

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

Amendment 1: Enhancement for Internet of Things Applications

IEEE Communications Society

Sponsored by the
Power Line Communications Standards Committee

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

IEEE Std 1901a™-2019
(Amendment to
IEEE Std 1901-2010)

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

Amendment 1: Enhancement for Internet of Things Applications

Sponsor

Power Line Communications Standards Committee
of the
IEEE Communications Society

Approved 21 March 2019

IEEE-SA Standards Board

Abstract: Physical (PHY) and media access control (MAC) layers of a broadband powerline communication technology called flexible channel wavelet PHY/MAC (FCW) for Internet of Things applications (IoTPLC) based on wavelet orthogonal frequency division multiplexing (wavelet OFDM) are specified in this amendment. Modes for operations in different channels (frequency bands) with different values of carrier spacing are defined.

Keywords: extended ISP (E-ISP), flexible channel wavelet (FCW) PHY/MAC, IEEE 1901a, Internet of Things (IoT), medium access control (MAC), physical layer (PHY), power line communication (PLC), wavelet orthogonal frequency division multiplexing (wavelet OFDM)

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2019 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 10 May 2019. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-5679-1 STD23624
Print: ISBN 978-1-5044-5680-7 STDPD23624

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

This entity-based standard was created under the leadership of the following individuals:

Jean-Philippe Faure, *Chair*
Markus Rindchen, *Vice Chair*

At the time this IEEE standard was completed, the Standard for Internet of Things Powerline Communication Working Group had the following membership:

ACN Advanced Communications Networks SA	Panasonic
HD-PLC Alliance	Power Plus Communications AG

The Working Group gratefully acknowledges the contributions of the following entities and participants. Without their assistance and dedication, this standard would not have been completed.

ACN Advanced Communications Networks SA.....	Stephan Horvath David Naughton
HD-PLC Alliance.....	Michimasa Aramaki Hisao Koga Makato Hirano Ryo Sakaji Kaiyun Cheng
Panasonic.....	Jean-Philippe Faure Naohiro Kawabata
Power Plus Communications AG.....	Markus Rindchen C. Scott Willy

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Ericsson AB	Panasonic Corporation of North	Renesas Electronics Corporation
HD-PLC Alliance	America	Siemens Corporation
IoTecha Corp	Power Plus Communications AG	STMicroelectronics
National Taiwan University	Qingdao Eastsoft Communication	Wi-SUN Alliance
	Technology Co., Ltd.	

When the IEEE-SA Standards Board approved this standard on 21 March 2019, it had the following membership:

Gary Hoffman, *Chair*
Vacant Position, *Vice Chair*
Jean-Philippe Faure, *Past Chair*
Konstantinos Karachalios, *Secretary*

Masayuki Ariyoshi
Ted Burse
Stephen D. Dukes
J. Travis Griffith
Guido Hiertz
Christel Hunter
Thomas Koshy
Joseph L. Koepfinger*

Thomas Koshy
John D. Kulick
David J. Law
Joseph Levy
Howard Li
Xiaohui Liu
Kevin Lu
Daleep Mohla
Andrew Myles

Annette D. Reilly
Dorothy Stanley
Sha Wei
Phil Wennblom
Philip Winston
Howard Wolfman
Feng Wu
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 1901a-2019, IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications—Amendment: Enhancement for Internet of Things Applications.

This amendment specifies physical (PHY) and media access control (MAC) layers of a broadband powerline communication technology called flexible channel wavelet (FCW) for Internet of Things applications (IoTPLC) based on wavelet orthogonal frequency division multiplexing (wavelet OFDM). This amendment defines modes for operations in different channels (frequency bands) with different values of carrier spacing. FCW PHY/MAC can be used for wired communications via physical media such as, but not limited to, electric power lines and coaxial cables.

With the growth of IoT applications, the requirements for communications are increasingly diverse. Some IoT applications, such as 8k/4k video applications for entertainment or security, need to communicate data at very high speed. Other IoT applications, such as IoT for smart cities, energy management, building control, and light control, need long distance communication instead of very high speed communication. The different modes specified in IEEE Std 1901a intend to address this diversity of requirements.

Contents

1. Overview	10
1.1 Scope	10
1.4 Overview of annexes	11
3.1 Definitions	11
3.2 Acronyms and abbreviations	12
4.4 General description of the coexistence architecture	13
6. Frame formats.....	14
6.6 In-home and access wavelet MPDU formats.....	14
6.7 Flexible Channel Wavelet MPDU formats	18
14. Wavelet physical layer	28
14.1 Introduction	28
17. Flexible Channel Wavelet physical layer	32
17.1 Introduction	32
17.2 PLCP sublayer.....	35
17.3 PHY encoder.....	40
17.4 PMD	95
17.5 PLME	97
17.6 PMD sublayer service.....	98
18. Extended inter-system protocol (E-ISP).....	101
18.1 E-ISP overview.....	101
18.2 Coexistence signal definition.....	102
18.3 Coexistence signaling scheme	103
18.4 Coexistence resources.....	107
18.5 E-ISP resource allocation	108
18.6 Start-up and resynchronization procedures.....	109
18.7 E-ISP EMI control procedures.....	110
18.8 E-ISP time slot reuse	110
18.9 Generic management messages	110
18.10 Signal transmission and detection.....	113
Annex A (normative) List of the IEEE 1901 MAC and PHY management variables.....	114
Annex X (informative) Bibliography	115
Annex Y (informative) Multi-hop communication in 1901 networks	116

IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications—Amendment 1: Enhancement for Internet of Things Applications

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.¹

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 ~~striketrough~~ (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 1.1 as follows:

The project defines a standard for high-speed (>100 Mbps at the physical layer) communication devices via electric power lines, so-called broadband over power line (BPL) devices. This standard uses transmission frequencies below 100 MHz. It is usable by all classes of BPL devices, including BPL 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), smart energy applications, transportation platform (vehicle) applications, Internet of Things applications, and other data distribution (<100 m between devices). This standard focuses on the balanced and efficient use of the power line communications channel by all classes of BPL devices, defining detailed mechanisms for coexistence and interoperability between different BPL

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

devices, and assuring that desired bandwidth and quality of service may be delivered. The standard addresses the necessary security questions to provide privacy of communications between users and allow the use of BPL 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.

1.4 Overview of annexes

Insert the following text at the end of 1.4:

- Annex X (informative) Multi-hop communication in 1901 networks

3.1 Definitions

Insert the following definitions in alphabetical order into 3.1:

Advanced DOF (ADOF mode): The optional diversity-orthogonal frequency division multiplexing (OFDM) for frame body mode (DOF mode), supported in SCW and flexible channel wavelet (FCW) operation, using a low-density parity check code (LDPC) forward error correction (FEC) for error-correction coding.

in-home wavelet: Applies either to single channel wavelet (SCW) or flexible channel wavelet (FCW).

ISP state wavelet: Applies either to single channel wavelet (SCW) or flexible channel wavelet (FCW).

wavelet BM: Either single channel wavelet (SCW) basic service set manager (BM) or flexible channel wavelet (FCW) BM.

wavelet BSS: Either single channel wavelet (SCW) basic service set (BSS) or flexible channel wavelet (FCW) BSS.

wavelet CBC: Either single channel wavelet (SCW) cipher block chaining (CBC) or flexible channel wavelet (FCW) CBC.

wavelet channel estimation: Either single channel wavelet (SCW) channel estimation or flexible channel wavelet (FCW) channel estimation.

wavelet MAC: Either single channel wavelet (SCW) or flexible channel wavelet (FCW) medium access control (MAC).

wavelet PHY: Either single channel wavelet (SCW) or flexible channel wavelet (FCW) physical layer (PHY).

wavelet station: A station using a IEEE 1901 wavelet physical layer (PHY)/medium access control (MAC) (either single channel wavelet [SCW] or flexible channel wavelet [FCW] or both).

wavelet system: A system using a IEEE 1901 wavelet physical layer (PHY)/medium access control (MAC) (either single channel wavelet [SCW] or flexible channel wavelet [FCW] or both).

Change the following definitions as follows:

in-home wavelet system: An in-home system using ~~the~~ IEEE 1901 wavelet physical layer (PHY)/medium access control (MAC).

resync signal: Signal that is transmitted by a system in order to request a resynchronization in other systems. Any in-home system that detects such a signal should enter the resynchronization state. An access system does not need to enter the resynchronization state. The resync signal is defined differently for each type of system, as follows:

- Coexistence protocol (CXP): Phase vector Φ_6 in the field R
- Inter-system protocol (ISP) in-home wavelet system: Phase vector Φ_3 in the field WRF
- ISP orthogonal frequency division multiplexing (OFDM): Phase vector Φ_2 in the field ORF

3.2 Acronyms and abbreviations

Change the following abbreviations and acronyms as follows:

ISPSTW ISP state in-home wavelet system

Insert the following abbreviations and acronyms into 3.2 in alphabetical order:

ADOF	advanced DOF
FCW	flexible channel wavelet
FH	frame header
SCW	single channel wavelet

4.3.3.1 Physical network

Change the first paragraph of 4.3.3.1 as follows:

The physical network (PHYNET) of a given STA is the set of STAs whose PHYs interoperate with the STA's PHY (without use of relays or repeaters). Interoperability involves readability of the frame control (FC) and use of diversity-orthogonal frequency division multiplexing (OFDM) for frame body (DOF) (either SCW or FCW ~~wavelet~~) or ROBO (FFT) mode (i.e., it is the set of interoperable PHYs whose unrepeated transmissions can be received by the STA's PHY). All STAs in a PHYNET have the potential to interfere with each other. However, they also have the capability to minimize mutual interference through coordination, such as simple communications or coexistence modes (refer to Clause 15 and 15.6.2).

4.4 General description of the coexistence architecture

Change 4.4 as follows:

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

- a) 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.
- b) 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.
- c) Extended inter-system protocol (E-ISP): A mechanism for allowing the coexistence of one access system and three in-home systems.

All IEEE 1901 SCW and FFT stations shall support ISP.

IEEE 1901 FCW stations operating in the channel interoperable with SCW shall support ISP.

All IEEE 1901 FCW stations shall support E-ISP.

The support of CXP is optional.

4.4.1 Overview of 1901 coexistence mechanisms

Change 4.4.1 as follows:

IEEE 1901 stations using ISP shall be capable of coexisting, ~~using ISP, with all IEEE 1901 stations (whether wavelet or FFT),~~ 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 SCW, 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 the ~~wavelet~~ SCW OFDM PHY (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 or 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 ~~different~~ 1901 SCW 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 ~~and~~ SCW 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 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 SCW and FFT in-home device and every access 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.

4.4.2 Frequency bands

Change the first and second paragraphs of 4.4.2 as follows:

The IEEE 1901 coexistence mechanisms (ISP, E-ISP, and CXP) operate within the frequency range 2 MHz to 30 MHz. This is divided into two frequency bands, channel #x for the lower band and channel #y for the higher band.

In ISP and E-ISP, the boundary between the channels is configured to be one of two values by signaling in Field ACF2 on the access ISP window.

4.4.3 ISP signaling

Change 4.4.3 as follows:

Power line communication systems conforming to the SCW PHY or the FFT PHY of the IEEE 1901 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

6.6 In-home and access wavelet MPDU formats

Change the title of 6.6 as follows:

6.6 In-home and access Single Channel ~~W~~Wavelet MPDU formats

6.6.1 General wavelet MPDU format

Change the title of 6.6.1 as follows:

6.6.1 General SCWavelet MPDU format

Change the second paragraph of 6.6.1 as follows:

This subclause specifies the general SCW MPDU format. Some Control frames contain only the Frame Control field. Data frames, Management frames, and some Control frames contain the Frame Control, Frame Body, and Padding fields. Each field in the Frame Control is defined in 6.6.1.1. Each Control frame format is defined in 6.6.1.1.2. The Data frame format and Management frame format are defined in 6.6.9 and 6.6.11, respectively.

Figure 6-17—Wavelet MPDU frame format

Change the title of Figure 6-17 as follows:

Figure 6-17—SCWavelet MPDU frame format

6.6.1.1.2 Frame Type (FT) field

Change the title of 6.6.1.1.2 as follows:

6.6.1.1.2 SCW Frame Type (FT) field

Change 6.6.1.1.2 as follows:

The SCW Frame Type (FT) field contains the identifier of the specific type of frame that is being transmitted. The valid values for this field are listed in Table 6-440.

Table 6-440—Frame Type (FT) Field

Change the title of Table 6-440 as follows:

Table 6-440—SCW Frame Type (FT) Field

6.6.4 Beacon frame format

Change the title of 6.6.4 as follows:

6.6.4 SCW Beacon frame format

Change the second paragraph of 6.6.4 as follows:

The frame format of the SCW Beacon frame is as defined in Figure 6-20.

Figure 6-20—Wavelet Beacon frame format

Change the title of Figure 6-20 as follows:

Figure 6-20—SCWavelet Beacon frame format

6.6.5 ACK frame format

Change the title of 6.6.5 as follows:

6.6.5 SCW ACK frame format

Change the first paragraph of 6.6.5 as follows:

The frame format of the SCW ACK frame is shown in Figure 6-36.

Figure 6-36—ACK frame format

Change the title of Figure 6-36 as follows:

Figure 6-36—SCW ACK frame format

6.6.6 Request Channel Estimation (RCE) frame format

Change the title of 6.6.6 as follows:

6.6.6 SCW Request Channel Estimation (RCE) frame format

Change the first paragraph of 6.6.6 as follows:

The ~~frame Variant field~~ format of the SCW RCE frame is as defined in Figure 6-38.

Figure 6-38—RCE frame format

Change the title of Figure 6-38 as follows:

Figure 6-38—SCW RCE frame format

6.6.7 Channel Estimation Response (CER) frame format

Change the title of 6.6.7 as follows:

6.6.7 SCW Channel Estimation Response (CER) frame format

Change the first paragraph of 6.6.7 as follows:

The SCW CER frame is defined in Figure 6-40.

Figure 6-40—CER frame format

Change the title of Figure 6-40 as follows:

Figure 6-40—SCW CER frame format

6.6.8 Stream End frame format

Change the title of 6.6.8 as follows:

6.6.8 SCW Stream End frame format

Change the third paragraph of 6.6.8 as follows:

The frame format of the SCW Stream End frame is as defined in Figure 6-43.

Figure 6-43—Stream End frame format

Change the title of Figure 6-43 as follows:

Figure 6-43—SCW Stream End frame format

6.6.9 Data MPDU format

Change the title of 6.6.9 as follows:

6.6.9 SCW Data MPDU format

Change the second paragraph of 6.6.9 as follows:

The frame format of the SCW Data frame is as defined in Figure 6-45.

Figure 6-45—Wavelet Data frame format

Change the title of Figure 6-45 as follows:

Figure 6-45—SCWavelet Data frame format

6.6.10 RTS/CTS frame format

Change the title of 6.6.10 as follows:

6.6.10 SCW RTS/CTS frame format

Change the first paragraph of 6.6.10 as follows:

The frame format of the SCW RTS (Request to Send)/CTS (Clear to Send) frame is as defined in Figure 6-50. The RTS/CTS frame does not have a Data Body field.

Figure 6-50—RTS/CTS frame format

Change the title of Figure 6-50 as follows:

Figure 6-50—SCW RTS/CTS frame format

6.6.11 Management frames

Change the title of 6.6.11 as follows:

6.6.11 SCW Management frames

6.6.11.1 Management frame format

Change the title of 6.6.11.1 as follows:

6.6.11.1 SCW Management frame format

Change the first paragraph of 6.6.11.1 as follows:

The frame format of the SCW Management frame is as defined in Figure 6-52. The Management frame has a Subtype field that shows the type of the Management frame. Most Management frames have Frame Bodies.

Figure 6-52—Management frame format

Change the title of Figure 6-52 as follows:

Figure 6-52—SCW Management frame format

Insert the following subclauses after 6.6:

6.7 Flexible Channel Wavelet MPDU formats

6.7.1 FCW MPDU format

The MPDU format comprises a set of fields that occur in a fixed order. The MPDU Data frame format is composed of subframes that are generated by combining MSDUs and a Subframe Header. The MPDU Management frame format is composed of the MAC Frame Header and management information.

This subclause specifies the FCW MPDU format. Some Control frames contain only the Frame Control field. Data frames, Management frames, and some Control frames contain the Frame Control, Frame Body, and Padding fields. Each field in the Frame Control is defined in 6.7.1.1. Each Control frame format is defined in 6.7.1.1.2. The Data frame format and Management frame format are defined in 6.7.9 and 6.7.11, respectively.

The Frame Header is defined as the specific set of fields in the Frame Control shown in Figure 6-61. The Frame Header might be received by any STA within the same BSS as well as by STAs that belong to other BSSs. Each field in the Frame Control except the Frame Header and each MPDU Frame Body field shall only be demodulated by particular stations that are specified by the DA field. The one exception to this rule occurs when the entire frame is modulated using DOF mode, which makes it readable by any STA within receiving range.

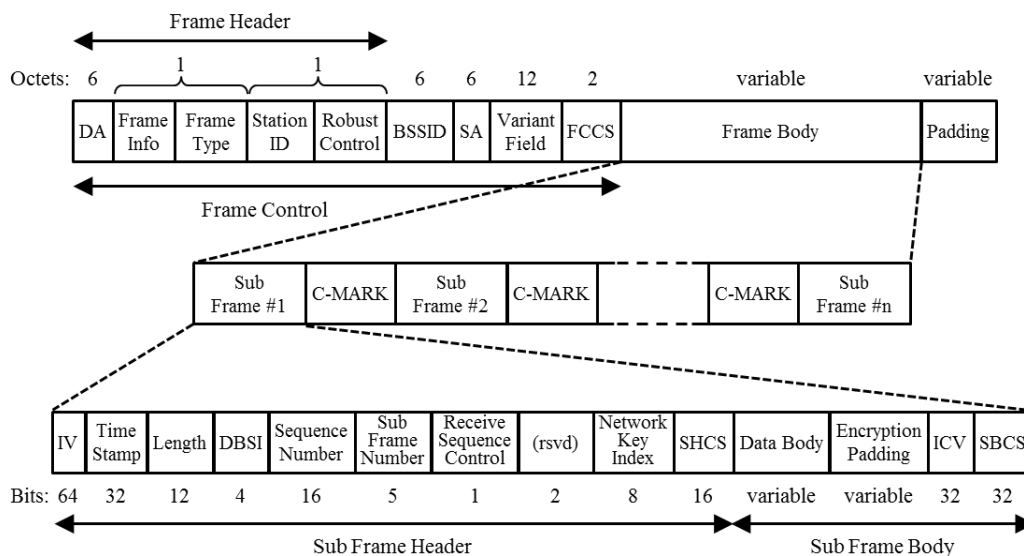


Figure 6-61—FCW MPDU frame format

6.7.1.1 Frame Control field

6.7.1.1.1 Address fields

There are three Address fields, BSSID, DA, and SA, in the Frame Control field.

DA is assigned to the Frame Header field.

6.7.1.1.1.1 Address representation

Refer to 6.6.1.1.1.1.

6.7.1.1.1.2 Address designation

Refer to 6.6.1.1.1.2.

6.7.1.1.1.3 BSS ID field

Refer to 6.6.1.1.1.3.

6.7.1.1.1.4 Destination Address (DA) field

Refer to 6.6.1.1.1.4.

6.7.1.1.1.5 Source Address field

Refer to 6.6.1.1.1.5.

6.7.1.1.2 FCW Frame Type (FT) field

The FCW Frame Type (FT) field contains the identifier of the specific type of frame that is being transmitted. The valid values for this field are listed in Table 6-511.

Table 6-511—FCW Frame Type (FT) Field

MPDU type value	MPDU type		Number of subframes
0000	DATA	User data	1 to MAX_SUBFRAMES
0001	ACK	Acknowledgment	0
0010	RCE	Channel estimation request	1
0011	CER	Channel estimation response	1
0100	BEACON	Beacon	1
0101	SrEND	End of stream	0
0110	MANAGEMENT	MAC control data	1
0111	RTS/CTS	Request to send/clear to send	0 or 1
1000 to 1111	Reserved		

6.7.1.1.3 Station ID field

Refer to 6.6.1.1.3.

6.7.1.1.4 Robust Control field

Refer to 6.6.1.1.4.

6.7.1.1.5 Variant field (VF)

Refer to 6.6.1.1.5.

6.7.1.1.6 Frame Control Check Sequence (FCCS) field

Refer to 6.6.1.1.6.

6.7.1.1.7 Frame Info field

The Frame Info field contains the PHY layer control information. Figure 6-62 shows the format of the Frame Info field.

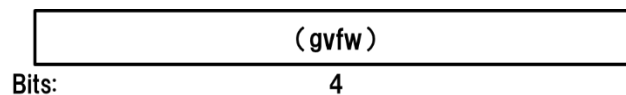


Figure 6-62—Frame Info field

6.7.1.2 Frame Body field

Refer to 6.6.1.2.

6.7.1.3 Padding field

Refer to 6.6.1.3.

6.7.2 Concatenation of subframes

Refer to 6.6.2.

6.7.3 Concatenation formats inside subframes

Refer to 6.6.3.

6.7.4 FCW Beacon frame format

The Beacon frame indicates the beginning of a beacon cycle. The data body of the Beacon frame has a transmission schedule that is sent in DOF mode. Refer to 14.3.8.1.2.4.

The frame format of the FCW Beacon frame is as defined in Figure 6-63.

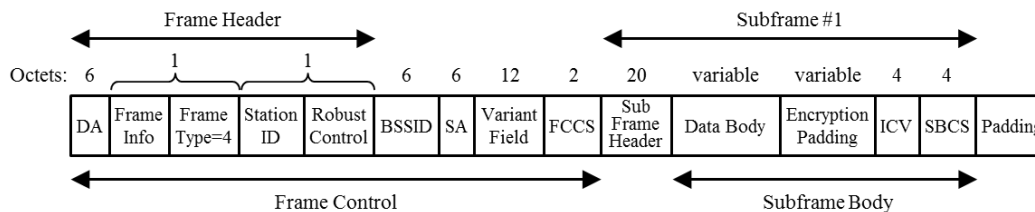


Figure 6-63—FCW Beacon frame format

6.7.4.1 Variant field

Refer to 6.6.4.1.

6.7.4.2 Subframe Header

Refer to 6.6.4.2.

6.7.4.3 Data Body

Refer to 6.6.4.3.

6.7.4.4 Extended Information Blocks

Refer to 6.6.4.4.

6.7.5 FCW ACK frame format

The frame format of the FCW ACK frame is shown in Figure 6-64.

The ACK frame is used as a reply for DATA frame reception. The ACK frame might notify a transmitter STA of normal reception by the recipient STA or a discarded DATA frame, or it might serve as a request for a retransmission.

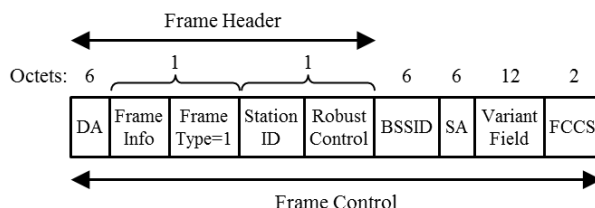


Figure 6-64—FCW ACK frame format

6.7.5.1 Variant field

Refer to 6.6.5.1.

6.7.6 FCW Request Channel Estimation (RCE) frame format

The frame format of the FCW RCE frame is as defined in Figure 6-65.

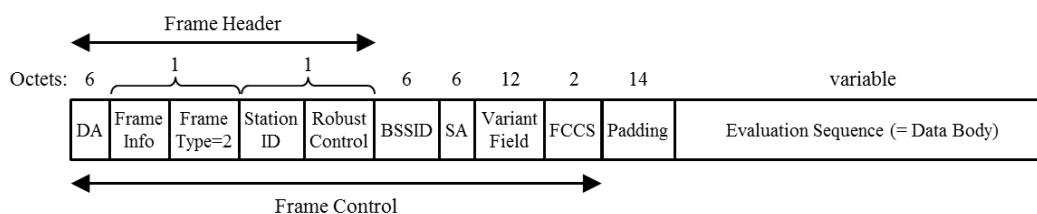


Figure 6-65—FCW RCE frame format

The Request Channel Estimation (RCE) frame is used to request channel estimation from the MAC of another station. A RCE frame has one subframe. The RCE Frame Body field contains the Evaluation Sequence, and it is modulated in all 2PAM.

6.7.6.1 Variant field

Refer to 6.6.6.1.

6.7.6.2 Evaluation sequence

Refer to 6.6.6.2.

6.7.7 FCW Channel Estimation Response (CER) frame format

The FCW CER frame is defined in Figure 6-66.

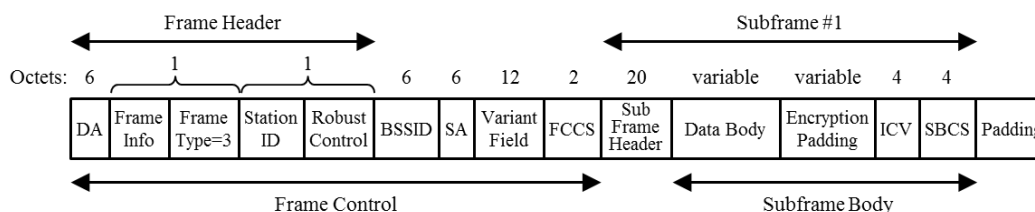


Figure 6-66—FCW CER frame format

The Channel Estimation Response (CER) frame is the response to an RCE request frame. The RCE Frame Body has one segment block and an E-Mark.

6.7.7.1 Variant field

Refer to 6.6.7.1.

6.7.7.2 Subframe Header field

Refer to 6.6.7.2.

6.7.7.3 Data Body field

Refer to 6.6.7.3.

6.7.8 FCW Stream End frame format

The Stream End frame is broadcast to indicate that a stream of some link finished the Data frame transmission in the CFP.

The Stream End frame is sent to start transmission of the subsequent stream in the CFP where one exists or to start the CP period time earlier when data communication ends well before the CFP period allocation time. The Stream End frame is not sent if the remaining allocation time is insufficient.

The frame format of the FCW Stream End frame is as defined in Figure 6-67.

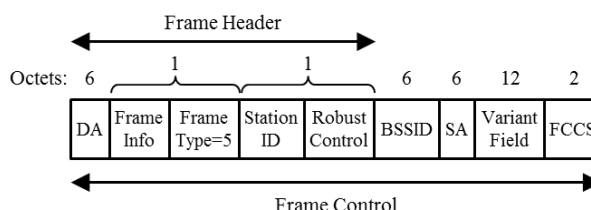


Figure 6-67—FCW Stream End frame format

6.7.8.1 Variant field

Refer to 6.6.8.1.

6.7.9 FCW Data MPDU format

The Data frame is used to send the MSDU passed from the upper layers. The Data frame has a Frame Body consisting of from one to MAX_SUBFRAMES.

The frame format of the FCW Data frame is as defined in Figure 6-68.

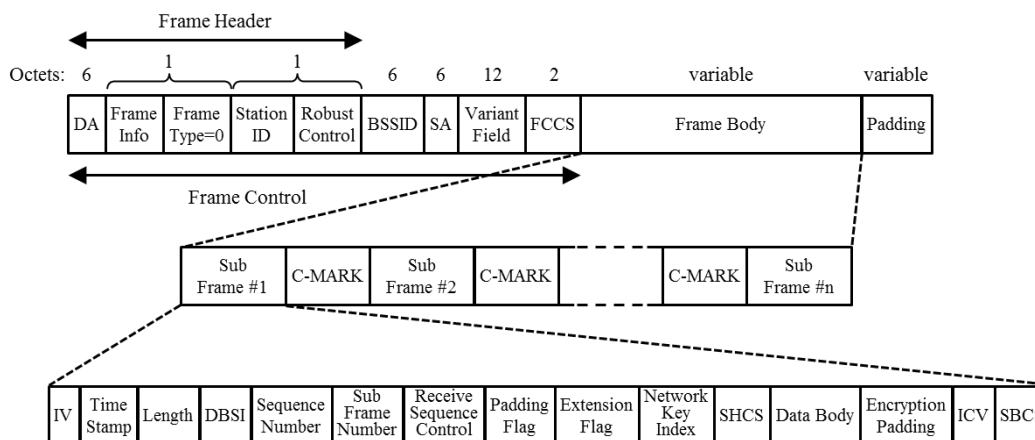


Figure 6-68—FCW Data frame format

6.7.9.1 Variant field

Refer to 6.6.9.1.

6.7.9.2 Subframe format

Refer to 6.6.9.2.

6.7.10 FCW RTS/CTS frame format

The frame format of the FCW RTS (Request to Send)/CTS (Clear to Send) frame is as defined in Figure 6-69. The RTS/CTS frame does not have a Data Body field.

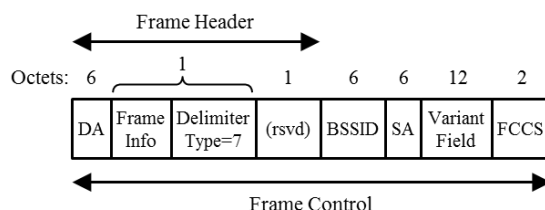


Figure 6-69—FCW RTS/CTS frame format

The RTS/CTS frame is used by STAs to handle hidden node interference with CSMA transmissions. A transmitter STA sends an RTS frame and a receiver STA sends a CTS frame in response.

6.7.10.1 Variant field

Refer to 6.6.10.1.

6.7.11 FCW Management frames

6.7.11.1 FCW Management frame format

The frame format of the FCW Management frame is as defined in Figure 6-70. The Management frame has a Subtype field that shows the type of the Management frame. Most Management frames have Frame Bodies.

The management message is contained in the Data Body of a Management frame. The format of each management message depends on the value of the Management Subtype field that is a subfield of the Variant field.

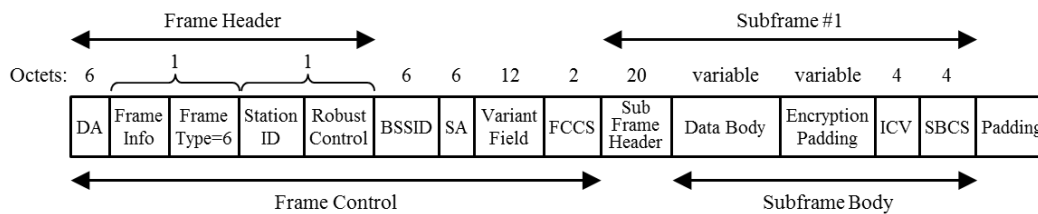


Figure 6-70—FCW Management frame format

6.7.11.1.1 Variant field

Refer to 6.6.11.1.1.

6.7.11.2 Bandwidth reservation

Refer to 6.6.11.2.

6.7.11.3 Authentication

Refer to 6.6.11.3.

6.7.11.4 Channel estimation

Refer to 6.6.11.4.

6.7.11.5 Probe

Refer to 6.6.11.5.

6.7.11.6 NEK update

Refer to 6.6.11.6.

6.7.11.7 EAPOL

Refer to 6.6.11.7.

6.7.11.8 ISP Information Indication

Refer to 6.6.11.8.

6.7.11.9 PHY Capabilities

Refer to 6.6.11.9.

6.7.11.10 Vendor-Specific Management frame

Refer to 6.6.11.10.

Insert the following subclauses after 8.2.12:

8.2.13 FCW channel selection

In an FCW OFDM system, 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.

8.2.13.1 Initial channel and mode of operation

Channel selection shall proceed as follows:

- a) For any given network, the 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 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 system as defined in this clause.
- d) 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.

8.2.13.2 Changing channel and mode of operation

When a change of mode and channel is required due to various reasons, the channel of operation may be changed as follows:

- 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.

8.2.13.3 Selection of optimum channel and mode of operation

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

8.2.13.4 Example of intelligent channel selection (informative)

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.

10.1.4 Wavelet in-home and access synchronization

Change the title of 10.1.4 as follows:

10.1.4 Wavelet PHY/MAC in-home and access synchronization

10.1.4.1 Maintaining NTB synchronization

Change the third paragraph of 10.1.4.1 as follows:

The BSS synchronization function (BSF) is applied only to the wavelet MAC. The BSF synchronizes the timers of all STAs that are associated in the same BSS, but the BSF synchronizes access method timing and TDMA allocations. Every STA shall use the Beacon Offset field of the Beacon frame to maintain its local BSF timer.

Table 10-10—Core TSPEC Parameters for Wavelet

Change the title of Table 10-10 as follows:

Table 10-10—Core TSPEC Parameters for Wavelet MAC

14. Wavelet physical layer

Change the title of Clause 14 as follows:

14. Single Channel Wavelet physical layer

14.1 Introduction

Change the first and second paragraph of 14.1 as follows:

This clause defines the physical layer of the SCW~~wavelet~~ OFDM system. 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.

A SCW~~wavelet~~ OFDM frame may be transmitted either directly at baseband or by modulation to a bandpass carrier. In in-home and access applications, baseband is mandatory, while bandpass is optional. Baseband operation may be done at variable bandwidths being compatible with fixed frequency wideband operation, although it is fixed frequency wideband. Bandpass operation is frequency agile, operating at variable bandwidths over a wider range of frequencies. This agility allows channel allocation for QoS traffic classes.

14.1.1 Characteristics

Change 14.1.1 as follows:

The in-home baseband SCW~~wavelet~~ OFDM PHY shall place 512 evenly spaced carriers into the frequency band from DC to 31.25 MHz and use the frequency band from 1.8 MHz to 28 MHz. When notches used for amateur radio spectrums, 360 carriers in the range from 2 MHz to 28 MHz are used to carry information. And the range from 30 MHz to 50 MHz is defined as an optional upper band in this specification. But the optional upper band may be defined depending on country regulations and may include frequencies above or below 50 MHz. In high-speed mode, every carrier can be modulated with M-PAM (M: 2, 4, 8, 16, and optional 32) for its primary modulation. In diversity mode, every carrier can be modulated with 2PAM for the primary modulation, and further frequency diversity can be provided in order to improve the ability of the PHY to operate under adverse conditions. The kinds of FEC used include Reed–Solomon encoder/decoder, convolution encoder/Viterbi decoder, Reed–Solomon encoder/decoder, and convolution encoder/Viterbi decoder (Concatenated encoder/decoder) or LDPC-CC encoder/decoder.

The bandpass SCW~~wavelet~~ OFDM PHY as an optional for access networks and for indoor networks places 1024 evenly spaced carriers into any bands lying in the range 1.8 MHz to 50 MHz. The tone mask for bandpass communication allows the use of more carriers since, for example, tones near DC do not need to be nulled. The adaptive coding, modulation, and diversity on used carriers is identical to the baseband case described in the previous paragraph.

14.1.4 MAC parameters

Change the title of 14.1.4 as follows:

14.1.4 SCW MAC parameters

Table 14-1—MAC Internal Parameters

Change the title of Table 14-1 as follows:

Table 14-1—SCW MAC Internal Parameters

Change line SYMBOL_TIME in Table 14-1 as follows:

SYMBOL_TIME	SCW ~~wavelet~~ OFDM symbol time	8.192 μ s 16.384 μ s : (optional) 32.768 μ s : (optional)
-------------	---	---

14.2.2 PLCP frame format

Change the first and second paragraph of 14.2.2 as follows:

Figure 14-1 shows the format for the SCW PPDU including the SCW~~wavelet~~ OFDM PPDU preamble, TMI, Frame Control, Frame Length, Frame Body, and Pad bits.

The preamble length is from 11 to 17 SCW~~wavelet~~ OFDM symbols. The TMI and FL are each one SCW~~wavelet~~ OFDM symbol, and the Frame Control is 8 SCW~~wavelet~~ OFDM symbols. The TMI symbol consists of 1-bit No-Payload flag, 8-bit TMI (or 5-bit TMI), and 6-bit tail. The TMI value may have a 5-bit length. The 5-bit TMI is used only when 1901 wavelet PHY communicates with a legacy HD-PLC node. The No-Payload flag means that only the preamble, TMI, and FC are transmitted. The TMI value of DOF mode (but not ADOF) is always zero. The Frame Control has 34 bytes of frame control information and a 6-bit tail. The FL symbol consists of a 16-bit FL, an 8-bit CRC, and a 6-bit tail. The Frame Body is variable data and a 6-bit tail. All tail-bits are set to zero.

Change the sixth paragraph of 14.2.2 as follows:

In terms of modulation, the TMI and FL are transmitted using one of the available diversity modes and a convolutional code with the coding rate $R = 1/2$. Frame Control is transmitted using one of the available diversity modes and the concatenated code ($R = 1/2$, RS(50, 34)). The FEC of the Frame Body uses a Reed–Solomon code (RS(255,239)), a concatenated code (R is variable, RS(255,239)) or an LDPC code (R is variable). In the case of the use of a diversity mode Frame Body, a concatenated code ($R = 1/2$, RS(56, 40)), or an LDPC code ($R = 1/2$) is used. The Frame Body and pad bits appended are transmitted at the data rate determined by the TMI field and may constitute multiple PAM SCW~~wavelet~~ OFDM symbols or the diversity mode for Frame Body. Only 2PAM is used in the diversity mode. The TMI, Frame Control, and Frame Length fields are required for decoding the Frame Body of the PPDU frame. TMI, Frame Control, FL, and Frame Body have a 6-bit tail at the end of each field. However, the PPDU frame format for the RCE frame does not have the tail of the Frame Body and F-pad. Each of these fields is described in detail in 14.3.

Figure 14-1—PPDU frame format

Change the title of Figure 14-1 as follows:

Figure 14-1—SCW PPDU frame format

14.2.2.1 Overview of the PPDU encoding/decoding process

Change the items a) and b) of 14.2.2.1 as follows:

- a) Produce the PPDU Preamble field. The preamble including of short preamble is composed of $(2.5+11)$ SCW~~wavelet~~ OFDM symbols used for signal training. Refer to 14.3.8.2 for details.
- b) Produce the PPDU Header field from the TMI, Frame Control, and Frame Length fields by filling in the appropriate bit fields. The TMI and Frame Length fields of the PPDU Header are encoded by a convolutional code at a rate of $R = 1/2$ and are subsequently mapped onto a 2PAM encoded SCW~~wavelet~~ OFDM symbol. Frame Control is encoded by a concatenated code at a rate of $R = 1/2$ and RS(50,34) and is modulated by 2PAM.

14.2.2.2 Modulation-dependent parameters

Change the first paragraph of 14.2.2.2 as follows:

A channel estimation request frame (RCE frame) includes a SCW~~wavelet~~ 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.

14.3.7.1 Bit interleaver for one wavelet OFDM symbol

Change the title of 14.3.7.1 as follows:

14.3.7.1 Bit interleaver for one SCW~~wavelet~~ OFDM symbol

14.3.7.2 Bit interleaver for multiple wavelet OFDM symbols (optional)

Change the title of 14.3.7.2 as follows:

14.3.7.2 Bit interleaver for multiple SCW~~wavelet~~ OFDM symbols (optional)

14.3.8 Wavelet process

Change the title of 14.3.8 as follows:

14.3.8 SCW~~Wavelet~~ process

Change the first paragraph of 14.3.8 as follows:

This subclause describes functions that are needed for SCW~~wavelet~~ OFDM transmission.

14.3.8.2.9 Postamble (optional)

Change the first paragraph of 14.3.8.2.9 as follows:

Figure 14-20 shows the SCW PPDU frame format with postamble. The postamble is the signal type that is almost the same as the preamble (using different phase vector), consisting of six symbols, and it is added to the end of PPDU frame.

Figure 14-20—PPDU frame format with postamble

Change the title of Figure 14-20 as follows:

Figure 14-20—SCW PPDU frame format with postamble

14.4.1 Block diagram of the transmitter and receiver

Change the title of 14.4.1 as follows:

14.4.1 Block diagram of the SCW transmitter and receiver

Change 14.4.1 as follows:

The general block diagram of the transmitter and receiver for the SCW~~wavelet~~ PHY is shown in Figure 14-29. The transmitter's PHY receives its inputs from the MAC sublayer. The receiver's PHY provides its outputs to the MAC sublayer. The transmitter's PHY includes scrambler block, Reed–Solomon encoder block, convolutional encoder block, puncturing block, bit interleaver block, mapping block, IDWT (inverse discrete wavelet transformer) block, insert preamble block, ramp block, and AFE (analog front end) block. The LDPC encoder block is optional. The scrambler block produces a scrambled data sequence from received data from the MAC sublayer. Then, these data are coded as concatenated code by using Reed–Solomon encoder block, convolutional block, and puncturing block or LDPC code by using the LDPC encoder block. The bit interleaver block interleaves data from the puncturing block. However, these data are coded by using only the Reed–Solomon encoder block in the case of Reed–Solomon mode only. Then three blocks (convolutional, puncturing, and bit interleaver blocks) are not used in this mode. Evaluation data for the RCE frame is input into the mapping block directly. The mapping block produces a plurality of bit streams from the bit interleaver block so as to map the bit streams to signal point data of respective carriers for wavelet OFDM. The IDWT block modulates the respective carriers by wavelet waveforms that are orthogonal to each other based upon the signal point data of the respective carriers mapped by the mapping block so as to produce time waveform data. The insert preamble block inserts the preamble that is generated (in advance) by the IDWT block. The ramp block performs ramp processing to the output composite waveform of the IDWT block. The AFE block converts the time waveform data into an analog time waveform signal. On the receiver side, opposite operations are done.

14.4.2 Major specifications

Change 14.4.2 as follows:

Table 14-12 lists the major specifications of the SCW~~wavelet~~~~OFDM~~ PHY. Basically, mandatory SCW~~wavelet~~ OFDM consists of 512-point IDWT with 61.03515625 kHz carrier spacing and bandwidth (1.8 MHz to 28 MHz). This list includes extended major parameters of the SCW~~wavelet~~~~OFDM~~ PHY. Channels can be created above and below 30 MHz, allowing use of a band that is greater than 30 MHz. For instance, a transmission signal can be upconverted to the upper channel and downconverted again upon receipt. Baseband communication as mandatory can use both channels. The number of carriers is decided on carrier spacing and bandwidth. And the phase vector is constituted by repeating the phase group from carrier number 1 to 512 according to the number of carriers. Optional upper bands may be defined depending on country regulations and may include frequencies above or below 50 MHz.

These carrier spacings are realized with 512-point, 1024-point, and 2048-point IDWT. The ability to support symbol sizes of 16.384 μ s and 32.768 μ s is optional for stations using SCW~~wavelet~~ PHY. Stations that support these optional symbol sizes shall be capable of upbanding the corresponding baseband anywhere in the 2 MHz to 30 MHz frequency range.

Table 14-12—Wavelet OFDM Major Specifications

Change the title of Table 14-12 as follows:

Table 14-12—SCWWavelet OFDM Major Specifications

Change the first line in Table 14-12 as follows:

Communication Method	<u>SCW</u> Wavelet OFDM
----------------------	-------------------------

Insert the following clauses after Clause 16:

17. Flexible Channel Wavelet physical layer

17.1 Introduction

With the growth of IoT applications the requirements for communications are increasingly diverse. Depending on the IoT application, high-speed communication may be required, and in some cases long-distance communication may be required. By changing modes for operations in different channels with different values of carrier spacing, it is possible to deal with both of these requirements flexibly.

This clause defines the physical layer of the FCW OFDM system. 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.

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

- 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.
- A PMD system whose function defines the characteristics and method of transmitting and receiving data through a power line between two or more stations, each using the wavelet OFDM system.
- A PHY layer management entity (PLME) that provides PHY management services.

17.1.1 Characteristics

The baseband FCW PHY shall place 512 evenly spaced carriers into one channel. For example, when the channel is from DC to 31.25 MHz it uses the frequency band from 1.8 MHz to 28 MHz. When there are notches used for amateur radio spectrums, 360 carriers in the range from 2 MHz to 28 MHz are used to carry information. FCW also provides for the frequency band to be expanded as an option from 31.25 MHz to 62.5 MHz by doubling the sampling rate, and further up to 100 MHz by increasing the sampling rate by a factor of four and using the carriers corresponding to that band. FCW further provides for the subdivision into two or four channels in the frequency band using the 512-point baseband FCW PHY. Therefore, it has

the concept of a plurality of channels in the power line communication in the same way of wireless communication. The frequency band may be defined depending on country regulations and may include frequencies above 30 MHz. In high-speed mode, every carrier can be modulated with M-PAM (M: 2, 4, 8, 16, and optional 32) for its primary modulation. In diversity mode, every carrier can be modulated with 2PAM for the primary modulation, and further frequency diversity can be provided in order to improve the ability of the PHY to operate under adverse conditions. The kinds of FEC used include Reed–Solomon encoder/decoder, convolution encoder/Viterbi decoder, Reed–Solomon encoder/decoder, and convolution encoder/Viterbi decoder (Concatenated encoder/decoder) or LDPC-CC encoder/decoder.

17.1.2 PHY functions

Refer to 14.1.2.

17.1.2.1 PLCP sublayer

Refer to 14.1.2.1.

17.1.2.2 PMD sublayer

Refer to 14.1.2.2.

17.1.2.3 PLME

Refer to 14.1.2.3.

17.1.3 Service specification method

Refer to 14.1.3.

17.1.4 SCW and FCW MAC parameters

Much of a particular MAC implementation's behavior is determined by a set of internal parameters. These parameters are used in both SCW and FCW MAC descriptions in this and the following subclauses. The assumed default values for these parameters are listed in Table 17-1.

FCW stations shall support $n_{sl} = 1$ (symbol length of 8.192 μs), $n_{sl} = 2$ (symbol length of 16.384 μs) and $n_{sl} = 4$ (symbol length of 32.768 μs). For $n_{sl} = 1$ (symbol length of 8.192 μs), the FCW parameters are the same parameters as the SCW MAC. 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 17-1—SCW and FCW MAC Internal Parameters ($n_{sl} = 1, 2, 4, 1/2, 1/4$)

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	Max. 30 s
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

17.2 PLCP sublayer

17.2.1 Introduction

Refer to 14.2.1.

17.2.2 PLCP frame format

Figure 17-1 shows the format for the FCW PPDU including the FCW OFDM PPDU preamble, TMI, Frame Header (FH), Frame Length (FL), Frame Body (FB), and Pad bits.

The preamble length is from 11 to 68 FCW OFDM symbols. The TMI and FL are each one FCW OFDM symbol, and the Frame Header is 8 FCW OFDM symbols. The TMI symbol consists of 1-bit No-Payload flag, 8-bit TMI, 1-bit FH flag, and 6-bit tail. The No-Payload flag means that only the preamble, TMI, and FH are transmitted. The TMI value of DOF mode (but not ADOF) is always zero. The Frame Header has 8 bytes of a part of Frame Control of MPDU and a 6-bit tail. The FL symbol consists of a 11-bit FL, an 8-bit CRC, and a 6-bit tail. The Frame Body is variable data and a 6-bit tail. All tail-bits are set to zero.

The FL indicates the number of symbols composed of Frame Body and F-pad. And it is also referenced as the common information with Frame Header among all STAs in the BSS. Since the FL is calculated with LENGTH_FB and tone map for transmission, it requires some delay for its calculation. The LENGTH_FB shows information bytes. Therefore, the FL is allocated between the Frame Header and the Frame Body in order to make implementation easy. If the FL value is 0xFFFFE, it indicates that the frame is transmitted with Postamble. (If errors are detected at the FL in receiving process in PHY layer, the FL value is set to 0xFFFF.)

In the transmitter, the PLCP sublayer converts the Frame Control (34 bytes) of the MPDU to the Frame Header (8 bytes) and a part (26 bytes) of Frame Body of the PPDU.

In the receiver, the PLCP sublayer converts the Frame Header and a part of Frame Body of the PPDU to the Frame Control of the MPDU.

In terms of modulation, the TMI and FL are transmitted with a diversity mode for them and convolutional code with the coding rate $R = 1/2$. Frame Header is transmitted with a diversity mode for it and concatenated code ($R = 1/2$, RS(24, 8)). Also, the FEC of Frame Body forms Reed–Solomon code (RS(255,239)), concatenated code (R is variable, RS(255,239)), or LDPC code (R is variable). In the case of the diversity mode in Frame Body, concatenated code ($R = 1/2$, RS(56, 40)) or LDPC code ($R = 1/2$) is used. The Frame Body and pad bits appended are transmitted at the data rate determined by the TMI field and may constitute multiple PAM FCW OFDM symbols or the diversity mode for Frame Body. Only 2PAM is used in the diversity mode. The TMI, Frame Header, and Frame Length fields are required for decoding the Frame Body of the PPDU frame. TMI, Frame Header, FL, and Frame Body have a 6-bit tail at the end of each field. However, the PPDU frame format for the RCE frame does not have the tail of the Frame Body and F-pad. Each of these fields is described in detail in 17.3.

LDPC-CC can be used in place of the concatenated code in the Frame Body. In that case the 6-bit tail of the Frame Body is replaced with a tail of LDPC-CC, wherein the tail and F-pad bits are all set to a value of '0'. Refer to Table 14-4.

Note: Although only the FCW frame format is described here, the SCW frame format may also be applied.