OFDM Physical Layer Specification for the 5 GHz Band

Introduction

This clause describes the physical layer for the Orthogonal Frequency Division Multiplexing (OFDM) system. The Radio Frequency LAN system is initially aimed for the 5.15, 5.25 and 5.725 GHz U-NII bands as provided in the USA according to Document FCC 15.407.

The OFDM system provides a wireless LAN with a 20 Mbit/s data payload communication capability. This modulation scheme is very robust against delay spread which is very severe in high speed wireless systems.

Scope

This clause describes the physical layer services provided to the 802.11 wireless LAN MAC by the 5 GHz (bands) OFDM system. The OFDM PHY layer consists of two protocol functions:

a) A physical layer convergence function which adapts the capabilities of the physical medium dependent system to the Physical Layer service. This function shall be supported by the Physical Layer Convergence Procedure (PLCP) which defines a method of mapping the 802.11 MAC sublayer Protocol Data Units (MPDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated physical medium dependent system.

b) A Physical Medium Dependent (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.

OFDM Physical Layer Functions

The 5 GHz OFDM PHY architecture is depicted in the reference model shown in Figure 11. The OFDM physical layer contains three functional entities: the physical medium dependent function, the physical layer convergence function and the layer management function. Each of these functions is described in detail in the following subclauses.

The OFDM Physical Layer service shall be provided to the Medium Access Control through the physical layer service primitives described in clause 12.

Physical Layer Convergence Procedure Sublayer

In order to allow the 802.11 MAC to operate with minimum dependence on the PMD sublayer, a physical layer convergence sublayer is defined. This function simplifies the physical layer service interface to the 802.11 MAC services.

Physical Medium Dependent Sublayer

The physical medium dependent sublayer provides a means to send and receive data between two or more stations. This clause is concerned with the 5 GHz bands using OFDM.

Physical Layer Management Entity (LME)

The Physical LME performs management of the local Physical Layer Functions in conjunction with the MAC Management entity.

Service Specification Method and Notation

The models represented by figures and state diagrams are intended to be illustrations of the functions provided. It is important to distinguish between a model and a real implementation. The models are optimized for simplicity and clarity of presentation, the actual method of implementation is left to the discretion of the 802.11 OFDM PHY compliant developer.

The service of a layer or sublayer is the set of capabilities that it offers to a user in the next higher layer (or sublayer). Abstract services are specified here by describing the service primitives and parameters that characterize each service. This definition is independent of any particular implementation.

OFDM PHY Specific Service Parameter Lists

Introduction

The architecture of the 802.11 MAC is intended to be physical layer independent. Some physical layer implementations require medium management state machines running in the medium access control sublayer in order to meet certain PMD requirements. These physical layer dependent MAC state machines reside in a sublayer defined as the MAC subLayer Management Entity (MLME). The MLME in certain PMD implementations may need to interact with the Physical LME (PLME) as part of the normal PHY SAP primitives. These interactions are defined by the Physical Layer Management Entity parameter list currently defined in the PHY Service Primitives as TXVECTOR and RXVECTOR. The list of these parameters and the values they may represent are defined in the specific physical layer specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the OFDM PHY.

All of the values included in the TXVECTOR or RXVECTOR described in this subclause are considered mandatory unless otherwise specified. 20 Mbit/s is the only rate currently supported. Other data rates may be defined for possible future use.

TXVECTOR Parameters

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

Parameter	Associate Primitive	Value
LENGTH	PHY-TXSTART.request (TXVECTOR)	1-65535
DATATRATE	PHY-TXSTART.request (TXVECTOR)	20
SERVICE	PHY-TXSTART.request (TXVECTOR)	null
TXPWR_LEVEL	PHY-TXSTART.request (TXVECTOR)	1-8

Table 75, TXVECTOR Parameters

TXVECTOR LENGTH

The LENGTH parameter has the value from 1 to 65535. This parameter is used to indicate the number of octets in the MPDU which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octet transfers which will occur between the MAC and the PHY after receiving a request to start the transmission.

TXVECTOR DATARATE

The DATARATE parameter describes the bit rate at which the PLCP should transmit the PSDU. Its value can be any of the rates as defined in Table 75, TXVECTOR Parameters, and supported by the conformant OFDM PHY.

TXVECTOR SERVICE

The SERVICE parameter should be reserved for future use.

TXVECTOR TXPWR_LEVEL

The TXPWR_LEVEL parameter has the value from 1 to 8. This parameter is used to indicate the number of TxPowerLevel attributes defined in the MIB for the current MPDU transmission.

RXVECTOR Parameters

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

Parameter	Associate Primitive	Value
LENGTH	PHY-RXSTART.indicate (RXVECTOR)	1-65535
RSSI	PHY-RXSTART.indicate (RXVECTOR)	0 - RSSI Max
DATARATE	PHY-RXSTART.request (RXVECTOR)	20
SERVICE	PHY-RXSTART.request (RXVECTOR)	null

Table 76, RXVECTOR Parameters

RXVECTOR LENGTH

The LENGTH parameter has the value from 1 to 65535. This parameter is used to indicate the value contained in the LENGTH field which the PLCP has received in the PLCP Header. The MAC and 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.

RXVECTOR RSSI

The Receive Signal Strength Indicator (RSSI) is a parameter takes a value from 0 through RSSI Max. This parameter is a measure by the PHY sublayer of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured between during Start Symbol (SS) period when the OFDM signal detected from the repetition of the SS signals. RSSI is intended to be used in a relative manner. Absolute accuracy of the RSSI reading is not specified.

OFDM Physical Layer Convergence Procedure Sublayer

Introduction

This clause provides a convergence procedure in which MPDUs are converted to and from PPDUs. During transmission, the MPDU 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 demodulation and delivery of the MPDU.

Physical Layer Convergence Procedure Frame Format

Figure 107 shows the format for the PPDU including the OFDM PLCP preamble, the OFDM PLCP header and the MPDU. The PLCP preamble contains the following fields: AGC pull-in (AGC) and Start symbol (SS). The PLCP header contains the following fields: unique word (UW), 802.11 signaling (SIGNAL), 802.11 service(SERVICE), length(LENGTH), and CCITT CRC-16. All of these fields are described in detail in clause 1.3.3.

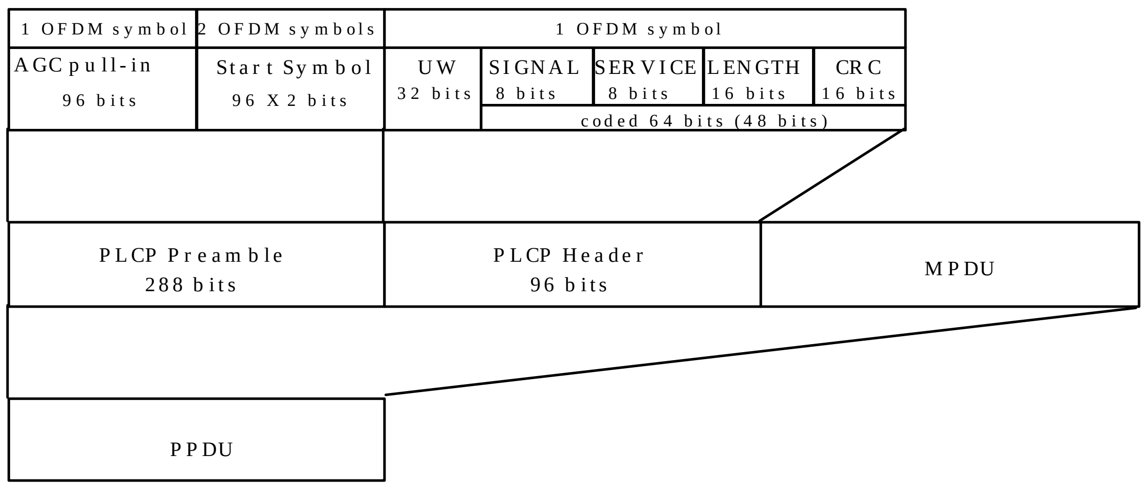

Figure 107, PLCP Frame Format

PLCP Field Definitions

The entire PLCP preamble and header shall be transmitted using the 20 Mbit/s DQPSK-OFDM modulation described in clause 1.5.7. All transmitted bits except for PLCP preamble and UW shall be scrambled using the feedthrough scrambler described in clause 1.3.5 and encoded using the convolutional encoder described in clause 1.3.3.8.

PLCP AGC pull-in (AGC)

The AGC synchronization field (1 OFDM symbol) shall consist of 96 bits. This field shall be provided so that the receiver can perform the operations needed to pull-in the AGC control signal. This pattern shall not be correlated to the Start Symbol (SS) which is described in clause 1.3.3.2 (Pattern will be TBD). This field shall not be scrambled nor encoded.

PLCP Start Symbol (SS)

The Start Symbols (SS) shall be provided to perform detect the transmitted signal and to perform symbol timing synchronization within the PLCP preamble. The SS shall be a 96 x 2 (192) bit field, pattern will be TBD. The LSB shall be transmitted first in time. This field shall not be scrambled nor encoded.

PLCP Unique Word (UW)

The Unique Word (UW) shall be provided to firm frame synchronization within the PLCP header. The UW shall be a 32 bit field, pattern will be TBD. The LSB shall be transmitted first in time. This field shall not be scrambled nor encoded.

PLCP 802.11 Signal Field (SIGNAL)

The 8 bit 802.11 Signal Field indicates to the PHY the modulation that will be used for transmission (and reception) of the MPDU. The data rate shall be equal to the Signal Field value multiplied by 100kbit/s. The OFDM PHY currently supports one modulation service (data rate) given by the following 8 bit words, where the LSB shall be transmitted first in time:

a) C8h (MSB to LSB) for 20 Mbit/s

The OFDM PHY rate change capability is described in clause 1.3.6. This field shall be protected by the CCITT CRC-16 frame check sequence described in clause 1.3.3.7. This field shall be encoded by the convolutional encoder described in clause 1.3.3.8.

PLCP 802.11 Service Field (SERVICE)

The 8 bit 802.11 service field shall be reserved for future use. The value of 00h signifies 802.11 device compliance. All the other values are reserved. The LSB shall be transmitted first in time. This field shall be protected by the CCITT CRC-16 frame check sequence described in clause 1.3.3.7. This field shall be encoded by the convolutional encoder described in clause 1.3.3.8.

PLCP Length Field (LENGTH)

The PLCP length field shall be an unsigned 16 bit integer which indicates the number of octets in the MPDU which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octet transfers that will occur between the MAC and the PHY after receiving a request to start transmission. The transmitted value shall be determined from the LENGTH parameter in the TXVECTOR issued with the PHY-TXSTART.request primitive described in clause 12.3.5.4. The LSB (least significant bit) shall be transmitted first in time. This field shall be protected by the CCITT CRC-16 frame check sequence described in clause 1.3.3.7. This field shall be encoded by the convolutional encoder described in clause 1.3.3.8.

PLCP CRC Field (CCITT CRC-16)

The 802.11 SIGNAL, 802.11 SERVICE, and LENGTH fields shall be protected with a CCITT CRC-16 FCS (frame check sequence). The CCITT CRC-16 FCS shall be the ones complement of the remainder generated by modulo 2 division of the protected PLCP fields by the polynomial:

$$x^{16} + x^{12} + x^5 + 1$$

The protected bits shall be processed in transmit order. All FCS calculations shall be made prior to data scrambling.

Figure 108, CCITT CRC-16 Implementation

Convolutional encoder

The 802.11 SIGNAL, SERVICE, LENGTH, CRC and MPDU shall be coded with a convolutional encoder of r=1/2 as shown in Figure 109. The encoded two bits out of six bits shall be stolen in order to change the coding rate to 3/4 (punctured). This bit stealing procedure is described in Figure 110. As the figure shows, three bits of the source data are encoded to six bits by the encoder and two of the six bits are taken out by the bit-stealing function. In the reception, the stolen bits are substituted by dummy bits. Decoding by the Viterbi algorithm is recommended.

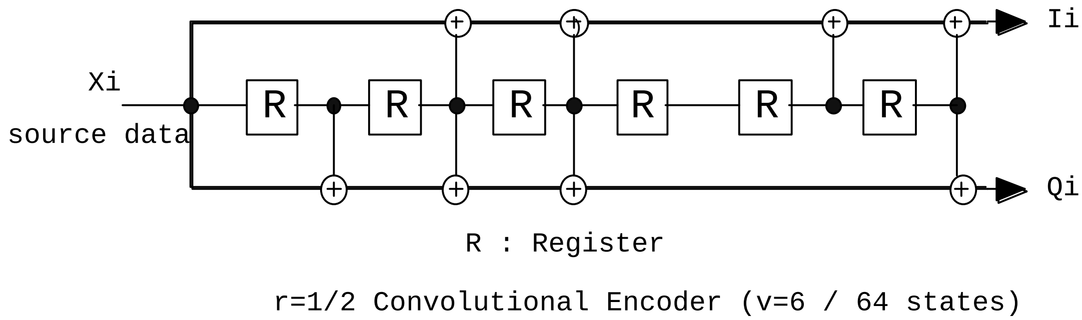

Figure 109, Convolutional encoder

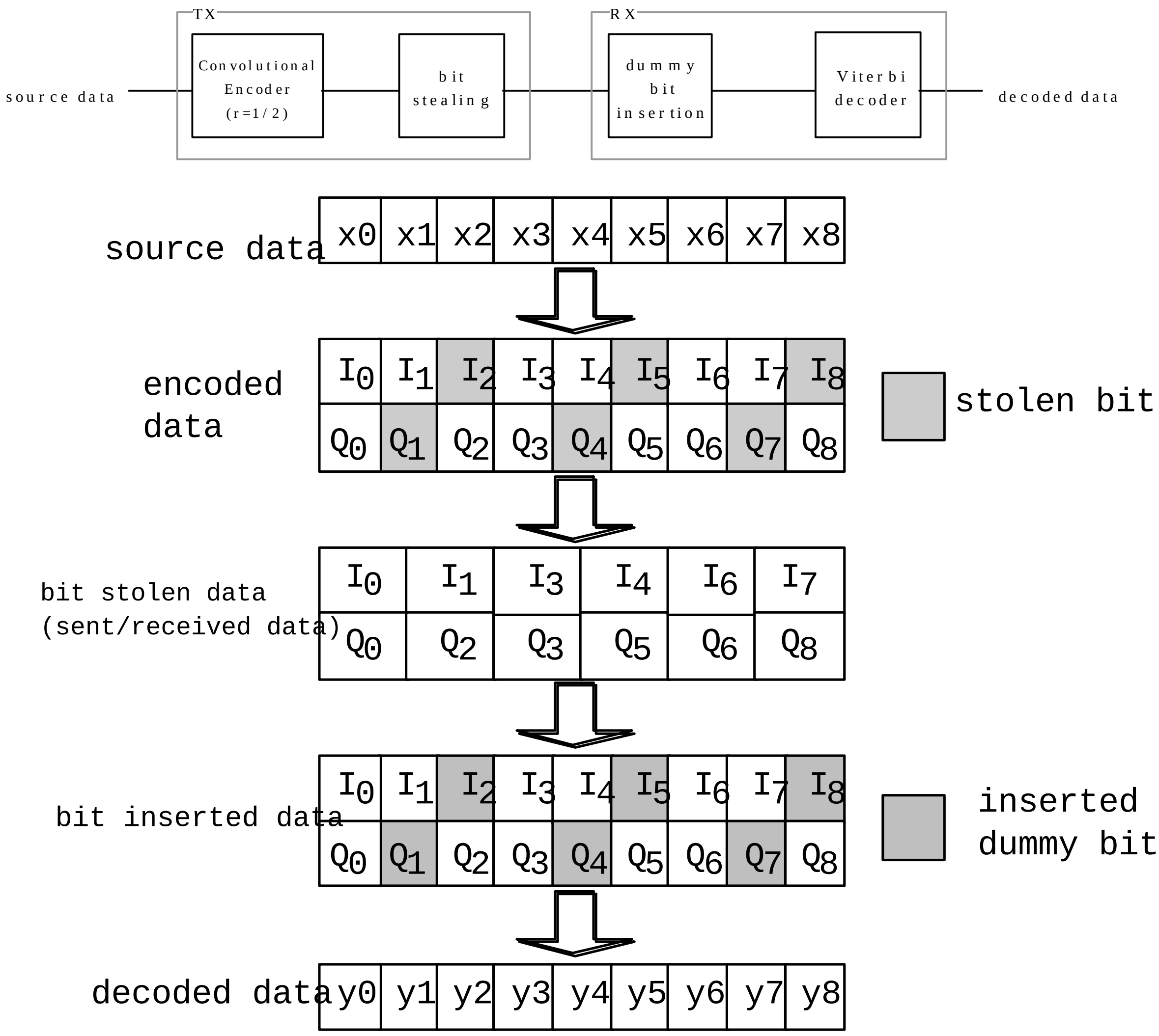

Figure 110, bit-stealing and bit-insertion procedure

Bit stuff

The coded MPDU length shall be multiples of an OFDM symbol (96 bits). In case the coded MPDU length is not a multiple of 96 bits, appropriate length bits are stuffed by any bits in order to make the length a multiple of 96 bits.

Clear Channel Assessment (CCA)

PLCP shall provide the capability to perform CCA and report the result to the MAC. CCA shall report a busy medium (frequency) upon detecting the RSSI, which is reported by the primitive PMD_RSSI.indicate, above the TIThreshold which is given by “aTIThreshold”. This medium status report is indicated by the primitive PHY_CCA.indicate.

PLCP / OFDM PHY Data Scrambler and Descrambler

The polynomial $G(z) = z^{-7} + z^{-4} + 1$ shall be used to scramble ALL bits transmitted by the OFDM PHY except for the AGC pull-in, the Start Symbols and UW. The feedthrough configuration of the scrambler and descrambler is self synchronizing and requires no prior knowledge of the transmitter initialization of the scrambler for receive processing. Figure 111 and Figure 112 show typical implementations of the data scrambler and descrambler. Other implementations are possible.

The scrambler should be initialized to any state except all ones when transmitting.

Figure 111, Data Scrambler

Figure 112, Data Descrambler

PLCP Data Modulation and Modulation Rate Change

The PLCP preamble shall be transmitted using the 20 Mbit/s DQPSK-OFDM modulation. For the future systems, the 802.11 SIGNAL field shall indicate the modulation that shall be used to transmit the MPDU. The transmitter and receiver shall initiate the modulation and demodulation indicated by the 802.11 SIGNAL field starting with the first symbol (2 bits) of the MPDU. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR issued with the PHY-TXSTART.request primitive described in clause 1.2.2.

PLCP Transmit Procedure

The PLCP transmit procedure is shown in Figure 113.

In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through Station Management via the PLME. Other transmit parameters such as DATARATE and TX power are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR) as described in clause 1.2.2.

Based on the status of CCA indicated by PHY-CCA.indicate, the MAC will assess that the channel is clear. A clear channel shall be indicated by PHY-CCA.indicate(IDLE). If the channel is clear, transmission of the PPDU shall be initiated by issuing the PHY-TXSTART.request (TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters SIGNAL (DATARATE), SERVICE and LENGTH and the PMD parameter of TXPWR_LEVEL. The PLCP header parameter LENGTH is indicated by the TXVECTOR.

The PLCP shall issue PMD_TXPWRLVL and PMD_RATE primitives to configure the PHY. The PLCP shall then issue a PMD_TXSTART.request and transmission of the PLCP preamble based on the parameters passed in the PHY-TXSTART.request primitive. Once PLCP preamble and UW transmission is completed, the PHY entity shall immediately initiate data encoding and data scrambling. The encoded and scrambled data shall be then exchanged between the MAC and the PHY by a series of PHY-DATA.request(DATA) primitives issued by the MAC and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated with the first data symbol of the MPDU as described in clause 1.3.6. The PHY proceeds with MPDU transmission through a series of data octet transfers from the MAC. The PLCP header parameters, CRC and MPDU are encoded by the convolutional encoder with the bit-stealing function described in clause 1.3.3.8. At the PMD layer, the data octets are sent in LSB to MSB order and presented to the PHY layer through PMD_DATA.request primitives. Transmission can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal termination occurs after the transmission of the final bit of the last MPDU octet according to the number supplied in the OFDM PHY preamble LENGTH field. The packet transmission shall be completed and the PHY entity shall enter the receive state (i.e. PHY-TXSTART shall be disabled). Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. In case that the coded MPDU (CMPDU) is not multiples of 96 bits, bits shall be stuffed to make the CMPDU length multiples of 96 bits.

In the PMD, the Guard Interval (GI) of 24 bits (12 samples) shall be inserted in every 96 bits as a countermeasure against the delay spread.

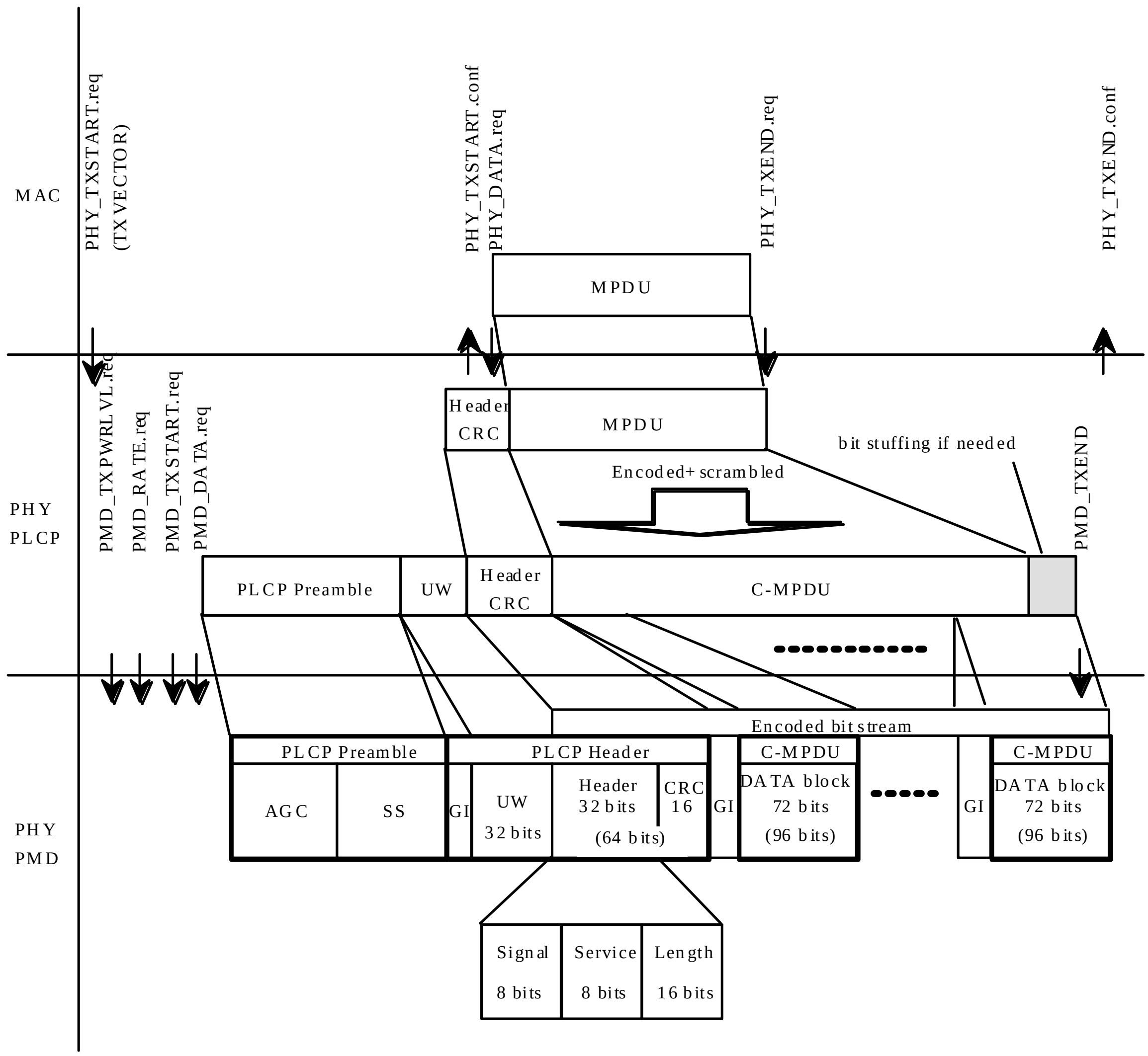

Figure 113, PLCP Transmit Procedure

A typical state machine implementation of the PLCP transmit procedure is provided in Figure 114.

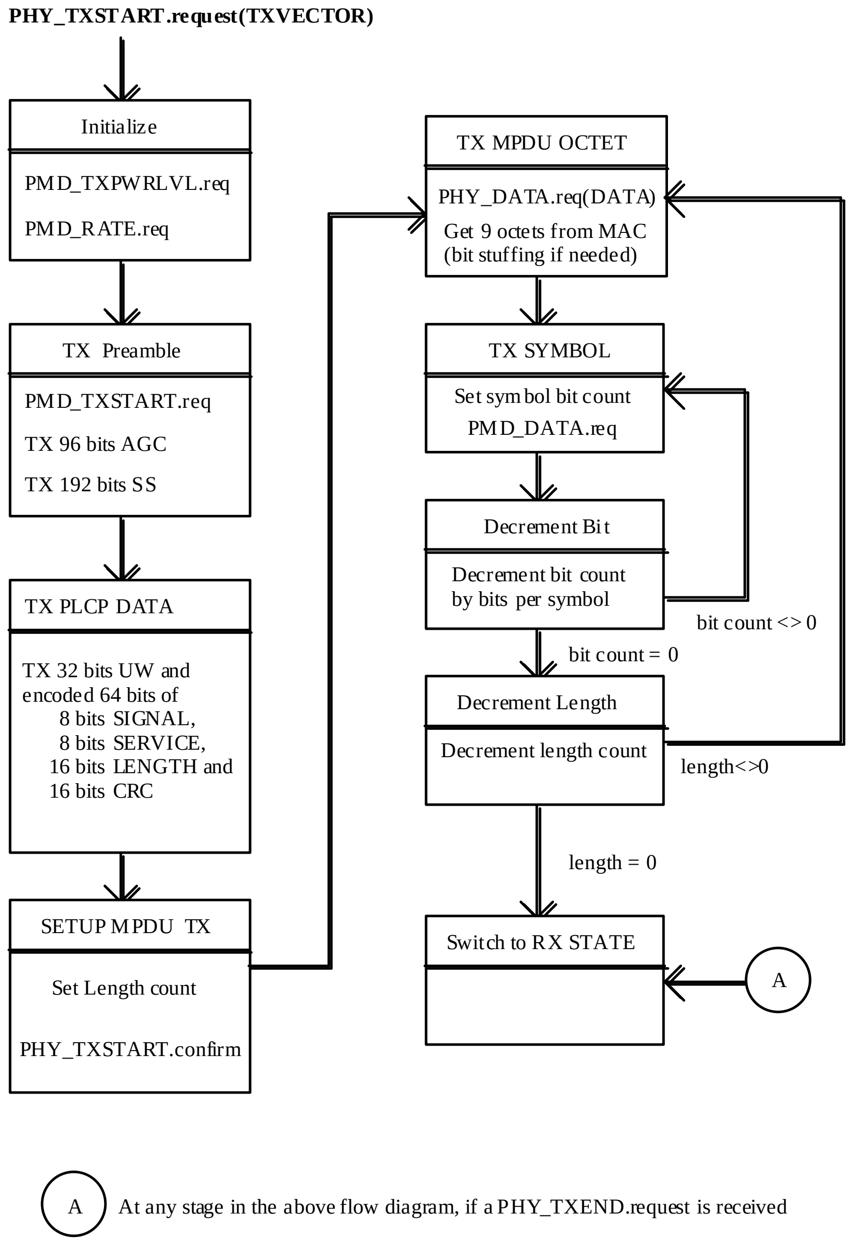

Figure 114, PLCP Transmit State Machine

PLCP Receive Procedure

The PLCP receive procedure is shown in Figure 115.

In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through Station Management via the PLME, the PHY is set to the appropriate frequency. Other receive parameters such as RSSI and indicated DATARATE may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY_CCA.indicate. PHY_CCA.indicate (BUSY) shall be issued for reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD_RSSI is issued to update the RSSI and parameter reported to the MAC.

After PHY-CCA.indicate is issued, the PHY entity shall begin searching for the UW. Once the UW is detected, FEC decode and CCITT CRC-16 processing shall be initiated and the PLCP 802.11 SIGNAL, 802.11 SERVICE and LENGTH fields are received, decoded (Viterbi decoder is recommended) and checked by CCITT CRC-16 FCS. If the CCITT CRC-16 FCS check fails, the PHY receiver shall return to the RX Idle state as depicted in Figure 116. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX Idle state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL field, the SERVICE field, the MPDU length in bytes and RSSI.

The received MPDU bits are assembled into octets, decoded and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the 802.11 SIGNAL field shall be initiated with the first symbol of the MPDU as described in clause 1.3.6. The PHY proceeds with MPDU reception. After the reception of the final bit of the last MPDU octet indicated by the PLCP preamble LENGTH field, the receiver shall be returned to the RX Idle state as shown in Figure 116. A PHY-RXEND.indicate(NoError) primitive shall be issued.

In the event that a change in RSSI would cause the status of CCA to return to the IDLE state before the complete reception of the MPDU as indicated by the PLCP LENGTH field, the error condition PHY-RXEND.indicate(CarrierLost) shall be reported to the MAC. The OFDM PHY will ensure that the CCA will indicate a busy medium for the intended duration of the transmitted packet.

If the PLCP header is successful, but the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is successful, but the SERVICE field is out of 802.11 OFDM specification, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Also, in both cases, the OFDM PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame as indicated by the LENGTH field. The intended duration is indicated by the LENGTH field.

Even if data is received after exceeding the indicated data length, the data should be the stuffed bits for a consistent OFDM symbol.

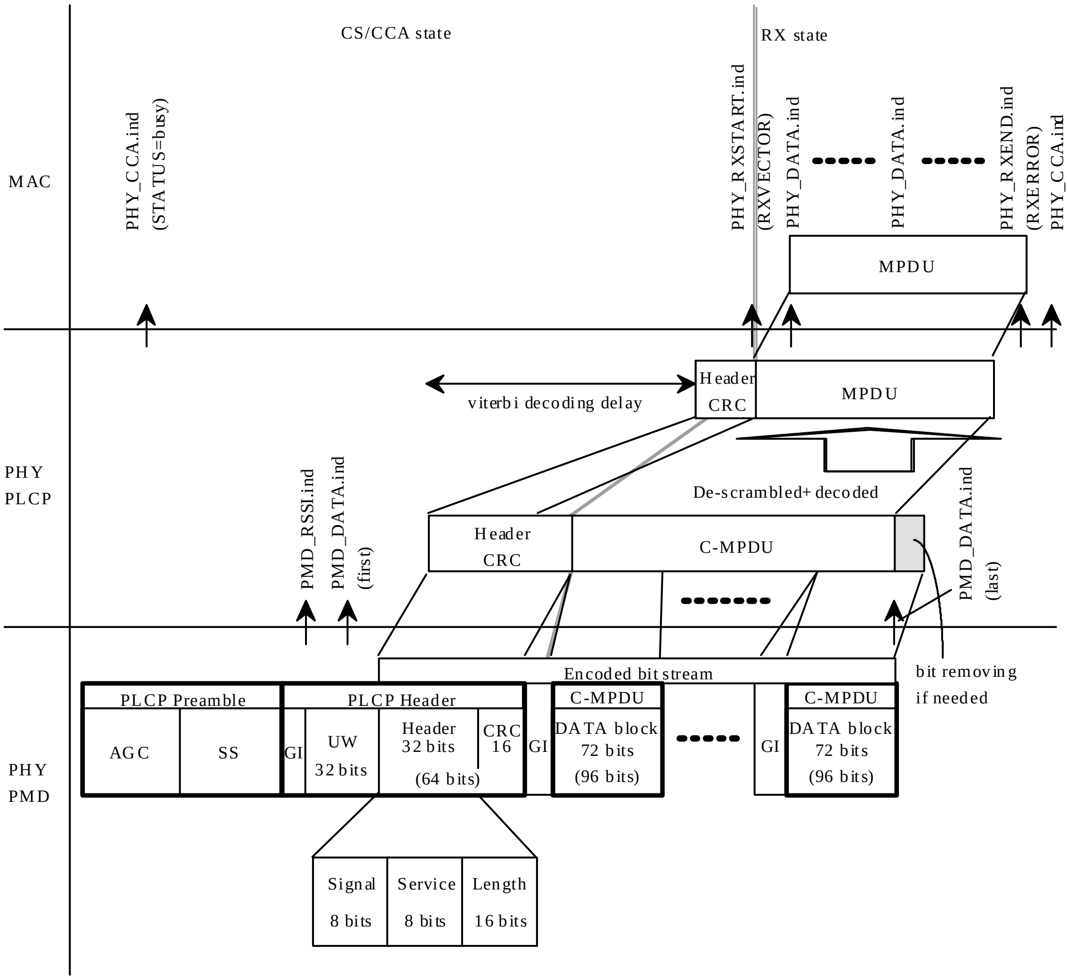

Figure 115, PLCP Receive Procedure

A typical state machine implementation of the PLCP receive procedure is provided in Figure 116.

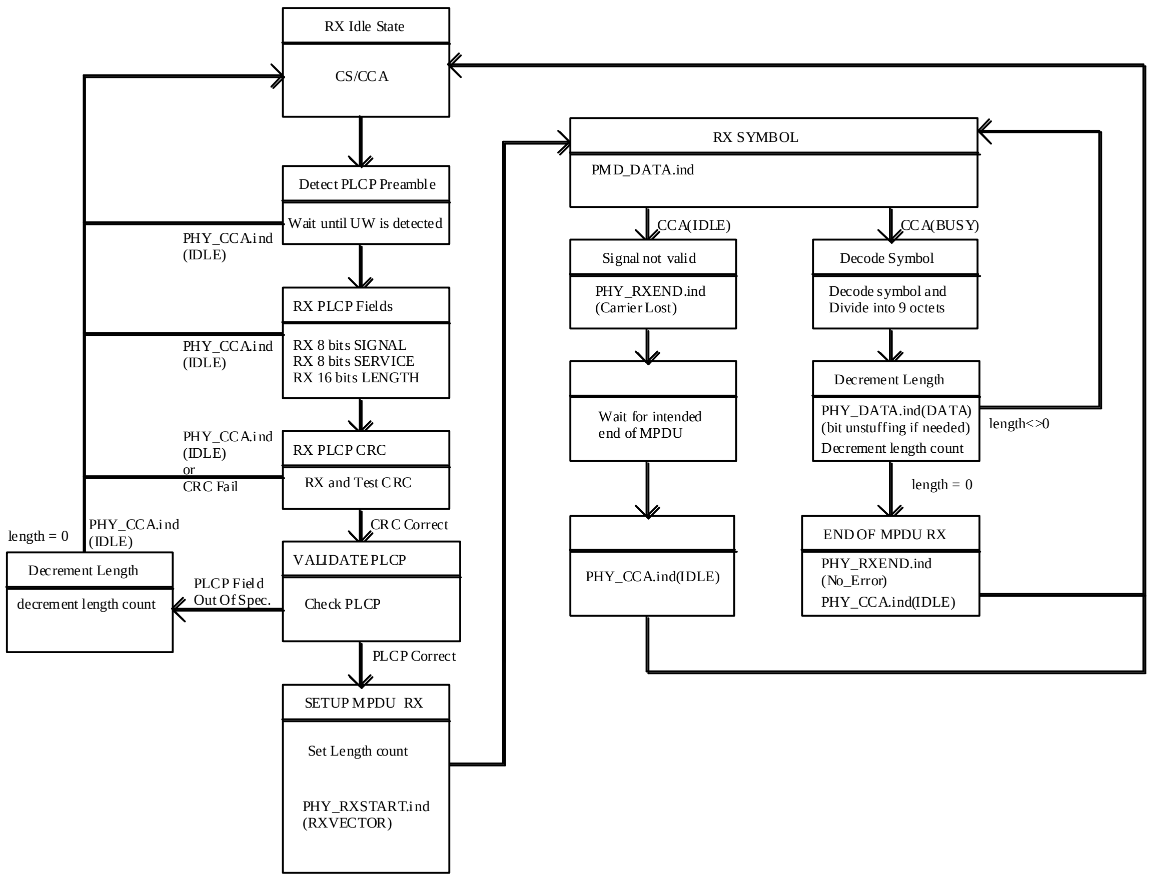

Figure 116, PLCP Receive State Machine

OFDM Physical Layer Management Entity (PLME)

PLME_SAP Sublayer Management primitives

Table 77 lists the MIB attributes which may be accessed by the PHY sublayer entities and intra layer of higher Layer Management Entities (LME). These attributes are accessed via the PLME-GET, PLME-SET and PLME-RESET primitives defined in clause 10.

OFDM Physical Layer Management Information Base

All OFDM Physical Layer Management Information Base attributes are defined in clause 13 with specific values defined in Table 77.

Managed Object	Default Value / Range	Operational Semantics
agPhyOperationGroup		
aPHYType	OFDM-5. (04)	Static
aTempType	implementation dependent	Static
aCWmin	15	Static
aCWmax	1023	Static
aRegDomainsSupported	implementation dependent	Static
aCurrentRegDomain	implementation dependent	Static

aSlotTime	TBD	Static
aCCATime	TBD	Static
aRxTxTurnaroundTime	TBD	Static
aTxPLCPDelay	TBD	Static
aRxTxSwitchTime	TBD	Static
aTxRFDelay	TBD	Static
aSIFSTime	TBD	Static
aRxRFDelay	TBD	Static
aRxPLCPDelay	TBD	Static
aMACProcessingDelay	TBD	Static
aPreambleLength	288 bits	Static
aPLCPHeaderLength	96 bits	Static
agPhyRateGroup		
aSupportedDataRatesTx	28h	Static
aSupportedDataRatesRx	28h	Static
aMPDUMaxLength	65535	Static
agPhyAntennaGroup		
aDiversitySupport	implementation dependent	Static
agPhyTxPowerGroup		
aNumberSupportedPowerLevels	implementation dependent	Static
aTxPowerLevel1	implementation dependent	Static
aTxPowerLevel2	implementation dependent	Static
aTxPowerLevel3	implementation dependent	Static
aTxPowerLevel4	implementation dependent	Static
aTxPowerLevel5	implementation dependent	Static
aTxPowerLevel6	implementation dependent	Static
aTxPowerLevel7	implementation dependent	Static
aTxPowerLevel8	implementation dependent	Static
aCurrentTxPowerLevel	implementation dependent	Dynamic
agPhyOFDMGroup		
aCurrentFrequency	implementation dependent	Dynamic
aTIThreshold	implementation dependent	Dynamic
agPhyPwrSavingGroup		
aDozeTurnonTime	implementation dependent	Static
aCurrentPowerState	implementation dependent	Dynamic
agAntennasListGroup		
aDiversitySelectRx	implementation dependent	Dynamic

Table 77, MIB Attribute Default Values / Ranges

Notes: The column titled Operational Semantics contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. MIB Attributes defined as dynamic can be modified by some management entity.

OFDM Physical Medium Dependent Sublayer

Scope and Field of Application

This clause describes the PMD services provided to the PLCP for the OFDM Physical Layer. Also defined in this clause are the functional, electrical and RF characteristics required for interoperability of implementations conforming to this specification. The relationship of this specification to the entire OFDM PHY Layer is shown in Figure 117.

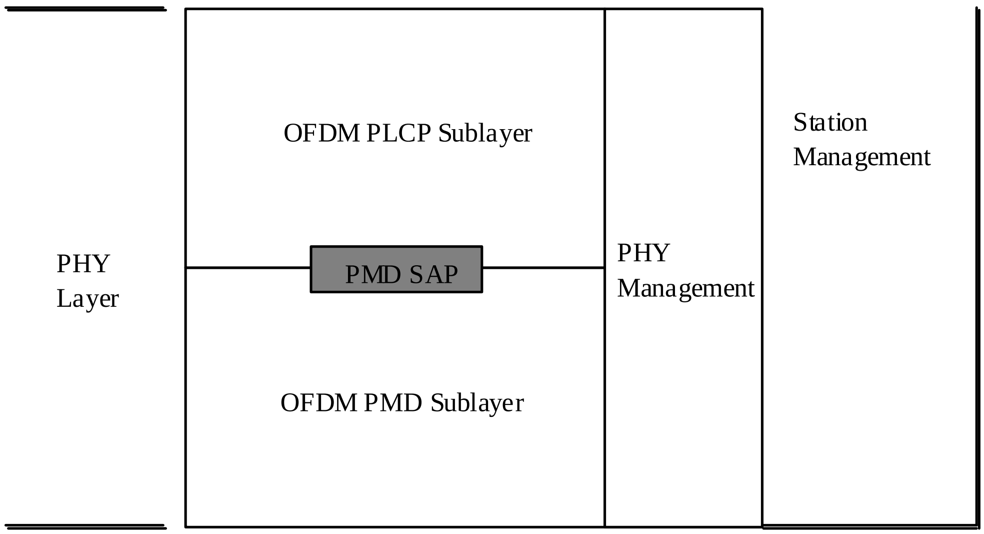

Figure 117, PMD Layer Reference Model

Overview of Service

The OFDM Physical Medium Dependent Sublayer accepts Physical Layer Convergence Procedure sublayer service primitives and provides the actual means by which data shall be transmitted or received from the medium. The combined function of OFDM PMD sublayer primitives and parameters for the receive function results in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality shall be provided for data transmission.

Overview of Interactions

The primitives associated with the 802.11 PLCP sublayer to the OFDM PMD falls into two basic categories:

a) Service primitives that support PLCP peer-to-peer interactions.
b) Service primitives that have local significance and support sublayer-to-sublayer interactions.

Basic Service and Options

All of the service primitives described in this clause are considered mandatory unless otherwise specified.

PMD_SAP Peer-to-Peer Service Primitives

The following table indicates the primitives for peer-to-peer interactions.

Primitive	Request	Indicate	Confirm	Response

PMD_DATA	X	X		

Table 78, PMD_SAP Peer-to-Peer Service Primitives

PMD_SAP Sublayer-to-Sublayer Service Primitives

The following table indicates the primitives for sublayer-to-sublayer interactions.

Primitive	Request	Indicate	Confirm	Response
PMD_TXSTART	X			
PMD_TXEND	X			
PMD_TXPWRLVL	X			
PMD_RATE	X			
PMD_RSSI		X		

Table 79, PMD_SAP Sublayer-to-Sublayer Service Primitives

PMD_SAP Service Primitive Parameters

The following table shows the parameters used by one or more of the PMD_SAP Service Primitives.

Parameter	Associate Primitive	Value
TXD_UNIT	PMD_DATA.request	One(1), Zero(0): one OFDM symbol (= 96 bits) value
RXD_UNIT	PMD_DATA.indicate	One(1), Zero(0): one OFDM symbol (= 96 bits) value
TXPWR_LEVEL	PMD_TXPWRLVL.request	1, 2, 3, 4 (max of 4 levels)
RATE	PMD_RATE.request	C8h for 20 Mbit/s
RSSI	PMD_RSSI.indicate	0-8 bits of RSSI

Table 80, List of Parameters for the PMD Primitives

PMD_SAP Detailed Service Specification

The following clause describes the services provided by each PMD primitive.

PMD_DATA.request

Function

This primitive defines the transfer of data from the PLCP sublayer to the PMD entity.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_DATA.request(TXD_UNIT)

The TXD_UNIT parameter shall be the 96-bit combination of “0” and “1” for one symbol of OFDM modulation. If the length of a C-MPDU is shorter than 96 bits, “0” bits are added to be a 96-bit OFDM symbol. This parameter represents a single block of data which in turn shall be used by the PHY to be encoded into OFDM transmitted symbol.

When Generated

This primitive shall be generated by the PLCP sublayer to request transmission of one OFDM symbol. The data clock for this primitive shall be supplied by PMD layer based on the OFDM symbol clock.

Effect of Receipt

The PMD performs the differential encoding, interleaving and transmission of the data.

PMD_DATA.indicate

Function

This primitive defines the transfer of data from the PMD entity to the PLCP sublayer.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_DATA.indicate(RXD_UNIT)

The RXD_UNIT parameter shall be the 96-bit combination of “0” and “1” for one symbol of OFDM modulation. This parameter represents a single symbol which has been demodulated by the PMD entity.

When Generated

This primitive generated by the PMD entity, forwards received data to the PLCP sublayer. The data clock for this primitive shall be supplied by PMD layer based on the OFDM symbol clock.

Effect of Receipt

The PLCP sublayer interprets the bits which are recovered as part of the PLCP convergence procedure or passes the data to the MAC sublayer as part of the MPDU.

PMD_TXSTART.request

Function

This primitive, generated by the PHY PLCP sublayer, initiates PPDU transmission by the PMD layer.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_TXSTART.request

When Generated

This primitive shall be generated by the PLCP sublayer to initiate the PMD layer transmission of the PPDU. The PHY-TXSTART.request primitive shall be provided to the PLCP sublayer prior to issuing the PMD_TXSTART command.

Effect of Receipt

PMD_TXSTART initiates transmission of a PPDU by the PMD sublayer.

PMD_TXEND.request

Function

This primitive, generated by the PHY PLCP sublayer, ends PPDU transmission by the PMD layer.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_TXEND.request

When Generated

This primitive shall be generated by the PLCP sublayer to terminate the PMD layer transmission of the PPDU.

Effect of Receipt

PMD_TXEND terminates transmission of a PPDU by the PMD sublayer.

PMD_TXPWRLVL.request

Function

This primitive, generated by the PHY PLCP sublayer, selects the power level used by the PHY for transmission.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_TXPWRLVL.request(TXPWR_LEVEL)

TXPWR_LEVEL selects which of the transmit power levels should be used for the current packet transmission. The number of available power levels shall be determined by the MIB parameter aNumberSupportedPowerLevels. Clause 1.5.7.2 provides further information on the OFDM PHY power level control capabilities.

When Generated

This primitive shall be generated by the PLCP sublayer to select a specific transmit power. This primitive shall be applied prior to setting PMD_TXSTART into the transmit state.

Effect of Receipt

PMD_TXPWRLVL immediately sets the transmit power level to that given by TXPWR_LEVEL.

PMD_RATE.request

Function

This primitive, generated by the PHY PLCP sublayer, selects the modulation rate which shall be used by the OFDM PHY for transmission.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_RATE.request(RATE)

RATE selects which of the OFDM PHY data rates shall be used for MPDU transmission. Clause 1.5.6.4 provides further information on the OFDM PHY modulation rates. The OFDM PHY rate change capability is fully described in clause 1.3.

When Generated

This primitive shall be generated by the PLCP sublayer to change or set the current OFDM PHY modulation rate used for the MPDU portion of a PPDU.

Effect of Receipt

The receipt of PMD_RATE selects the rate which shall be used for all subsequent MPDU transmissions. This rate shall be used for transmission only. The OFDM PHY shall still be capable of receiving all the required OFDM PHY modulation rates.

PMD_RSSI.indicate

Function

This primitive, generated by the PMD sublayer, provides to the PLCP and MAC entity the Received Signal Strength.

Semantic of the Service Primitive

The primitive shall provide the following parameters:

PMD_RSSI.indicate(RSSI)

The RSSI shall be a measure of the RF energy received by the OFDM PHY. RSSI indications of up to 8 bits (256 levels) are supported.

When Generated

This primitive shall be generated by the PMD when the OFDM PHY is in the receive state. It shall be continuously available to the PLCP which in turn provides the parameter to the MAC entity.

Effect of Receipt

This parameter shall be provided to the PLCP layer for information only. The RSSI may be used as part of a Clear Channel Assessment scheme.

PMD Operating Specifications General

The following clauses provide general specifications for the DQPSK-OFDM Physical Medium Dependent sublayer. These specifications apply to both the receive and the transmit functions and general operation of the OFDM PHY.

Outline description

The general block diagram of transmitter and receiver for the OFDM PHY is shown in Figure 118. Major specifications for OFDM PHY are listed in Table 81.

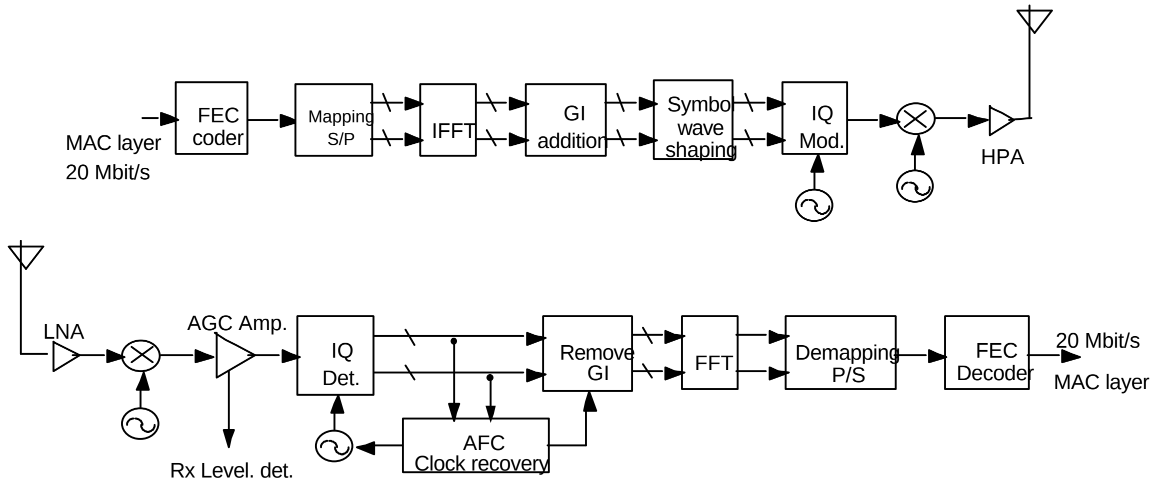

Figure 118, An Example of Transmitter and Receiver Block Diagram for OFDM PHY

Information data rate	20 Mbit/s
Modulation	DQPSK-OFDM
Coding rate	3/4
Number of subcarriers	48
OFDM symbol duration	3.6 μs
Guard interval	0.86 μs * (T_{GI}+ T_{prefix}+ $T_{postfix}$)
Occupied Bandwidth	17.5 MHz

(* Refer to clause 1.5.6.8)

Table 81, OFDM PHY Major Parameters of OFDM PHY

Operating Frequency Range

The OFDM PHY shall operate in the frequency ranges of 5.15 to 5.35 and 5.725 to 5.825 GHz as allocated by regulatory bodies in the USA.

Number of Operating Channels

The channel center frequencies and CHNL_ID numbers shall be as shown in Table 82. Operation is specified as 5.15 to 5.35 and 5.725 to 5.825 GHz.

CHNL_ID	Frequency
1	5176.4680 MHz
2	5199.9974 MHz
3	5223.5268 MHz
4	5247.0562 MHz
5	5270.5856 MHz
6	5294.1150 MHz
7	5317.6444 MHz
8	5752.9383 MHz
9	5776.4677 MHz
10	5799.9971 MHz

Table 82, OFDM PHY Frequency Channel Plan

In a multiple cell network topology, overlapping and/or adjacent cells using different channels can operate simultaneously.

Transmission Data Rates

The specified information data rate is 20 Mbit/s at the present time.

Because convolutional encoding (coding rate = 3/4) is applied for MPDU transmission at the PLCP sublayer, the channel data rate shall be 20 x 4/3 = 26.67 Mbit/s (refer to clause 1.3.3.8).

Interleaving

The interleaving shall be performed to randomize the successive error bit pattern for convolutional encoding (refer to clause 1.3.3.8). The interleaving procedure is carried out before DQPSK mapping. The interleaving procedure is shown in Figure 119.

Figure 119 , Interleaving Procedure

The *k*th transfer data block $E_k(i)$ provided by PLCP as TXD_UNIT parameter which is convolutionally encoded 96 bit data for one OFDM symbol are interleaved according to the following relationship.

$$C_{i,k} = E_k\left(\mathrm{int}\ (i/8) + 12 \cdot (i \bmod 8)\right)$$

where $0 \le i \le 95$, i is integer.

Modulation

The interleaved binary sequence $C_{i,k}$ shall be mapped into DQPSK vector signals.

First, the interleaved data $C_{i,k}$ are paired to $(x_{l,k}, y_{l,k})$ dibit pattern as follows:

$$\begin{cases} x_{l,k} = C_{2l,k} \\ y_{l,k} = C_{2l+1,k} \end{cases}$$

where $0 \le l \le 47$ and l is integer

The dibit pattern $(x_{l,k}, y_{l,k})$ is differentially coded into complex vector signals $A_{l,k}$. Conversion from $(x_{l,k}, y_{l,k})$ to $A_{l,k}$ is performed as per the following equation and Table 83.

$$A_{l,k} = e^{j\theta_{l,k}}$$

where $\theta_{l,k} = \theta_{l,k-1} + \theta_c(x_{l,k}, y_{l,k})$ and $\theta_{l,0} = 0$

Dibit pattern $(x_{l,k}, y_{l,k})$ **$x_{l,k}$ is first in time**	**Phase Change $\theta_c(x_{l,k}, y_{l,k})$** **(+jω)**
00	0

01	π/2
11	π
10	3π/2 (-π/2)

Table 83, DQPSK Mapping

Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM) shall be performed as per the following Inverse Discrete Fourier Transform (IDFT) operation.

$$a_k(t) = \sum_{n=-N/2+1}^{N/2} A'_{n,k} \, e^{j2\pi \frac{n}{T_w} t}$$

$$A'_{n,k} = \begin{cases} 0 & (24 < n \le N/2) \\ A_{n+23,k} & (1 \le n \le 24) \\ 0 & (n = 0) \\ A_{n+24,k} & (-24 \le n \le -1) \\ 0 & (-N/2+1 \le n < -24) \end{cases}$$

where $N = 2^m$, m is integer and $m \ge 6$.

The subcarrier frequency allocation is shown in Figure 120. To avoid difficulties in D/A and A/D converter offsets and carrier feedthrough in the RF system, the subcarrier falling at D.C. (n = 0) is not used.

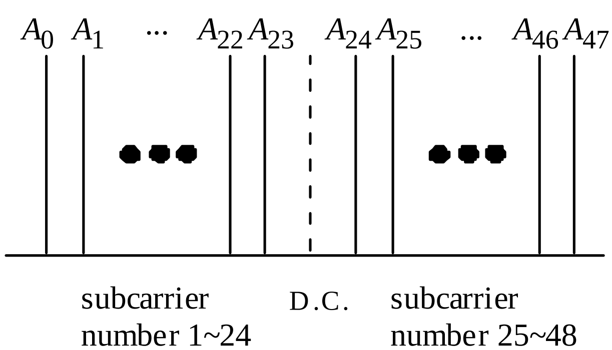

Figure 120, Subcarrier Frequency Allocation

OFDM Symbol generation

The guard interval should be introduced in each OFDM symbol to avoid multipath effects. The guard interval consists of a cyclic extension of the IDFT output blocks. IDFT output signal $a_k(t)$ is described as a discrete signal as follows

$$a_k(t) = \{P_0, P_1, \cdots, P_{N_{DFT}-1}\}$$

where N_{DFT} is the number of DFT points.

The last N_{GI} points signal are cyclically added at the beginning of $a_k(t)$. Here, N_{GI} is the number of DFT samples corresponding to the time of 2 (T_{prefix} + T_{postfix}) + T_{GI} where T_{prefix}, T_{postfix} and T_{GI} are specified later.

$$a'_k(t) = \left\{ P_{N_{DFT}-N_{GI}}, P_{N_{DFT}-N_{GI}+1}, \cdots, P_{N_{DFT}-1}, P_0, P_1, \cdots, P_{N_{DFT}-1} \right\}$$

The cyclic extension in the case of 64-points-IDFT is shown in Figure 121.

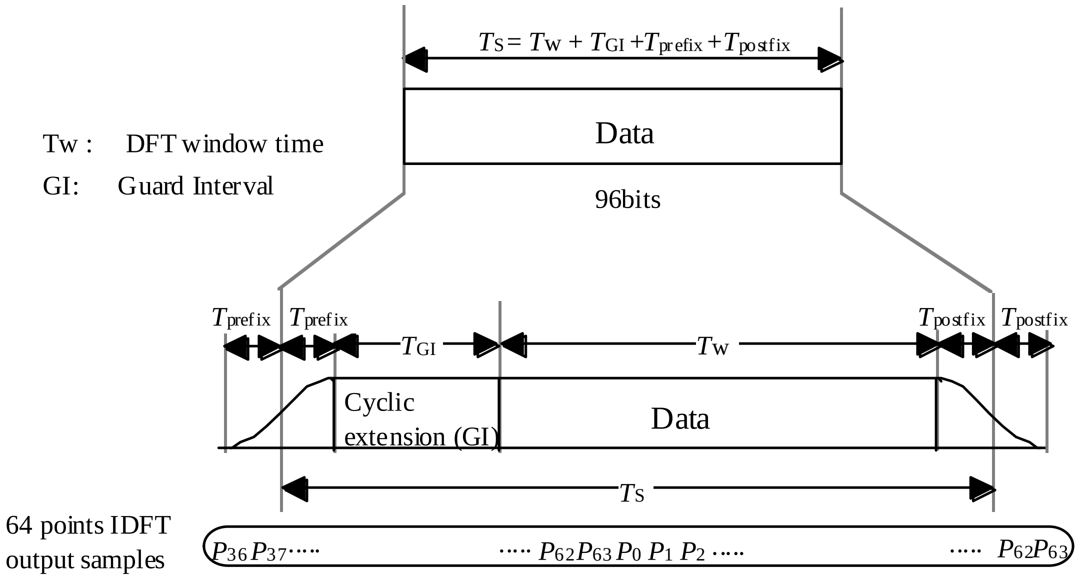

Figure 121, Cyclic Extension

The raised cosine window $r_C(t)$ shall be multiplied with every OFDM symbol. The OFDM symbol is added to the output of the previous OFDM symbol with a delay of T_S. There is over lap region in such a situation. The specification is described in Figure 122. The OFDM signal with raised cosine window $s(t)$ shall be specified as follows:

$$s(t) = \mathrm{Re}\left(\sum_k r_c(t - kT_S) a'_k(t - kT_S) \cdot e^{j2\pi f_c t} \right)$$

where

$$r_c(t) = \begin{cases} \frac{1}{2} - \frac{1}{2}\cos\frac{\pi t}{2T_{prefix}} & \left(0 \le t < 2T_{prefix}\right) \\ 1 & \left(2T_{prefix} \le t \le 2T_{prefix} + T_{GI} + T_W\right) \\ \frac{1}{2} + \frac{1}{2}\cos\frac{\pi\left\{t - \left(2T_{prefix} + T_{GI} + T_W\right)\right\}}{2T_{postfix}} & \left(2T_{prefix} + T_{GI} + T_W < t \le 2T_{prefix} + T_{GI} + T_W + 2T_{postfix}\right) \\ 0 & (\text{elsewhere}) \end{cases}$$

and f_c is center carrier frequency.

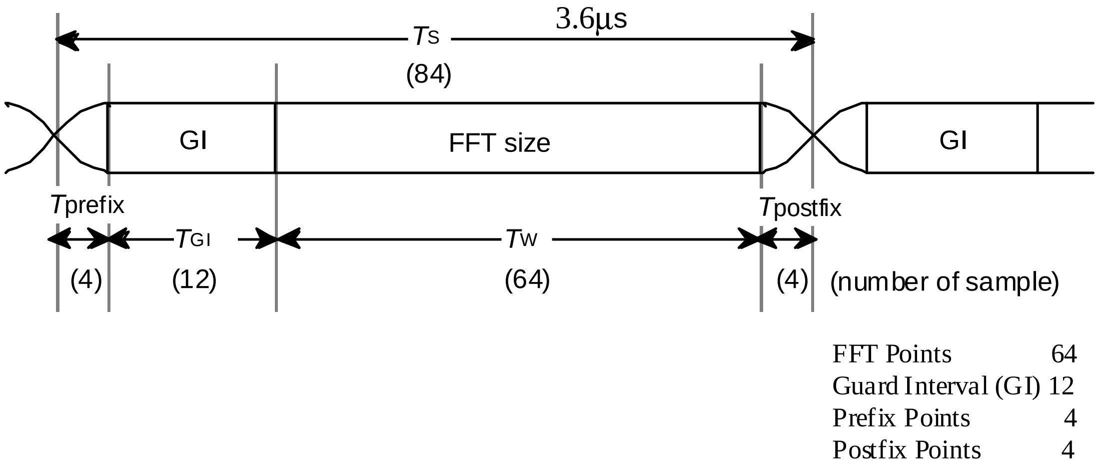

Figure 122, Raised Cosine Windowing

The interval of T_S shall be 3.6 µs, $T_{GI} = T_S / 7$ and $T_{prefix} = T_{postfix} = T_S / 21$.

AGC pull-in symbol format

The AGC pull-in symbol shall consist of the 96 bit fixed sequence specified in PLCP without scrambling and convolutional encoding. The signal for the AGC pull-in symbol shall be generated by DQPSK-OFDM modulation, cyclic extension and the raised cosine window as described in clause 1.5.6.6, 1.5.6.7 and 1.5.6.8. The symbol format for AGC pull-in is shown in Figure 123. A 64-points-IDFT's case is illustrated in this figure. The cyclic extension interval for the AGC pull-in shall be 2($T_{prefix} + T_{postfix}$) and does not includes the interval of T_{GI}.

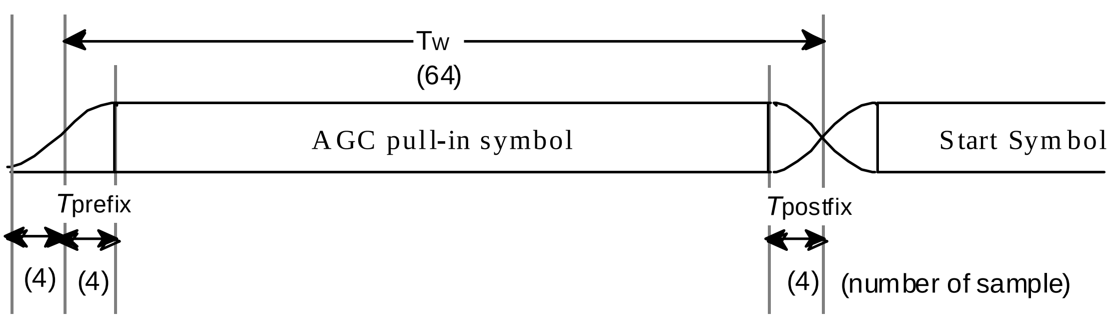

Figure 123, AGC Symbol Format

Start Symbol (SS) format

The Start Symbol (SS) shall consist of the 96 bit fixed sequence specified in PLCP without scrambling and convolutional encoding. The signal for SS shall be generated by DQPSK-OFDM modulation, cyclic extension and the raised cosine window as described in clause 1.5.6.6, 1.5.6.7 and 1.5.6.8. The symbol format for SS is shown in Figure 124. A 64-points-IDFT's case is illustrated in this figure. The cyclic extension interval for the SS shall be $T_W+T_{prefix}+T_{postfix}$.

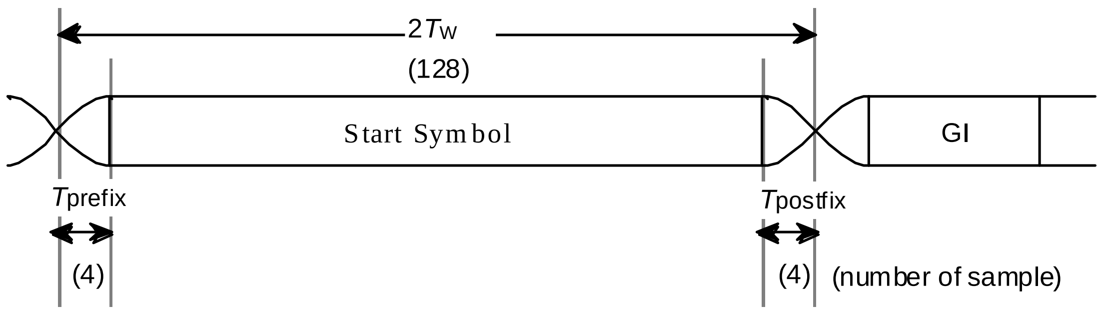

Figure 124, Start Symbol Format

OFDM Frame Format

The OFDM frame format shall be specified in Figure 125. The frame format consists of AGC pull-in symbol, Start Symbol (SS), the sequence of Unique Word (UW), PHY header and data (refer to 1.3.3.4~1.3.3.7). These symbols shall be also generated by using cyclic extension and raised cosine window. The illustration is the case of using 64-points IDFT.

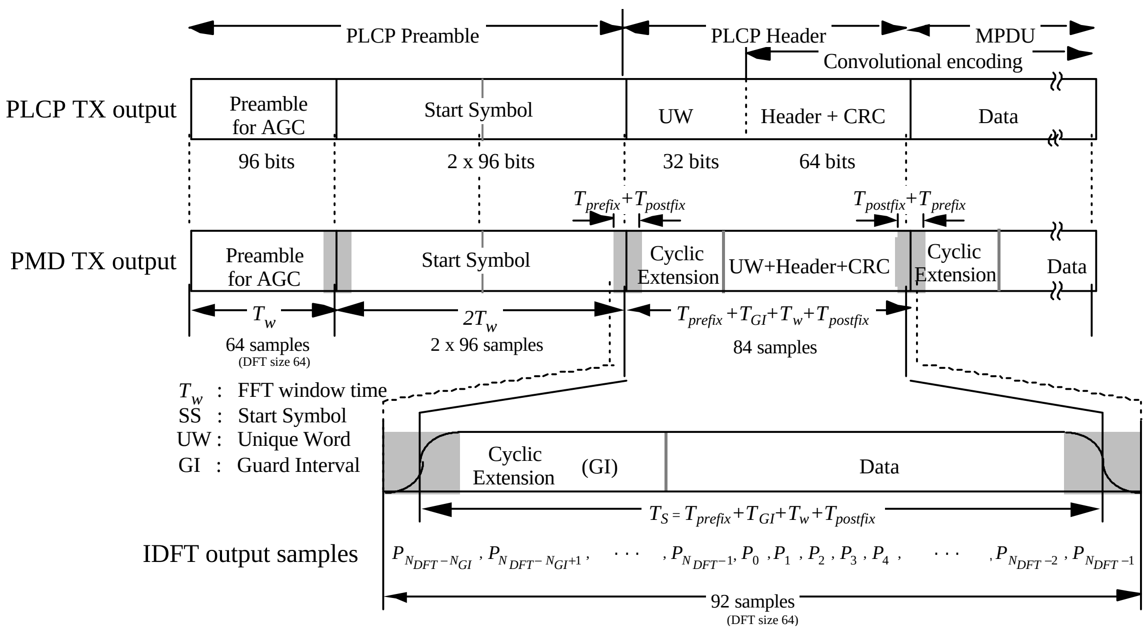

Figure 125, OFDM Frame Format

Transmit and Receive In Band and Out of Band Spurious Emissions

The OFDM PHY shall conform to in-band and out-of-band spurious emissions as set by regulatory bodies. For the USA, refer to FCC xx.xxx.

TX RF Delay

The TX RF Delay time shall be defined as the time between the issuance of a PMD.DATA.request to the PMD and the start of the corresponding symbol at the air interface. The TX RF Delay shall be less than (T.B.D.) µs.

Slot Time

The slot time for the OFDM PHY shall be (T.B.D.) μs, which is the sum of the RX to TX turnaround time ((T.B.D.) μs), MAC processing delay ((T.B.D.) μs) and the RSSI detect time ((T.B.D.) μs). The propagation delay shall be regarded as being included in the RSSI detect time.

Transmit and Receive Antenna Port Impedance

The transmit and receive antenna port(s) impedance shall be 50Ω if the port is exposed.

Transmit and Receive Operating Temperature Range

Three temperature ranges for full operation compliance to the OFDM PHY are specified in clause 13. Type 1, defined as 0°C to 40°C, is designated for office environments. Type 2, defined as –20°C to +50°C, and Type 3, defined as –30°C to +70°C, are designated for industrial environments.

PMD Transmit Specifications

The following portion of these subclauses describes the transmit functions and parameters associated with the Physical Medium Dependent sublayer. In general, these are specified by primitives from the PLCP and the Transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed onto the medium.

Transmit Power Levels

The maximum allowable output power is shown in Table 84.

Frequency Band	Maximum Output Power with up to 6 dBi antenna gain
5.15 - 5.25 GHz	50 mW
5.25 - 5.35 GHz	250 mW
5.725 - 5.825 GHz	1 W

Table 84, Transmit Power Levels

Transmit Power Level Control

If a conformant PMD implementation has the ability to transmit in a manner that results in the EIRP of the transmit signal exceeding the level of 100 mW, at least one level of transmit power control shall be implemented. The number of transmit power control level is less or equal than 4. This transmit power control shall be such that the level of the emission is reduced to a level at or below 100 mW under the influence of said power control.

Transmit Spectrum Mask

The transmitted spectral products shall be less than - y_1 dBc (dB from each carrier level) for $f_c - x_2$ MHz $< f < f_c - x_1$ MHz and $f_c + x_1$ MHz $< f < f_c + x_2$ MHz and $- y_2$ dBc for $f < f_c - x_2$ MHz and $f > f_c + x_2$ MHz where f_c is the channel center frequency. The transmit spectral mask is shown in Figure 126. The measurements shall be made using 1 MHz resolution bandwidth. **x_1, x_2, y_1, y_2 : T.B.D.**

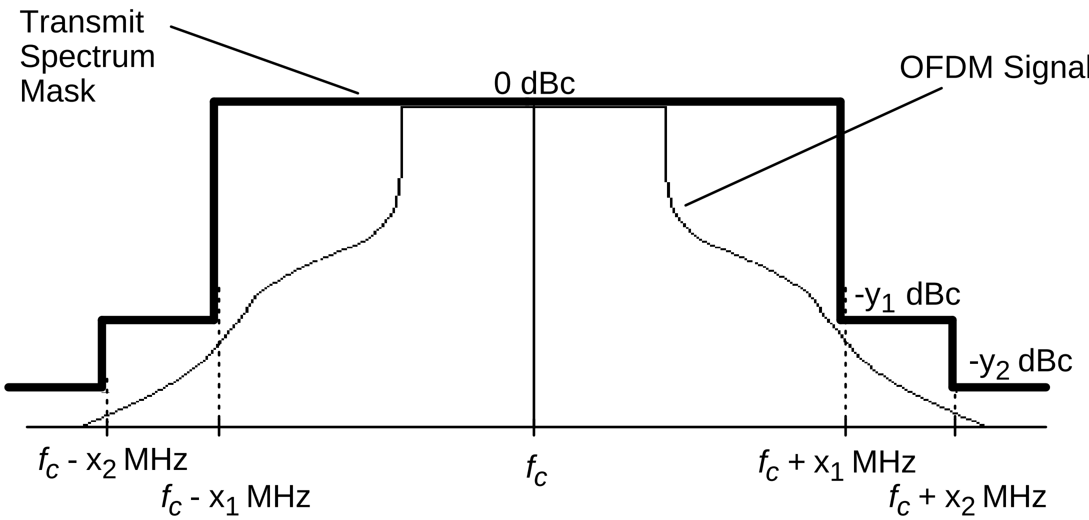

Figure 126, Transmit Spectrum Mask

Transmit Center Frequency Tolerance

The center frequency tolerance shall be ± 10 ppm maximum.

Transmission Spurious

The transmission spurious from compliant device shall conform to the local geographic regulations.

Frequency Stability

The frequency stability is the largest deviation that can be accepted from the assigned frequency of the frequency of the occupied bandwidth due to emissions. Absolute accuracy is ± 10 ppm or less.

Transmit Modulation Accuracy

It is the actual value of the error of the signal point vector (the square root of the result of dividing the sum of the squares of the errors of the signal point vectors by the number of phase identification points within the frame). It shall be measured when only one OFDM subcarrier is used and no other subcarriers are used. It is to be 10.0 % or less.

PMD Receiver Specifications

The following clauses describe the receive functions and parameters associated with the Physical Medium Dependent sublayer.

Receiver Minimum Input Level Sensitivity

The Packet Error Rate (PER) shall be less than 10% at an MPDU length of 1000 bytes for an input level of –79 dBm measured at the antenna connector.

Receiver Maximum Input Level

The receiver shall provide a maximum PER of 10% at an MPDU length of 1000 bytes for a maximum input level of –20 dBm measured at the antenna.

Receiver Adjacent Channel Rejection

Adjacent channel rejection is defined between any two channels defined in clause 1.5.6.3.

The adjacent channel rejection shall be equal to or better than (T.B.D.) dB with an PER of 10% at an MPDU length of 1000 bytes.

The adjacent channel rejection shall be measured using the following method:

Input a modulated signal at a level 6 dB greater than specified in clause 1.5.8.1. In an adjacent channel (any two channels as defined by the channel numbering), input a signal modulated in a similar fashion which adheres to the transmit mask specified in clause 1.5.7.3. to a level (T.B.D.) dB above the level specified in clause 1.5.8.1. The adjacent channel signal shall be derived from a separate signal source. It cannot be a frequency shifted version of the reference channel. Under these conditions, the PER shall be no worse than 10%.

Reception Level Detection

The OFDM PHY shall provide the capability to detect the reception level. The reception level detection values (RF level predicted values) for RF input level of –93 dBm ~ –43 dBm have monotonically increasing characteristics, and absolute accuracy is ± 6 dB.