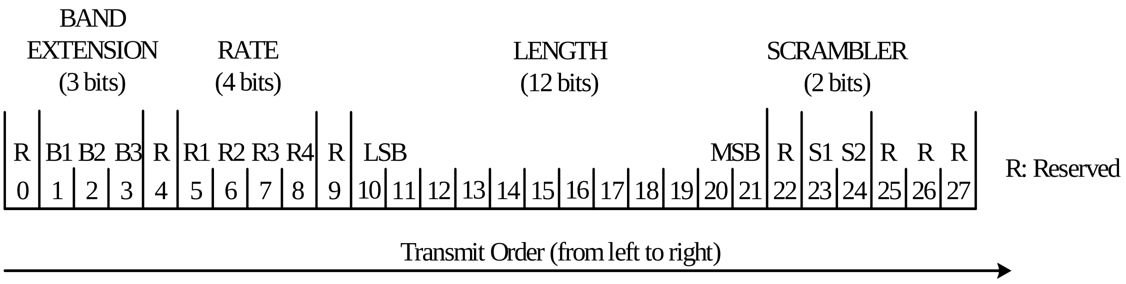


Figure 10—PLCP Header Bit Assignment

12.3.4.1 Band Extension Field (Band Extension)

Depending on the mode of transmission for the frame payload, the bits B1-B3 shall be set according to the values in Table 10.

Table 16—Band Extension Parameters

Mode	B1 - B3
1	001
2	010
Reserved	000,011 - 111

12.3.4.2 Data rate (RATE)

Depending on the information data rate (RATE), the bits R1-R4 shall be set according to the values in Table 11.

12.3.4.3 PLCP length field (LENGTH)

The PLCP Length field shall be an unsigned 12-bit integer that indicates the number of octets in the frame payload (which does not include the FCS, the tail bits, or the pad bits).

12.3.4.4 PLCP scramble field (SCRAMBLER)

The bits S1-S2 shall be set according to the scrambler seed identifier value. This two-bit value corresponds to the seed value chosen for the data scrambler.

12.3.5 Header modulation

The PLCP header, MAC header, HCS, and tail bits shall be modulated using an information data rate of 55 Mb/s.

Table 17—Rate dependent parameters

Rate (Mb/s)	R1 - R4
55	0000
80	0001
110	0010
160	0011
200	0100
320	0101
480	0110
Reserved	0111 - 1111

12.3.6 Optional band extension

If the frame payload is transmitted using Mode 2, then an optional band extension field will follow the PLCP header. The optional band extension field will not be used when the frame payload is transmitted using Mode 1.

The structure of the optional band extension for Mode 2 is shown in Figure 6. This field consists of scrambled pad bits spanning four OFDM symbols followed by 8 repetitions of the channel estimation sequence. The channel estimation sequence shall be constructed by passing the frequency-domain sequence, defined in Table 9, though the IFFT, and pre-appending the output with 32 "zero samples" and appending a guard interval consisting of 5 "zero samples" to the resulting time-domain output. This portion of the preamble can be used to estimate the channel frequency response for the upper four bands, for fine carrier frequency estimation, and fine symbol timing.

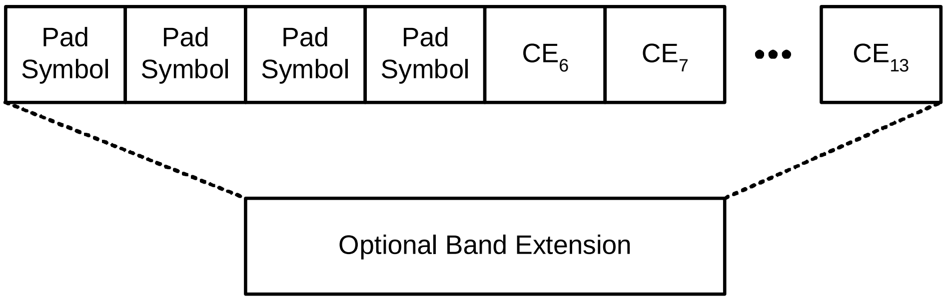


Figure 11—Format for the optional band extension

12.3.7 Data scramble

A side-stream scrambler shall be used for the MAC header, HCS, and MAC frame body. The PLCP preamble, PLCP header, and tail bits shall not be scrambled. The polynomial generator, $g(D)$, for the pseudo random binary sequence (PRBS) generator shall be $g(D) = 1 + D^{14} + D^{15}$, where D is a single bit delay element. The polynomial not only forms a maximal length sequence, but is also a primitive polynomial. Using this generator polynomial, the corresponding PRBS, x_n, is generated as

$$x_n = x_{n-14} \oplus x_{n-15}$$

where " $\oplus$ " denotes modulo-2 addition. The following sequence defines the initialization sequence, x_{init}, which is specified by the parameter "seed value" in Table 12.

$$x_{init} = [x^i_{n-1} \quad x^i_{n-2} \quad \cdots \quad x^i_{n-14} \quad x^i_{n-15}]$$

where x^i_{n-k} represents the binary initial value at the output of the kth delay element.

The scrambled data bits, s_n, are obtained as follows:

$$s_n = b_n \oplus x_n$$

where b_n represents the unscrambled data bits. The side-stream de-scrambler at the receiver shall be initialized with the same initialization vector, x_{init}, used in the transmitter scrambler. The initialization vector is determined from the seed identifier contained in the PLCP header of the received frame.

The 15-bit seed value shall correspond to the seed identifier as shown in Table 12. The seed identifier value is set to 00 when the PHY is initialized and is incremented in a 2-bit rollover counter for each frame that is sent by the PHY. The value of the seed identifier that is used for the frame is sent in the PLCP header.

Table 18—Scrambler Seed Selection

Seed Identifier (b_1,b_0)	**Seed Value** $(x_{14}, ..., x_0)$
0,0	0011 1111 1111 111
0,1	0111 1111 1111 111
1,0	1011 1111 1111 111
1,1	1111 1111 1111 1111

12.3.8 Tail Bits

The tail bit field shall be six bits of "0", which are required to return the convolutional encoder to the "zero state". This procedure improves the error probability of the convolutional decoder, which relies on the future bits when decoding the message stream. All tail bit fields (after the PHY header, after the HCS, and after the MAC frame payload) shall be produced by replacing the six scrambled bits with six "zero" bits.

12.3.9 Convolutional Encoder

The PLCP header, MAC header, and HCS shall be coded with a convolutional encoder of rate R = 11/32. The MAC frame body and tail bits shall be coded with a convolutional encoder of rate R = 11/32, 1/2, 5/8, or 3/4, corresponding to the desired data rate. The convolutional encoder shall use the rate R = 1/3 industry-standard generator polynomials, $g_0 = 133_8$, $g_1 = 145_8$, and $g_2 = 175_8$, as shown in Figure 7. The bit denoted as "A" shall be the first bit generated by the encoder, followed by the bit denoted as "B", and finally, by the bit denoted as "C". The various coding rates are derived from the rate R = 1/3 convolutional code by employing "puncturing". Puncturing is a procedure for omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy "zero" metric into the convolutional decoder on the receive side in place of the omitted bits. The puncturing patterns are illustrated in Figure 8 through Figure 11.

Decoding by the Viterbi algorithm is recommended.

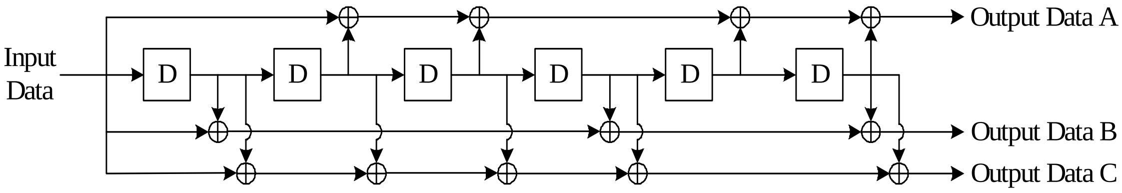


Figure 12—Convolutional Encoder: Rate R=1/3, Constraint Length k=7

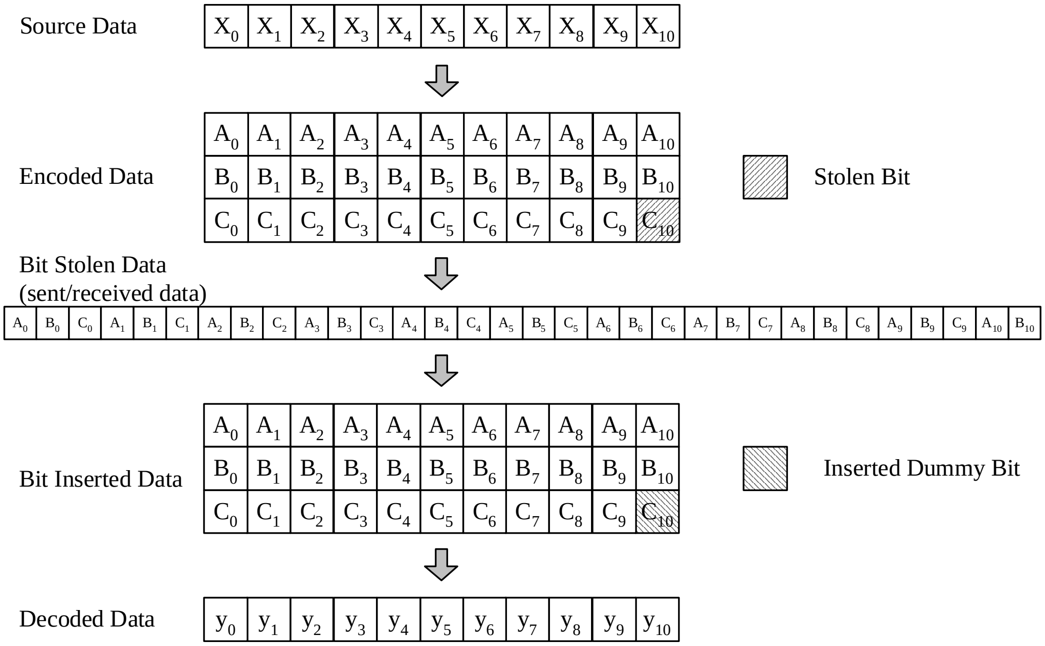


Figure 13—An example of the bit stealing and bit insertion procedure (R=11/32)

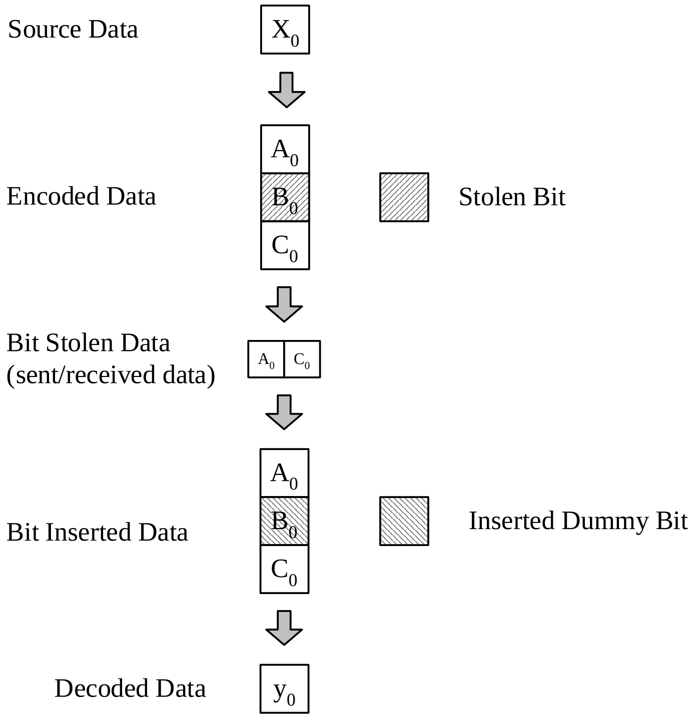


Figure 14—An example of the bit stealing and bit insertion procedure (R=1/2)

Figure 15—An example of the bit stealing and bit insertion procedure (R=5/8)

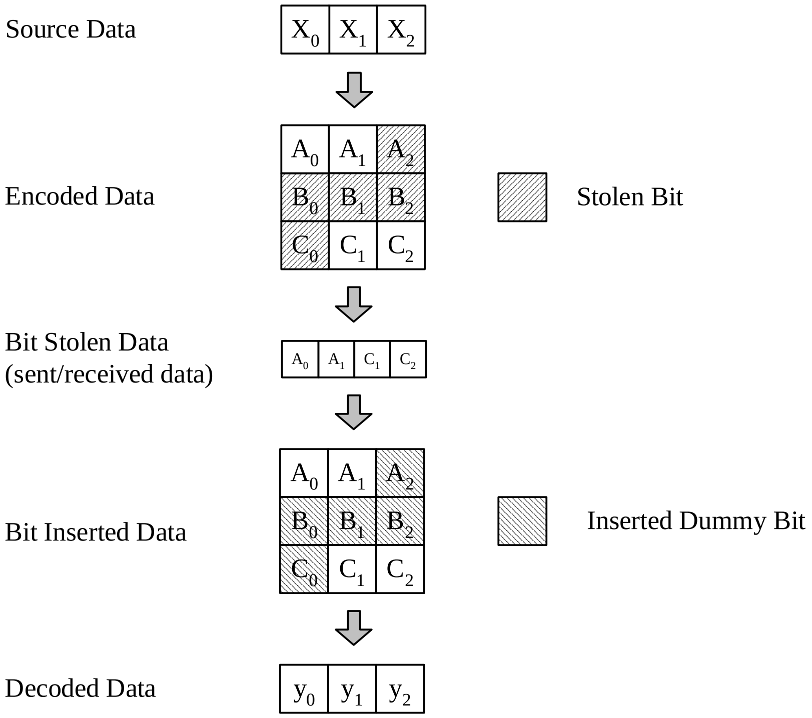


Figure 16—An example of the bit stealing and bit insertion procedure (R=3/4)

12.3.10 Pad bits

The number of pad bits that are inserted is a function of the code rate R and the number of bits in the frame payload (LENGTH), FCS, and tail bits. Pad bits shall be inserted in order to ensure that there is alignment on the OFDM symbol boundaries. The number of OFDM symbols, N_{SYM}, is computed as follows:

$$N_{SYM} = \text{Ceiling}\,[\text{Ceiling}\,[1/R \times (8 \times (\text{LENGTH} + \text{FCS}) + 6)] / N_{CBPS}]$$

The function Ceiling (**.**) is a function that returns the smallest integer value greater than or equal to its argument value. The appended bits ("pad bits") are set to "zeros" and are subsequently scrambled with the rest of the bits.

12.3.11 Bit interleaving

The coded bit stream is interleaved prior to modulation. Bit interleaving provides robustness against burst errors. The bit interleaving operation is performed in two stages: symbol interleaving followed by tone interleaving. The symbol interleaver permutes the bits across OFDM symbols to exploit frequency diversity across the sub-bands, while the tone interleaver permutes the bits across the data tones within an OFDM symbol to exploit frequency diversity across tones and provide robustness against narrow-band interferers. We constrain our symbol interleaver to interleave among $3N_{CBPS}$ coded bits for Mode 1 devices and $7N_{CBPS}$ coded bits for Mode 2 devices, where N_{CBPS} is the number of coded bits per OFDM symbol.

The bit interleaving operation is described here for devices operating in Mode 1. First, the coded bits are grouped together into blocks of $3N_{CBPS}$ coded bits, which corresponds to three OFDM symbols. Each group of coded bits is then permuted using a regular symbol block interleaver of size N_{CBPS} x 3. Let the sequences *{U(i)}* and *{S(j)}*, where *i, j* = 0,…, $3N_{CBPS}$ -1, represent the input and output bits of the symbol block interleaver, respectively. The input-output relationship of this interleaver is given by:

$$S(j) = U\left\{ \text{Floor}\left(\frac{i}{N_{CBPS}} \right) + 3\text{Mod}\left(i, N_{CBPS}\right) \right\}$$

where the function Floor(**.**) returns the largest integer value less than or equal to its argument value and where the function Mod(**.**) returns the remainder after division of N_{CBPS} by *i*. If the coded bits available at the input of the symbol block interleaver correspond to less than $3N_{CBPS}$ coded bits, the output of the encoder is padded out to $3N_{CBPS}$ bits. Note that the pad bits are inserted at the input of the scrambler to ensure that the pad bits do not introduce any structure.

The output of the symbol block interleaver is then passed through a tone block interleaver. The outputs of the symbol block interleaver after grouped together into blocks of N_{CBPS} bits and then permuted using a regular block interleaver of size N_{Tint} x 10, where $N_{Tint} = N_{CBPS}/10$. Let the sequences *{S(i)}* and *{V(j)}*, where *i, j* = 0,…, N_{CBPS} -1, represent the input and output bits of the tone interleaver, respectively. The input-output relationship of the tone block interleaver is given by:

$$T(j) = S\left\{ \text{Floor}\left(\frac{i}{N_{T\text{int}}} \right) + 10\text{Mod}\left(i, N_{Tint}\right) \right\}$$

where the function Mod(**.**) returns the remainder after division of N_{Tint} by *i*.

12.3.12 Subcarrier Constellation Mapping

The OFDM subcarriers shall be modulated using QPSK modulation. The encoded and interleaved binary serial input data shall be divided into groups of 2 bits and converted into complex numbers representing QPSK constellation points. The conversion shall be performed according to the Gray-coded constellation mappings, illustrated in Figure 12, with the input bit, b_0, being the earliest in the stream. The output values, *d*, are formed by multiplying the resulting (I + jQ) value by a normalization factor of K_{MOD}, as described in the following equation:

$$d = (I + jQ) \times K_{MOD}.$$

The normalization factor, K_{MOD}, depends on the base modulation mode, as prescribed in Table 13. In practical implementations, an approximate value of the normalization factor can be used, as long as the device conforms to the modulation accuracy requirements.

For QPSK, b_0 determines the I value and b_1 determines the Q value, as illustrated in Table 14.

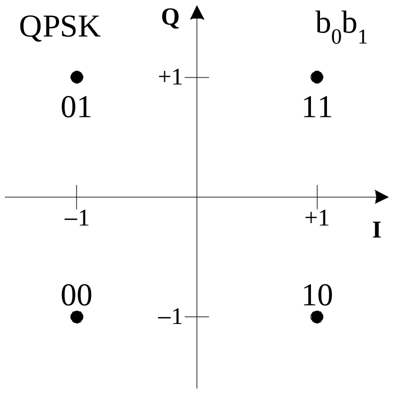


Figure 17—QPSK Constellation Bit Encoding

Table 19—Modulation Dependent Normalization Factor K_{MOD}

Modulation	**K_{MOD}**
QPSK	$\frac{1}{\sqrt{2}}$

Table 20—QPSK Encoding Table

Input Bit (bo b1)	**I out**	**Q out**
00	-1	-1
01	-1	1
10	1	-1
11	1	1

12.3.13 OFDM Modulation

For information data rates of 50, and 80 Mb/s, the stream of complex numbers is divided into groups of 50 complex numbers. We shall denote these complex numbers $c_{n,k}$, which corresponds to subcarrier n of OFDM symbol k, as follows:

$$\begin{aligned} c_{n,k} &= d_{n+50\times k} & \qquad n = 0,1,\ldots,49, k = 0,1,\ldots,\mathrm{N_{SYM}}-1 \\ c_{(n+50),k} &= d^{*}_{(49-n)+50\times k} & \end{aligned}$$

where $\mathrm{N_{SYM}}$ denotes the number of OFDM symbols in the MAC frame body, tail bits, and pad bits.

For information data rates of 110, 160, 200, 320 and 480 Mb/s, the stream of complex numbers is divided into groups of 100 complex numbers. We shall denote these complex numbers $c_{n,k}$, which corresponds to subcarrier n of OFDM symbol k, as follows:

$$c_{n,k} = d_{n+100\times k} \qquad n = 0,1,\ldots,99, k = 0,1,\ldots,\mathrm{N_{SYM}}-1$$

where NSYM denotes the number of OFDM symbols in the MAC frame body, tail bits, and pad bits.

An OFDM symbol $r_{data,k}$(t) is defined as

$$r_{data,k}(t) = \sum_{n=0}^{N_{SD}} c_{n,k} \exp(j2\pi M(n)\Delta_F(t-T_{CP})) + p_{\mathrm{mod}(k,127)} \sum_{n=-N_{ST}/2}^{N_{ST}/2} P_n \exp(j2\pi n\Delta_F(t-T_{CP}))$$

where N_{SD} is the number of data subcarriers, N_{ST} is the number of total subcarriers, and the function *M(n)* defines a mapping from the indices 0 to 99 to the logical frequency offset indices -56 to 56, excluding the locations reserved for the pilot subcarriers, guard subcarriers and the DC subcarrier (as described below):

$$M(n) = \begin{cases} n-56 & n=0 \\ n-55 & 1 \le n \le 9 \\ n-54 & 10 \le n \le 18 \\ n-53 & 19 \le n \le 27 \\ n-52 & 28 \le n \le 36 \\ n-51 & 37 \le n \le 45 \\ n-50 & 46 \le n \le 49 \\ n-49 & 50 \le n \le 53 \\ n-48 & 54 \le n \le 62 \\ n-47 & 63 \le n \le 71 \\ n-46 & 72 \le n \le 80 \\ n-45 & 81 \le n \le 89 \\ n-44 & 90 \le n \le 98 \\ n-43 & n=99 \end{cases}$$

The subcarrier frequency allocation is shown in Figure 13.. To avoid difficulties in DAC and ADC offsets and carrier feed-through in the RF system, the subcarrier falling at DC (0th subcarrier) is not used.

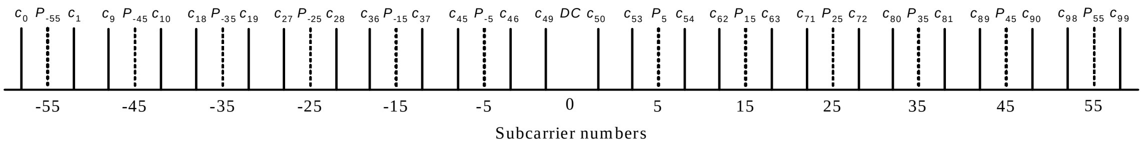


Figure 18—Subcarrier Frequency Allocation

12.3.13.1 Pilot Subcarriers

In each OFDM symbol, twelve of the subcarriers are dedicated to pilot signals in order to make coherent detection robust against frequency offsets and phase noise. These pilot signals shall be put in subcarriers -55, -45, -35, -25, -15 -5, 5, 15, 25, 35, 45, and 55. The pilot signals shall be BPSK modulated by a pseudo-random binary sequence, generated using a linear feedback shift register (LFSR), to prevent the generation of spectral lines. The contribution due to the pilot subcarriers for the k^{th} OFDM symbol is given by the inverse Fourier Transform of the sequence P_n:

$$P_n = \begin{cases} \dfrac{1+j}{\sqrt{2}} & n = 15,45 \\ \dfrac{-1+j}{\sqrt{2}} & n = -5,-25,-35,-45 \\ \dfrac{-1-j}{\sqrt{2}} & n = 5,25,35,55 \\ \dfrac{1-j}{\sqrt{2}} & n = -15,-45 \\ 0 & n = \pm 1,\ldots,\pm 4,\pm 6,\ldots,\pm 14,\pm 16,\ldots,\pm 24,\pm 36,\ldots,\pm 44,\pm 46,\ldots,\pm 54,\pm 56 \end{cases}$$

The polarity of the pilot subcarriers is controlled by the following pseudo-random LFSR sequence, p_l:

$p_{0\ldots126}$ = {1, 1, 1, 1, -1, -1, -1, 1, -1, -1, -1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, 1, 1, -1, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, 1, -1, 1, -1, -1, 1, -1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1, -1, -1, -1, 1, -1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, -1, 1, 1, -1, 1, -1, 1, 1, 1, -1, -1, 1, -1, -1, -1, 1, 1, 1, -1, -1, -1, -1, -1, -1, -1}.

Only one element of this sequence is used for an OFDM symbol.

12.3.13.2 Guard Subcarriers

In each OFDM symbol ten subcarriers are dedicated to guard subcarriers or guard tones. The guard subcarriers can be used for various purposes, including relaxing the specs on transmit and receive filters. The magnitude level of the guard tones is not specified other than the definition below, and implementations can use reduced power for these subcarriers if desired. The guard subcarriers shall be located in subcarriers -61, -60, …, -57, and 57, 58, …, 61. The same linear-feedback shift register (LFSR) sequence , p_l , that is used to scramble the pilot subcarriers is used to generate the modulating data for the guard subcarriers. The guard subcarrier symbol definition for the n^{th} subcarrier of the k^{th} symbol is given as follows:

$$\begin{aligned} P_{n,k} &= p_{\mathrm{mod}(k+l,127)}\left(\frac{1+j}{\sqrt{2}}\right), \quad l = 0,1,2,3,4; \;\; n = -61+l \\ P_{n,k} &= P^{*}_{-n,k}, \qquad\qquad\qquad\qquad\qquad n = 57,\ldots,61 \end{aligned}$$

In this numbering, it is assumed that $k=0$ corresponds to the first channel estimation symbol CE_0. The elements from the sequence, p_l, are selected independently for the pilots and the guard subcarriers in this section.

12.3.14 Time Domain Spreading

For data rates of 55, 80, 110, 160 and 200 Mbps a time-domain spreading operation is performed with a spreading factor of 2. The time-domain spreading operation consists of transmitting the same information over two OFDM symbols. These two OFDM symbols are transmitted over different sub-bands to obtain frequency diversity. For example, if the device uses a time-frequency code [1 2 3 1 2 3], as specified in Table 16, the information in the first OFDM symbol is repeated on sub-bands 1 and 2, the information in the second OFDM symbol is repeated on sub-bands 3 and 1, and the information in the third OFDM symbol is repeated on sub-bands 2 and 3.

12.4 General Requirements

12.4.1 Operating Band Frequencies

12.4.1.1 Operating Frequency Range

This PHY operates in the 3.1 - 10.6 GHz frequency as regulated in the United States by the Code of Federal Regulations, Title 47, Section 15, as well as in any other areas that the regulatory bodies have also allocated this band.

12.4.1.2 Band Numbering

The relationship between center frequency and band number is given by the following equation:

$$\text{Band Center Frequency} = \begin{cases} 2904 + 528 \times n_b & n_b = 1\ldots4 \\ 3168 + 528 \times n_b & n_b = 5\ldots13 \end{cases}$$

This definition provides a unique numbering system for all channels that have a spacing of 528 MHz and lie within the band 3.1 - 10.6 GHz. In this proposal, bands 1 through 3 are used for Mode 1 devices (mandatory mode), while bands 1 through 3 and 6 through 9 are used for Mode 2 devices (optional mode). The remaining channels are reserved for future use. Table 15 summarizes the band allocation.

Table 21—OFDM PHY Band Allocation

BAND_ID	Lower Frequency	Center Frequency	Upper Frequency
1	3168 MHz	3432 MHz	3696 MHz
2	3696 MHz	3960 MHz	4224 MHz
3	4224 MHz	4488 MHz	4752 MHz

Table 21—OFDM PHY Band Allocation

BAND_ID	Lower Frequency	Center Frequency	Upper Frequency
4	4752 MHz	5016 MHz	5280 MHz
5	5544 MHz	5808 MHz	6072 MHz
6	6072 MHz	6336 MHz	6600 MHz
7	6600 MHz	6864 MHz	7128 MHz
8	7128 MHz	7392 MHz	7656 MHz
9	7656 MHz	7920 MHz	8184 MHz
10	8184 MHz	8448 MHz	8712 MHz
11	8712 MHz	8976 MHz	9240 MHz
12	9240 MHz	9504 MHz	9768 MHz
13	9768 MHz	10032 MHz	10296 MHz

The frequency of operation for Mode 1 and Mode 2 devices is shown in Figure 14 and Figure 15, respectively.

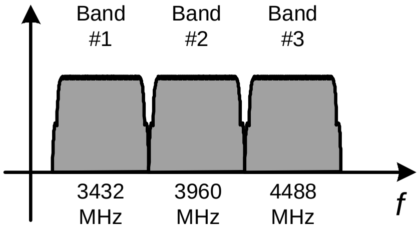


Figure 19—Frequency of Operation for a Mode 1 Device

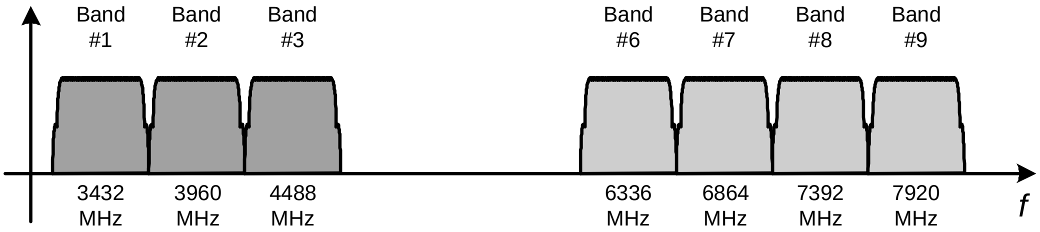


Figure 20—Frequency of Operation for a Mode 2 Device

12.4.2 Channelization

Channelization for different piconets is achieved by using different time-frequency codes for different piconets. In addition, different preamble patterns are used for the different piconets. Table 16 defines the time-frequency codes and preamble pattern for each piconet.

Table 22—Time Frequency Codes and Preamble Patterns for Different Piconets

Channel Number	Preamble Pattern	Mode 1: Length 6 Time Frequency Code						Mode 2: Length 7 Time Frequency Code						
1	1	1	2	3	1	2	3	1	2	3	4	5	6	7
2	2	1	3	2	1	3	2	1	7	6	5	4	3	2
3	3	1	1	2	2	3	3	1	4	7	3	6	2	5
4	4	1	1	3	3	2	2	1	3	5	7	2	4	6

12.4.3 PHY Layer Timing

The values for the PHY layer timing parameters are defined in Table 17.

Table 23—PHY Layer Timing Parameters

PHY Parameter	Value
pMIFSTime	2 uS
pSIFSTime	10 uS
pCCADetectTime	4.6875 uS
pChannelSwitchTime	9.0 ns

12.4.3.1 Interframe Spacing

A conformant implementation shall support the interframe spacing parameters given in Table 18.

12.4.3.2 Receive-to-Transmit Turnaround Time

The RX-to-TX turnaround time shall be pSIFSTime. This turnaround time shall be measured at the air interface from the trailing edge of the last received OFDM symbol to the leading edge of the first transmitted OFDM symbol of the PLCP preamble for the next frame.

Table 24—Interframe Spacing Parameters

802.15.3 MAC Parameter	Corresponding PHY Parameter
MIFS	pMIFSTime
SIFS	pSIFSTime
pBackoffSlot	pSIFSTime + pCCADetectTime
BIFS	pSIFSTime + pCCADetectTime
RIFS	2*pSIFSTime + pCCADetectTime

12.4.3.3 Transmit-to-Receive Turnaround Time

The TX-to-RX turnaround time shall be pSIFSTime. This 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 frame.

12.4.3.4 Time Between Successive Transmissions

The time between uninterrupted successive transmissions by the same DEV shall be pMIFSTime. This time shall be measured at the air interface from the trailing edge of the last OFDM symbol transmitted to the leading edge of the first OFDM symbol of the PLCP preamble for the following frame.

12.4.3.5 Channel Switch Time

The channel switch time is defined as the interval from when the trailing edge of the last valid OFDM symbol is on air until the PHY is ready to transmit or receive from the air another OFDM symbol on a new channel. The channel switch time shall not exceed pChannelSwitchTime.

12.4.4 Header Check Sequence

The combined PLCP and MAC headers shall be protected with a CCITT CRC-16 header check sequence (HCS). The PHY parameter, pLengthHCS shall be 2 for this PHY. The CCITT CRC-16 HCS shall be the ones complement of the remainder generated by the modulo-2 division of the protected combined PLCP and MAC headers by the polynomial: $x^{16} + x^{12} + x^5 + 1$. The protected bits shall be processed in the transmit order. All HCS calculations shall be made prior to data scrambling. A schematic of the processing order is shown in Figure 16.

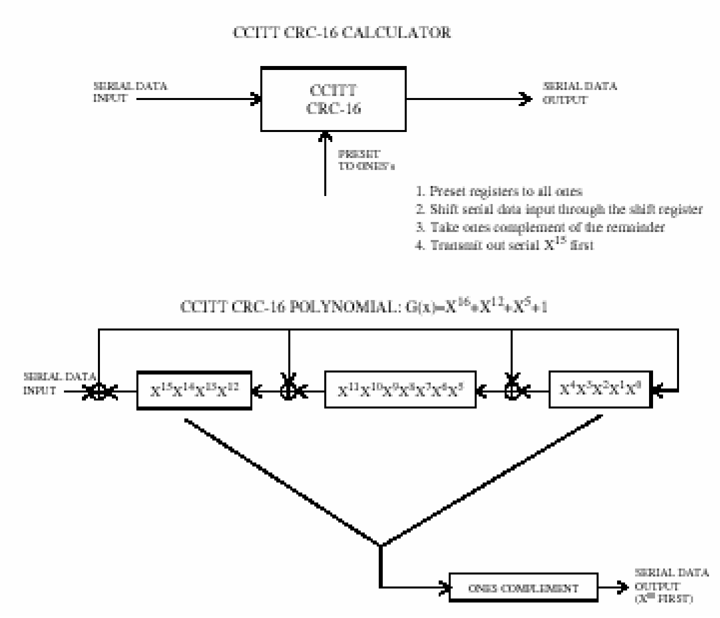


Figure 21—CCITT CRC-16 Implementation

The CRC-16 described in this subclause is the same one used in the IEEE 802.15.3 draft standard.

12.5 Transmitter Specifications

12.5.1 Transmit PSD Mask

The transmitted spectrum shall have a 0 dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 260 MHz, -12 dBr at 285 MHz frequency offset, and -20 dBr at 330 MHz frequency offset and above. The transmitted spectral density of the transmitted signal mask shall fall within the spectral, as shown in Figure 17.

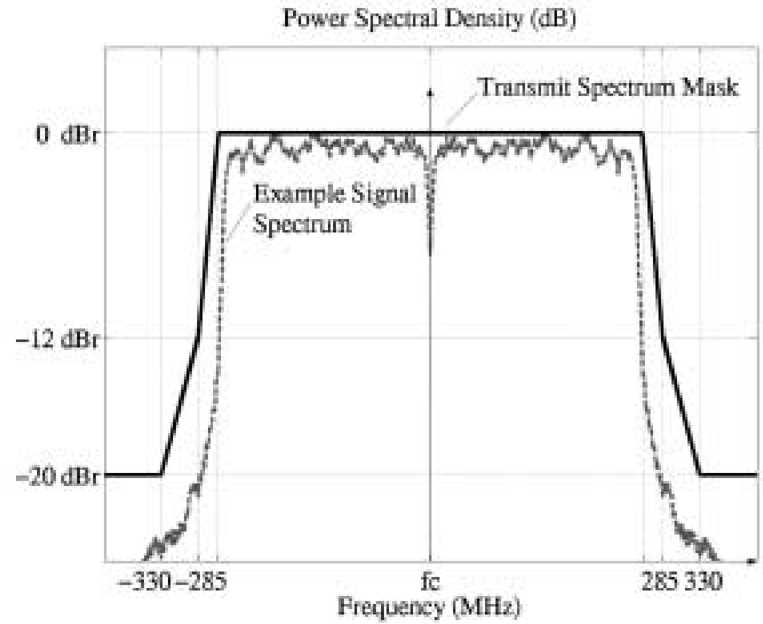


Figure 22—Transmit Power Spectral Density Mask

12.5.2 Transmit Center Frequency Tolerance

The transmitted center frequency tolerance shall be +/- 20 ppm maximum.

12.5.3 Symbol Clock Frequency Tolerance

The symbol clock frequency tolerance shall be 20 ppm maximum.

12.5.4 Clock Synchronization

The transmit center frequency and the symbol clock frequency shall be derived from the same reference oscillator.

12.6 Receiver Specification

12.6.1 Receiver Sensitivity

For a packet error rate (PER) of less than 8% with a PSDU of 1024 bytes, the minimum receiver sensitivity numbers for the various rates and modes are listed in Table 19.

12.6.2 Receiver CCA Performance

The start of a valid OFDM transmission at a receiver level equal to or greater than the minimum 55 Mb/s sensitivity (-83.5 dBm) shall cause CCA to indicate busy with a probability > 90% within 4.6875 us. If the preamble portion was missed, the receiver shall hold the carrier sense (CS) signal busy for any signal 20 dB above the minimum 55 Mb/s sensitivity (-63.5 dBm).

Table 25—Receiver Performance Requirements

Data Rate (Mb/s)	Minimum Sensitivity (dBm) for Mode 1	Minimum Sensitivity (dBm) for Mode 2
55	-83.5	-81.5
80	-81.7	-79.7
110	-80.5	-78.5
160	-78.7	-76.7
200	-77.2	-75.2
320	-75.1	-73.1
480	-72.7	-70.7

12.7 UWB PHY Management

The PHY PIB comprises the managed objects, attributes, actions, and notifications required to manage the PHY layer of a DEV. The encoding of the PHY data rates used in the Supported Data Rates field in the Capability IE, 7.4.11, is given in Table 89.

Table 26—UWB PHY supported data rate encoding

Rate supported (Mb/s)	b0	b1	b2	b3	b4

The encoding of the supported PHY data rates into an octet number is accomplished by adding bits b5-b7, all set to zero, to the encoding given in Table 89. Bit b0 is the lsb while bit 7 is the msb. Thus a DEV that supports 11, 22 and 33 Mb/s would have a Supported Data Rates field 01000 (lsb to msb) and an octet encoding of 0x2.

The encoding of the preferred fragment size used in the Capability IE, 7.4.11, is given in Table 90.

The encoding of the DataRate parameter used in the PLME SAP, 6.4, and the encodings of the TXDataRate and RXDataRate parameters used in the PHY SAP, 6.7, are based on the value for the data rate sent in the PHY header, Table 80 and is given in Table 91.

Table 27—UWB PHY preferred fragment size encoding

Field value	Preferred fragment size (octets)

Table 28—Encoding of the UWB PHY data rates for the PHY SAP

Modulation	Data Rate	TXDataRate/ RXDataRate value

The PHY dependent PIB values for the 2.4 GHz PHY are given in Table 92 and Table 93. The PHY PIB characteristics group, Table 92, contains information that is common to most 2.4 GHz implementations.

The PHY PIB implementation group, Table 93, contains information that is more characteristic of a particular PHY implementation than of the PHY as a whole.

Table 29—PHY PIB characterisitcs group parameters

Managed Object	Octets	Definition	Access
PHYPIB_Type	1	0x01=UWB	Read only
PHYPIB_RegdomainsSupported	Variable	One octet for each regulatory domain supported as defined in PHYPIB_CurrentRegDomain	Read only
PHYPIB_CurrentRegDomain	1	0x00=European Telecommunications Standards Institute (ETSI)	Read only
PHYPIB_DataRateVector	1	Encodes the data rates, defined in Table 89 and 11.7	Read only
PHYPIB_NumChannelsSupported	1	Value=0x05, see 11.2.3	Read only
PHYPIB_CurrentChannel	1	Indicates the channel that is currently being used. See 11.2.3	Read only
PHYPIB_CCAThreshold	1	The CCA threshold in dBm, encoded in 2’s complement format. The value is implementation dependent but no larger than the value listed in 11.6.5.	Read only
PHYPIB_FrameLengthMax	2	pMaxFrameBodySize, 11.2.8.1	Read only

Table 30—PHY PIB implementation group parameters

Managed Object	Octets	Definition	Access
PHYPIB_DiversitySupported	1	Numeric entry that indicates the number of antennas that are available.	Read only
PHYPIB_MaxTXPower	1	The maximum TX power that the DEV is capable of using, 7.4.11, implementation dependent.	Read only
PHYPIB_TXPowerStepSize	1	The step size for power control supported by the DEV, 7.4.12, implementation dependent.	Read only
PHYPIB_NumPMLevels	1	Number of power management levels supported. The range is 1 to 255 and the value is implementation dependent.	Read only
PHYPIB_PMLevelReturn	1	Value=0x05, see 11.2.3	Read only
PHYPIB_CurrentChannel	Variable	Table of vectors with number of entries given by PHYPIB_NumPMLevels. Each vector is the time required to change between power saving states of the PHY. Vector number 0 is the time required to change the PHY from the off state to a state where it is ready to receive commands. Other values are implementation dependent.	Read only