



IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications

Amendment 3: Enhanced Flexible Channel Wavelet (FCW) Physical and Media Access Control Layers for Use on Any Media

IEEE Communications Society

Developed by the
Power Line Communications Standards Committee

IEEE Std 1901c™-2024
(Amendment to IEEE Std 1901™-2020)

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Approved 15 February 2024

IEEE SA Standards Board

Abstract: Physical (PHY) and media access control (MAC) layers of an improved flexible channel wavelet (FCW) technology to be usable for communication on any media called extended flexible channel wavelet (FCW) PHY/MAC are specified in this amendment. New communication channels are defined in low-frequency bands to extend the communication range and increase the robustness of communication, and how the IEEE Std 1588 precision time protocol (PTP) works over wavelet networks is specified to enhance network functions.

Keywords: any media, channel notification, coaxial cables, extended flexible channel wavelet (FCW) PHY/MAC, IEEE Std 1588, IEEE Std 1901, Internet of Things (IoT), medium access control (MAC), near field communication, physical layer (PHY), power lines, precision time protocol (PTP), signal cables, smart city, smart energy, smart grid, underwater communication, wavelet orthogonal frequency division multiplexing (wavelet OFDM)

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Introduction

This introduction is not part of IEEE Std 1901c-2024, IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications Amendment 3: Enhanced Flexible Channel Wavelet (FCW) Physical and Media Access Control Layers for Use on Any Media.

This amendment specifies physical (PHY) and media access control (MAC) layers of an improved flexible channel wavelet (FCW) technology to be usable for communication on any media called extended flexible channel wavelet (FCW) PHY/MAC. This amendment defines new communication channels in low-frequency bands to extend the communication range and increase the robustness of communication and specifies how the IEEE Std 1588 precision time protocol (PTP) works over wavelet networks. Extended FCW PHY/MAC is used for transmission over various media, including, but not limited to, power lines (ac or dc), coaxial cables, signal cables, optical fiber, light (visible, infrared), and radio waves.

With the growth of IoT applications, the requirements for communications are increasingly diverse. The IEEE 1901 networking technology can contribute to local area networks (LANs) in buildings, Smart Energy/Smart Grid applications, transportation platforms applications, underwater applications, and other data distribution. In these applications there is a demand for new usages of IEEE 1901 networks such as setting up underwater networks to communicate among drones, monitoring cameras, and various sensors, and building near-field communication systems cooperating with wireless charging for EVs, e-bikes, and robots.

New communication channels extended to low-frequency bands are needed to address long-range and robust communication on these new media and making IEEE Std 1588 precision time protocol (PTP) work over wavelet networks is effective to enhance network functions in these applications. This amendment specifies how to apply IEEE 1901 specifications on any media, and it is intended to achieve seamless communication over different media and between different communication channels.

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

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

1. Overview

1.1 Scope

Change subclause 1.1 as follows:

~~The scope of This standard is to define~~ defines medium access control (MAC) and physical layer (PHY) specifications for high-speed (>100 Mb/s at the physical layer) communication devices ~~via electric power lines, so called broadband over power line (BPL) devices~~ as well as lower speed Internet of Things

communication devices. ~~This standard uses transmission frequencies below 100 MHz. It is usable by all classes of BPL devices, for communications on any media including BPL, but not limited to, communications on power lines (AC or DC), coaxial cables, signal cables, optical fiber, and communications using light (visible, infrared), and radio waves. It is applicable to communication devices used for the first-mile/last-mile connection (<1500 m to the premise) to broadband services as well as BPL devices used in buildings for local area networks (LANs), in buildings, Smart Energy/Smart Grid applications, transportation platform platforms (vehicle, bike, robot) applications, underwater applications, Internet of Things applications, and other data distribution (<100 m between devices). This standard focuses on the balanced and efficient use of the. This standard defines how to apply PHY/MAC specifications for transmission over various media (e.g., communications on power lines, coaxial cables, signal cables, underwater communication, near field communications using loop antennas). This standard uses transmission frequencies below 100 MHz for communications on power line communications channel by all classes of BPL devices, defining detailed mechanisms for coexistence and interoperability between different BPL devices, lines and assuring that desired bandwidth and quality of service may be delivered. transmission frequencies below 125 MHz for communications on coaxial cables, signal cables or using radio waves.~~ The standard addresses the necessary security, privacy, authentication, and authorization questions to provide ~~privacy of secure~~ communications between users and allow the use of BPL network operations. This allows this standard to be used for security-sensitive services. It is limited to the physical layer and the medium access sublayer of the data link layer, as defined by the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Basic Reference Model. The standard is usable by all classes of broadband over power line (BPL) devices, including BPL devices used for the first-mile/last-mile connection (at least 1500 m to the premise) to broadband services as well as BPL devices used in buildings for local area networks (LANs). This standard defines detailed mechanisms for coexistence and interoperability between different BPL devices assuring a balanced and efficient use of the power line communications medium by all classes of BPL devices, and that desired bandwidth and quality of service may be delivered.

1.2 Purpose

Change subclause 1.2 as follows:

New modulation techniques offer the possibility to use ~~the power lines~~ any media for high-speed or long-range (lower speed) communications. ~~This new high-speed medium is open and locally shared by several BPL devices. Without an independent, openly defined standard, BPL devices serving different applications will conflict with one another and provide unacceptable service to all parties. The standard will provide The standard enables a minimum implementation subset that allows fair coexistence of the BPL devices. The full implementation will provide interoperability among BPL devices, as well as interoperability seamless integration~~ with other networking protocols, such as bridging for seamless interconnection via the IEEE Std 802.1X™ 2020. ~~It is also the intent 1 series of this effort to progress quickly toward a robust standard so power line applications may begin to impact the marketplace. Standards for Local and Metropolitan Area Network and enables seamless communications over different media and between high-speed and long-range (lower speed) networks. The standard also complies with electromagnetic compatibility (EMC) limits for communications on power lines set by national regulators, so as to enable successful coexistence with between BPL systems and wireless and telecommunications systems. The standard also complies with EMC limits for communications using radio waves set by national regulators.~~

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Add the following references to Clause 2:

IEEE Std 1588™-2002, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IEEE Std 1588™-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IEEE Std 1588™-2019, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

4.4 General description of the coexistence architecture

Change subclause 4.4 as follows:

Coexistence as described within this standard can be implemented in ~~two~~ three ways:

- Inter-system protocol (ISP): A mechanism for allowing the coexistence of IEEE access, IEEE in-home, low-rate wideband services (LRWBS), and ITU-T G.hn systems.
- Coexistence protocol (CXP): A mechanism for allowing any type of BPL system, including IEEE 1901 and ITU-T G.hn systems, to coexist. CXP allows any number of systems to coexist and supports priority-based resource sharing.
- Extended inter-system protocol (E-ISP): A mechanism for allowing the coexistence of one access system and three in-home systems.

All in-home IEEE 1901 SCW and FFT stations shall support ISP.

All in-home IEEE 1901 FCW and Extended FCW stations operating in the channel interoperable with SCW shall support ISP.

All ~~access~~ IEEE 1901 FCW and Extended FCW stations ~~shall~~ should support E-ISP.

The support of CXP is optional.

Coexistence mechanisms for the Extended FCW system are applied to the case only that Extended FCW is used on power lines.

Table 4-3—Overview of coexistence requirements (Informative)

<u>Mode of operation</u>		<u>SCW</u>	<u>FCW</u>	<u>Extended FCW</u>		<u>FFT</u>
<u>Media</u>		<u>Power lines</u>	<u>Power lines</u>	<u>Power lines</u>	<u>Other than Power lines</u>	<u>Power lines</u>
<u>Channel</u>	<u>x-1</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>N/A</u>	<u>N/A</u>
	<u>x-2 to x-15</u>	<u>N/A</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>N/A</u>	<u>N/A</u>
	<u>x-16 to x-27</u>	<u>N/A</u>	<u>N/A</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>	<u>N/A</u>	<u>N/A</u>
	<u>FFT</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>	<u>In-home: Mandatory</u> <u>Access: Optional</u>

4.4.1 Overview of 1901 coexistence mechanisms

Change subclause 4.4.1 as follows:

IEEE 1901 stations using ISP shall be capable of coexisting with all “IEEE 1901 ISP-conformant” G.hn devices, and with all LRWBS devices. Additionally, other “non-IEEE 1901 devices” can be managed using CXP to create other access and in-home combinations.

ISP is a resource-sharing mechanism that regulates access to the power line medium. In particular, ISP is designed for G.hn, 1901 access, 1901 in-home SCW, FCW and Extended FCW operating in channel x-1, and FFT in-home, and LRWBS. CXP, defined in Annex P, is a more general resource-sharing mechanism that allows non-1901 devices to efficiently share resources with each other and with 1901 stations. ISP and CXP are compatible. It is optional for power line communication systems conformant with the IEEE 1901 standard to implement CXP. ISP and CXP as specified in the standard operate on live alternating current (AC) power lines.

Access and in-home systems each consist of one master node and one or more slave nodes when transmitting or receiving ISP signals. ISP defines five categories of systems:

- 1901 access systems whether operating in TDM or FDM mode
- 1901 in-home systems that use any of the SCW OFDM PHY, FCW OFDM PHY operating in channel x-1, and Extended FCW OFDM PHY operating in channel x-1 (IH-W)
- 1901 in-home systems that use the FFT OFDM PHY (IH-O)
- G.hn systems
- LRWBS

The overhead of the ISP protocol ranges between 0.5% and 2.5%, depending on how many systems are running simultaneously.

ISP handles the situation when multiple BPL systems are in range of each other, i.e., when one or more BPL devices of a system can interfere with one of more BPL devices of another system. Specifically, the following situations are considered:

- Coexistence between an access BPL system (operating in TDM or FDM mode) and one or more in-home BPL systems, regardless of the PHY
- Coexistence among different in-home BPL systems equipped with 1901 SCW, FCW operating in channel x-1, Extended FCW operating in channel x-1, or FFT PHYs

When multiple 1901 systems share the same electrical wires, it is necessary to allocate resources. For example, when an access and an in-home system are in range of each other, 50% of the channel resources are available to the access system and 50% of the channel resources are available to the in-home system. Resource allocation is described in 16.5.

IEEE 1901 ~~access~~, in-home SCW, FCW and Extended FCW operating in channel x-1, and FFT in-home devices shall indicate their presence and requirements by transmitting a set of simple ISP signals. The particular ISP waveform used by 1901 BPL stations is defined in 16.2. ISP signals ~~shall~~ should be transmitted by all systems conforming to this standard, including the case when only one system is present.

On the basis of detected ISP signals, every 1901 in-home SCW, FCW and Extended FCW operating in channel x-1, and FFT in-home device will be able to determine its network status, i.e., identify BPL systems within interference range. Depending on the network status, different resource allocations will be carried out, as specified in 16.2.

4.4.3 ISP signaling

Change subclause 4.4.3 as follows:

Power line communication systems conforming to the SCW wavelet PHY (any of SCW, FCW operating in channel x-1, and Extended FCW operating in channel x-1) or the FFT PHY of the IEEE 1901 in-home standard shall coexist on a power line communication medium by sending and receiving signals, termed the inter-system protocol (ISP) signals, contained within ISP fields that make up the ISP window. Excluding a few exceptions, each system sends and receives ISP signals every synchronization period.

6 Frame formats

6.7 Flexible Channel Wavelet MPDU formats

6.7.4 FCW Beacon frame format

6.7.4.3 Data Body

Change subclause 6.7.4.3 as follows:

Refer to 6.6.4.3.

6.7.4.3.1 Schedule Information Blocks

Refer to 6.6.4.3.1.

6.7.4.3.2 Extended Information Block (EIB)

The EIB format is defined in Figure 6-25.

The Information ID is an 8-bit field that shows the kind of information carried by the EIB. Valid values for the Information ID field are defined in Table 6-510.

Table 6-510—Information IDs for EIBs

Value	Definition
<u>0–2</u>	<u>(reserved)</u>
<u>3</u>	<u>DVTP Information</u>
<u>4</u>	<u>Current NEK</u>
<u>5</u>	<u>ISP Information</u>
<u>6</u>	<u>RSN Information</u>
<u>7</u>	<u>Camellia Information</u>
<u>8–12</u>	<u>(reserved)</u>
<u>13</u>	<u>Channel Selection</u>
<u>14–254</u>	<u>(reserved)</u>
<u>255</u>	<u>End of Blocks</u>

Information IDs 0 to 2, 8 to 12, and 14 to 254 are reserved for future specifications. If the STA receives the EIB of which the Information ID is the reserved value, the STA discards the EIB.

Detailed structures of the EIBs for the valid Information IDs are defined in 6.7.4.4.

NOTE—The value of 13 in Table 6-510 is also valid when using the SCW Beacon frame format.

6.7.4.4 Extended Information Blocks

Change subclause 6.7.4.4 as follows and renumber figures 6-64 to 6-70 of Clause 6 as figures 6-66 to 6-72 respectively:

Refer to 6.6.4.4. This subclause defines the details of the EIBs for each Information ID.

6.7.4.4.1 DVTP Information type

Refer to 6.6.4.4.1.

6.7.4.4.2 Current NEK type

Refer to 6.6.4.4.2.

6.7.4.4.3 ISP Information type

Refer to 6.6.4.4.3.

6.7.4.4.4 RSN Information type

Refer to 6.6.4.4.4.

6.7.4.4.5 Camellia Information type

Refer to 6.6.4.4.5.

6.7.4.4.6 End of Blocks type

Refer to 6.6.4.4.6.

6.7.4.4.7 Channel Selection type

If the Information ID is 13, the EIB shows the information for channel selection.

The format of the Channel Selection Information type EIB is defined in Figure 6-64.

	Length	Information ID = 13	Message ID	Channel selection information
Bits:	8	8	8	variable

Figure 6-64—Channel Selection Information type EIB format (Beacon frame)

The EIB has the information depending on the message ID. The message ID is an 8-bit field that identifies the Channel Selection Information type. Valid values for the message ID field are defined in Table 6-511.

Table 6-511—Message IDs

Value	Definition
0	Channel Notification
1-255	(reserved)

NOTE—This type of EIB format is also valid when using the SCW Beacon frame format.

6.7.4.4.7.1 Channel Notification (Message ID = 0)

If the message ID is 0, the EIB shows the information for channel notification. The EIB notifies the information about the channel that is determined to be used in the network due to a vendor-specific algorithm.

The format of the Channel Notification for Channel Selection Information type EIB is defined in Figure 6-65.

	Length	Information ID = 13	Message ID = 0	Destination Channel	Channel notification information
Bits:	8	8	8	8	variable

Figure 6-65—Channel Notification format for Channel Selection Information type EIB

The destination channel is an 8-bit field and shall specify one of the channel IDs in 17.3.8.5.2. The STAs receiving this EIB shall change their own channel to the destination channel.

Insert the following subclauses after subclause 6.7:

6.8 Extended Flexible Channel Wavelet MPDU formats

Extended FCW MPDU format can apply both SCW MPDU format and FCW MPDU format. The BM and STAs in a network shall use the same type of format. Refer to either the description in subclause 6.6 or 6.7 according to the using format.

When the channel notification in 6.7.4.4.7.1 applies to Extended FCW, the destination channel shall specify one of the channel IDs in 19.3.8.5.2.

8. MAC sublayer functional description

8.2.2.2.1.1 Subframe concatenation

Change the second paragraph in subclause 8.2.2.2.1.1 as follows:

For concatenation of unicast subframes, Ssubframes are retransmission units in the 1901 MAC selective-ARQ, and when the receiving STA detects no error in either the subframe's SHCS or SBCS, it reports normal reception of the subframe by setting the bit corresponding to the response ACK's SFN (subframe no.) to one. The sending STA treats subframes corresponding to SFNs that are not set to one in the ACK frame despite having been sent as transmission errors and resends the data in subframe blocks.

Insert the following paragraph after the second paragraph in subclause 8.2.2.2.1.1:

For concatenation of broadcast subframe, data retransmission in units of subframe blocks using ACK frame is not performed.

Change title of subclause 8.2.13 as follows:

8.2.13 FCW and Extended FCW channel selection

Change subclause 8.2.13 as follows:

In an FCW OFDM and Extended FCW systems, since there are multiple modes and channels, a specific one is selected from among them, and the system is operated in that mode and channel.

The operator determines the optimum ~~mode and~~ channel taking into consideration system performance and requirements.

Change title of subclause 8.2.13.1 as follows:

8.2.13.1 Initial channel ~~and mode of~~ operation

Change subclause 8.2.13.1 as follows:

Initial ~~C~~channel selection ~~shall~~ should proceed as follows:

- a) For any given network, the default ~~mode and~~ channel of operation is determined by the network operator.
- b) A single STA is appointed as BM by the network operator, and the BM is configured to the default ~~a fixed mode and~~ channel.
- c) Each STA cycles over each ~~mode and~~ channel defined by the specifications or assigned in advance by the operator. In each ~~mode and~~ channel, the STA listens for the presence of a BM for at least one beacon interval. Where the STA detects the beacon transmitted by a BM, the STA joins the network according to the procedure described in 10.5 and operates as ~~an FCW~~ or Extended FCW system as defined in this clause.
- d) If the channel of operation should be changed from the default, the steps described in 8.2.13.2 may be performed. ~~Where no beacon is detected, the STAs continue to cycle over modes and channels until a BSS to which the STA may join is detected.~~

NOTE—The default setting is not defined in this standard. It depends on the use case.

Change title of subclause 8.2.13.2 as follows:

8.2.13.2 Changing channel ~~and mode of~~ operation

Change subclause 8.2.13.2 as follows:

Changing channel should either use the following options. ~~When a change of mode and channel is required due to various reasons, the channel of operation may be changed as follows:~~

Option 1:

- a) The operator changes the ~~mode and~~ channel on the BM.
- b) The STA detects that the current ~~mode and~~ channel have been changed (e.g., when the beacon is not received by the STA for a specified period, or when channel change information is included in the beacon).
- c) The STA begins cycling over each ~~mode and~~ channel, searching for a BSS to which it may connect, ~~as described in 8.2.13.1.~~

Option 2:

- a) The network operator or BM decides that the current channel should be changed.
- b) BM notifies STAs of the new channel. The beacon frame format described in 6.7.4.4.7.1 shall be used for notification.
- c) BM and STAs switch to the new channel after receiving the notification.

Change title of subclause 8.2.13.3 as follows:

8.2.13.3 Selection of optimum channel ~~and mode of operation~~

Change subclause 8.2.13.3 as follows:

The selection of the optimum channel ~~and mode of operation~~ is implementation specific.

8.2.13.4 Example of intelligent channel selection (informative)

Change subclause 8.2.13.4 as follows:

Note that when the operator changes the ~~mode and~~ channel on the BM, upon joining, the BM also obtains the corresponding transmission characteristics (e.g., CINR characteristics or PHY rate) in accordance with the channel estimation procedure described in 8.2.9. This information may be used to inform the choice of ~~mode and channel~~, and may be used as a decision metric for channel selection.

Since the decision algorithm differs depending on the use case of the system and is not uniquely determined, it is not specified in this standard.

17. Flexible Channel Wavelet physical layer

Insert the following subclause after subclause 17.2.2.2 and renumber Figure 17-2 to Figure 17-10 of Clause 17 as Figure 17-3 to Figure 17-11:

17.2.2.3 Synchronization Point for Timestamp on Precision Time Protocol over wavelet network (optional)

In order to operate precision time protocol over a wavelet network (refer to Annex ZB), it is necessary to define the timing of getting timestamp information in an FCW PPDU frame. Figure 17-2 shows the synchronization point for the timestamp. Specifically, this point is the tail sample in the SYNCM symbol that configures a preamble signal in Figure 14-19.

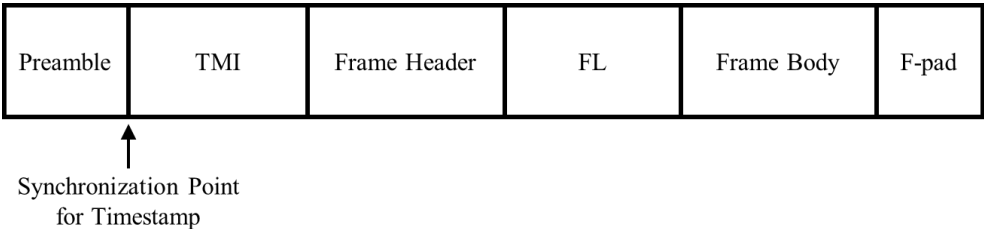


Figure 17-2—Synchronization point for timestamp in FCW PPDU frame

NOTE—The synchronization point for timestamp is the same when using the SCW frame format.

17.3.8.5.2 Channel plan and Channel ID

Change the sentence just following Table 17-5 as follows:

FCW stations shall support at least one of the following Channel IDs ~~x-1, x-2, x-3, x-4, x-5, x-6, and x-7,~~
x-8, x-9, x-10, x-11, x-12, x-13, x-14, and x-15.

Change the sentence just preceding Figure 17-9 as follows:

When a FCW STA is operating in CID x-1, the FCW STA ~~shall~~ should detect any SCW STA and the FCW STA ~~shall~~ should use SCW PHY/MAC frames.

17.5.2 PHY MIB

Change subclause 17.5.2 as follows and renumber Table 17-23 and Table 17-24 of Clause 17 as Table 17-24 and Table 17-25:

Refer to 14.5.2. All wavelet OFDM PHY MIB attributes are listed in Annex A. Some specific values are defined in Table 14-17 and values for precision time protocol over wavelet network (refer to Annex ZB) are defined in Table 17-23. The column titled “Operational semantics” in Table 17-23 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entities.

Table 17-23—MIB attribute default values/ranges for precision time protocol over wavelet network (optional)

<u>Managed Object</u>	<u>Default Value/Range</u>	<u>Operational Semantics</u>
1901 PHY Sync Parameter Table		
<u>plc1901TxSyncDelay</u>	<u>Implementation dependent</u>	<u>Static</u>
<u>plc1901RxSyncDelay</u>	<u>Implementation dependent</u>	<u>Static</u>

Insert the following subclauses after subclause 17.5.3:

17.5.4 TxSyncDelay derivation

The plc1901TxSyncDelay is a parameter of timing offset between the synchronization point on the transmitted frame in 17.2.2.3 and the PMD_TX_SYNC.indication in 17.6.5.11.

Since this depends on the implementation of this standard and the transmit state to generate PMD_TX_SYNC.indication, the value is determined by the frame encoding simulation and the processing delay through AFE (analog front end).

17.5.5 RxSyncDelay derivation

The plc1901RxSyncDelay is a parameter of timing offset between the synchronization point on the received frame in 17.2.2.3 and the PMD_RX_SYNC.indication in 17.6.5.12.

Since this depends on the implementation of this standard and the receive state to generate PMD_RX_SYNC.indication, the value is determined by the frame decoding simulation and the processing delay through AFE (analog front end).

17.6.4.2 PMD_SAP sublayer-to-sublayer service primitives

Change subclause 17.6.4.2 as follows:

Table 17-~~2423~~ indicates the primitives for sublayer-to-sublayer interactions.

Table 17-2423—PMD_SAP Sublayer-to-Sublayer Service Primitives

Primitive	Request	Indicate	Confirm	Response
PMD_TXSTART	X	—	—	—
PMD_TXEND	X	—	—	—
PMD_TX_TMI_T	X	—	—	—
PMD_TX_TMI_R	X	—	—	—
PMD_RX_TMI	X	—	—	—
PMD_RSSI	—	X	—	—
PMD_TX_FH_FC_SELECT	X	—	—	—
PMD_RX_FH_FC_SELECT	—	X	—	—
<u>PMD_TX_SYNC</u>	<u>—</u>	<u>X</u>	<u>—</u>	<u>—</u>
<u>PMD_RX_SYNC</u>	<u>—</u>	<u>X</u>	<u>—</u>	<u>—</u>

Insert the following subclauses after subclause 17.6.5.10:

17.1.1.11 PMD_TX_SYNC.indication

17.6.5.11.1 Function

This primitive, generated by the PMD sublayer, provides the timing of sending out the transmit frame.

17.6.5.11.2 Semantic of the service primitive

This primitive provides the following parameters:

PMD_TX_SYNC.indication ()

17.6.5.11.3 When generated

This primitive is generated by the PMD when the state of wavelet OFDM PHY changes to a certain transmit state and provides the timing. A certain transmit state is a state in which the time difference is fixed relative to the transmission waveform on the transmission medium, such as the completion of ToneMap symbol encoding. It is available continuously on the external system timer.

17.6.5.11.4 Effect of receipt

This indication is provided to the system timer to snapshot the hardware timestamp of the wavelet frame transmission.

17.6.5.12 PMD_RX_SYNC.indication

17.6.5.12.1 Function

This primitive, generated by the PMD sublayer, provides the timing of receive frame.

17.6.5.12.2 Semantic of the service primitive

This primitive provides the following parameters:

PMD_RX_SYNC.indication ()

17.6.5.12.3 When generated

This primitive is generated by the PMD when the state of wavelet OFDM PHY changes to a certain receive state and provides the timing. A certain receive state is a state in which the time difference is fixed relative to the received waveform on the transmission medium, such as the completion of ToneMap symbol decoding. It is available continuously on the external system timer.

17.6.5.12.4 Effect of receipt

This indication is provided to the system timer to snapshot the hardware timestamp of the wavelet frame received.

Insert the following clauses after Clause 18:

19. Extended Flexible Channel Wavelet physical layer for any media

19.1 Introduction

With the growth of IoT applications, the requirements for communications are increasingly diverse. Depending on the IoT application, high-speed or long-distance communication with robustness is required. Changing modes for operations in different channels with different values of carrier spacing provides flexibility to deal with these requirements. Communications using any media including, but not limited to, communications on power lines (AC or DC), coaxial cables, signal cables, optical fiber, and communications using light (visible, infrared), and radio waves are defined in this clause. It is applicable to communication devices used for local area networks (LANs) in buildings, Smart Energy/Smart Grid applications, transportation platforms (vehicle, bike, robot) applications, underwater applications, Internet of Things applications, and other data distribution.

This clause defines the physical layer of the Extended FCW OFDM system for any media. Wavelet OFDM modulation is resilient to selective frequency channel and narrowband noise, and provides very efficient frequency utilization, partly because it does not require guard intervals (GIs). Wavelet OFDM is intrinsically robust against narrowband noise since its very low side-lobes, much lower than conventional OFDM, allow good noise rejection and limited spectral leakage.

An Extended FCW OFDM frame shall be transmitted directly at baseband. The wavelet OFDM PHY consists of three protocol functions, as follows:

- a) A PHY convergence function, which adapts the capabilities of the PMD system to the PHY service. This function is supported by the physical layer convergence protocol (PLCP), which defines a method of mapping the 1901 PSDUs 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 (PMD) system.
- b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through any media between two or more stations, each using the wavelet OFDM system.
- c) A PHY layer management entity (PLME) that provides PHY management services.

19.1.1 Characteristics

The Extended FCW PHY provides a plurality of communication channels on any media. 512 evenly spaced carriers shall be placed into each channel. The base communication channel is from DC to 31.25 MHz. Extended FCW PHY supports the capability to change the sampling rate by a factor of $1/2^n$ where $n = [-2..5]$ which provides channels with bandwidth ranging from 0.9765625 MHz to 125 MHz. It also supports the capability to change the channel offset which provides 27 different channels in total within the DC to 125 MHz frequency band (Figure 19-2).

In high-speed mode, every carrier can be modulated with M-PAM (M: 2, 4, optional 8, optional 16, and optional 32) for its primary modulation. Further frequency diversity can be provided in order to improve the ability of the PHY to operate under adverse conditions. In diversity mode, every carrier can be modulated with 2PAM for the primary modulation. Robustness is also improved using FEC which includes Reed–Solomon encoder/decoder, Convolutional encoder/Viterbi decoder (Concatenated encoder/decoder) or LDPC-CC encoder/decoder.

Extended FCW PHY provides the capability to notch frequency when needed. For example notches can be used to limit unwanted emissions in amateur radio spectrums.

Country regulations may define limitations on the use of frequencies.

19.1.2 PHY functions

Refer to 17.1.2.

19.1.2.1 PLCP sublayer

Refer to 17.1.2.1.

19.1.2.2 PMD sublayer

Refer to 17.1.2.2.

19.1.2.3 PLME

Refer to 17.1.2.3.

19.1.3 Service specification method

Refer to 17.1.3.

19.1.4 SCW, FCW, and Extended FCW MAC parameters

Much of a particular MAC implementation's behavior is determined by a set of internal parameters. These parameters are used in SCW, FCW, and Extended FCW MAC descriptions in this and the following subclauses. The assumed default values for these parameters are listed in Table 19-1.

Extended FCW stations shall support $n_{sl} = 1$ (symbol length of 8.192 μs), $n_{sl} = 2$ (symbol length of 16.384 μs), $n_{sl} = 4$ (symbol length of 32.768 μs), $n_{sl} = 8$ (symbol length of 65.536 μs), $n_{sl} = 16$ (symbol length of 131.072 μs), and $n_{sl} = 32$ (symbol length of 262.144 μs). The Extended FCW parameters are the same as the SCW MAC when $n_{sl} = 1$ (symbol length of 8.192 μs), and the same as the FCW MAC when $n_{sl} = 2$ (symbol length of 16.384 μs) and $n_{sl} = 4$ (symbol length of 32.768 μs). Support for $n_{sl} = 1/2$ (symbol length of 4.096 μs) and $n_{sl} = 1/4$ (symbol length of 2.048 μs) is optional.

Table 19-1—SCW, FCW, and Extended FCW MAC internal parameters
($n_{sl} = 1, 2, 4, 8, 16, 32, 1/2, 1/4$)

Parameter	Definition	Value
BEACON_CYCLE	Duration time between beginnings of two adjacent beacon regions	Variable
MIN_CP_TIME	Minimum CP (contention period) duration required in a beacon cycle	$1.5 \times n_{sl}$ ms
BP_TIME	Duration of a beacon region	$1.7 \times n_{sl}$ ms
BP_CW	Contention window size for beacon backoff	15
MAX_SUBFRAMES	Maximum number of subframes in a data frame	60
MAX_MSDU_SIZE	Maximum allowable length of an MSDU	1518
MAX_TONE_MAPS	Maximum number of TMI	255 31 (optional)
MAX_FRAME_LENGTH	Maximum frame length	1023 symbols
MAX_ACTIVE_STA_COUNT	Maximum number of active STAs in a BSS	15
SYMBOL_TIME	FCW OFDM symbol time	$8.192 \times n_{sl}$ μ s
SLOT_TIME	Backoff slot time for CSMA/CA	6 symbols or 4 symbols (in the case of Short Preamble)
SLOT_TIME_DVTP	Slot time for DVTP	$54 \times n_{sl}$ μ s
CE_SEQUENCE_SIZE	Assessment sequence length	128 symbols
CE_TM_LIFETIME	Lifetime of Tone maps	Variable
CIFS_TIME	Duration time of CIFS	$100 \times n_{sl} \pm 10$ μ s
RIFS_TIME	Duration time of RIFS	$50 \times n_{sl} \pm 10$ μ s
SIFS_TIME	Duration time of SIFS	$100 \times n_{sl} \pm 10$ μ s
RCG	Gap time between the end of received RTS and the beginning to transmit CTS	$50 \times n_{sl} \pm 10$ μ s
CMG	Gap time between the end of received CTS and the beginning to transmit an MPDU	$50 \times n_{sl} \pm 10$ μ s
POST_GUARD_SIZE	Value of the Post Guard field when the scheduling information is not going to be changed	2 (Stand-alone mode) 5 (Subnet mode)
BAND_RETRY_LIMIT	Bandwidth reserve consecutive retry limit	Arbitrary
LS_TIMEOUT	Link status timeout	Max. 10 s
SUBNET_CHECK_TIME	Subnet check time	10 s
AUTH_CT_REQ_WAIT_TIME	Maximum challenge request wait time	1000 ms
AUTH_CT_RSP_WAIT_TIME	Maximum challenge reply wait time	1000 ms
AUTH_RSP_WAIT_TIME	Maximum authentication reply wait time	1000 ms
AUTH_START_WAIT_TIME	Minimum authentication start wait time	1000 ms
DEAUTH_IND_RSP_WAIT_TIME	Maximum deauthentication notice reply wait time	1000 ms
CE_RSP_WAIT_TIME	Maximum CER receipt wait time	3000 ms
BAND_RSP_WAIT_TIME	Maximum bandwidth reserve reply wait time	1000 ms
SCHED_AGING_WAIT_RSP_TIME	Schedule management table aging notice reply wait timer	15 000 ms
TIME_INIT_WAIT	The time for a STA to investigate whether a BM exists or not just after start-up	1 s
TIME_NOMINATE	Maximum wait time for performing nomination procedure	1 s
TIME_STATIS_COL	Maximum Time for informing the statistics information	Arbitrary Recommended value: 10 s
SHORTFRAME_LEN	The length of the smallest frame such as ACK frame which has no payload	23 symbols
WAIT_REVERSE_TIME	The waiting time in Bidirectional Transmission	600 μ s
CERC_REL_TIME	The time for a BM to release CE region assigned to a STA in Channel Estimation Region	Max. BEACON_CYCLE $\times$ 40
DVTP_DELETION_TIME	The time for a BM to delete assigned STID in DVTP	Min. 6 s
BSS_BANDKEEP_TIME	The time to keep bandwidth in Bandwidth negotiation among BSSs	2 s
BSS_SUBNETALONE_TIME	The time to receive no Beacon from other BSSs changing into normal alone mode from subnet mode	Arbitrary Recommended value: 10 s
RSSI_MAX	Maximum value of RSSI	255

19.2 PLCP sublayer

19.2.1 Introduction

Refer to 17.2.1.

19.2.2 PLCP frame format

The format for the Extended FCW PPDU including Preamble, TMI, Frame Header, Frame Length, Frame Body and Pad bits is the same as the format for FCW PPDU in Figure 17-1.

The preamble length is from 11 to 68 Extended FCW OFDM symbols. The TMI and FL are each one Extended FCW OFDM symbol, and the Frame Header is 8 Extended FCW OFDM symbols. The configuration of each symbol and the modulation type (e.g., PAM, FEC) are the same as those of FCW in 17.2.2.

NOTE—Although only the FCW frame format is described here as the Extended FCW frame format, the SCW frame format in Figure 14-1 may also be applied.

19.2.2.1 Overview of the PPDU encoding/decoding process

Refer to 17.2.2.1.

19.2.2.2 Modulation-dependent parameters

A channel estimation request frame (RCE frame) includes an Extended FCW OFDM symbol array for evaluation data, or in other words, the STA sends a CE request to obtain CINR properties and determine the parameters, such as tone map carrier and modulation information.

If the destination address written in the Frame Header matches the address of the receiver STA, it shall return a CER frame that includes these tone map parameters, after performing channel estimation and determining parameters such as tone map and FEC. With this operation, the tone maps of Source STA and Destination STA are shared.

The tone map includes Modulation Type, FEC Type, and Diversity Mode Flag. Refer to 6.6.7.3.

Here, we show the example of how to calculate the DATARATE and Frame Length:

The possible rates of the convolutional codes (conv_rate) are: 1/2, 2/3, 3/4, 4/5, 5/6, 6/7, 7/8.

The possible rates of the RS code (rs_rate) are: 40/56, 239/255.

The possible rates of the LDPC-CC codes (ldpc-cc_rate) are: 1/2, 2/3, 3/4, 4/5.

Each DATARATE is calculated as follows.

As the first, we show the calculation of DATARATE with Reed–Solomon code and concatenated code:

$\text{DATARATE (Mb/s)} = \text{symbits} \times \text{conv_rate} \times \text{rs_rate} / \text{symbol_duration}$

$\text{symbol_duration} = \text{number_carriers} / \text{sample_rate}$

$\text{symbits} = \text{number of bits per symbol}$

In the case of DOF mode, symbits = 50 is specially set.

NOTE—Modes are described in Table 19-4 and Table 19-5.

An example of the Reed–Solomon code with ALL 8PAM (with 510 carriers) and rs_rate (239/255),

$\text{symbits} = 510 \times 3 = 1530$

when XB1-1Ch mode $\text{DATARATE} = 1530 \times 239 / 255 / 8.192 = 175.05 \text{ [Mb/s]}$

when XB1-2Ch mode $\text{DATARATE} = 1530 \times 239 / 255 / 16.384 = 87.52 \text{ [Mb/s]}$