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IEEE Standard for Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 6: TV White Space Between 54 MHz and 862 MHz Physical Layer

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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3 Park Avenue
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USA

IEEE Std 802.15.4m™-2014
(Amendment to
IEEE Std 802.15.4™-2011
as amended by IEEE Std 802.15.4e™-2012,
IEEE Std 802.15.4f™-2012,
IEEE Std 802.15.4g™-2012,
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Approved 27 March 2014

IEEE-SA Standards Board

Abstract: In this amendment to IEEE Std 802.15.4™-2011, outdoor low-data-rate, wireless, television white space (TVWS) network requirements are addressed. Alternate physical layers (PHYs) are defined as well as only the medium access control (MAC) modifications needed to support their implementation.

Keywords: ad hoc network, IEEE 802.15.4™, IEEE 802.15.4m™, low data rate, low power, LR-WPAN, mobility, PAN, personal area network, radio frequency, RF, short range, TV white space, wireless, wireless personal area network, WPAN

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Introduction

This introduction is not part of IEEE Std 802.15.4m-2014, IEEE Standard for Local and metropolitan area networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)—Amendment 6: TV White Space Between 54 MHz and 862 MHz Physical Layer.

This amendment specifies alternate physical layers (PHYs) in addition to those of IEEE Std 802.15.4-2011. In addition to the new PHYs, the amendment also defines the medium access control (MAC) modifications needed to support their implementation.

The alternate PHYs support principally outdoor, low-data-rate, wireless, TV white space (TVWS) network applications under multiple regulatory domains. The TVWS PHYs are as follows:

- Frequency Shift Keying (TVWS-FSK) PHY
- Orthogonal Frequency Division Multiplexing (TVWS-OFDM) PHY
- Narrow Band Orthogonal Frequency Division Multiplexing (TVWS-NB-OFDM) PHY

The TVWS PHYs support multiple data rates in bands ranging from 54 MHz to 862 MHz.

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[1]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

2. Normative references

Insert the following new references alphabetically into Clause 2:

IEEE Std 802®, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture.[2,3]

IETF RFC 6225, Dynamic Host Configuration Protocol Options for Coordinate-Based Location Configuration Information, Internet Engineering Task Force.[4]

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

Insert the following new definitions alphabetically into 3.1:

dependent device: A device that operates without direct Internet access to a database and depends on another device for channel availability information.

independent device: A device that has direct access to the television white space (TVWS) database via the Internet.

super personal area network (PAN) coordinator: The PAN coordinator of a television white space (TVWS) multichannel cluster tree PAN (TMCTP), which has access to the TVWS geolocation database and provides synchronization services for the TMCTP.

television white space (TVWS) channel: Spectrum unit allocation as defined by the television bands channel availability database.

television white space (TVWS) multichannel cluster tree personal area network (PAN) (TMCTP): A PAN operating in a TVWS band employing a super PAN coordinator to form a multichannel cluster tree topology.

television white space (TVWS) multichannel cluster tree personal area network (PAN) (TMCTP) child (TMCTP-child) PAN coordinator: A logical child device that is responsible for maintaining synchronization with its TMCTP-parent device in the TMCTP while it operates as the coordinator of a PAN.

television white space (TVWS) multichannel cluster tree personal area network (PAN) (TMCTP) parent (TMCTP-parent) PAN coordinator: A logical parent device that is responsible for providing synchronization services to its TMCTP-child devices in the TMCTP while it operates as the coordinator of a PAN.

3.2 Acronyms and abbreviations

Insert the following new abbreviations alphabetically into 3.2:

BOP	beacon only period
DA	device announcement
DBS	dedicated beacon slot
GDB	geolocation database
SPC	super PAN coordinator
TMCTP	TVWS multichannel cluster tree PAN
TVWS	television white space
TVWSPS	television white space power saving

4. General description

4.2 Components of the IEEE 802.15.4 WPAN

Insert the following new paragraph at the end of 4.2:

A TVWS multichannel cluster tree PAN (TMCTP) includes at least one FFD, which operates as both the PAN coordinator and the super PAN coordinator (SPC). The SPC communicates with other PAN coordinators on their dedicated channels during the beacon only period (BOP), as described in 5.1.1.1.3.

4.3 Network topologies

4.3.2 Peer-to-peer network formation

Insert the following new paragraph (including Figure 2a) at the end of 4.3.2:

A TMCTP is a form of cluster tree network where the SPC is the overall PAN coordinator providing synchronization services to other PAN coordinators in the cluster. The SPC also has access to the geolocation database (GDB) server to provide TVWS channel availability information to other PAN coordinators. Each PAN coordinator may use a different channel allocated by the SPC. An example is shown in Figure 2a. In the TMCTP, collisions between clusters can be reduced because each cluster uses its own channel; in addition, the coverage area is increased through the TMCTP parent-child structure. Each TMCTP-parent PAN coordinator, including the SPC, communicates with its TMCTP-child PAN coordinators during the CAP or CFP of the TMCTP-parent PAN coordinator superframe and receives beacon frames of its TMCTP-child PAN coordinators on a dedicated channel during the dedicated beacon slots (DBS) assigned to them in the BOP, as shown with an asterisk (*) in Figure 2a.

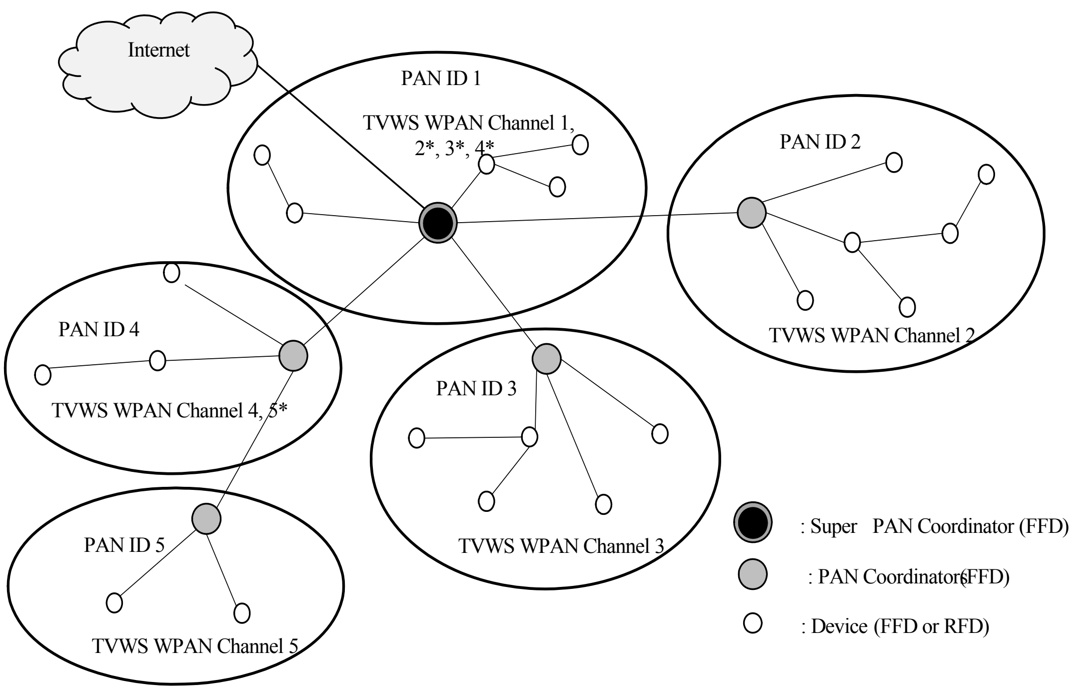

Figure 2a—Example of TVWS multichannel cluster tree PAN

4.5 Functional overview

4.5.1 Superframe structure

Insert the following new subclause (4.5.1.5, including Figure 5ba) after 4.5.1.4:

4.5.1.5 Superframe extension for TVWS multichannel cluster tree PAN (TMCTP)

TVWS allows the optional use of a superframe structure in a TMCTP that is extended by the addition of a BOP to the active portion of the superframe. The format of the TMCTP superframe is defined by the SPC which sends an enhanced beacon containing a TMCTP Specification IE, as in 5.2.4.35. The TMCTP superframe is bounded by network beacons sent by the SPC. The active portion of the TMCTP superframe is composed of a beacon, a CAP, a CFP, and a BOP. An example of a TMCTP superframe including a BOP is illustrated in Figure 5ba. The BOP is composed of one or more DBSs. A DBS is used to communicate beacons between a TMCTP-parent PAN coordinator and one of its TMCTP-child PAN coordinator(s). More information on the TMCTP superframe structure can be found in 5.1.1.8.

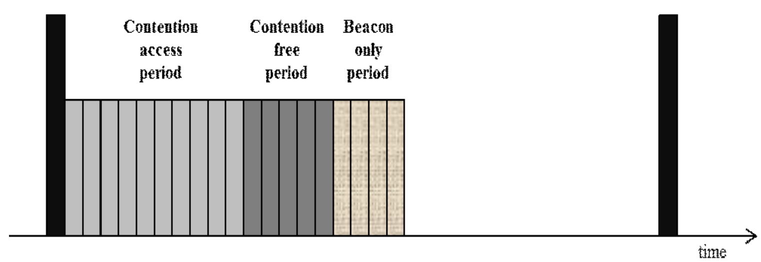

Figure 5ba—TMCTP superframe extension

4.5.2 Data transfer model

4.5.2.3 Peer-to-peer data transfers

Insert the following text as the second paragraph of 4.5.2.3:

For effective peer-to-peer data transfer (unicast), a MAC-layer destination address is needed at a source device. A device announcement (DA) as described in 5.1.6.7 can be used for exchanging 16-bit short or 64-bit extended addresses among devices within radio communication range.

4.5.5 Power consumption considerations

Insert the following new subclause (4.5.5.3) after 4.5.5.2:

4.5.5.3 TVWS low-energy mechanisms

Energy efficiency is an important feature in most of the applications in IEEE 802.15.4 systems. In the TVWS band, besides meeting the application demands on low energy consumption, devices are also required to be able to meet TVWS regulatory requirements.

For TVWS, a low energy mechanism that is capable of reducing energy consumption and at the same time holds the characteristics to be compliant to regulatory requirements is specified.

Insert the following new subclause (4.5.7) after 4.5.6:

4.5.7 Overview of TVWS operation

This clause provides an overview of operation of IEEE 802.15.4 devices in TVWS bands.

TVWS operation defined in this standard differs from that with the use of other license exempt and licensed band, in that there is an additional requirement to determine which TVWS frequency allocations are available for use at a given time and geographic location. Devices have access to TVWS channel availability information, such as via the Internet to a database, for determination of available TVWS spectrum. Access of a TVWS channel based on sensing alone is not assumed for TVWS, but is not excluded either.

An independent device is a device that has access to the TVWS database via the Internet. A dependent device is one that has no connection to the database and so must depend upon another device to acquire channel availability information.

Because relevant regulations may vary from region to region, this standard provides methods that may be used to meet the requirements of regional regulations without any specific direction on how those requirements may be met.

5. MAC protocol

5.1 MAC functional description

5.1.1 Channel access

5.1.1.1 Superframe structure

Insert the following new paragraph after the first paragraph of 5.1.1.1:

When operating as a TMCTP, the superframe includes the beacon only period as described in 5.1.1.1.3, and the structure of the superframe is described in 5.1.1.8.

Insert the following new subclause (5.1.1.1.3) after 5.1.1.1.2:

5.1.1.1.3 Beacon only period (BOP)

When present, the BOP shall follow the CAP and CFP, if the CFP is present. When there is no CFP, the BOP shall follow the CAP. The CAP and CFP comprise the first 16 slots of the superframe as described in 5.1.1.8, and the BOP shall commence on the slot boundary immediately following. The BOP shall complete before the end of the active portion of the superframe. The BOP duration depends on the number of DBSs one of which is allocated to each TMCTP-child PAN coordinator. All DBSs shall be located within the BOP and occupy contiguous slots. The BOP, therefore, grows or shrinks depending on the total length of all of the combined DBSs. Multiple base slots in the BOP can be allocated to a DBS according to the length of the beacon to be sent by the TMCTP-child coordinator which will occupy the DBS.

CSMA is not used for beacon transmissions in the BOP. A TMCTP-child PAN coordinator transmitting in the BOP shall ensure that its beacon transmission is complete within one IFS period before the end of its DBS. The IFS period is described in 5.1.1.3.

Change the first paragraph of 5.1.1.3 as indicated:

5.1.1.3 Interframe spacing (IFS)

The MAC sublayer needs a finite amount of time to process data received by the PHY. To allow for this, two successive frames transmitted from a device shall be separated by at least an IFS period; if the first transmission requires an acknowledgment, the separation between the acknowledgment frame and the second transmission shall be at least ~~an~~ the IFS period or *aTurnaroundTime*, whichever is greater. The length of the IFS period is dependent on the size of the frame that has just been transmitted. Frames (i.e., MPDUs) of up to *aMaxSIFSFrameSize* shall be followed by a short interframe space (SIFS) period of a duration of at least *macSIFSPeriod*. Frames (i.e., MPDUs) with lengths greater than *aMaxSIFSFrameSize* shall be followed by a long interframe spacing (LIFS) period of a duration of at least *macLIFSPeriod*. These concepts are illustrated in Figure 10.

Replace Figure 10 with the following figure:

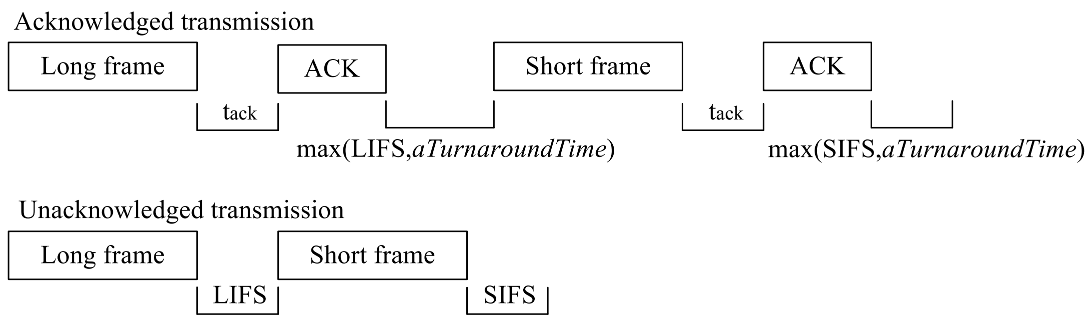

Figure 10—IFS

5.1.1.7 LE functional description

Insert the following list item at the end of the dashed list in 5.1.1.7:

— *macTvwsPsEnabled*

Insert the following new subclause (5.1.1.8, including Figure 11i) after 5.1.1.7.4:

5.1.1.8 Superframe use for TMCTP operation

The TMCTP superframe is an extension of the basic superframe defined in 5.1.1.1. The active portion of the TMCTP superframe is composed of four parts, which is illustrated in Figure 5ba.

— The beacon, as described in 5.2.2.1, which is used to set the timing allocations and to communicate management information for the PAN.
— The CAP, as described in 5.1.1.1.1, which is used to communicate command frames and/or data.
— The CFP, as described in 5.1.1.1.2, which is composed of GTSs. No transmissions within the CFP shall use a CSMA-CA mechanism to access the channel.
— The BOP, as described in 5.1.1.1.3, which is composed of one or more DBSs. A DBS is used to communicate beacons between a TMCTP-parent PAN coordinator (including the SPC) and one of its TMCTP-child PAN coordinator(s) in a TMCTP.

The SD and BI of the TMCTP superframe are the same as described in 5.1.1.1. The MAC PIB attribute *macTmctpExtendedOrder* describes the extended length of the active portion of the superframe. The value of *macTmctpExtendedOrder* and the extended duration, ED, are related as follows:

$$\mathrm{ED} = aBaseSuperframeDuration \times 2^{macTmctpExtendedOrder}$$

$$= aBaseSlotDuration \times aNumSuperframeSlots \times 2^{macTmctpExtendedOrder}$$

for

$$0 \le macTmctpExtendedOrder \le (macBeaconOrder - macSuperframeOrder) \le macBeaconOrder \le 14$$

The ED of each TMCTP superframe shall be divided into $aNumSuperframeSlots \times 2^{macTmctpExtendedOrder}$ equally spaced slots of duration *aBaseSlotDuration* in a BOP. The BOP consists of multiple DBSs. Each DBS is composed of one or more base slots, which are *aBaseSlotDuration* in length. The total duration of the active portion of each TMCTP superframe consists of the base superframe duration, SD, and the extended duration for the BOP, ED:

$$ESD = SD + ED$$

An example of a TMCTP superframe structure is shown in Figure 11i, according to various values of the *macBeaconOrder* (BO), the *macSuperframeOrder* (SO), and the *macTmctpExtendedOrder* (EO).

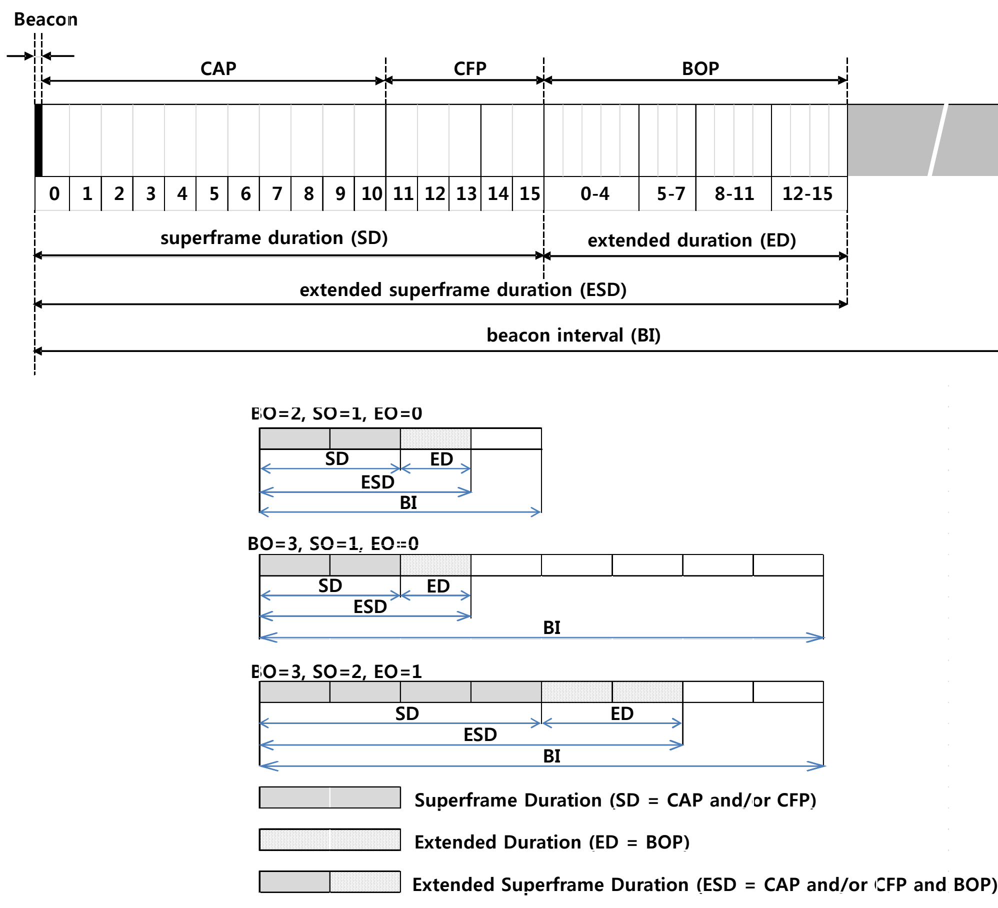

Figure 11i—An example of the TMCTP superframe structure

5.1.6 Transmission, reception, and acknowledgment

5.1.6.2 Reception and rejection

Change the fourth list item after the sixth paragraph of 5.1.6.2 as indicated:

— If a short destination address is included in the frame, it shall match either *macShortAddress* or the broadcast address. Otherwise, if an extended destination address is included in the frame, it shall match <u>either</u> *macExtendedAddress* <u>or, if *macGroupRxMode* is set to TRUE, an EUI-64 group address, as defined in IEEE Std 802</u>.

5.1.6.4 Use of acknowledgments and retransmissions

Change 5.1.6.4 as indicated:

A data or MAC command frame shall be sent with the AR field set appropriately for the frame. A beacon or acknowledgment frame shall always be sent with the AR field set to indicate no acknowledgment requested. Similarly, any frame that is broadcast <u>or has a group address as the extended destination address, as defined in IEEE Std 802,</u> shall be sent with its AR field set to indicate no acknowledgment requested.

5.1.6.4.2 Acknowledgment

Change the third paragraph of 5.1.6.4.2 as indicated:

The transmission of an acknowledgment frame in a nonbeacon-enabled PAN or in the CFP shall commence t_{ack} after the reception of the last symbol of the data or MAC command frame. The transmission of an acknowledgment frame in the CAP shall commence either t_{ack} after the reception of the last symbol of the data or MAC command frame or at a backoff period boundary. In the latter case, the transmission of an acknowledgment frame shall commence between t_{ack} and (t_{ack} + *aUnitBackoffPeriod*) after the reception of the last symbol of the data or MAC command frame. The value of t_{ack} is 1 ms for the SUN PHYs<u>,</u> ~~and~~ LECIM PHYs<u>, and TVWS PHYs</u>. The value of t_{ack} is equal to *macSIFSPeriod* for all other PHYs.

Insert the following sentence at the end of the last paragraph ("When in TSCH mode, ... to* macTsAckWait*.") of 5.1.6.4.2:

For TVWS RDEVs, the enhanced acknowledgment frame shall include the Timestamp Difference IE as defined in 5.2.4.34.2 if the RNG field of the PHR is set to 1 in the frame being acknowledged.

Insert the following new subclause (5.1.6.7, including Figure 29a) after 5.1.6.6:

5.1.6.7 Device announcement

To facilitate data transfer effectively between two or more peer devices, a device announces its address and its neighbors' addresses to its neighbor devices by broadcasting beacons with a Device Announcement IE (DA IE) (5.2.4.36).

A device shall broadcast a beacon frame with a DA IE upon receiving a MLME-DA.request primitive (6.2.24.1) from the next higher layer. It may also broadcast beacons with a DA IE at other times. After transmitting a beacon with the DA IE requested by an MLME-DA.request, the device shall send an MLME-DA.confirm, as described in 6.2.24.2, to the next higher layer.

Upon receiving a beacon frame with a DA IE, a device shall indicate the address of the transmitting device and the addresses list in the DA IE to its next higher layer using the MLME-DA.indication primitive (6.2.24.3). A device may check whether or not its address is known at the transmitting device by tracking the received beacon frames with a DA IE. If not, the device may broadcast a beacon with a DA IE to announce its address at the appropriate time.

The message sequence chart for a broadcast beacon with a DA IE to announce the address of a device and its neighbors' addresses is illustrated in Figure 29a.

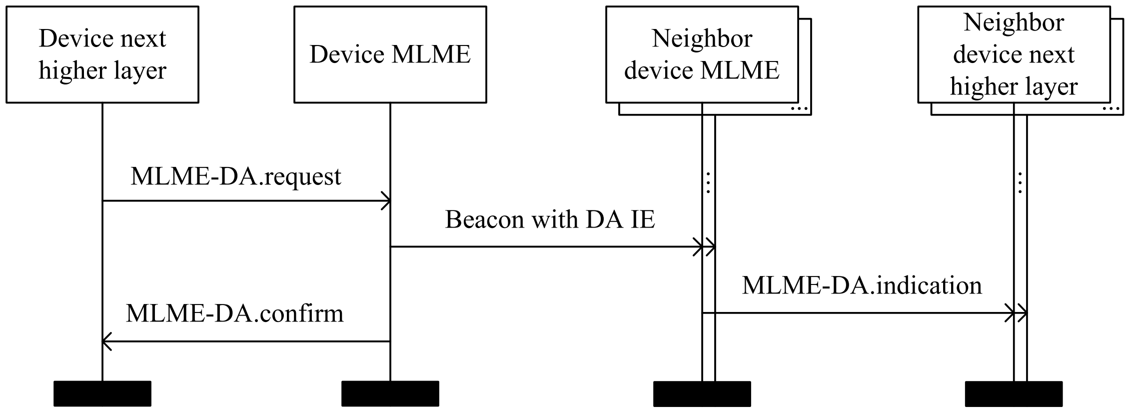

Figure 29a—Message sequence chart for broadcast beacon with DA IE upon receiving MLME-DA.request primitive

5.1.8 Ranging

5.1.8.4 The ranging exchange

Change the fourth paragraph of 5.1.8.4 as indicated:

For the UWB PHY, in ~~In~~ all of these timestamp reports, the timestamp itself shall consist of the 12 octets defined for the timestamp report in 14.7.1, 14.7.2, and 14.7.3. Use of nonzero timestamp reports is limited to RDEVs. Only devices that have *phyRanging* set to TRUE shall return a nonzero timestamp report to a next higher layer.

Insert the following new paragraph at the end of 5.1.8.4:

For TVWS RDEVs, the Timestamp IE and the Timestamp Difference IE are provided for exchanging timing information between TVWS RDEVs to support the ranging feature.

Insert the following new subclauses (5.1.14 and 5.1.15, including Figure 34x to Figure 34aa) after 5.1.13:

5.1.14 Starting and maintaining TVWS multichannel cluster tree PANs (TMCTP)

This subclause specifies the procedures for TMCTP formation.

Figure 34x shows an example with a suggested message sequence for TMCTP formation between the SPC, which is the TMCTP-parent PAN coordinator, and a TMCTP-child PAN Coordinator. The example is explained as follows:

In step A, the SPC obtains the list of available TVWS channels from the GDB through the Internet. The protocol used to access the GDB over the Internet is outside the scope of this standard. Alternatively, the SPC may obtain the list of available TVWS channels from another device. The SPC maps the TVWS channels to corresponding PHY channels, selects one of the available PHY channels, and transmits its beacon through that channel. The TMCTP-child PAN coordinator completes the scan procedure over all PHY channels.

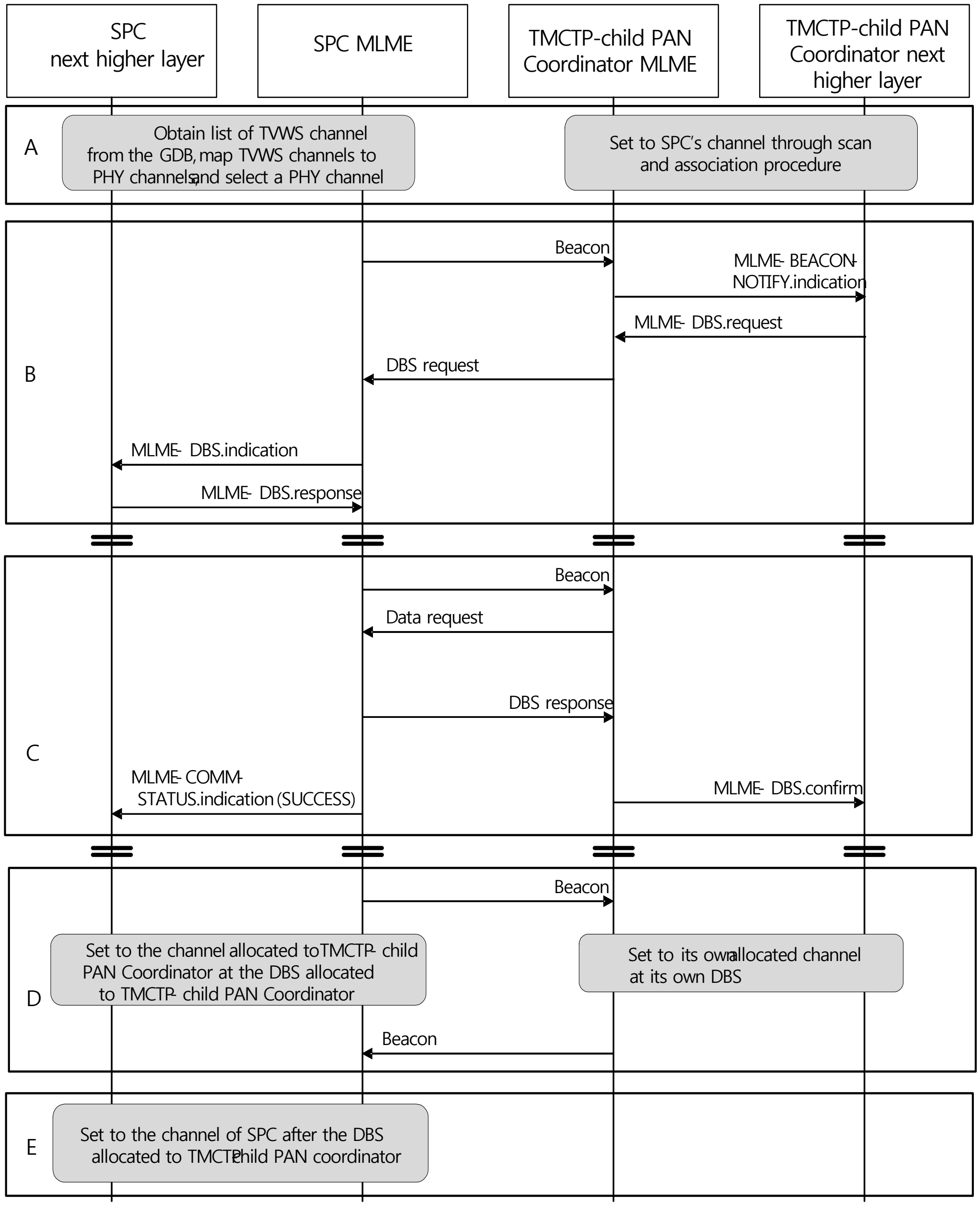

Figure 34x—Example message sequence chart between SPC and TMCTP-child PAN coordinator

In Step B, the SPC transmits an enhanced beacon containing a TMCTP Extended Superframe Specification IE as described in 5.2.4.35. Upon successful reception of the beacon from the SPC, the TMCTP-child PAN coordinator may request a DBS allocation or a DBS deallocation by sending a DBS request frame, as described in 5.3.14, to the SPC. Upon receiving the DBS request, the SPC will allocate or deallocate a DBS slot and a channel and generate a DBS response frame, as described in 5.3.15, to report the slot and the channel allocated or deallocated. The SPC can generate the DBS response frame for the deallocation without the request of the TMCTP-child PAN coordinator.

In Step C, the SPC indicates pending data for the TMCTP-child PAN coordinator in its beacon. The TMCTP-child PAN coordinator sends the data request command frame. Upon receiving the data request, the SPC replies with the DBS response generated in Step B. The SPC then sends its own beacon frame.

In Step D, the SPC switches to the channel allocated to the TMCTP-child PAN coordinator and listens for the beacon frame from the TMCTP-child PAN coordinator. If the SPC does not receive a beacon frame from the TMCTP-child PAN coordinator within three BIs, the SPC switches to the SPC channel and sends a DBS response frame to the TMCTP-child PAN coordinator in next superframe of the SPC.

In Step E, upon receiving the beacon frame during the slot allocated to the TMCTP-child PAN coordinator on the channel allocated to the TMCTP-child PAN coordinator, the SPC switches to its own dedicated channel.

During the CAP of the SPC, each TMCTP-child PAN coordinator sends a DBS request to the SPC and receives a DBS response from the SPC. The SPC switches to the channel allocated to the TMCTP-child PAN coordinator before the DBS slot time allocated to the TMCTP-child PAN coordinator. Each TMCTP-child PAN coordinator forms an independent PAN by transmitting its beacon during the allocated DBS slot.

Figure 34y provides another example for TMCTP formation between two PAN coordinators, where one is the TMCTP-parent PAN coordinator and the other is a TMCTP-child PAN Coordinator.

In Step A, the TMCTP-child PAN coordinator performs a scan procedure and waits for the beacon of the TMCTP-parent PAN coordinator.

In Step B, the TMCTP-parent PAN coordinator sends an enhanced beacon containing a TMCTP Specification IE, as in 5.2.4.35. Upon successful reception of the beacon from the TMCTP-parent PAN coordinator, the TMCTP-child PAN coordinator requests a channel and a slot by using the DBS request sent to the TMCTP-parent PAN coordinator. Upon receiving the DBS request, the TMCTP-parent PAN coordinator either directly generates the DBS response frame reporting the slot and the channel allocated or deallocated, or sends the DBS Request Command Frame to the SPC and then receives the DBS Response Command Frame from the SPC. The TMCTP-parent PAN coordinator may generate the DBS response frame for the deallocation without a request of the TMCTP-child PAN coordinator.

In Step C, the TMCTP-parent PAN coordinator sends a beacon. The TMCTP-parent PAN coordinator switches to the channel allocated to the TMCTP-child PAN coordinator and receives the beacon frame from the TMCTP-child PAN coordinator.

In Step D, upon receiving the beacon frame during the slot allocated to the TMCTP-child PAN coordinator on the channel allocated to the TMCTP-child PAN coordinator, the TMCTP-parent PAN coordinator switches to its own dedicated channel.

During CAP of the TMCTP-parent PAN coordinator, which has a relay capability or a channel allocation capability, each TMCTP-child PAN coordinator sends a DBS request to the TMCTP-parent PAN coordinator and receives the DBS response from the TMCTP-parent PAN coordinator. The TMCTP-parent PAN coordinator switches to the channel allocated to the TMCTP-child PAN coordinator during the DBS slot allocated to each TMCTP-child PAN coordinator. Each TMCTP-child PAN coordinator manages its own WPAN by transmitting a beacon during the allocated DBS slot time.

Figure 34z shows an example of the multichannel allocation for the network topology as presented in Figure 2a. In this case, the SPC operates on the dedicated channel, which is Channel 1 in this figure, and switches to the dedicated channels of TMCTP-child PAN coordinators 2, 3, and 4 during their DBSs. Similarly TMCTP-child PAN coordinator 4 operates on the dedicated channel, which is Channel 4, and switches to the dedicated channel of TMCTP-child PAN coordinator 5 during its DBS to communicate with TMCTP-child PAN coordinator 5.

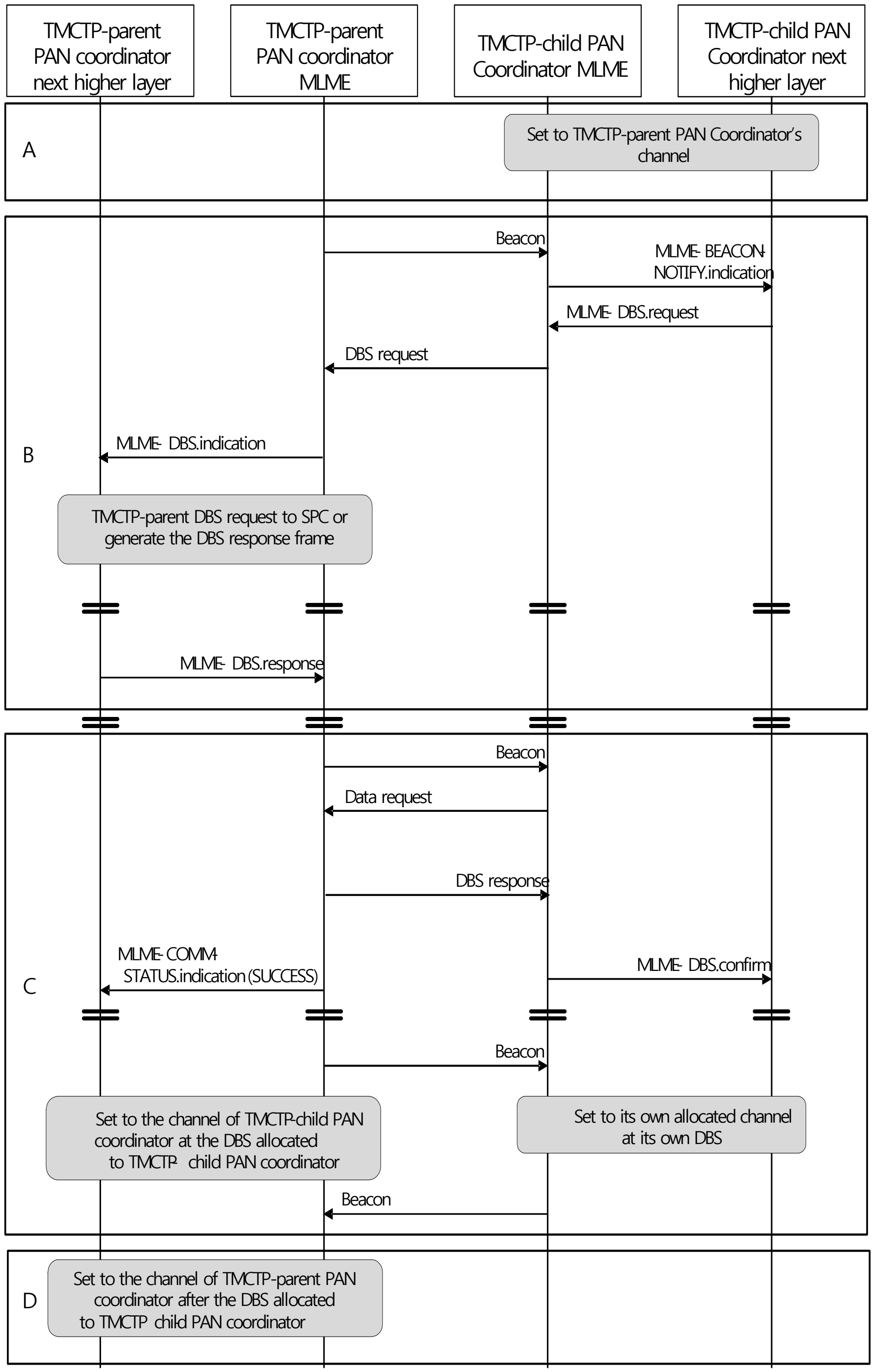

Figure 34y—Example message sequence chart between TMCTP PAN coordinators

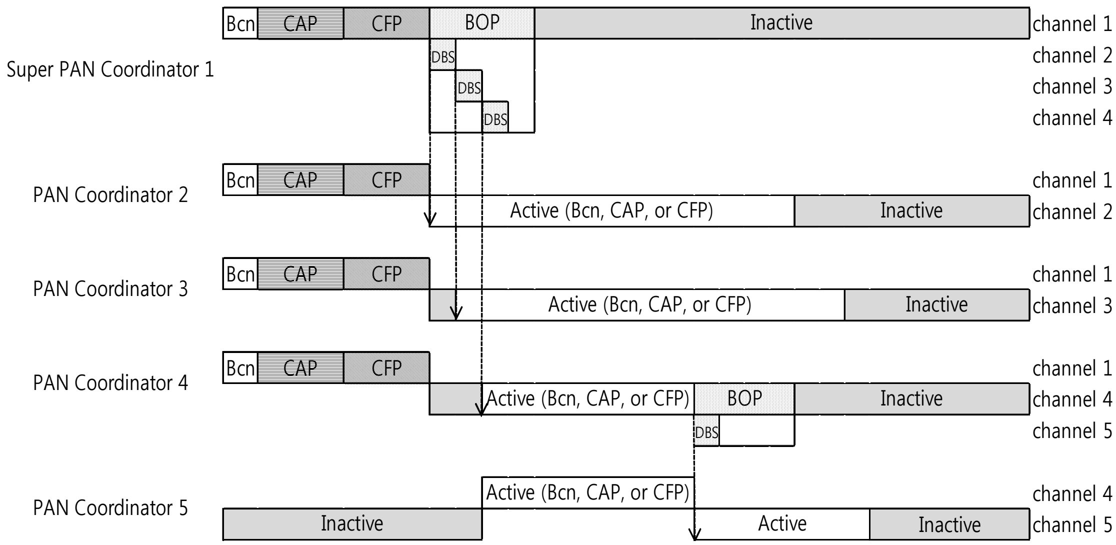

Figure 34z—Example TMCTP BOP allocation

5.1.15 TVWS power saving (TVWSPS)

This subclause defines a scalable and symmetrical power saving model for a wide range of LR-WPAN applications operating in TVWS. The TVWS power saving mechanism is activated when *macTvwsPsEnabled* is set to TRUE. The power saving mechanism is indicated by the MLME-BEACON-NOTIFY.indication primitive as described in 6.2.4.1 and MCPS-DATA.indication primitive as described in 6.3.

A TVWS device may be either an initiating device or a responding device. A responding device switches on its receiver during periodic listening periods *macTvwsPsListeningInterval* apart, each with listening duration *macTvwsPsListeningDuration*. In between listening periods, the responding device may be in sleep mode with the receiver disabled. To poll the responding device, an initiating device transmits frames containing a TVWS Power Saving (TVWSPS) IE (see 5.2.4.30) followed by a channel listening period (sufficiently long to receive an ACK frame from the responding device) at *macTvwsPsPollingInterval*, for total duration *macTvwsPsPollingDuration* or until receiving an acknowledgment frame, whichever occurs first. The total duration of the frame containing the TVWSPS IE and the channel listening period following the frame transmission may be shorter than *macTvwsPsPollingInterval*.

To increase the likelihood of detection, the value of *macTvwsPsPollingInterval* should be less than or equal to *macTvwsPsListeningDuration*, and the value of *macTvwsPsPollingDuration* should be more than or equal to *macTvwsPsListeningInterval*. The TVWSPS IE may be included in an enhanced beacon, data, or multi-purpose frame.

An initiating or responding device indicates the Rendezvous Time as the starting of the data transaction (e.g. ad-hoc listening period), as set by *macTvwsPsRendezvousTime*, and the Data Transaction Duration as the expected duration to complete the data transaction, as set by *macTvwsPsTransDuration*.

Upon receiving a frame with a TVWSPS IE, the responding device shall enable an ad hoc listening period to receive the data from the initiating device at the Rendezvous Time indicated in the received TVWS IE, or transmits the data requested by the initiating device at the indicated Rendezvous Time.

Two cases of the TVWSPS protocol are illustrated in Figure 34aa. In the first example, initiating device 1 has pending data to transmit to the responding device. In the second example, initiating device 2 is requesting data from the responding device.

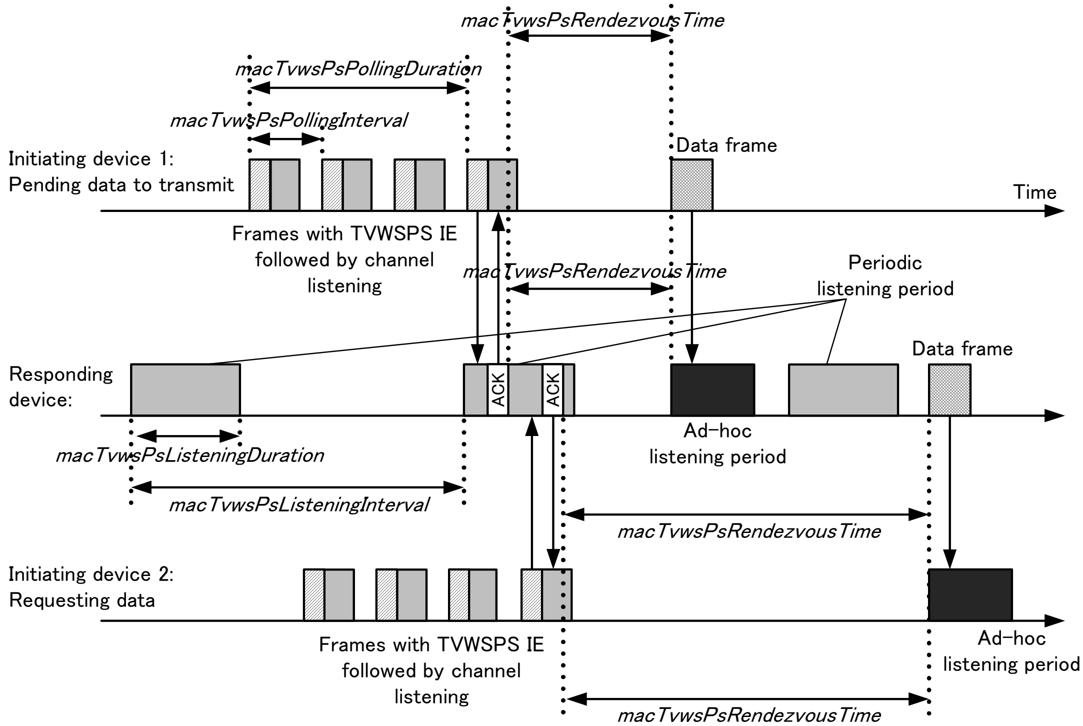

Figure 34aa—TVWS power saving mechanism

5.2 MAC frame formats

5.2.1 General MAC frame format

5.2.1.9 FCS field

Change the end of the first paragraph of 5.2.1.9 as indicated:

~~Only d~~<u>D</u>evices compliant with one or more of the SUN <u>and TVWS</u> PHYs shall implement the 4-octet FCS; <u>for</u> ~~For~~ these devices, the default FCS length shall be 4 octets.

5.2.2 Format of individual frame types

5.2.2.1 Beacon frame format

5.2.2.1.1a Information elements field

Insert the following new row into Table 3b:

Table 3b—EBR IEs per enabled attribute

Attribute Request Identifier	PIB attribute	IE type	IEs to include
5	*macDAenabled*	Header	Device Announcement (5.2.4.36)

5.2.4 Information element

5.2.4.2 Header information elements

Insert the following new row into Table 4b:

Table 4b—Element IDs, Header IEs

Element ID	Content length	Name	Description
0x19	variable	DA	Defined in 5.2.4.36

5.2.4.5 MLME information elements

Insert the following new rows into Table 4d, and change the reserved row as indicated:

Table 4d—Sub-ID allocation for short format

Sub-ID value	Content length	Name	Description
0x2a	13	TVWSPS IE	Description of parameters for TVWS power saving mechanism, as defined in 5.2.4.30
0x2b	9	TVWS PHY Operating Mode Description IE	Description of a specific TVWS PHY operating mode, as defined in 5.2.4.31
0x2c	variable	TVWS Device Capabilities IE	Description of TVWS PHY-specific device capabilities, as defined in 5.2.4.32
0x2d	1	TVWS Device Category IE	Description of the device regulatory category, as defined in 5.2.4.33.1
0x2e	variable	TVWS Device Identification IE	Description of the device assigned identification, as defined in 5.2.4.33.2

Table 4d—Sub-ID allocation for short format *(continued)*

Sub-ID value	Content length	Name	Description
0x2f	variable	TVWS Device Location IE	Description of location of device, as defined in 5.2.4.33.3
0x30	variable	TVWS Channel Information Query Request/Response IE	Description of the query request and response protocol for channel information, as defined in 5.2.4.33.4
0x31	variable	TVWS Channel Information Source Description IE	Description of channel information source for channel enabling, as defined in 5.2.4.33.5
0x32	variable	Channel Timing Management IE	Description of the information for management in timing schedule for channel, as defined in 5.2.4.33.6
0x33	4	Timestamp IE	TX timestamp information as described in 5.2.4.34.1
0x34	4	Timestamp Difference IE	Timing difference for ranging support, as described in 5.2.4.34.2
0x35	variable	TMCTP Specification IE	Description of information for TMCTP protocols, as defined in 5.2.4.35
0x36–0x3f	—	Reserved	—

Insert the following new subclauses (5.2.4.30 to 5.2.4.36, including Figure 48aae to Figure 48aaw and Table 4z to Table 4an) after 5.2.4.29.2:

5.2.4.30 TVWS Power Saving (TVWSPS) IE

The TVWSPS IE is used by a device to initiate a TVWSPS transaction. The content of the IE shall be formatted as shown in Figure 48aae.

Octets: 1	4	3	3	2
PS Control	Periodic Listening Interval	Periodic Listening Duration	Rendezvous Time	Data Transaction Duration

Figure 48aae—TVWSPS IE

The PS Control field indicates the types of operation intended by the source device. A value of 0 indicates the announcement of a responding device's Periodic Listening Interval and Periodic Listening Duration and that only the Periodic Listening Interval field and Periodic Listening Duration field are valid. A value of 1 indicates that an initiating device has pending data to be transmitted to the responding device. When value 1 is set, only the Rendezvous Time field and Data Transaction Duration field are valid. A value of 2 indicates that an initiating device is requesting data from the responding device. When value 2 is set, only the Rendezvous Time field and Data Transaction Duration field are valid. All other values are reserved.

The Periodic Listening Interval field is the time between the start of a periodic listening period and the start of the subsequent periodic listening period (see 5.1.15) in milliseconds, with a range as given in Table 52. When generated, this field shall be set to the value of *macTvwsPsListeningInterval*.

The Periodic Listening Duration field is the time between the start and the end of a periodic listening period, in milliseconds, with a range given in Table 52. When generated, this field shall be set to the value of *macTvwsPsListeningDuration*.

The Rendezvous Time field is the time in milliseconds between the end of the acknowledgment frame sent by a responding device or received by an initiating device and the start of the data transaction between the two devices. When generated, the value of this field is set to *macPSRendezvousTime*, with a valid range given in Table 52.

The Data Transaction Duration field is the time needed to complete the transaction between the initiating and responding devices. When generated, this field is set to the value of *macTvwsPsTransDuration*, with a valid range given in Table 52. A value of 0 indicates that the field shall be ignored.

5.2.4.31 TVWS PHY Operating Mode Description IE

The TVWS PHY Operating Mode Description IE is used with the PHY Parameter Change IE (5.2.4.23) to signal dynamically a change in operating channel, band or other PHY operating parameters when the resulting change will be to a configuration defined by the operating TVWS PHY. The TVWS PHY Operating Mode Description IE is an MLME IE as defined in 5.2.4.5. The content field shall be formatted as shown in Figure 48aaf.

Octets: 9
TVWS PHY Operating Mode Description

Figure 48aaf—TVWS PHY Operating Mode Description IE

The TVWS PHY Operating Mode Description field shall be encoded as shown in Table 4z. The specific parameters are encoded depending on the PHY type indicated.

Table 4z—TVWS PHY Operating Mode Description field

<table>
<tr><th>Bit number</th><th colspan="2">Description</th></tr>
<tr><td>0:7</td><td colspan="2">Band ID. The band ID described in Table 4ab.</td></tr>
<tr><td>8:15</td><td colspan="2">PHY Channel ID. The channel identification for the 802.15.4 TVWS PHY channel as defined in 8.1.2.9.</td></tr>
<tr><td>16:17</td><td colspan="2">PHY Type Selector:
0 = TVWS-FSK PHY (20.1)
1 = TVWS-OFDM PHY (20.2)s
2 = TVWS-NB-OFDM PHY (20.3)
3 = Reserved</td></tr>
<tr><td colspan="3">18:31 for TVWS-FSK Operating Parameters: when PHY Type Selector is set to 0</td></tr>
<tr><td rowspan="9"></td><td>18</td><td>FEC
0 = not enabled
1 = enabled</td></tr>
<tr><td>19:20</td><td>FEC Scheme
0 = the first FEC scheme as defined in 20.1.2.2
1 = the second FEC scheme as defined in 20.1.2.2
2 = the third FEC scheme defined as defined in 20.1.2.2

NOTE: This field is reserved if FEC is not enabled.</td></tr>
<tr><td>21</td><td>Interleaving
0 = not enabled
1 = enabled

NOTE: This field is reserved if FEC is not enabled or the FEC Scheme field value is not 1.</td></tr>
<tr><td>22</td><td>Spreading
0 = not enabled
1 = enabled</td></tr>
<tr><td>23</td><td>Data Whitening
0 = not enabled
1 = enabled</td></tr>
<tr><td>24–26</td><td>TVWS-FSK Mode as in Table 201</td></tr>
<tr><td>27</td><td>Modulation index option:
When TVWS-FSK Mode field value = 1, 2 or 3:
0 = modulation index is 0.5
1 = modulation index is 1.0
When TVWS-FSK Mode field value = 4 or 5, reserved.</td></tr>
<tr><td>28</td><td>SFD Length
0 = 16-bit SFD
1 = 24-bit SFD</td></tr>
<tr><td>29:31</td><td>Reserved</td></tr>
</table>

Table 4z—TVWS PHY Operating Mode Description field *(continued)*

Bit number		Description
18:31 for TVWS-OFDM Operating Parameters: when PHY Type selector is set to 1		
	18:19	Modulation 0 = BPSK, 1 = QPSK, 2 = 16-QAM, 3 =Reserved
	20:22	MCS Mode 0–5 as given in Table 205 6–7 Reserved
	23:31	Reserved
18:31 for NB-OFDM Operating Parameters: when PHY Type selector is set to 2		
	18:21	MCS Mode 0–8 as given in Table 214 9–15 Reserved
	22	Channel aggregation 0 = not enabled 1 = enabled
	23:31	Reserved
32:71		TVWS Available Frequency Range as described in Figure 48aaq; only present when Band ID field value is <= 5

5.2.4.32 TVWS Device Capabilities IE

The TVWS Device Capabilities IE declares the TVWS capabilities supported by a device. The presence of this IE in a transmitted frame indicates that the device supports operation of a TVWS PHY defined in this standard. The IE content shall be as shown in Figure 48aag.

Octets: 1	3	3	variable
TVWS PHY Type	Supported Bands	TVWS Supported PHY Features	TVWS Supported Channels

Figure 48aag—TVWS Device Capabilities IE

The TVWS PHY Type field indicates the PHY type being described in the IE. This field shall be set to one of the non-reserved values shown in Table 4aa.

Table 4aa—TVWS PHY Type field

Value	Description
0	TVWS-FSK
1	TVWS-OFDM
2	TVWS-NB-OFDM
3–255	Reserved

The Supported Bands field is a bitmap indicating the bands supported by the device. A value of one indicates that the band is supported, and zero indicates the band is not supported. The supported bands shall be encoded as shown in Table 4ab. The device shall indicate only those bands that are implemented and defined for the indicated PHY type. The use of the bands defined in Table 4ab facilitates communication to be maintained when a band becomes unavailable, using the same PHY/MAC capabilities.

Table 4ab—Supported Bands field

Bit number	Band ID
0	TVWS Band USA
1	TVWS Band UK
2	TVWS Band Japan
3	TVWS Band Canada
4	TVWS Band Korea
5	TVWS Band EU
6	450–470 MHz
7	470–510 MHz
8	779–787 MHz
9	863–870 MHz
10	896–901 MHz
11	901–902 MHz
12	902–928 MHz
13	917–923.5 MHz
14	928–960 MHz
15	920–928 MHz
16	950–958 MHz
17	2400–2483.5 MHz
18–23	Reserved

The TVWS Supported PHY Features field indicates the supported features of a TVWS PHY. The content depends on the value of the TVWS PHY Type field. For each of the possible PHY types, the features shall be encoded as shown in Table 4ac, Table 4ad, and Table 4ae accordingly.

Table 4ac—TVWS-FSK PHY Supported Features field

Bit number	Description
0	24-bit SFD length supported
1	First FEC scheme as defined in 20.1.2.2
2	Second FEC scheme as defined in 20.1.2.2
3	Interleaver for the second FEC scheme as defined in 20.1.2.2
4	Third FEC scheme as defined in 20.1.2.2
5	Spreading factor 2 supported
6	Spreading factor 4 supported
7	Spreading factor 8 supported
8	Spreading factor 16 supported
9	Data whitening supported
10	Alternating spreading pattern supported
11	Non-alternating spreading pattern supported
12	Ranging supported
13:20	Support for TVWS-FSK Mode; Bit 13 = Mode#1 with h=0.5; Bit 14 = Mode#1 with h=1; Bit 15 = Mode#2 with h=0.5; Bit 16 = Mode#2 with h=1; Bit 17 = Mode#3 with h=0.5; Bit 18 = Mode#3 with h=1; Bit 19 = Mode#4; Bit 20 = Mode#5
21:23	Reserved

Table 4ad—TVWS-OFDM PHY Supported Features field

Bit number	Description
0:2	Support for MCS3, MCS4, MCS5; Bit 0=MCS3 supported; Bit 1=MCS4 supported; Bit 2=MCS5 supported as defined in 20.2.2.
3:6	Number of STF TVWS-OFDM symbols supported
7	Ranging supported
8:23	Reserved

Table 4ae—TVWS-NB-OFDM PHY Supported Features field

Bit number	Description
0	Channel aggregation supported
1	Cyclic prefix 1/16 supported
2	Cyclic prefix 1/8 supported
3	Guard interval 1/16 supported
4	Guard interval 1/8 supported
5	Symbol interval 1/16 supported
6	Symbol interval 1/8 supported
7	Ranging supported
8:23	Reserved

The Channels Supported field is a set of channel lists that shall be formatted as described in Figure 48aah.

Octets: 1/variable	1/variable	...	1/variable
Channel List for Band 1	Channel List for Band 2		Channel List for Band *n*

Figure 48aah—TVWS Supported Channels bitmap

The TVWS Supported Channels field content depends on the value of the Supported Bands field. For each defined band, the channel numbering is given in 8.1.2.9. For each band indicated as supported, a corresponding channel bit map shall be constructed, resulting in a list of channel bit maps as illustrated in Figure 48aah. Each channel bit map will be encoded as shown in Table 4af. The first bit field of each map indicates whether all channels in that band are supported. If this field is set to one, then all channels defined for the band in 8.1.2.9 are supported, and the channel list is 1 octet, with bits 1 to 7 set to zero. If the first bit field is set to zero (i.e. not all channels in that band are supported), then the subsequent bit fields indicate which individual channels are supported. The bit field corresponding to a channel number shall be set to one to indicate that the channel is supported and set to zero to indicate the channel is not supported. Bit maps are allocated on octet boundaries; unused bits are reserved. When multiple bands are supported, as indicated in the Supported Bands field, the corresponding channel lists are concatenated in order, such that the channel lists occur in the order of the bands given in Table 4ab, i.e. channel list corresponding to the band indicated by Bit 0 of the Supported Bands field is transmitted first if Bit 0 is set to one. The term ‘channel’ here refers to a WPAN channel. The mapping between a TVWS channel and a PHY channel is not within the scope of this standard.

Table 4af—Channel List format

Bit number	Description
0	All channels in band supported
1	Channel 1 supported
2	Channel 2 supported
...	...
n	Channel *n* supported, where *n* is the number of channels supported for the band in 8.1.2.9

5.2.4.33 TVWS Enabling IEs

5.2.4.33.1 TVWS Device Category IE

The TVWS Device Category IE shall be formatted as in Figure 48aai. This IE contains a Device Category field, the value of which shall be set to one of the non-reserved values given in Table 4ag.

Octets: 1
Device Category

Figure 48aai—TVWS Device Category IE

Table 4ag—Device Category field

Value	Description
0	Stationary and independent device
1	Stationary and dependent device
2	Non-stationary and independent device
3	Non-stationary and dependent device
4–255	Reserved

5.2.4.33.2 TVWS Device Identification IE

The TVWS Device Identification IE contains one of several types of identification, including a regulator assigned device approval identification, a manufacturer serial number, or implementation specific value. A number of IDs may be included in a single MAC frame as required. The format is shown in Figure 48aaj.

Octets: 1	variable
ID Type	Device ID

Figure 48aaj—TVWS Device Identification IE

The ID Type field shall be set to one of the non-reserved values in Table 4ah.

Table 4ah—ID Type field

Value	Description
0	US specific regulator assigned ID
1	UK specific regulator assigned ID
2	Canada specific regulator assigned ID
3	Japan specific regulator assigned ID
4	Korea specific regulator assigned ID
5	EU specific regulator assigned ID
6	Manufacturer serial number
7	Vendor specific
8–255	Reserved

For an ID Type field indicated as regulator assigned, the Device ID field is comprised of two fields, formatted as shown in Figure 48aak. For other non-reserved values in Table 4ah, the Device ID field contains only the ID String field.

Octets: 1	variable
Device Category	ID String

Figure 48aak—Device ID field

The Device Category field is as shown in 5.2.4.33.1.

The ID String field is a counted string as shown in Figure 48aal.

Octets: 1	variable
Length	Array of Octets

Figure 48aal—ID String field

The Length field specifies the number of octets that follows in the Array of Octets field. The encoding of characters into the Array of Octets is outside the scope of this standard.

5.2.4.33.3 TVWS Device Location IE

The TVWS Device Location IE contains a list of geolocation coordinates, as shown in Figure 48aam. Each location list entry is 16 octets long, encoded as shown in Table 4ai. The encoding is based on IETF RFC 6225. The field contents are as described in IETF RFC 6225.

Octets: 1	variable		
Number of Locations	Device Locations Info		
	Octets: 1	16	...
	Location ID	Device Locations List Element	...

Figure 48aam—TVWS Device Location IE

The Number of Locations field indicates how many locations for which a device is requesting the channel list information. The Location ID field provides an ID of a particular location for which a device is requesting channel list info. The Device Locations List Element field shall be encoded as shown in Table 4ai.

Table 4ai—Device Locations List Element field

Bit number	Content
0:5	Latitude Uncertainty
6:39	Latitude
40:45	Longitude Uncertainty
46:79	Longitude
80:83	Altitude Type
84:89	Altitude Uncertainty
90:119	Altitude
120:121	Version
122:124	Resolution
125:127	Datum

5.2.4.33.4 TVWS Channel Information Query Request/Response IE

The TVWS Channel Information Query Request/Response IE is used to request channel information and, in response to the request, to deliver the channel information if available. The format is shown in Figure 48aan.

Octets: 1	1	0/variable
Channel List ID	Channel Info Status	Channel List Info

Figure 48aan—TVWS Channel Information Query Request/Response IE

The Channel List ID field is incremented when the channel data is updated. When the Channel Info Status field indicates that this is a channel data request, the Channel List ID field is set to the ID value provided when channel data was last received. If channel data has not been received the Channel List ID field is set to 0 in the request.

The Channel Info Status field indicates if this IE is a request or a response, and if a response, the nature of the response shall be set to one of the values in Table 4ak. The value of the Channel Info Status field shall be one of those described in Table 4aj.

Table 4aj—Channel Info Status field

Channel Info Status	Description
0	Channel list requested/ response
1:3	Number of locations
4:7	Reserved

When the Channel Info Status field indicates a request, device identification IEs and a device location IE may be included in the request frame.

When the Channel Info Status field indicates a response with available channel list for verified device locations, the Number of Channels and TVWS Available Channel Description fields are included in the IE. For other status values these fields are not present.

Each entry in the Channel List Info field contains the specific information on available channels as shown in Figure 48aao.

Octets: 1	0/1	0/1	0/variable
Location ID	Channel List Status	Number of Channels	TVWS Available Channel Description

Figure 48aao—Channel List Info field

The Channel List Status field shall be present when Channel Info Status value is a response, as shown in Table 4ak.

Table 4ak—Channel List Status field

Status	Description
0	Available channel list verified for a device location
1	Request not successful due to device ID not being verified
2	Request not successful due to device location being out of the geographic coordinate
3	Request not successful due to one or more parameters having invalid values
4–255	Reserved

The TVWS Available Channel Description field is encoded as shown in Figure 48aap.

Octets: 5	1	2
TVWS Available Frequency Range	Maximum TX Power	Valid Time

Figure 48aap—TVWS Available Channel Description field

TVWS Available Frequency Range field is encoded as shown in Figure 48aaq. Maximum TX Power field contains the maximum allowed transmit power authorized for TVWS channel, in 0.5 dBm increments, in the range of –64 dBm to 63.5 dBm. The Valid Time field contains the time, in minutes from the time of transmission, that the channel availability data is expected to remain valid; a valid time of zero indicates that the channel is available until further notice (e.g., as might be used for contact verification).

Octets: 3	2
Starting Frequency	Width

Figure 48aaq—TVWS Available Frequency Range field

Starting Frequency field is in 1kHz units and specifies the starting frequency where the TVWS spectrum is available. Width field is in 1kHz units and specifies the width of the available TVWS spectrum.

5.2.4.33.5 TVWS Channel Information Source Description IE

The TVWS Channel Information Source Description IE is used to advertise the availability of a device capable of providing channel availability data to peer devices. The IE shall be formatted as shown in Figure 48aar.

Octets: 1	0/16	0/8	0/8
Source Info	Location of Known Source	Address of Known Source	TVWS Available Channel Description of Known Source

Figure 48aar—Channel Information Source Description IE

The Source Info field is encoded as shown in Table 4al.

Table 4al—Source Info field

Bit number	Description
0	Indication that Location of Known Source field is present
1	Indication that Address of Known Source field is present
2	Indication that TVWS Available Channel Description of Known Source field is present
3–7	Reserved

The Location of Known Source field, when present, is the location of the device acting as the source of channel availability data and shall be formatted as shown in Table 4ai.

The Address of Known Source field when present, contains the 64-bit extended address of the known source device.

The TVWS Available Channel Description of Known Source field, when present, contains the TVWS channel being used by the known source and shall be formatted as shown in Figure 48aap.

5.2.4.33.6 Channel Timing Management IE

The content of the Channel Timing Management IE shall be formatted as shown in Figure 48aas.

Octets: 1	0/variable
CTM Control	Channel Timing Information

Figure 48aas—Channel Timing Management IE

The CTM Control field indicates the purpose and content of the IE and shall be set to one of the non-reserved values given in Table 4am. When the IE contains a request, the CTM Control field indicates the type of request. When the IE contains a response to a request, the CTM Control field indicates the status of the request and content of the response. The Channel Timing Information field shall only be present, when it is a response to a request. See 5.5.1 for details on the use of the CTM Control field in various scenarios.

Table 4am—CTM Control field

Value	Description
0	Request for channel timing information
1	Success with full channel timing information on the available channels
2	Success with subset of channel timing information on the available channels
3	Success with no channel timing changes from previous query
4	Request declined due to unspecified reason
5	Request declined because of no capability for providing channel timing information
6	Request declined, database access timeout
7–255	Reserved

Channel Timing Information field shall be encoded as shown Table 4an. The information in Table 4an may be aggregated to show multiple durations of the channel time scheduling.

Table 4an—Channel Timing Information field

Name	Length (octet)	Value
TVWS Available Frequency Range	5	The TVWS Available Frequency Range field indicates the range of the available TVWS frequency, as indicated in Figure 48aaq.
Channel Availability Starting Time	8	The Channel Availability Starting Time field indicates the starting time in Coordinated Universal Time (UTC) from when the channel indicated in the Channel Number field is available for operation.
Valid Time	2	The Valid Time field indicates the duration of frequency availability as described in Figure 48aap.

5.2.4.34 Ranging Support IEs

5.2.4.34.1 Timestamp IE

The Timestamp IE is encoded as shown in Figure 48aat.

Octets:4
Transmit Timestamp

Figure 48aat—Timestamp IE

The Transmit Timestamp field shall be set to the time, in units of 10 picoseconds, in the transmitter time reference at the antenna, when the packet containing this IE is transmitted. The timing reference is as given in *macSyncSymbolOffset* (Table 52). The timestamp value shall be updated at transmission of the packet.

5.2.4.34.2 Timestamp Difference IE

The Timestamp Difference IE is encoded as shown in Figure 48aau.

Octets:4
RX TX Time Difference

Figure 48aau—Timestamp Difference IE

The RX TX Time Difference field contains the difference in time, in units of 10 picoseconds, at the device generating this IE, from the time the frame containing the IE is transmitted to the time a RFRAME was received. The reference for these time values is given by *macSyncSymbolOffset*. This IE shall be generated and included in the acknowledgment when an RFRAME is received by a TVWS RDEV with the AR field of the MHR set to 1.

5.2.4.35 TMCTP Specification IE

The TMCTP Specification IE shall be formatted as illustrated in Figure 48aav.

Bits: 0–3	4	5	6	7	8–15	16–23	variable
Beacon Only Period Order	TMCTP Frame Pending	Dedicated Beacon Slot Allocation Capability	Channel Allocation Capability	Channel Allocation Relay Capability	Hop Count to SPC	Number of PAN IDs Pending	PAN ID List

Figure 48aav—TMCTP Specification IE

The Beacon Only Period Order field specifies the length of the extended duration. The relationship between *macTmctpExtendedOrder* and the extended duration is explained in 5.1.1.8.

The TMCTP Frame Pending field shall be set to one if the TMCTP-parent PAN coordinator has more frames for the TMCTP-child PAN coordinator. Otherwise, this field shall be set to zero.

The Dedicated Beacon Slot Allocation Capability field shall be set to one if the device is capable of allocating a DBS to the TMCTP-child PAN coordinator; it shall be set to zero otherwise.

The Channel Allocation Capability field shall be set to one if the device is capable of allocating a dedicated channel to the TMCTP-child PAN coordinator; it shall be set to zero otherwise.

The Channel Allocation Relay Capability field shall be set to one if the device is capable of relaying a DBS request of the TMCTP-child PAN coordinator; it shall be set to zero otherwise.

The Hop Count to SPC field indicates the number of hops to reach the SPC.

The Number of PAN IDs Pending field indicates the number of PAN IDs contained in the PAN ID List field of the beacon frame.

The size of the PAN ID List field is determined by the values specified in the Number of PAN IDs Pending field of the beacon frame and contains the list of PAN IDs of the TMCTP-child PAN coordinators that currently have messages pending with the TMCTP-parent PAN coordinator.

5.2.4.36 Device Announcement IE

The Device Announcement IE can be used for a device to announce its neighbors' addresses if *macDAenabled* is TRUE. The Device Announcement IE shall be formatted as illustrated in Figure 48aaw.

Bits: 0	1	2–5	6–15	16–20	21–23	variable
Address Mode	Addresses Pending	Reserved	Number of Addresses	Sequence Number	Page Number	Address List

Figure 48aaw—Device Announcement IE

When Address Mode field is set to zero, each address included in Address List is a 16-bit short address. When Address Mode field is set to one, each address included in Address List is a 64-bit extended address. The Number of Addresses field is the number of neighbor addresses included in the Address List field of this DA IE.

The Address Pending field shall be set to one when the set of neighbor addresses is to be announced in multiple beacons. An Addresses Pending field set to one indicates that this IE contains a subset of the set of neighbor addresses known by the device and more neighbor addresses are to be sent in following beacon frames with a DA IE; the Sequence Number field shall be set to a value identifying the set of addresses to be announced, and the Page Number field shall be set to 1 for the first subset of address and incremented by 1 for each subsequent subset of addresses. An increment in the Sequence Number indicates that a new set of neighbor addresses is being announced. The Sequence Number shall be incremented when any address in the set of neighbor addresses has been changed. The Address Pending field shall be set to zero when the set of addresses to be announced is contained in a single DA IE. When Addresses Pending field is set to zero, the Sequence Number and Page Number fields shall be set to zero.

5.3 MAC command frames

Insert the following new rows into Table 5, and change the reserved row as indicated:

Table 5—MAC command frames

Command frame identifier	Command frame name	RFD		Subclause
		Tx	Rx	
0x21	DBS Request	—	—	5.3.14
0x22	DBS Response	—	—	5.3.15
0x23–0xff	Reserved	—	—	—

Insert the following new subclauses (5.3.14 to 5.3.15.2, including Figure 59ad.1 to Figure 59ad.4) after 5.3.13.3.2:

5.3.14 DBS Request Command

The DBS Request Command is used in a TMCTP enabled PAN to request allocation of a DBS and a channel. The DBS Request Command shall be formatted as shown in Figure 59ad.1.

Octets: 11–25	1	4
MHR	Command Frame Identifier	DBS Request Information

Figure 59ad.1—TMCTP DBS Request Command Frame

5.3.14.1 MHR fields

The Destination Addressing Mode field and Source Addressing Mode field shall be set to indicate short addressing.

The Frame Pending field, the AR field, and the Frame Version field shall be set to zero, one, and two, respectively.

The Destination PAN Identifier field shall contain the PAN identifier of the SPC, and the Destination Address field shall contain the address of the SPC. The Source PAN Identifier field shall contain the value of *macPANId*. The network management entity should assure that each PAN coordinator has a unique PAN Id; the method is out of scope of this standard. The Source Address field shall contain the value of *macShortAddress*.

5.3.14.2 DBS Request Information field

The DBS Request Information field shall be encoded as shown in Figure 59ad.2.

Bits: 0:15	**16:19**	**20:22**	**23**	**24:31**
Requester Short Address	DBS Length	Reserved	Characteristics Type	Number of the Descendant

Figure 59ad.2—DBS Request Information field

The Requester Short Address field contains the short address of the coordinator requesting a DBS and shall be set to *macShortAddress* upon transmission.

The DBS Length field shall contain the number of *aBaseSlotDuration* being requested for a DBS.

The Characteristics Type field shall be set to one if the characteristics refer to a DBS allocation or zero if the characteristics refer to a DBS deallocation.

The Number of the Descendant field indicates the actual or expected number of TMCTP-child PAN coordinators. It may be set to zero if the PAN coordinator is not clear about how many descendants it will have.

5.3.15 DBS Response Command

The DBS Response Command is used in a TMCTP PAN to report the results of a DBS allocation request. The DBS Response Command shall be formatted as shown in Figure 59ad.3.

Octets: 11–25	**1**	**10**
MHR	Command Frame Identifier	DBS Response Information

Figure 59ad.3—TMCTP DBS Response Command format

5.3.15.1 MHR fields

The Destination Addressing Mode field and Source Addressing Mode field shall be set to indicate short addressing.

The Frame Pending field, the AR field, and the Frame Version field shall set to zero, one, and two, respectively.

The Destination PAN Identifier field shall contain the source PAN identifier from the DBS request frame, and the Destination Address field shall contain the source address from the DBS request frame. The Source PAN Identifier field shall contain the value of *macPANId*, and the Source Address field shall contain the value of *macShortAddress*.

5.3.15.2 DBS Response Information field

The DBS Response Information field shall be encoded as shown in Figure 59ad.4.

Octets:2	**1**	**1**	**1**	**3**	**1**	**1**
Requester Short Address	Allocated DBS Starting Slot	Allocated DBS Length	Allocated PHY Channel Number	Start Band Edge	Starting PHY Channel ID	Ending PHY Channel ID

Figure 59ad.4—DBS Response Information field

The Requester Short Address field contains the short address of the coordinator requesting a DBS and shall be set to *macShortAddress* upon transmission.

The Allocated DBS Starting Slot field shall contain the first slot of the allocated DBS in the BOP. The unit is the *aBaseSlotDuration*, as described in Table 51.

The Allocated DBS Length field shall contain the length of the allocated DBS. If the Allocated DBS Length field is equal to zero, it indicates that the DBS slot and the dedicated channel are deallocated.

The Allocated PHY Channel Number field shall contain the channel number that the coordinator intends to use for all future communications.

The Start Band Edge field is the frequency in kHz indicating the lower edge of band that the coordinator intends to use for all future communications and shall be set to the current value of *macStartBandEdge*.

The Starting PHY Channel ID field shall contain the lowest channel number, which is assigned by the TMCTP-parent PAN coordinator, including the SPC.

The Ending PHY Channel ID field shall contain the highest channel number, which is assigned by the TMCTP-parent PAN coordinator, including the SPC.

Insert the following new subclauses (5.5 and 5.5.1, including Figure 59ah) after 5.4.2.1.2:

5.5 TVWS access procedures

In certain regulatory domains, an independent device operating in TVWS is required to communicate with a database which stores information on operation of primary incumbent systems to obtain permission and radio resource information, prior to starting communications. This database to protect primary systems is typically, but not limited to, a GDB. When a GDB is employed as the database, an independent device first communicates with the GDB to obtain permission to operate in TVWS. The communication between the independent device and the GDB is outside the scope of this standard. In this case, the independent device determines its geolocation to be reported to the GDB. The GDB then provides available channels and relevant operating information. Upon receiving permission from the GDB, the independent device may start a network and begin enabling other devices. Figure 59ah shows the state transition diagram of the enabling procedure for a dependent device.

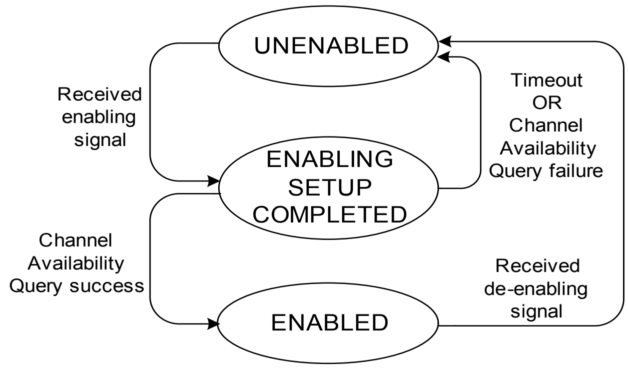

Figure 59ah—State transition of a dependent device

A dependent device, prior to receiving channel availability information (such as at power on or reset condition) begins in the UNENABLED state. The device may perform a channel scan or other procedure to detect transmissions that are active on the channel and determine a suitable source of channel availability data (e.g. an independent device advertisement). Upon receiving an enabling signal (e.g. a beacon or an enhanced beacon) from an independent device, the state transitions to ENABLING SETUP COMPLETED. From the ENABLING SETUP COMPLETED state, the dependent device will initiate the exchange of information in order to be enabled, as required by the particular regulatory domain in which it is operating. The information exchange is facilitated by several IEs as specified in 5.2.4.33.1 and 5.2.4.33.2. Information on the list of locations of particular valid channel is contained in the IE specified in 5.2.4.33.3. Information on the list of available channels is contained in the IE specified in 5.2.4.33.4. A device that has access to channel availability information advertises that fact using the Channel information source description IE as specified in 5.2.4.33.5. Upon successfully completing a channel availability query the state transitions to ENABLED. In this state, the dependent device is able to conduct data communications.

5.5.1 Channel timing management (CTM)

Channel timing management facilitates assessment of the available timing schedule when a channel is available. CTM is used by employing the CTM IE as in 5.2.4.33.6. Upon receipt of MLME-CTM.request, the MLME shall schedule transmission for a CTM IE as in 5.2.4.33.6. The CTM IE may be contained in an enhanced beacon frame.

A device transmits a CTM request to a PAN coordinator that is capable of database access as indicated in the enabling signal. The PAN coordinator capable of database access visits the database and obtains the channel time information for available channels. The PAN coordinator may respond to a request by sending the CTM IE with CTM Control field set to Request Declined, to indicate that it has no capability to provide schedule information.

A device may transmit a CTM request to query for channel information from another device. A device shall respond to a CTM request using a CTM IE with the CTM Control field set to Success if it is capable of providing channel time information on WPAN channels obtained from a database. Otherwise it shall respond with the CTM Control field set to Request Declined, to indicate that it has no capability to provide schedule information on available channels due to various reasons.

When the information in a CTM response is identical to the information in the most recently transmitted CTM response to the same requesting device, the responding device may set the CTM Control field value in a query response to Successful with no channel schedule changes from the last query and leave the Channel Timing Information field empty.

6. MAC services

6.2 MAC management service

Insert the following new rows at the end of Table 8:

Table 8—Summary of the primitives accessed through the MLME-SAP

Name	Request	Indication	Response	Confirm
MLME-DBS	6.2.23.1	6.2.23.2	6.2.23.3	6.2.23.4
MLME-DA	6.2.24.1	6.2.24.3		6.2.24.2

6.2.4 Communications notification primitives

6.2.4.1 MLME-BEACON-NOTIFY.indication

Insert the following new parameters at the end of the list in 6.2.4.1 (before the closing parenthesis):

PeriodicListeningInterval
PeriodicListeningDuration
RendezvousTime
TransactionDuration
DeviceCategory
DeviceIDType
DeviceID
NumberofLocations
DeviceLocationsInfo
ChannelListID
ChannelInfoStatus
NumberofChannels
TVWSAvailableChannelDescription
SourceInfo
LocationofKnownSource
AddressofKnownSource
TVWSAvailableChannelDescriptionofKnownSource
CTMControl
ChannelTimingInformation
ChannelListInfo
ChannelListStatus

Insert the following new rows at the end of Table 16:

Table 16—MLME-BEACON-NOTIFY.indication parameters

Name	Type	Valid range	Description
PeriodicListeningInterval	Integer	0 to 4294967296	Time, in ms of the Periodic listening interval field of a received TVWSPS IE. See 5.2.4.30 for the information contained in this parameter.
PeriodicListeningDuration	Integer	0 to 16777215	Time, in ms of the Periodic listening duration field of a received TVWSPS IE. See 5.2.4.30 for the information contained in this parameter.
RendezvousTime	Integer	0 to 16777215	Time, in ms of the Rendezvous time field of a received TVWSPS IE. See 5.2.4.30 for the information contained in this parameter.
TransactionDuration	Integer	0 to 65535	Time, in ms of the Transaction duration field of a received TVWSPS IE. See 5.2.4.30 for the information contained in this parameter.
DeviceCategory	Integer	0–255	Contains the value of the Device Category field of a received TVWS Device Category IE as described in 5.2.4.33.1.
DeviceIDType	Integer	0–255	Contains the value of the device ID Type field of a received TVWS Device Identification IE as described in 5.2.4.33.2.
DeviceID	Set of octets	See Figure 48aak and Figure 48aal.	Contains the value of the ID String field and Device ID field of a received TVWS Device Identification IE as described in 5.2.4.33.2.
NumberofLocations	Integer	0–255	Contains the value of the Number of Locations field in a received TVWS Device Location IE as described in 5.2.4.33.3.
DeviceLocationsInfo	Set of octets	—	Contains a list of locations; Location ID and Device Locations List Element for each location as described in 5.2.4.33.3.
ChannelListID	Integer	0–255	Contains the Channel List ID contained in a received TVWS Channel Information Query Request/Response IE as described in 5.2.4.33.4.
ChannelInfoStatus	Integer	See Table 4aj.	Indication on number of locations and whether the channel information query is a request or a response, as indicated in a received TVWS Channel Information Query Request/Response IE as described in 5.2.4.33.4.
NumberofChannels	Integer	0–255	The number of TVWS channels contained in the received TVWS Channel Information Query Request/Response IE that contains a channel list as described in 5.2.4.33.4.

Table 16—MLME-BEACON-NOTIFY.indication parameters *(continued)*

Name	Type	Valid range	Description
TVWSAvailableChannelDescription	Set of octets	See Figure 48aap.	Description on each TVWS channel in a received TVWS Channel Information Query Request/Response IE that contains a channel list. 5.2.4.33.4 describes the information contained in this parameter.
SourceInfo	Integer	See Table 4al.	Set to the value of the Source Info field of a received TVWS Channel Information Source Description IE as described in 5.2.4.33.5.
LocationofKnownSource	Set of octets	See Table 4ai.	The location of known source field value of a received TVWS Channel Information Source Description IE as described in 5.2.4.33.5.
AddressofKnownSource	Device address	Extended IEEE address	Set to the value of the Address of Known Source field of a received TVWS Channel Information Source Description IE as shown in 5.2.4.33.5.
TVWSAvailableChannelDescriptionofKnownSource	Set of octets	See Figure 48aap.	Set to the value of the TVWS Available Channel Description of Known Source field of a received TVWS Channel Information Source Description IE. 5.2.4.33.5 describes the information contained in this parameter.
CTMControl	Integer	See Table 4am.	Set to the value of the CTM Control field of a received Channel Timing Management IE as described in 5.2.4.33.6.
ChannelTimingInformation	Set of octets	See Table 4an.	Set to the value of the Channel Timing Information field of a received Channel Timing Management IE as described in 5.2.4.33.6.
ChannelListInfo	Set of octets	See Figure 48aao.	Contains the channel list of the received IE as described in 5.2.4.33.4.
ChannelListStatus	Integer	See Table 4ak.	Set to the value of the channel list status of the received IE as described in 5.2.4.33.4.

6.2.12 Primitives for updating the superframe configuration

6.2.12.1 MLME-START.request

Insert the following new parameters at the end of the list in 6.2.12.1 (before closing parenthesis):

DeviceCategory
DeviceIDType
DeviceID
NumberofLocations
DeviceLocationsInfo
ChannelListID
ChannelInfoStatus
SourceInfo
LocationofKnownSource
AddressofKnownSource
TVWSAvailableChannelDescriptionofKnownSource
CTMControl
ChannelListInfo

Insert the following new rows at the end of Table 34:

Table 34—MLME-START.request parameters

Name	Type	Valid range	Description
DeviceCategory	Integer	0–255	As described in 5.2.4.33.1.
DeviceIDType	Integer	0–255	As described in 5.2.4.33.2.
DeviceID	Set of octets	See Figure 48aak and Figure 48aal.	As described in 5.2.4.33.2.
NumberofLocations	Integer	0–255	As described in 5.2.4.33.3.
DeviceLocationsInfo	Set of octets	—	As described in 5.2.4.33.3.
ChanneListID	Integer	0–255	As described in 5.2.4.33.4.
ChannelInfoStatus	Integer	See Table 4aj.	As described in 5.2.4.33.4.
SourceInfo	Integer	See Table 4al.	As described in 5.2.4.33.5.
LocationofKnownSource	Set of octets	See Table 4ai.	As described in 5.2.4.33.5.
AddressofKnownSource	Device address	Extended IEEE address	As described in 5.2.4.33.5.
TVWSAvailableChannelDescriptionofKnownSource	Set of octets	See Figure 48aap.	As described in 5.2.4.33.5.
CTMControl	Integer	See Table 4am.	As described in 5.2.4.33.6.
ChannelListInfo	Set of octets	See Figure 48aao.	As described in 5.2.4.33.4.

Insert the following new subclauses (6.2.23 to 6.2.24.3, including Table 44ad to Table 44aj) after 6.2.22.3:

6.2.23 TMCTP DBS allocation primitives

These primitives are used in a TMCTP enabled PAN to allocate a DBS between a TMCTP-parent PAN coordinator and its TMCTP-child PAN coordinator.

6.2.23.1 MLME-DBS.request

The MLME-DBS.request primitive is used when a TMCTP-child PAN coordinator requests the allocation or deallocation of a DBS and a channel to its TMCTP-parent PAN coordinator including the SPC.

The semantics of this primitive are:

```
MLME-DBS.request          (
                          RequesterCoordAddr,
                          RequestType,
                          DBSLength,
                          NumberOfDescendents,
                          SecurityLevel,
                          KeyIdMode,
                          KeySource,
                          KeyIndex
                          )
```

The primitive parameters are defined in Table 44ad.

Table 44ad—MLME-DBS.request parameters

Name	Type	Valid range	Description
RequesterCoordAddr	Device Short address	0x0000–0xffff	The short device address of the (original) source requester PAN coordinator.
RequestType	Enumeration	ALLOCATION, DEALLOCATION	If the request is for allocation or deallocation of TMCTP DBS.
DBSLength	Integer	0x00–0xff	Number of BOP slots being requested for the DBS.
NumberOfDescendents	Integer	0x00–0xff	The actual or expected number of descendant PAN coordinators. Set as zero if the PAN coordinator is not clear about how many descendants it will have.
SecurityLevel	Integer	As in Table 46	
KeyIdMode	Integer		
KeySource	Set of octets		
KeyIndex	Integer		

On receipt of an MLME-DBS.request primitive, the MLME generates a DBS request command, as described in 5.3.14.

The SecurityLevel parameter specifies the level of security to be applied to the DBS request command frame. Typically, the DBS request command should not be implemented using security. However, if the TMCTP-child PAN coordinator requesting DBS allocation shares a key with the TMCTP-parent PAN coordinator, then security may be specified.

6.2.23.2 MLME-DBS.indication

The MLME-DBS.indication primitive is generated to indicate the reception of a DBS request command.

The semantics of this primitive are:

```
MLME-DBS.indication          (
                             CoordAddress,
                             RequesterCoordAddr,
                             RequestType,
                             DBSLength,
                             NumberOfDescendents,
                             SecurityLevel,
                             KeyIdMode,
                             KeySource,
                             KeyIndex
                             )
```

The primitive parameters are defined in Table 44ae.

Table 44ae—MLME-DBS.indication parameters

Name	Type	Valid range	Description
CoordAddress	Device Short address	0x0000–0xffff	The short address of the Coordinator that sent the TMCTP DBS Request
RequesterCoordAddr	Device Short address	0x0000–0xffff	The short device address of the (original) source requester PAN coordinator.
RequestType	Enumeration	ALLOCATION, DEALLOCATION	Indicates if the received request is for an allocation or deallocation of TMCTP DBS.
DBSLength	Integer	0x00–0xff	The value of the DBSLength field of the received TMCTP DBS Request
NumberOfDescendents	Integer	0x00–0xff	The number of TMCTP-child PAN coordinators. Set as zero if the PAN coordinator is not clear about how many descendants it will have.

Table 44ae—MLME-DBS.indication parameters *(continued)*

Name	Type	Valid range	Description
SecurityLevel	Integer	As in Table 46	
KeyIdMode	Integer		
KeySource	Set of octets		
KeyIndex	Integer		

When the next higher layer of a TMCTP-parent PAN coordinator receives an MLME-DBS.indication primitive, the TMCTP-parent PAN coordinator determines whether to accept or reject the DBS allocation request using an algorithm which is outside the scope of this standard.

6.2.23.3 MLME-DBS.response

The MLME-DBS.response primitive is used to initiate a response to an MLME-DBS.indication primitive.

The semantics of this primitive are:

```
MLME-DBS.response          (
                           CoordAddress,
                           RequesterCoordAddr,
                           DBSStartingSlot,
                           DBSLength,
                           ChannelNumber,
                           StartBandEdge,
                           StartingChNum,
                           EndingChNum,
                           SecurityLevel,
                           KeyIdMode,
                           KeySource,
                           KeyIndex
                           )
```

The primitive parameters are defined in Table 44af.

Table 44af—MLME-DBS.response parameters

Name	Type	Valid range	Description
CoordAddress	Device Short address	0x0000–0xffff	The short address of the Coordinator that sent TMCTP DBS Request
RequesterCoordAddr	Device Short address	0x0000–0xffff	The short device address of the (original) source requester PAN coordinator.
DBSStartingSlot	Integer	0x0000–0xffff	The first slot of the allocated DBS in the BOP

Table 44af—MLME-DBS.response parameters *(continued)*

Name	Type	Valid range	Description
DBSLength	Integer	0x00–0xff	The size, in BOP slots, of the allocated DBS.
ChannelNumber	PHY Channel ID	See 8.1.2.9	The channel number that the coordinator intends to use for all future communications
StartBandEdge	Set of octets	As in Figure 59ad.4.	The frequency in kHz indicating the lower edge of the band, as described in 5.3.15.2.
StartingChNum	PHY Channel ID	See 8.1.2.9	The lowest channel number, which is assigned by the TMCTP-parent PAN coordinator
EndingChNum	PHY Channel ID	See 8.1.2.9	The highest channel number, which is assigned by the TMCTP-parent PAN coordinator
SecurityLevel	Integer	As in Table 46	
KeyIdMode	Integer		
KeySource	Set of octets		
KeyIndex	Integer		

When the MLME of a TMCTP-parent PAN coordinator receives an MLME-DBS.response primitive, it generates a DBS response command, as described in 5.3.15, and attempts to send it to the TMCTP-child PAN coordinator requesting the allocation of a DBS and a channel.

6.2.23.4 MLME-DBS.confirm

The MLME-DBS.confirm primitive is used to inform the next higher layer of the initiating device whether its request for the allocation of a DBS and a channel was successful or unsuccessful.

The semantics of this primitive are:

```
MLME-DBS.confirm            (
                            RequesterCoordAddr,
                            DBSStartingSlot,
                            DBSLength,
                            ChannelNumber,
                            StartBandEdge,
                            StartingChNum,
                            EndingChNum,
                            Status
                            )
```


The primitive parameters are defined in Table 44ag.

Table 44ag—MLME-DBS.confirm parameters

Name	Type	Valid range	Description
RequesterCoordAddr	Integer	0x0000–0xffff	The short device address of the (original) source requester PAN coordinator.
DBSStartingSlot	Integer	0x0000–0xffff	The first slot of the allocated DBS in the BOP
ChannelNumber	PHY Channel ID	See 8.1.2.9	The channel number that the coordinator intends to use for all future communications
StartBandEdge	Set of octets	As in Figure 59ad.4.	The frequency in kHz indicating the lower edge of the band, as described in 5.3.15.2.
StartingChNum	PHY Channel ID	See 8.1.2.9	The lowest channel number, which is assigned by the TMCTP-parent PAN coordinator
EndingChNum	PHY Channel ID	See 8.1.2.9	The highest channel number, which is assigned by the TMCTP-parent PAN coordinator
Status	Enumeration	SUCCESS, NO_ACK, DENIED, UNAVAILABLE_KEY, UNSUPPORTED_SECURITY, INVALID_PARAMETER	The status of the attempt of the allocation of a DBS and a channel.

If the DBS allocation request was successful, then the status parameter will be set to SUCCESS. Otherwise, the status parameter will be set to indicate the type of failure.

6.2.24 Primitives for device announcement

These primitives are used for device announcement.

6.2.24.1 MLME-DA.request primitive

The MLME-DA.request primitive prompts the device to announce its address to neighbor devices.

The semantics of this primitive are:

```
MLME-DA.request              (
                             CoordAddrMode,
                             CoordPANId,
                             CoordAddress,
                             DaSequenceNum,
                             DaPageNum,
                             DaAddrMode,
                             DaAddrNum,
                             DaAddrList
                             )
```

The primitive parameters are defined in Table 44ah.

Table 44ah—MLME-DA.request parameters

Name	Type	Valid range	Description
CoordAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the coordinator to which this device is associated with.
CoordPANId	Integer	0x0000–0xffff	The identifier of the PAN to which this device is associated with.
CoordAddress	Device address	As specified by the CoordAddrMode parameter	The address of the coordinator to which this device is associated with.
DaSequenceNum	Integer	0–31	The sequence number of device announcement
DaPageNum	Integer	0–7	The page number of DA IE transmitted in a round of device announcement
DaAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the neighbors' addresses to be transmitted.
DaAddrNum	Integer	0–1023	The number of neighbors' addresses to be transmitted.
DaAddrList	Addresses list	As specified by the DaAddrMode parameter	The neighbors' addresses list to be transmitted.

6.2.24.2 MLME-DA.confirm primitive

The MLME-DA.confirm primitive reports results of broadcasting the beacon frame with DA IE.

The semantics of this primitive are:

```
MLME-DA.confirm              (
                             Status
                             )
```


The primitive parameters are defined in Table 44ai.

Table 44ai—MLME-DA.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS, FAILURE	The results of broadcasting a beacon frame with DA IE.

6.2.24.3 MLME-DA.indication primitive

The MLME-DA.indication primitive indicates reception of a beacon frame with a DA IE.

The semantics of this primitive are:

```
MLME-DA.indication          (
                            CoordAddrMode,
                            CoordPANId,
                            CoordAddress,
                            DaSequenceNum,
                            DaPageNum,
                            AddrMode,
                            Address,
                            DaAddrNum,
                            DaAddrMode,
                            DaAddrList
                            )
```

The primitive parameters are defined in Table 44aj.

Table 44aj—MLME-DA.indication parameters

Name	Type	Valid range	Description
CoordAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the coordinator with which the beacon transmitting device is associated
CoordPANId	Integer	0x0000–0xffff	The identifier of the PAN with which the beacon transmitting device is associated
CoordAddress	Device address	As specified by the CoordAddrMode parameter	The address of the coordinator with which the beacon transmitting device is associated
DaSequenceNum	Integer	0–31	The sequence number of device announcement
DaPageNum	Integer	0–7	The page number of DA IE transmitted in a round of device announcement
AddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the beacon transmitting device

Table 44aj—MLME-DA.indication parameters *(continued)*

Name	Type	Valid range	Description
Address	Device address	As specified by the AddrMode parameter	The address of the beacon transmitting device
DaAddrNum	Integer	0–1023	The number of addresses included in the Address List field of a DA IE
DaAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the addresses included in the Address List field of a DA IE, if DaAddrNum is not zero
DaAddrList	Addresses list	As specified by the DaAddrMode parameter	The addresses included in a DA IE, if DaAddrNum is not zero

6.3 MAC data service

6.3.2 MCPS-DATA.confirm

Change the following rows in Table 47 as shown:

Table 47—MCPS-DATA.confirm parameters

Name	Type	Valid range	Description
RangingCounterStart	Unsigned Integer	0x00000000–0xffffffff	A count of the time units corresponding to an RMARKER at the antenna at the beginning of a ranging exchange, as described in 14.7.1 <u>for the UWB PHY and Annex T for TVWS PHYs. For TVWS PHYs, counter units are as given in 5.2.4.34.1.</u> A value of 0x00000000 is used if ranging is not supported, not enabled or if counter was not used for this PPDU.
RangingCounterStop	Unsigned Integer	0x00000000–0xffffffff	A count of the time units corresponding to an RMARKER at the antenna at the end of a ranging exchange, as described in 14.7.1 <u>for the UWB PHY and Annex T for TVWS PHYs. For TVWS PHYs, counter units are as given in 5.2.4.34.1.</u> A value of 0x00000000 is used if ranging is not supported, not enabled, or if the counter is not used for this PPDU.

6.3.3 MCPS-DATA.indication

Insert the following new parameters at the end of the list in 6.3.3 (before the closing parenthesis):

PeriodicListeningInterval
PeriodicListeningDuration
RendezvousTime
TransactionDuration

Insert the following new rows at the end of Table 48:

Table 48—MCPS-DATA.indication parameters

Name	Type	Valid range	Description
PeriodicListeningInterval	Integer	0 to 4294967296	Time in milliseconds of the Periodic Listening Interval field of a received TVWSPS IE.
PeriodicListeningDuration	Integer	0 to 16777215	Time in milliseconds of the Periodic Listening Duration field of a received TVWSPS IE.
RendezvousTime	Integer	0 to 16777215	Time in milliseconds of the Rendezvous Time field of a received TVWSPS IE.
TransactionDuration	Integer	0 to 65535	Time in milliseconds of the Data Transaction Duration field of a received TVWSPS IE.

6.4 MAC constants and PIB attributes

6.4.2 MAC PIB attributes

Change the following row of Table 52 as indicated, and insert the new rows at the end of the table:

Table 52—MAC PIB attributes

Attribute	Type	Range	Description	Default
macFCSType	Integer	0–1	The type of the FCS. A value of zero indicates a 4-octet FCS, as specified in 5.2.1.9. A value of one indicates a 2-octet FCS, as specified in 5.2.1.9. This attribute in only valid for SUN, <u>LECIM, and TVWS</u> PHYs.	0
<u>*macTvwsPsListeningDuration*</u>	<u>Integer</u>	<u>0–16777215</u>	<u>Time in milliseconds between the start and the end of a periodic listening period when TVWS PS is enabled.</u>	<u>0</u>
<u>*macTvwsPsListeningInterval*</u>	<u>Integer</u>	<u>0–4294967296</u>	<u>Time in milliseconds between the start of a periodic listening period and the start of the subsequent periodic listening period when TVWS PS is enabled.</u>	<u>0</u>
<u>*macTvwsPsPollingDuration*</u>	<u>Integer</u>	<u>0–16777215</u>	<u>Time in milliseconds that the initiating device repeats the polling operation when TVWS PS is enabled.</u>	<u>0</u>

Table 52—MAC PIB attributes *(continued)*

Attribute	Type	Range	Description	Default
macTvwsPsPollingInterval	Integer	0–16777215	Time in milliseconds between transmissions of the MAC frames containing the TVWSPS IE during the polling phase when TVWS PS is enabled.	0
macTvwsPsRendezvousTime	Integer	0–16777215	The Rendezvous Time field is the time in milliseconds between the end of the acknowledgment frame sent by a responding device or received by an initiating device and the start of the data transaction between the two devices when TVWS PS is enabled.	0
macTvwsPsTransDuration	Integer	0–65535	Time in milliseconds needed to complete the transaction between the initiating and responding devices when TVWS PS is enabled.	0
macTvwsPsEnabled	Boolean	TRUE, FALSE	Indicates that TVWS PS is enabled.	FALSE
macStartBandEdge	Integer	0–16777215	Frequency in kHz indicating the lower edge of the band.	608000
macEndBandEdge	Integer	0–16777215	Frequency in kHz indicating the upper edge of the band.	614000
macGroupRxMode	Boolean	TRUE, FALSE	Enables the reception of EUI-64 group addresses.	FALSE
macTmctpExtendedOrder	Integer	0–14	The extended length of the active portion of the superframe, as defined in 5.1.1.8.	0

6.4.3 Calculating PHY dependent MAC PIB values

6.4.3.2 General MAC PIB attributes for functional organization

Insert the following new row at the end of Table 52a:

Table 52a—General MAC PIB attributes for functional organization

Attribute	Type	Range	Description	Default
macDAenabled	Boolean	TRUE or FALSE	If TRUE, the device is capable of functionality specific to Device Announcement	Implementation specific

8. General PHY requirements

8.1 General requirements and definitions

Insert the following list items at the end of the second dashed list in 8.1:

— **TVWS-FSK PHY:** multi-rate and multi-regional frequency shift keying (FSK) PHY operating in multiple over-the-air data rates in support of various applications in TVWS, as defined in 20.1.

— **TVWS-OFDM PHY:** multi-rate and multi-regional orthogonal frequency division multiplexing (OFDM) PHY operating in multiple over-the-air data rates in support of various applications in TVWS, as defined in 20.2.

— **TVWS-NB-OFDM PHY:** multi-rate and multi-regional narrow band orthogonal frequency division multiplexing (NB-OFDM) PHY operating in multiple over-the-air data rates in support of various applications in TVWS, as defined in 20.3.

8.1.1 Operating frequency range

Change the first paragraph of 8.1.1 as indicated:

A compliant device shall operate in one or several frequency bands summarized in Table 66, Table 66a~~, and~~ Table 66b, and Table 4ab. Table 66a shows frequency bands for devices supporting the LECIM DSSS PHY, and Table 66b shows frequency bands for devices supporting the LECIM FSK PHY. Table 4ab shows the frequency bands for devices supporting the TVWS PHYs.

8.1.2 Channel assignments

Change 8.1.2.9 as follows:

8.1.2.9 Channel numbering for SUN and TVWS PHYs

The channel center frequency *ChanCenterFreq* for all SUN and TVWS PHYs, except the MR-O-QPSK PHY operating in the 868–870 MHz band, shall be derived as follows:

$$ChanCenterFreq = ChanCenterFreq_0 + NumChan \text{ x } ChanSpacing$$

where $ChanCenterFreq_0$ is the first channel center frequency in MHz, *ChanSpacing* is the separation between adjacent channels in MHz, *NumChan* is the channel number from 0 to *TotalNumChan*–1, and *TotalNumChan* is the total number of channels for the available frequency band. The parameters *ChanSpacing*, *TotalNumChan,* and $ChanCenterFreq_0$ for different frequency bands and modulation schemes are specified in Table 68d.

Three channels are available for the MR-O-QPSK PHY operating in the 868–870 MHz band. The channel center frequency for each of these channels is shown in Table 68e.

In the case of TVWS PHYs, $ChanCenterFreq_0$ is derived as follows:

$$ChanCenterFreq_0 = macStartBandEdge + ChanSpacing$$

TotalNumChan is derived as follows:

TotalNumChan = floor((*macEndBandEdge – macStartBandEdge*)/*ChanSpacing–1*)

macStartBandEdge and *macEndBandEdge* are set by the upper layers, appropriate for the band of operation at a particular time.

9. PHY services

9.2 PHY constants

Change the following rows of Table 70 as indicated:

Table 70—PHY constants

Constant	Description	Value
aMaxPHYPacketSize	The maximum PSDU size (in octets) the PHY shall be able to receive.	2047 for SUN, TVWS, and LECIM FSK PHYs. For LECIM DSSS PHY, this is not a constant; refer to *phyLECIMDSSSPSDUSize*. 127 for all other PHYs
aTurnaroundTime	RX-to-TX or TX-to-RX turnaround time (in symbol periods), as defined in 8.2.1 and 8.2.2.	For the SUN, TVWS, and LECIM FSK PHYs, the value is 1 ms expressed in symbol periods, rounded up to the next integer number of symbol periods using the ceiling() function.[a] For the LECIM DSSS PHY, the value is 1 ms expressed in modulation symbol periods, rounded up to the next integer number of symbol periods using the ceiling() function. The value is 12 for all other PHYs.

[a]The function ceiling() returns the smallest integer value greater than or equal to its argument value.

9.3 PHY PIB attributes

NOTE—The first paragraph of 9.3 is reproduced here to assist the reader in understanding the notation used in Table 71. No changes are made to this paragraph.

The PHY PIB comprises the attributes required to manage the PHY of a device. The attributes contained in the PHY PIB are presented in Table 71. Attributes marked with a dagger (†) are read-only attributes (i.e., attribute can only be set by the PHY), which can be read by the next higher layer using the MLME-GET.request primitive. All other attributes can be read or written by the next higher layer using the MLME-GET.request or MLME-SET.request primitives, respectively.

Change the following rows of Table 71 as indicated, and insert the new rows at the end of the table:

Table 71—PHY PIB attributes

Attribute	Type	Valid range	Description
phySymbolsPerOctet†	Float	0.4, 1.3, 1.6, 2, 4, 5.3, 8	The number of symbols per octet for the current PHY. For the UWB PHY this is defined in 14.2.3. For CSS PHY, 1.3 corresponds to 1 Mb/s, while 5.3 corresponds to 250 kb/s. For the MR-OFDM PHY, see 18.2.3.3. For the TVWS-FSK PHY, see 20.1.2.7. For the TVWS-OFDM PHY, see 20.2.2. For the TVWS-NB-OFDM PHY, see 20.3.3.13. This attribute is not used by the MR-O-QPSK PHY.
phyFSKFECEnabled	Boolean	TRUE, FALSE	A value of TRUE indicates that FEC is turned on. A value of FALSE indicates that FEC is turned off. This attribute is only valid for the MR-FSK PHY and TVWS-FSK PHY.
phyFSKPreambleLength	Integer	4–1000	The number of 1-octet patterns in the preamble, as described in 18.1.1.1 and 20.1.1.1. This attribute is only valid for the MR-FSK PHY and TVWS-FSK PHY.
phyFSKFECInterleavingRSC	Boolean	TRUE, FALSE	A value of TRUE indicates that interleaving is enabled for RSC. A value of FALSE indicates that interleaving is disabled for RSC. This attribute is only valid for the MR-FSK PHY and TVWS-FSK PHY.
phyLECIMFSKSpreadingFactor	Enumeration	1, 2, 4, 8, 16	The spreading factor (SF) to be used when *phyLECIMFSKSpreading* or *phyTvwsFskSpreadingEnabled* is TRUE. This attribute is only valid for the LECIM FSK PHY and TVWS-FSK PHY.
phyLECIMFSKSpreadingPattern	Enumeration	ALTERNATING_1/0, NON_ALTERNATING	Specifies the type of pattern used for spreading when spreading is enabled. This attribute is only valid for the LECIM FSK PHY and TVWS-FSK PHY.
phyTvwsFskSpreadingEnabled	Boolean	TRUE, FALSE	A value of TRUE indicates that spreading is turned on. A value of FALSE indicates that spreading is turned off. This attribute is only valid for the TVWS-FSK PHY.

Table 71—PHY PIB attributes *(continued)*

Attribute	Type	Valid range	Description
phyTvwsFskWhiteningEnabled	Boolean	TRUE, FALSE	A value of TRUE indicates that whitening is turned on. A value of FALSE indicates that whitening is turned off. This attribute is only valid for the TVWS-FSK PHY.
phyTvwsSfdLength	Integer	16 or 24	Length of the TVWS SFD field in bits. Valid values are 16 and 24. This attribute is only valid for the TVWS-FSK PHY.
phyTvwsFskFecScheme	Integer	0–2	A value of zero indicates that the first FEC scheme as defined in 20.1.2.2 is employed. A value of one indicates that the second FEC scheme as defined in 20.1.2.2 is employed. A value of two indicates that the third FEC scheme as defined in 20.1.2.2 is employed. The attribute is only valid for the TVWS-FSK PHY
phyTvwsChannelAggregation	Boolean	TRUE, FALSE	A value of TRUE indicates that channel aggregation is enabled. A value of FALSE indicates that channel aggregation is disabled. This attribute is only valid for the TVWS-NB-OFDM PHY.

9.4 PHY PIB attribute values for *phyMaxFrameDuration* and *phySHRDuration*

Change the first paragraph of 9.4 as shown:

For PHYs other than CSS, UWB, the LECIM PHYs, the TVWS PHYs, and the SUN PHYs, the attribute *phyMaxFrameDuration* is given by:

Insert the following new paragraphs at the end of 9.4:

For the TVWS-FSK PHY, the attribute *phyMaxFrameDuration* is given by:

$$phyMaxFrameDuration = (phyFSKPreambleLength + phyTvwsSfdLength/8 + 2 + aMaxPHYPacketSize) \times phySymbolsPerOctet$$

For the TVWS-OFDM PHY, the attribute *phyMaxFrameDuration* is given by:

$$phyMaxFrameDuration = (1, 2, 3 \text{ or } 4) + 2 + 1 + \text{ceiling}[(aMaxPHYPacketSize + 1) \times phySymbolsPerOctet]$$

where 1, 2, 3, or 4 correspond to the length of the STF as indicated in Figure 173.

For the TVWS-NB-OFDM PHY, the attribute *phyMaxFrameDuration* is given by:

$$phyMaxFrameDuration = 1 + 1 + 1 + \text{ceiling}[(aMaxPHYPacketSize + 1) \times phySymbolsPerOctet]$$

where ceiling() is a function that returns the smallest integer value greater than or equal to its argument value.

Insert the following new clause (Clause 20) after Clause 19:

20. TVWS PHYs

Three PHYs are specified: an FSK PHY (TVWS-FSK), as described in 20.1, an orthogonal frequency division multiplexing PHY (TVWS-OFDM) as described in 20.2 and a narrow-band orthogonal frequency division multiplexing PHY (TVWS-NB-OFDM) as described in 20.3.

A coexistence assurance analysis for all three PHYs can be found in Chang and Seibert [B.x1].[5] An example of encoding a TVWS-FSK packet, an example of encoding a TVWS-OFDM packet, and an example of encoding a TVWS-NB-OFDM packet can be found in Seibert [B.x3], Shin et al. [B.x4], and Lu et al. [B.x2], respectively.

20.1 TVWS-FSK PHY

20.1.1 PPDU format for TVWS-FSK

The TVWS-FSK PPDU shall support the format shown in Figure 170.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length *n*. Each string is numbered starting with b_0 on the left and ending with b_{n-1} on the right. When transmitted, they are processed from b_0 first to b_{n-1} last, without regard to their content or structure.

All reserved fields shall be set to zero upon transmission and shall be ignored after reception.

		Octets	
		2	**variable**
Preamble	SFD	As defined in 20.1.1.3	PSDU
SHR		PHR	PHY payload

Figure 170—Format of the TVWS-FSK PPDU

20.1.1.1 Preamble field

The Preamble field shall contain *phyFSKPreambleLength* (as defined in 9.3) multiples of the 8-bit sequence "01010101".

20.1.1.2 SFD

The SFD shall be a 16-bit sequence or, optionally, a 24-bit sequence selected from the list of values shown in Table 199. The SFD length is controlled by the PHY PIB attribute *phyTvwsSfdLength,* as defined in 9.3.

Devices that do not support the FEC (see 20.1.3) shall support the SFD associated with uncoded (PHR + PSDU). Devices that support FEC (see 20.1.3) shall support both SFD values shown in Table 199.

[5]The numbers in brackets correspond to the numbers of the bibliography in Annex A.

Table 199—TVWS-FSK SFD values

phyTvwsSfdLength	SFD value for coded (PHR + PSDU)	SFD value for uncoded (PHR + PSDU)
16 bits	0110 1111 0100 1110	1001 0000 0100 1110
24 bits	1100 0001 1000 1000 1101 0110	1000 0101 1111 1100 1011 0011

20.1.1.3 PHR

The format of the PHR is shown in Figure 171.

Bit string index	0	1	2	3	4	5–15
Bit mapping	R_0	RNG	PC	FCS	DW	L_{10}–L_0
Field name	Reserved	Ranging	Parity Check	FCS Type	Data Whitening	Frame Length

Figure 171—Format of the PHR for TVWS-FSK

The Ranging field (RNG) indicates whether ranging, as indicated in Annex T, is active. The Ranging (RNG) field shall be set to 1 when ranging is used and 0 when it is not.

The Parity Check field (PC) provides error detection. The Parity Check shall be computed from the modulo-2 addition of all bits in the PHR other than the Parity Check.

The FCS Type field (FCS) indicates the length of the FCS field described in 5.2.1.9 that is included in the MPDU. Table 200 shows the relationship between the contents of the FCS Type field and the length of the transmitted FCS.

Table 200—Relationship between FCS Type field and transmitted FCS length for TVWS-FSK

FCS Type field value	Transmitted FCS length
0	4 octets
1	2 octets

The Data Whitening field (DW) indicates whether data whitening of the PSDU is used upon transmission. When data whitening is used, the Data Whitening field shall be set to one. It shall be set to zero otherwise. Data whitening shall only be applied to the PSDU.

The Frame Length field (L_{10}–L_0) specifies the total number of octets (prior to FEC encoding, if enabled, as specified in 20.1.2.2) contained in the PSDU. The Frame Length field is an unsigned integer and shall be transmitted MSB first.

20.1.1.4 PSDU field

The PSDU field carries the PHY payload data of the PPDU.

20.1.2 Modulation and coding for TVWS-FSK

The modulation for the TVWS-FSK PHY is 2-level filtered FSK or 4-level filtered FSK, depending on the operating mode. The filtering method is needed to meet regulatory requirements in the band of operation. Table 201 shows the modulation and channel parameters for the operating modes of the TVWS-FSK PHY.

Table 201—TVWS-FSK modulation and channel parameters[a]

Parameter	Mode #1		Mode #2		Mode #3		Mode #4	Mode #5
Data rate (kb/s)	50		100		200		300	400
Modulation level	2-level		2-level		2-level		2-level	4-level
Modulation index- h	0.5	1.0	0.5	1.0	0.5	1.0	0.5	0.33
Channel spacing (kHz)	100	200	200	400	400	600	600	600

[a]Data rates shown are over-the-air data rates (the data rates transmitted over the air regardless of whether the FEC is enabled).

20.1.2.1 Reference modulator diagram

The functional block diagram in Figure 172 is provided as a reference for specifying the TVWS-FSK data flow processing functions.

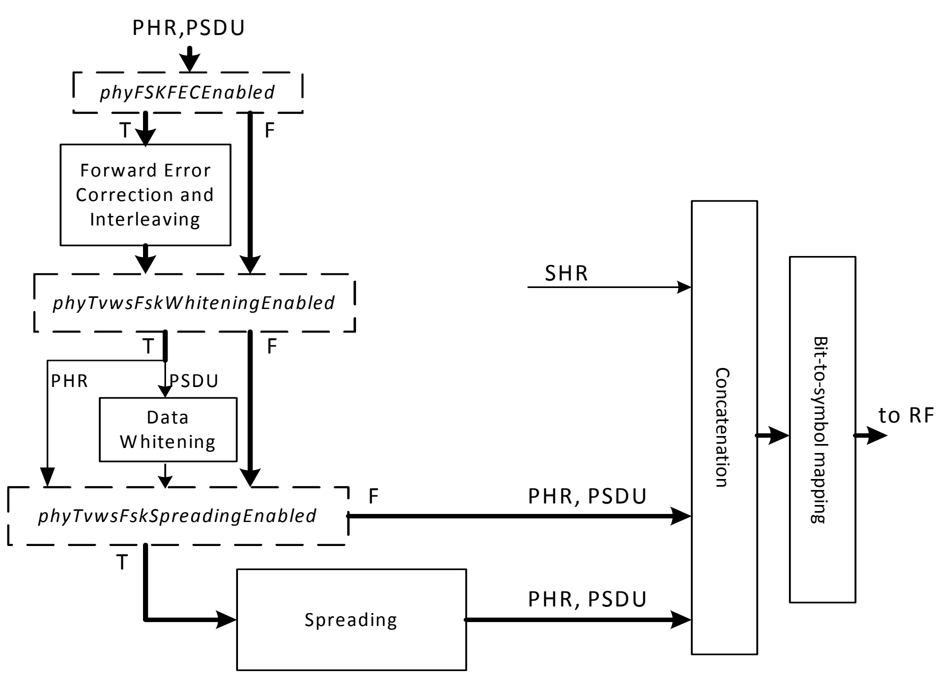

Figure 172—Reference modulator diagram for TVWS-FSK

20.1.2.2 Forward error correction (FEC) and interleaving

FEC support is optional. The use of FEC is controlled by the PHY PIB attribute *phyFSKFECEnabled*, as defined in 9.3. Three FEC schemes are included. The FEC scheme is controlled by the PHY PIB attribute *phyTvwsFskFecScheme* as defined in 9.3. The first FEC scheme shall be according to 19.2.2.4. For this scheme, interleaving shall always be used when FEC is enabled, and the interleaving scheme shall be as defined in 19.2.2.5. The second FEC scheme shall be according to the RSC FEC scheme defined in 18.1.2.4. For this scheme, interleaving shall be controlled by the value of the *phyFSKFECInterleavingRSC* PHY PIB attribute as defined in 18.1.2.5. The third FEC scheme shall be according to the NRNSC FEC scheme defined in 18.1.2.4. For this scheme, interleaving shall always be used when FEC is enabled, and the interleaving scheme shall be as defined in 18.1.2.5.

20.1.2.3 Data whitening

Data whitening is optional. The use of data whitening is controlled by the PIB attribute *phyTvwsFskWhiteningEnabled*, as defined in 9.3. The data whitening algorithm shall be as defined in 19.2.3.

20.1.2.4 Spreading

Spreading support is optional. The use of spreading is controlled by the PIB attribute *phyTvwsFskSpreadingEnabled*, as defined in 9.3. The spreading method shall be as defined in 19.2.2.6.

20.1.2.5 Bit-to-symbol mapping

The symbol encoding is shown in Table 202.

— For 2-level filtered FSK, the frequency deviation, f_{dev}, is equal to
(symbol rate × modulation index)/2.

— For 4-level filtered FSK, the frequency deviation, f_{dev}, is equal to
(3 × symbol rate × modulation index)/2.
Two bits shall be mapped to four frequency deviation levels for the PHR and PSDU.

The SHR shall always be encoded using 2-level modulation as specified in Table 202.

Table 202—TVWS-FSK symbol encoding

2-level	
Symbol (binary)	Frequency deviation
0	$-f_{dev}$
1	$+f_{dev}$
4-level	
Symbol (binary)	Frequency deviation
01	$-f_{dev}$
00	$-f_{dev}/3$
10	$+f_{dev}/3$
11	$+f_{dev}$

20.1.2.6 Modulation quality

The modulation quality shall be as given in 18.1.2.3.

20.1.2.7 Values for *phySymbolsPerOctet*

The values for *phySymbolsPerOctet* are as follows:

— For 2-level modulation and *phyFSKFECEnabled* = FALSE, *phySymbolsPerOctet* = 8.
— For 4-level modulation and *phyFSKFECEnabled* = FALSE, *phySymbolsPerOctet* = 4.
— For 2-level modulation and *phyFSKFECEnabled* = TRUE, *phySymbolsPerOctet* = 16.
— For 4-level modulation and *phyFSKFECEnabled* = TRUE, *phySymbolsPerOctet* = 8.

20.1.3 TVWS-FSK RF requirements

20.1.3.1 Operating frequency range

The TVWS-FSK PHY operates in the bands indicated in Table 4ab.

20.1.3.2 Clock frequency and timing accuracy

The clock frequency and time accuracy shall be within ±20 ppm.

20.1.3.3 Channel switch time

The channel switch time shall be as given in 19.2.4.3.

20.1.3.4 Receiver sensitivity

The receiver sensitivity shall be as given in 18.1.5.7.

20.1.3.5 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as given in 18.1.5.9.

20.1.3.6 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as given in 18.1.5.10.

20.1.3.7 Receiver maximum input level of desired signal

The TVWS-FSK PHY shall have a receiver maximum input level greater than or equal to –20 dBm using the measurement defined in 8.2.4.

20.1.3.8 Receiver ED

The TVWS-FSK PHY shall provide the receiver ED measurement as described in 8.2.5.

20.1.3.9 Link quality indicator

The TVWS-FSK PHY shall provide the LQI measurement as described in 8.2.6.

20.1.3.10 Clear channel assessment (CCA)

The TVWS-FSK PHY shall use one of the CCA methods as described in 8.2.7.

20.2 TVWS-OFDM PHY

The TVWS orthogonal frequency division multiplexing (TVWS-OFDM) PHY supports data rates ranging from 390.625 kb/s to 1562.5 kb/s. The subcarrier spacing is equal to 1250/128 kHz.

The symbol rate is 7.8125 ksymbols/sec, which corresponds to 128 µs per symbol. This symbol includes a quarter-duration cyclic prefix (CP; 25.6 µs) and a base symbol (102.4 µs).

20.2.1 PPDU format for TVWS-OFDM

The TVWS-OFDM PPDU shall be formatted as illustrated in Figure 173.

<table>
<tr><th colspan="4">Number of TVWS-OFDM symbols</th><th></th><th></th></tr>
<tr><th>variable (1–4)</th><th>2</th><th>1</th><th>variable</th><th>6 bits</th><th>variable</th></tr>
<tr><td>STF</td><td>LTF</td><td>As defined in 20.2.1.3</td><td>PSDU</td><td>TAIL</td><td>PAD</td></tr>
<tr><td colspan="2">SHR</td><td>PHR</td><td>PHY payload</td><td></td><td></td></tr>
</table>

Figure 173—Format of the TVWS-OFDM PPDU

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length n, numbered b_0 on the left and b_{n-1} on the right. When transmitted, they are processed from b_0 first to b_{n-1} last, without regard to their content of structure.

Definitions are provided in the frequency domain for the Short Training field (STF) in 20.2.1.1 and for the Long Training field (LTF) in 20.2.1.2. In each case, a normative set of operations is specified to transform the frequency domain fields to the time domain and to insert prescribed repetitions or CPs of these time domain sequences.

TAIL and PAD bits are appended to the PSDU for the purpose of FEC encoding, as described in 20.2.3.3. The PPDU Tail Bit field (TAIL) is described in 20.2.3.7. The method for adding pad bits (PAD) is described in 20.2.3.8.

20.2.1.1 Short Training field (STF)

Subclauses 20.2.1.1.1 through 20.2.1.1.4 describe the STF.

20.2.1.1.1 Frequency domain STF

Table 203 shows the frequency domain representation of the STF.

Table 203—Frequency domain representation of STF for TVWS-OFDM

Tone #	Value	Tone #	Value	Tone #	Value	Tone #	Value
–64	0	–32	$\sqrt{2}+\sqrt{2}j$	0	0	32	$\sqrt{2}+\sqrt{2}j$
–63	0	–31	0	1	0	33	0
–62	0	–30	0	2	0	34	0
–61	0	–29	0	3	0	35	0
–60	0	–28	0	4	0	36	0
–59	0	–27	0	5	0	37	0
–58	0	–26	0	6	0	38	0
–57	0	–25	0	7	0	39	0
–56	0	–24	$-\sqrt{2}-\sqrt{2}j$	8	$-\sqrt{2}-\sqrt{2}j$	40	$\sqrt{2}+\sqrt{2}j$
–55	0	–23	0	9	0	41	0
–54	0	–22	0	10	0	42	0
–53	0	–21	0	11	0	43	0
–52	0	–20	0	12	0	44	0
–51	0	–19	0	13	0	45	0
–50	0	–18	0	14	0	46	0
–49	0	–17	0	15	0	47	0
–48	$\sqrt{2}+\sqrt{2}j$	–16	$-\sqrt{2}-\sqrt{2}j$	16	$-\sqrt{2}-\sqrt{2}j$	48	$\sqrt{2}+\sqrt{2}j$
–47	0	–15	0	17	0	49	0
–46	0	–14	0	18	0	50	0
–45	0	–13	0	19	0	51	0
–44	0	–12	0	20	0	52	0
–43	0	–11	0	21	0	53	0
–42	0	–10	0	22	0	54	0
–41	0	–9	0	23	0	55	0
–40	$-\sqrt{2}-\sqrt{2}j$	–8	$\sqrt{2}+\sqrt{2}j$	24	$\sqrt{2}+\sqrt{2}j$	56	0
–39	0	–7	0	25	0	57	0
–38	0	–6	0	26	0	58	0
–37	0	–5	0	27	0	59	0
–36	0	–4	0	28	0	60	0
–35	0	–3	0	29	0	61	0
–34	0	–2	0	30	0	62	0
–33	0	–1	0	31	0	63	0

20.2.1.1.2 Time domain STF generation

Given a sequence of 128 samples $f(n)$, indexed by $n = 0, ..., 127$, the discrete Fourier transform (DFT) is defined as $F(k)$, where $k = 0, ..., 127$:

$$F(k) = \frac{1}{\sqrt{128}} \sum_{n=0}^{127} f(n) e^{-j2\pi kn/128}$$

The sequence $f(n)$ can be calculated from $F(k)$ using the inverse discrete Fourier transform (IDFT), where the k values numbered from 0 to 63 correspond to tones numbered from 0 to 63 and the k values numbered from 64 to 127 correspond to tones numbered from –64 to –1, respectively:

$$f(n) = \frac{1}{\sqrt{128}} \sum_{k=0}^{127} F(k) e^{j2\pi nk/128}$$

The time domain STF is obtained as follows:

$STF\_time = \mathrm{IDFT}(STF\_freq)$

where *STF_freq* is given in Table 203.

The CP is then prepended to the TVWS-OFDM symbol.

20.2.1.1.3 Time domain STF repetition

The sync sequence is repeated eight times per STF symbol, and the CP is also 1/4 symbol. Therefore, there are 10 repetitions of sync sequence in each STF TVWS-OFDM symbol. The number of STF TVWS-OFDM symbols varies from 1 to 4 as shown in Figure 173.

Figure 174 shows the STF structure. Each “s” in the figure represents one time-domain repetition of a subsequence of TVWS-OFDM.

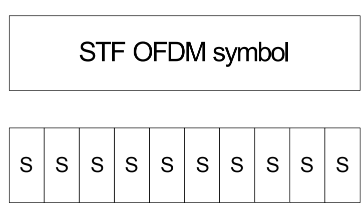

Figure 174—Structure of STF OFDM symbol for TVWS-OFDM

20.2.1.1.4 STF power boosting

Power boosting shall be applied to the STF TVWS-OFDM symbols in order to aid preamble detection. The boost shall be a multiplication by 2.

20.2.1.2 Long training field (LTF)

The LTF structure in both frequency and the time domain is described in 20.2.1.2.1 through 20.2.1.2.2.

20.2.1.2.1 Frequency domain LTF

Table 204 shows the frequency domain representation of the LTF.

Table 204—Frequency domain representation of LTF for TVWS-OFDM

Tone #	Value	Tone #	Value	Tone #	Value	Tone #	Value
–64	0	–32	–1	0	0	32	–1
–63	0	–31	1	1	–1	33	1
–62	0	–30	–1	2	1	34	–1
–61	0	–29	–1	3	–1	35	–1
–60	0	–28	1	4	1	36	1
–59	0	–27	1	5	–1	37	–1
–58	0	–26	–1	6	–1	38	1
–57	0	–25	1	7	–1	39	–1
–56	0	–24	1	8	1	40	–1
–55	0	–23	1	9	–1	41	1
–54	1	–22	1	10	1	42	–1
–53	–1	–21	1	11	–1	43	1
–52	–1	–20	–1	12	–1	44	–1
–51	–1	–19	1	13	–1	45	1
–50	1	–18	1	14	–1	46	1
–49	–1	–17	1	15	–1	47	–1
–48	–1	–16	1	16	1	48	–1
–47	1	–15	–1	17	–1	49	1
–46	–1	–14	1	18	1	50	1
–45	–1	–13	–1	19	–1	51	1
–44	1	–12	1	20	1	52	1
–43	1	–11	–1	21	1	53	–1
–42	–1	–10	1	22	1	54	1
–41	1	–9	–1	23	–1	55	0
–40	1	–8	–1	24	–1	56	0
–39	1	–7	1	25	1	57	0
–38	1	–6	–1	26	–1	58	0
–37	–1	–5	1	27	–1	59	0

Table 204—Frequency domain representation of LTF for TVWS-OFDM *(continued)*

Tone #	Value	Tone #	Value	Tone #	Value	Tone #	Value
–36	–1	–4	–1	28	1	60	0
–35	–1	–3	1	29	–1	61	0
–34	1	–2	–1	30	1	62	0
–33	–1	–1	–1	31	1	63	0

20.2.1.2.2 Time domain LTF generation

The time domain LTF is obtained as follows:

$$LTF\_time = \mathrm{IDFT}(LTF\_freq)$$

where *LTF_freq* is given in Table 204.

A 1/2 symbol CP is prepended to two consecutive copies of the base symbol as shown in Figure 175. For more details, see 20.2.3.6.

The time-domain LTF structure is shown in Figure 175, where T_{LTF} is the duration of the base symbol.

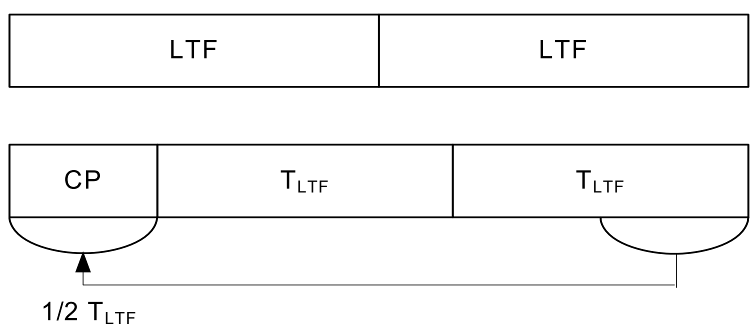

Figure 175—Structure of LTF for TVWS-OFDM

20.2.1.3 PHR

The PHR consists of the Frame Length field and frame control bits. The PHR structure shall be formatted as illustrated in Figure 176. All multi-bit fields are unsigned integers and shall be processed MSB first.

Bit string index	**0–4**	**5**	**6–7**	**8–18**	**19–27**	**28–43**	**44–49**
Bit mapping	R_4–R_0	RNG	RA_1–RA_0	L_{10}–L_0	S_8–S_0	H_{15}–H_0	T_5–T_0
Field name	Reserved	Ranging	Rate	Frame Length	Scrambling Seed	HCS	Tail

Figure 176—PHY header fields for TVWS-OFDM

The PHR occupies one TVWS-OFDM symbol. The PHR shall be transmitted using the lowest supported modulation and coding scheme (MCS) level, as described in Table 205. It is sent to the convolutional encoder starting from the leftmost bit in Figure 176 to the rightmost bit.

The Ranging field (RNG) is set to 1 to indicate that this particular frame is intended for ranging. If the frame is not intended for ranging the Ranging field (RNG) is set to 0.

The Rate field (RA_1-RA_0) specifies the data rate of the payload and is equal to the numerical value of the MCS for the mandatory mode and the numerical value of the MCS minus three for the optional 4 times overclock modes, as described in 20.2.2, expressed in binary format. The list of data rates for TVWS-OFDM can be found in 20.2.2.

The Frame Length field (L_{10}-L_0) specifies the total number of octets contained in the PSDU (prior to FEC encoding).

The Scrambler field (S_8-S_0) specifies the scrambling seed defined by the manufacturer.

The Header Check Sequence (HCS) field (H_{15}-H_0) is a 16-bit CRC taken over the PHY header (PHR) fields. The HCS shall be computed using the first 28 bits of the PHR. The HCS shall be calculated using the polynomial $G_{16}(x) = x^{16} + x^{12} + x^5 + 1$.

The HCS is the one's complement of the modulo 2 sum of the two remainders in a) and b):

a) The remainder resulting from $[x^k(x^{15}+ x^{14}+\ldots+1)]$ divided (modulo 2) by $G_{16}(x)$, where the value k is the number of bits in the calculation field.
b) The remainder resulting from the calculation field contents, treated as a polynomial, multiplied by x^{16} and then divided (modulo 2) by $G_{16}(x)$.

At the transmitter, the initial remainder of the division shall be preset to all ones and then be modified via division of the calculation field by the generator polynomial, $G_{16}(x)$. The one's complement of this remainder is the HCS field.

The Tail bit field (T_5-T_0), which consists of all zeros, is for Viterbi decoder flushing, as described in 20.2.3.7.

All reserved fields shall be set to zero upon transmission and shall be ignored upon reception.

20.2.1.4 PSDU field

The PSDU field carries the data of the PHY packet.

20.2.2 System parameters for TVWS-OFDM

For devices that support the TVWS-OFDM PHY, modes MCS0, MCS1, and MCS2 shall be supported, and modes MCS3, MCS4, and MCS5 are optional, as shown in Table 205.

The system parameters for the TVWS-OFDM PHY are shown in Table 205. Included in Table 205 are the data rates and the number of symbols per octet, which depend on both the MCS level and the TVWS-OFDM Mode. The nominal bandwidth is calculated by multiplying {the number of active tones + 1 for the DC tone} by {the subcarrier spacing}.

Table 205—System parameters for TVWS-OFDM

Parameter		Mandatory modes[a]	Optional modes
Nominal bandwidth (kHz)		1064.5	4258
Subcarrier spacing (kHz)		1250/128	4×1250/128
DFT size		128	128
Active tones		108	108
# Pilot tones		8	8
# Data tones		100	100
MCS0 (BPSK)	Data Rate (kb/s)	390.625	—
	phySymbolsPerOctet	8 bits/octet × 1/50 symbol/bits	—
MCS1 (QPSK)	Data Rate (kb/s)	781.250	—
	phySymbolsPerOctet	8 bits/octet × 1/100 symbol/bits	—
MCS2 (16-QAM)	Data Rate (kb/s)	1562.5	—
	phySymbolsPerOctet	8 bits/octet × 1/200 symbol/bits	—
MCS3 (BPSK)	Data Rate (kb/s)	—	1562.5
	phySymbolsPerOctet	—	8 bits/octet × 1/50 symbol/bits
MCS4 (QPSK)	Data Rate (kb/s)	—	3125
	phySymbolsPerOctet	—	8 bits/octet × 1/100 symbol/bits
MCS5 (16-QAM)	Data Rate (kb/s)	—	6250
	phySymbolsPerOctet	—	8 bits/octet × 1/200 symbol/bits

[a]For devices that support the TVWS-OFDM PHY

20.2.3 Modulation and coding for TVWS-OFDM

20.2.3.1 Reference modulator diagram

The reference modulator diagram is shown in Figure 177.

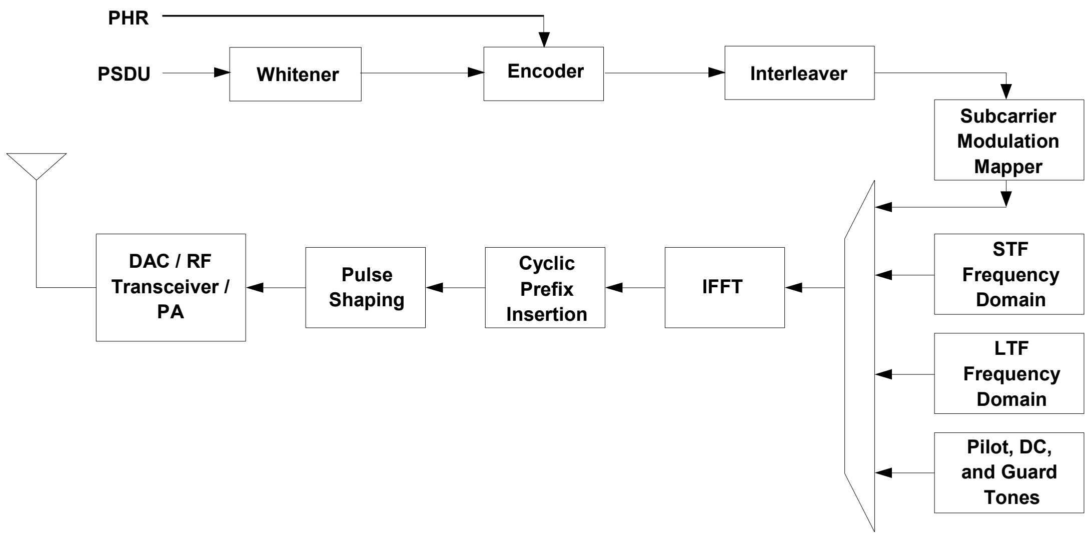

Figure 177—Reference modulator diagram for TVWS-OFDM

20.2.3.2 Bit-to-symbol mapping

Figure 178 shows the bit-to-symbol mapping for BPSK, QPSK, and 16-QAM.

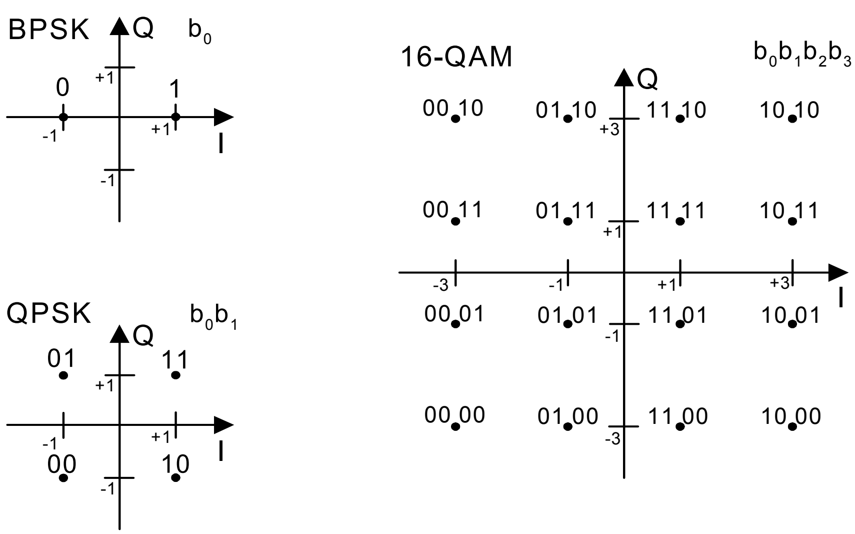

Figure 178—Bit-to-symbol mapping for TVWS-OFDM

The output values, d, are formed by multiplying the resulting $(I+jQ)$ value by a normalization factor K_{MOD}:

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

The normalization factor, K_{MOD}, depends on the base modulation mode, as described in Table 206. The purpose of the normalization factor is to achieve the same average power for all mappings.

Table 206—Modulation-dependent normalization factor K_{MOD} for TVWS-OFDM

Modulation	K_{MOD}
BPSK	1
QPSK	$1/\sqrt{2}$
16-QAM	$1/\sqrt{10}$

20.2.3.3 Forward error correction (FEC)

The DATA field shall be coded with a convolutional encoder of coding rate R = 1/2. The DATA field consists of the PHR when encoding the PHY header as shown in Figure 176. The DATA field consists of the PSDU, TAIL and PAD bits as shown in Figure 173 when encoding the remainder of the PPDU. The convolutional encoder shall use the generator polynomials expressed in octal representation, $g_0 = 133_8$ and $g_1 = 171_8$, of rate R = 1/2, as shown in Figure 179. The convolutional encoder shall be initialized to the all zeros state before encoding the PHR and then reset to the all zeros state before encoding the PSDU.

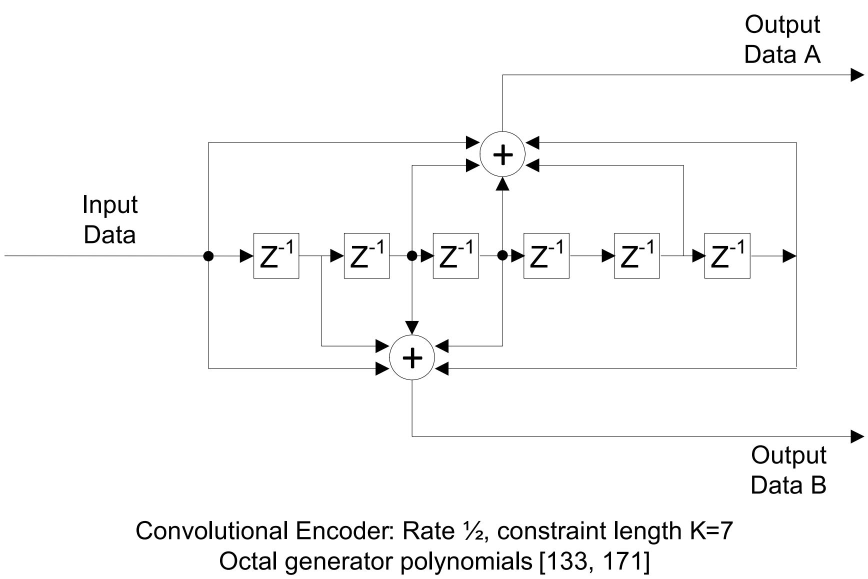

Figure 179—Rate 1/2 convolutional encoder for TVWS-OFDM

The first coded bit is from Output Data A, and the second coded bit is from Output Data B.

20.2.3.4 Interleaver

The interleaving process consists of two permutations. The index of the coded bit before the first permutation shall be denoted as k; i shall be the index after the first and before the second permutation; and j shall be the index after the second permutation, just prior to modulation mapping. The coded bits are written at the index given by j and read out sequentially. The index i is defined as follows:

$$i = \left(\frac{N_{cbps}}{N_{row}}\right) \times [k \bmod(N_{row})] + \mathrm{floor}\left(\frac{k}{N_{row}}\right)$$

where

N_{cbps} is the number of coded bits per symbol
k is 0, 1, 2,..., $(N_{cbps} - 1)$
N_{row} is 20

The process of interleaving for the first permutation is illustrated in Figure 180.

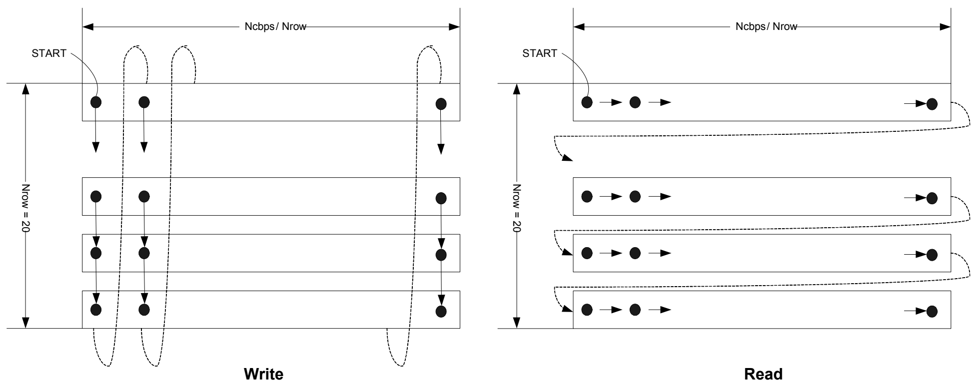

Figure 180—The process of interleaving for the first permutation

The index j is defined as follows:

$$j = s \times \mathrm{floor}\left(\frac{i}{s}\right) + \left[i + N_{cbps} - \mathrm{floor}\left(\frac{N_{row} \times i}{N_{cbps}}\right)\right] \bmod(s)$$

where

N_{cbps} is the number of coded bits per symbol
i is 0, 1, 2, …, $(N_{cbps}-1)$
N_{row} is 20

and

$$s = \max\left(\frac{N_{bpsc}}{2}, 1\right)$$

where N_{bpsc} is the number of bits per subcarrier and has the values 1, 2, and 4 for BPSK, QPSK, and 16-QAM, respectively. N_{cbps} is defined as follows: 100 bits for BPSK, 200 bits for QPSK, and 400 bits for 16-QAM.

20.2.3.5 Pilot tones/null tones

The numbers of pilot and null tones for TVWS-OFDM are defined as shown in Table 207.

Table 207—Number of pilot and null tones for TVWS-OFDM

Tone	Mandatory modes	Optional modes
Active tones	108	108
# Pilot tones	8	8
# Data tones	100	100
# DC null tones	1	1

The DC tone is numbered as 0, and the subcarriers for pilot and data tones are numbered as –54 to 54 with the DC tone unused as depicted in Figure 181.

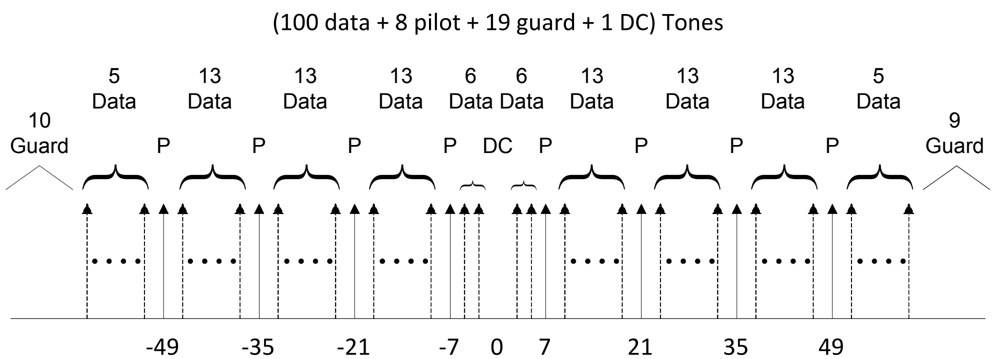

Figure 181—Pilot tones for TVWS-OFDM

The first output symbol is mapped to the most negative data carrier index in data tones, and the second output symbol is mapped to the second most negative data carrier index in data tones, and so on.The data carried on the pilot tones shall be determined by a PN9 pseudo-noise sequence, generated by the PN9 sequence generator shown in Figure 102, with the seed “111111111”. The first output bit is assigned to the most negative index in pilot tones. For example, the first output bit from the PN9 sequence is assigned to the pilot symbol with index –49, and the second output bit is assigned to the pilot symbol with index –35, and so on. Table 208 shows the mapping from PN9 bits to the pilot BPSK symbols for all MCS levels. Index *n* starts after the LTF from zero and is increased by one for every pilot subcarrier.

Table 208—Mapping from PN9 sequence to pilot BPSK symbols for TVWS-OFDM

Input bit ($PN9_n$)	BPSK symbol
0	$-1 + (0 \times j)$
1	$1 + (0 \times j)$

20.2.3.6 Cyclic prefix (CP)

For the STF, the CP is defined in 20.2.1.1.3. For the LTF, the CP is defined in 20.2.1.2.2. For the remaining TVWS-OFDM symbols, a CP shall be prepended to each base symbol. The duration of the CP (25.6 μs) shall be 1/4 of the base symbol (102.4 μs).

20.2.3.7 PPDU tail bit field (TAIL)

The PPDU tail bit field shall be six bits of 0, which are required to return the convolutional encoder to the "zero state." This procedure reduces the error probability of the convolutional decoder, which relies on future bits when decoding and which may not be available past the end of the message. The PPDU tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

20.2.3.8 Pad bits (PAD)

The number of bits in the DATA field shall be a multiple of N_{cbps}. To achieve that, the length of the message is extended so that it becomes a multiple of N_{dbps}, the number of data bits per TVWS-OFDM symbol. At least six bits are appended to the message, in order to accommodate the tail bits, as described in 20.2.3.7. The number of TVWS-OFDM symbols, N_{SYM}, the number of bits in the DATA field, N_{DATA}, and the number of pad bits, N_{PAD}, are computed using the length, in octets, of the PSDU (LENGTH is equal to the content of the Frame Length field in Figure 176) as follows:

$$N_{dbps} = N_{cbps} \times R$$

$$N_{SYM} = \text{ceiling}[(8 \times \text{LENGTH} + 6) / N_{dbps}]$$

$$N_{DATA} = N_{SYM} \times N_{dbps}$$

$$N_{PAD} = N_{DATA} - (8 \times \text{LENGTH} + 6)$$

The function ceiling (.) returns the smallest integer value greater than or equal to its argument value. The appended bits (i.e., pad bits) are set to zeros and are subsequently scrambled with the rest of the bits in the DATA field.

In the case where the DATA field consists of the PHR, the number of bits in the DATA field (PHR as shown in 20.2.1.3) shall be set to 50.

20.2.3.9 Scrambler and scrambler seeds

The input to the scrambler is the data bits followed by tail bits and then pad bits. The scrambler uses a PN9 sequence that is generated by the generator shown in Figure 102. The PN9 scrambler is initialized by the scrambling seed specified by 9 bits in the PHR, as shown in Figure 176. The leftmost value of the scrambling seed is placed into the leftmost delay element in Figure 102. The PN9 generator is clocked using the seed as the starting point and enabled after the first clock cycle. The PN9 generator shall be reinitialized to the seed after each packet (either transmit or receive).

The PN generator is defined by the schematic in Figure 102.

20.2.4 TVWS-OFDM RF requirements

20.2.4.1 Operating frequency range

The TVWS-OFDM PHY operates in the bands indicated in Table 4ab.

20.2.4.2 Pulse shaping

Pulse shaping shall be applied at the transmitter using a filter equivalent to the Root Raised Cosine filter with a roll-off factor of 0.5. The parameters of the filter shall be as needed to meet regulatory requirements in the band of operation. It is recommended that the receiver also use a filter equivalent to the Root Raise Cosine filter with a roll-off factor of 0.5.

20.2.4.3 Transmit power spectral density (PSD) mask

The TVWS-OFDM PHY transmit PSD mask shall conform with local regulations.

20.2.4.4 Receiver sensitivity

The sensitivity requirements, as described in 8.1.7, for every option and MCS mode are shown below in Table 209.

Table 209—TVWS-OFDM PHY sensitivity requirements

MCS mode	Sensitivity	
	Mandatory modes	Optional modes
0	–97 dBm	—
1	–94 dBm	—
2	–88 dBm	—
3	—	–91 dBm
4	—	–88 dBm
5	—	–82 dBm

20.2.4.5 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as given in 8.2.1.

20.2.4.6 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as given in 8.2.2.

20.2.4.7 Error-vector magnitude (EVM) definition

The relative constellation RMS error averaged over subcarriers, symbols, and packets shall not exceed the values shown in Table 210.

Table 210—TVWS-OFDM PHY EVM requirements

MCS mode	RMS error	
	Mandatory modes	Optional modes
0	–10 dB	—
1	–10 dB	—
2	–16 dB	—
3	—	–10 dB
4	—	–10 dB
5	—	–16 dB

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signal into a stream of complex samples. The sampled signal shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Detect the start of packet.
b) Detect the transition from STF to LTF, and establish fine timing (with one sample resolution).
c) Estimate the coarse and fine frequency offsets.
d) De-rotate the packet according to estimated frequency offset.
e) Estimate the complex channel response coefficients for each of the subcarriers.
f) For each data TVWS-OFDM symbol, transform the symbol into subcarrier received values, and divide each subcarrier value with the estimated channel response coefficient.
g) For each data-carrying subcarrier, find the closest constellation point, and compute the squared Euclidean distance from it.
h) Compute the RMS average of all errors in a packet. It is given by:

$$RMS_{error} = 20\log_{10}\left(\frac{1}{N_F}\sum_{i=1}^{N_F}\sqrt{\frac{\sum_{j=1}^{N_{SYM}}\sum_{k \in U_D}\Delta i, j, k^2}{100 \times N_{SYM} \times P_0}}\right)$$

with

$$\Delta(i, j, k)^2 = [I(i, j, k) - I_0(i, j, k)]^2 + [Q(i, j, k) - Q_0(i, j, k)]^2$$

where

N_{SYM}	is the number of TVWS-OFDM symbols in the packet
N_F	is the number of packets used for the measurement
U_D	is the index set of data tones
$[I_0((i,j,k),Q_0(i,j,k))]$	denotes the ideal symbol point of the *i*th packet, *j*th TVWS-OFDM symbol of the packet, and *k*th subcarrier of the TVWS-OFDM symbol in the complex plane

$[I((i,j,k),Q(i,j,k))]$	denotes the observed point of the ith packet, jth TVWS-OFDM symbol of the packet, and kth tone of the TVWS-OFDM symbol in the complex plane
P_0	is the average power of the constellation

The test shall be performed over at least $N_F = 20$ packets. The payload of the packets under test shall contain $N_{SYM} = 16$ TVWS-OFDM symbols. Random data shall be used for the payload.

20.2.4.8 Transmit center frequency and symbol tolerance

The transmit center frequency tolerance shall be ± 20 ppm maximum. The symbol clock frequency tolerance shall also be ± 20 ppm maximum. The transmit center frequency and the symbol clock frequency shall be derived from the same reference oscillator.

20.3 TVWS-NB-OFDM PHY

The TVWS narrow-band orthogonal frequency division multiplexing (TVWS-NB-OFDM) PHY supports data rates ranging from 156 kb/s to 1638 kb/s. The subcarrier spacing is constant and is equal to 125/126 kHz. The mandatory symbol rate is 0.962 kHz, which corresponds to 1039.5 µs per symbol. This symbol is composed of a 1/32 duration cyclic prefix (31.5 µs) and a base symbol (1008 µs). Optional cyclic prefix, whose duration is 1/16 (63.0 µs) or 1/8 (126.0 µs), is supported for larger multipath delay. Channel aggregation is also optionally supported for data rate enhancement to attain over 18 Mbps.

20.3.1 PPDU format for TVWS-NB-OFDM

The TVWS-NB-OFDM PPDU shall be formatted as illustrated in Figure 182. The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length n, numbered b_0 on the left and b_{n-1} on the right. When transmitted, they are processed from b_0 first to b_{n-1} last, without regard to their content or structure.

Number of TVWS-NB-OFDM symbols			
1	**1**	**1**	**variable**
STF	LTF	As defined in 20.3.1.3	PSDU
SHR		PHR	PHY payload

Figure 182—Format of the TVWS-NB-OFDM PPDU

Definitions are provided in the frequency domain for the Short Training field (STF) in 20.3.1.1 and for the Long Training field (LTF) in 20.3.1.2. In each case, a normative set of operations is specified to transform the frequency domain fields to the time domain and to insert prescribed repetitions or cyclic prefixes of these time domain sequences.

20.3.1.1 Short Training field (STF)

Subclauses 20.3.1.1.1 through 20.3.1.1.4 describe the STF.

20.3.1.1.1 Frequency domain STF

Table 211 shows the frequency domain representation of the STF.

Table 211—Frequency domain representation of STF for TVWS-NB-OFDM

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–192	–1.4142	–1.4142	–96	–1.4142	–1.4142	0	–1.4142	–1.4142	96	–1.4142	–1.4142
–191	0	0	–95	0	0	1	0	0	97	0	0
–190	0	0	–94	0	0	2	0	0	98	0	0
–189	0	0	–93	0	0	3	0	0	99	0	0
–188	1.6257	1.165	–82	1.165	–1.6257	4	–1.6257	–1.165	100	–1.165	1.6257
–187	0	0	–91	0	0	5	0	0	101	0	0
–186	0	0	–90	0	0	6	0	0	102	0	0
–185	0	0	–89	0	0	7	0	0	103	0	0
–184	–1.9829	–0.2611	–88	1.9829	0.2611	8	–1.9829	–0.2611	104	1.9829	0.2611
–183	0	0	–87	0	0	9	0	0	105	0	0
–182	0	0	–86	0	0	10	0	0	106	0	0
–181	0	0	–85	0	0	11	0	0	107	0	0
–180	1.546	–1.2688	–84	1.2688	1.546	12	–1.546	1.2688	108	–1.2688	–1.546
–179	0	0	–83	0	0	13	0	0	109	0	0
–178	0	0	–82	0	0	14	0	0	110	0	0
–177	0	0	–81	0	0	15	0	0	111	0	0
–176	0.5176	1.9319	–80	0.5176	1.9319	16	0.5176	1.9319	112	0.5176	1.9319
–175	0	0	–79	0	0	17	0	0	113	0	0
–174	0	0	–78	0	0	18	0	0	114	0	0
–173	0	0	–77	0	0	19	0	0	115	0	0
–172	–1.9733	0.3258	–76	0.3258	1.9733	20	1.9733	–0.3258	116	–0.3258	–1.9733
–171	0	0	–75	0	0	21	0	0	117	0	0
–170	0	0	–74	0	0	22	0	0	118	0	0
–169	0	0	–73	0	0	23	0	0	119	0	0
–168	–0.7654	–1.8478	–72	0.7654	1.8478	24	–0.7654	–1.8478	120	0.7654	1.8478
–167	0	0	–71	0	0	25	0	0	121	0	0
–166	0	0	–70	0	0	26	0	0	122	0	0
–165	0	0	–69	0	0	27	0	0	123	0	0
–164	1.165	–1.6257	–68	1.6257	1.165	28	–1.165	1.6257	124	–1.6257	–1.165
–163	0	0	–67	0	0	29	0	0	125	0	0
–162	0	0	–66	0	0	30	0	0	126	0	0
–161	0	0	–65	0	0	31	0	0	127	0	0
–160	1.9319	–0.5176	–64	1.9319	–0.5176	32	1.9319	–0.5176	128	1.9319	–0.5176

Table 211—Frequency domain representation of STF for TVWS-NB-OFDM *(continued)*

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–159	0	0	–63	0	0	33	0	0	129	0	0
–158	0	0	–62	0	0	34	0	0	130	0	0
–157	0	0	–61	0	0	35	0	0	131	0	0
–156	1.9904	0.196	–60	0.196	–1.9904	36	–1.9904	–0.196	132	–0.196	1.9904
–155	0	0	–59	0	0	37	0	0	133	0	0
–154	0	0	–58	0	0	38	0	0	134	0	0
–153	0	0	–57	0	0	39	0	0	135	0	0
–152	1.9829	0.2611	–56	–1.9829	–0.2611	40	1.9829	0.2611	136	–1.9829	–0.2611
–151	0	0	–55	0	0	41	0	0	137	0	0
–150	0	0	–54	0	0	42	0	0	138	0	0
–149	0	0	–53	0	0	43	0	0	139	0	0
–148	1.9733	–0.3258	–52	0.3258	1.9733	44	–1.9733	0.3258	140	–0.3258	–1.9733
–147	0	0	–51	0	0	45	0	0	141	0	0
–146	0	0	–50	0	0	46	0	0	142	0	0
–145	0	0	–49	0	0	47	0	0	143	0	0
–144	1.4142	–1.4142	–48	1.4142	–1.4142	48	1.4142	–1.4142	144	1.4142	–1.4142
–143	0	0	–47	0	0	49	0	0	145	0	0
–142	0	0	–46	0	0	50	0	0	146	0	0
–141	0	0	–45	0	0	51	0	0	147	0	0
–140	–0.3258	–1.9733	–44	–1.9733	0.3258	52	0.3258	1.9733	148	1.9733	–0.3258
–139	0	0	–43	0	0	53	0	0	149	0	0
–138	0	0	–42	0	0	54	0	0	150	0	0
–137	0	0	–41	0	0	55	0	0	151	0	0
–136	–1.9829	–0.2611	–40	1.9829	0.2611	56	–1.9829	–0.2611	152	1.9829	0.2611
–135	0	0	–39	0	0	57	0	0	153	0	0
–134	0	0	–38	0	0	58	0	0	154	0	0
–133	0	0	–37	0	0	59	0	0	155	0	0
–132	–0.196	1.9904	–36	–1.9904	–0.196	60	0.196	–1.9904	156	1.9904	0.196
–131	0	0	–35	0	0	61	0	0	157	0	0
–130	0	0	–34	0	0	62	0	0	158	0	0
–129	0	0	–33	0	0	63	0	0	159	0	0
–128	1.9319	–0.5176	–32	1.9319	–0.5176	64	1.9319	–0.5176	160	1.9319	–0.5176
–127	0	0	–31	0	0	65	0	0	161	0	0

Table 211—Frequency domain representation of STF for TVWS-NB-OFDM *(continued)*

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–126	0	0	–30	0	0	66	0	0	162	0	0
–125	0	0	–29	0	0	67	0	0	163	0	0
–124	–1.6257	–1.165	–28	–1.165	1.6257	68	1.6257	1.165	164	1.165	–1.6257
–123	0	0	–27	0	0	69	0	0	165	0	0
–122	0	0	–26	0	0	70	0	0	166	0	0
–121	0	0	–25	0	0	71	0	0	167	0	0
–120	0.7654	1.8478	–24	–0.7654	–1.8478	72	–0.7654	1.8478	168	–0.7654	–1.8478
–119	0	0	–23	0	0	73	0	0	169	0	0
–118	0	0	–22	0	0	74	0	0	170	0	0
–117	0	0	–21	0	0	75	0	0	171	0	0
–116	–0.3258	–1.9733	–20	1.9733	–0.3258	76	0.3258	1.9733	172	–1.9733	0.3258
–115	0	0	–19	0	0	77	0	0	173	0	0
–114	0	0	–18	0	0	78	0	0	174	0	0
–113	0	0	–17	0	0	79	0	0	175	0	0
–112	0.5176	1.9319	–16	0.5176	1.9319	80	0.5176	1.9319	176	0.5176	1.9319
–111	0	0	–15	0	0	81	0	0	177	0	0
–110	0	0	–14	0	0	82	0	0	178	0	0
–109	0	0	–13	0	0	83	0	0	179	0	0
–108	–1.2688	–1.546	–12	–1.546	1.2688	84	1.2688	1.546	180	1.546	–1.2688
–107	0	0	–11	0	0	85	0	0	181	0	0
–106	0	0	–10	0	0	86	0	0	182	0	0
–105	0	0	–9	0	0	87	0	0	183	0	0
–104	1.9829	0.2611	–8	–1.9829	–0.2611	88	1.9829	0.2611	184	–1.9829	–0.2611
–103	0	0	–7	0	0	89	0	0	185	0	0
–102	0	0	–6	0	0	90	0	0	186	0	0
–101	0	0	–5	0	0	91	0	0	187	0	0
–100	–1.165	1.6257	–4	–1.6257	–1.165	92	1.165	–1.6257	188	1.6257	1.165
–99	0	0	–3	0	0	93	0	0	189	0	0
–98	0	0	–2	0	0	94	0	0	190	0	0
–97	0	0	–1	0	0	95	0	0	191	0	0

20.3.1.1.2 Time domain STF generation

The STF sequence is defined based on Zadoff Chu Sequence with length N=96, a prime number H=19, and n=0, 1, …, N–1. The STF sequence $s(n)$ in the time domain is expressed as below:

$$s(n) = e^{jH\pi n^2/N}, n = 0, 1, 2 \ldots N-1$$

The discrete Fourier transform (DFT) of $s(n)$ is defined as $S(k)$, where k = 0, ..., N–1:

$$S(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} s(n) e^{-j2\pi kn/N}$$

The sequence $s(n)$ can be calculated from $S(k)$ using the inverse discrete Fourier transform (IDFT):

$$s(n) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} S(k) e^{j2\pi nk/N}$$

Given the frequency domain sequence *STF_freq* as specified in 20.3.1.1.1, the time domain STF can be generated as follows:

STF_time = IDFT(*STF_freq*)

The CP with 1/2 T_{STF} duration is then prepended to the STF TVWS-NB-OFDM symbol.

20.3.1.1.3 Time domain STF repetition

There are four repetitions of the STF in the time domain, and the CP with a duration of 1/2 T_{STF}, as shown in Figure 183.

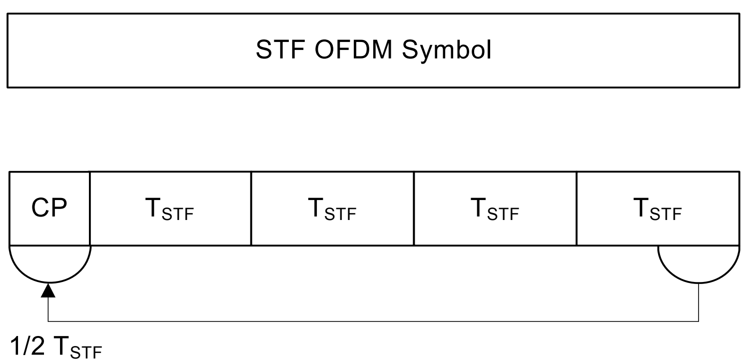

Figure 183—STF format for TVWS-NB-OFDM

The STF sequence, $STF\_time(n)$, is indexed by n=0, 1, 2, …, N_{ST}–1, where N_{ST} is the number of effective subcarriers. $STF\_time(n)$ consists of four repetitions of $S(k)$ and can be represented as follows:

$STF\_time(n)=S(MOD(n, N))$ for n=0, 1, …, 4×$N–1$

where N=96, and $MOD(n, N)$ is the modulo-N operation for any input n.

20.3.1.1.4 STF normalization

The STF uses a fewer number of tones than the PHR and PHY payload as shown in Figure 182. Hence, normalization of the frequency domain STF is required to ensure that the STF power is the same as the rest of the packet. In order to have the same power as the PHR and PHY payload, the normalization value is as follows:

$$\mathrm{sqrt}(N_{active}/N_{STF})$$

where N_{active} is the number of subcarriers used in the rest of the TVWS-NB-OFDM packet, and N_{STF} is the number of subcarriers used in the STF.

20.3.1.2 Long Training field (LTF)

Subclauses 20.3.1.2.1 through 20.3.1.2.4 describe the LTF.

20.3.1.2.1 Frequency domain LTF generation

Table 212 shows the frequency domain representation of the LTF.

Table 212—Frequency domain representation of LTF for TVWS-NB-OFDM

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–192	0.051	–0.051	–96	0.051	–0.051	0	0.051	–0.051	96	0.051	–0.051
–191	0	0	–95	0	0	1	0	0	97	0	0
–190	0.0687	–0.0221	–94	0.0221	0.0687	2	–0.0687	0.0221	98	–0.0221	–0.0687
–189	0	0	–93	0	0	3	0	0	99	0	0
–188	0.0319	0.0647	–82	–0.0319	–0.0647	4	0.0319	0.0647	100	–0.0319	–0.0647
–187	0	0	–91	0	0	5	0	0	101	0	0
–186	–0.068	–0.0243	–90	–0.0243	0.068	6	0.068	0.0243	102	0.0243	–0.068
–185	0	0	–89	0	0	7	0	0	103	0	0
–184	0.0625	0.0361	–88	0.0625	0.0361	8	0.0625	0.0361	104	0.0625	0.0361
–183	0	0	–87	0	0	9	0	0	105	0	0
–182	0.0059	–0.0719	–86	0.0719	0.0059	10	–0.0059	0.0719	106	–0.0719	–0.0059
–181	0	0	–85	0	0	11	0	0	107	0	0
–180	–0.06	–0.0401	–84	0.06	0.0401	12	–0.06	–0.0401	108	0.06	0.0401
–179	0	0	–83	0	0	13	0	0	109	0	0
–178	–0.0642	–0.033	–82	–0.033	0.0642	14	0.0642	0.033	110	0.033	–0.0642
–177	0	0	–81	0	0	15	0	0	111	0	0
–176	–0.0187	–0.0697	–80	–0.0187	–0.0697	16	–0.0187	–0.0697	112	–0.0187	–0.0697
–175	0	0	–79	0	0	17	0	0	113	0	0
–174	0.0721	–0.0035	–78	0.0035	0.0721	18	–0.0721	0.0035	114	–0.0035	–0.0721

Table 212—Frequency domain representation of LTF for TVWS-NB-OFDM *(continued)*

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–173	0	0	–77	0	0	19	0	0	115	0	0
–172	–0.0647	0.0319	–76	0.0647	–0.0319	20	–0.0647	0.0319	116	0.0647	–0.0319
–171	0	0	–75	0	0	21	0	0	117	0	0
–170	0.0719	0.0059	–74	0.0059	–0.0719	22	–0.0719	–0.0059	118	–0.0059	0.0719
–169	0	0	–73	0	0	23	0	0	119	0	0
–168	0	–0.0722	–72	0	–0.0722	24	0	–0.0722	120	0	–0.0722
–167	0	0	–71	0	0	25	0	0	121	0	0
–166	–0.0467	–0.055	–70	0.055	–0.0467	26	0.0467	0.055	122	–0.055	0.0467
–165	0	0	–69	0	0	27	0	0	123	0	0
–164	–0.0319	–0.0647	–68	0.0319	0.0647	28	–0.0319	–0.0647	124	0.0319	0.0647
–163	0	0	–67	0	0	29	0	0	125	0	0
–162	0.0485	–0.0535	–66	–0.0535	–0.0485	30	–0.0485	0.0535	126	0.0535	0.0485
–161	0	0	–65	0	0	31	0	0	127	0	0
–160	0.0187	0.0697	–64	0.0187	0.0697	32	0.0187	0.0697	128	0.0187	0.0697
–159	0	0	–63	0	0	33	0	0	129	0	0
–158	–0.0221	–0.0687	–62	0.0687	–0.0221	34	0.0221	0.0687	130	–0.0687	0.0221
–157	0	0	–61	0	0	35	0	0	131	0	0
–156	–0.0401	0.06	–60	0.0401	–0.06	36	–0.0401	0.06	132	0.0401	–0.06
–155	0	0	–59	0	0	37	0	0	133	0	0
–154	0.0467	0.055	–58	0.055	–0.0467	38	–0.0467	–0.055	134	–0.055	0.0467
–153	0	0	–57	0	0	39	0	0	135	0	0
–152	0.0625	0.0361	–56	0.0625	0.0361	40	0.0625	0.0361	136	0.0625	0.0361
–151	0	0	–55	0	0	41	0	0	137	0	0
–150	0.0309	0.0652	–54	–0.0652	0.0309	42	–0.0309	–0.0652	138	–0.0652	0.0309
–149	0	0	–53	0	0	43	0	0	139	0	0
–148	–0.0647	0.0319	–52	0.0647	–0.0319	44	–0.0647	0.0319	140	0.0647	–0.0319
–147	0	0	–51	0	0	45	0	0	141	0	0
–146	0.033	–0.0642	–50	–0.0642	–0.033	46	–0.033	0.0642	142	0.0642	0.033
–145	0	0	–49	0	0	47	0	0	143	0	0
–144	–0.051	0.051	–48	–0.051	0.051	48	–0.051	0.051	144	–0.051	0.051
–143	0	0	–47	0	0	49	0	0	145	0	0
–142	0.0642	0.033	–46	–0.033	0.0642	50	–0.0642	–0.033	146	0.033	–0.0642
–141	0	0	–45	0	0	51	0	0	147	0	0

Table 212—Frequency domain representation of LTF for TVWS-NB-OFDM *(continued)*

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–140	0.0647	–0.0319	–44	–0.0647	0.0319	52	0.0647	–0.0319	148	–0.0647	0.0319
–139	0	0	–43	0	0	53	0	0	149	0	0
–138	0.0652	–0.0309	–42	–0.0309	–0.0652	54	–0.0652	0.0309	150	0.0309	0.0652
–137	0	0	–41	0	0	55	0	0	151	0	0
–136	0.0625	0.0361	–40	0.0625	0.0361	56	0.0625	0.0361	152	0.0625	0.0361
–135	0	0	–39	0	0	57	0	0	153	0	0
–134	–0.055	0.0467	–38	–0.0467	–0.055	58	0.055	–0.0467	154	0.0467	0.055
–133	0	0	–37	0	0	59	0	0	155	0	0
–132	0.0401	–0.06	–36	–0.0401	0.06	60	0.0401	–0.06	156	–0.0401	0.06
–131	0	0	–35	0	0	61	0	0	157	0	0
–130	–0.0687	0.0221	–34	0.0221	0.0687	62	0.0687	–0.0221	158	–0.0221	–0.0687
–129	0	0	–33	0	0	63	0	0	159	0	0
–128	0.0187	0.0697	–32	0.0187	0.0697	64	0.0187	0.0697	160	0.0187	0.0697
–127	0	0	–31	0	0	65	0	0	161	0	0
–126	0.0535	0.0485	–30	–0.0535	0.0485	66	–0.0535	–0.0485	162	0.0535	–0.0485
–125	0	0	–29	0	0	67	0	0	163	0	0
–124	0.0319	0.0647	–28	–0.0319	–0.0647	68	0.0319	0.0647	164	–0.0319	–0.0647
–123	0	0	–27	0	0	69	0	0	165	0	0
–122	–0.055	0.0467	–26	0.0467	0.055	70	0.055	–0.0467	166	–0.0467	–0.055
–121	0	0	–25	0	0	71	0	0	167	0	0
–120	0	–0.0722	–24	0	–0.0722	72	0	–0.0722	168	0	–0.0722
–119	0	0	–23	0	0	73	0	0	169	0	0
–118	–0.0059	0.0719	–22	–0.0719	–0.0059	74	0.0059	–0.0719	170	0.0719	0.0059
–117	0	0	–21	0	0	75	0	0	171	0	0
–116	0.0647	–0.0319	–20	–0.0647	0.0319	76	0.0647	–0.0319	172	–0.0647	0.0319
–115	0	0	–19	0	0	77	0	0	173	0	0
–114	–0.0035	–0.0721	–18	–0.0721	0.0035	78	0.0035	0.0721	174	0.0721	–0.0035
–113	0	0	–17	0	0	79	0	0	175	0	0
–112	–0.0187	–0.0697	–16	–0.0187	–0.0697	80	–0.0187	–0.0697	176	–0.0187	–0.0697
–111	0	0	–15	0	0	81	0	0	177	0	0
–110	0.033	–0.0642	–14	0.0642	0.033	82	–0.033	0.0642	178	–0.0642	–0.033
–109	0	0	–13	0	0	83	0	0	179	0	0
–108	0.06	0.0401	–12	–0.06	–0.0401	84	0.06	0.0401	180	–0.06	–0.0401

Table 212—Frequency domain representation of LTF for TVWS-NB-OFDM *(continued)*

Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im	Tone #	Re	Im
–107	0	0	–11	0	0	85	0	0	181	0	0
–106	–0.0719	–0.0059	–10	–0.0059	0.0719	86	0.0719	0.0059	182	0.0059	–0.0719
–105	0	0	–9	0	0	87	0	0	183	0	0
–104	0.0625	0.0361	–8	0.0625	0.0361	88	0.0625	0.0361	184	0.0625	0.0361
–103	0	0	–7	0	0	89	0	0	185	0	0
–102	0.0243	–0.068	–6	0.068	0.0243	90	–0.0243	0.068	186	–0.068	–0.0243
–101	0	0	–5	0	0	91	0	0	187	0	0
–100	–0.0319	–0.0647	–4	0.0319	0.0647	92	–0.0319	–0.0647	188	0.0319	0.0647
–99	0	0	–3	0	0	93	0	0	189	0	0
–98	–0.0221	–0.0687	–2	–0.0687	0.0221	94	0.0221	0.0687	190	0.0687	–0.0221
–97	0	0	–1	0	0	95	0	0	191	0	0

20.3.1.2.2 Time domain LTF generation

The LTF sequence is defined based on Zadoff Chu Sequence with length N=192, a prime number H=53, and n=0, 1, …, N–1. The LTF sequence $l(n)$ in the time domain is expressed as below:

$$l(n) = e^{jH\pi n^2/N}, n = 0, 1, 2 \ldots N-1$$

The DFT of $l(n)$ is defined as $L(k)$, where k = 0, ..., N–1:

$$L(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} l(n) e^{-j2\pi kn/N}$$

The sequence $l(n)$ can be calculated from $L(k)$ using the IDFT:

$$l(n) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} L(k) e^{j2\pi nk/N}$$

Given the frequency domain sequence *LTF_freq* as specified in 20.3.1.2.1, the time domain LTF is obtained as follows:

LTF_time = IDFT(LTF_freq)

The CP with 1/2 LTF duration is then prepended to the LTF TVWS-NB-OFDM symbol.

20.3.1.2.3 Time domain LTF repetition

There are two repetitions of LTF in the time domain as shown in Figure 184. A 1/2 symbol CP is prepended to two consecutive copies of the base symbol with duration T_{LTF} as shown in Figure 184.

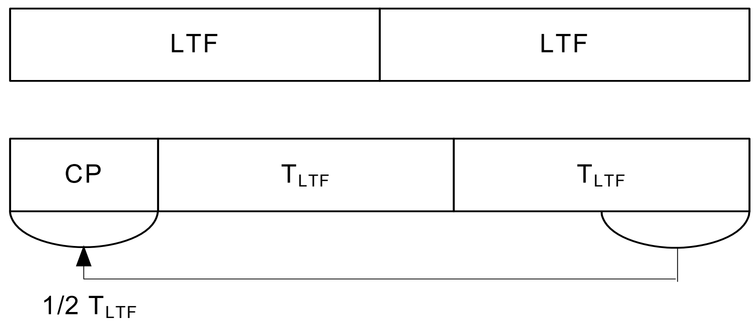

Figure 184—LTF format for TVWS-NB-OFDM

The LTF sequence, $LTF\_time(n)$, is indexed by n=0, 1, 2, …, N_{ST}–1, where N_{ST} is the number of effective subcarriers. $LTF\_time(n)$ is the two repetitions of $L(k)$ and can be represented as follows:

$$LTF\_time(n)=L(MOD(n, N)) \text{ for } n=0, 1, \ldots, 2\times N-1$$

where N=192, and $MOD(n, N)$ is the modulo-N operation for any input n.

20.3.1.2.4 LTF normalization

The LTF uses a fewer number of tones than the PHR and PHY payload as shown in Figure 182. Hence, normalization of the frequency domain LTF is required to ensure that the LTF power is the same as the rest of the packet. In order to have the same power as the PHR and PHY payload, the normalization value is as follows:

$$\mathrm{sqrt}(N_{active}/N_{LTF})$$

where N_{active} = 384, is the number of subcarriers used in the rest of the TVWS-NB-OFDM packet, and N_{LTF} is the number of subcarriers used in the LTF.

20.3.1.3 PHR

Figure 185 shows the PHR format for the TVWS-NB-OFDM PHY.

The Ranging field (RNG) is set to 1 to indicate that this particular frame is intended for ranging. If the frame is not intended for ranging, the Ranging field (RNG) is set to 0.

The Rate field (M_3-M_0) specifies the data rate of the payload and is equal to the numerical value of the MCS index as described in 20.3.3, expressed in binary format. The list of data rates for the TVWS-NB-OFDM PHY can be found in 20.3.3.

The Frame Length field (L_{10}-L_0) specifies the total number of octets contained in the PSDU (prior to FEC encoding).

Bit string index	0	1	2–5	6–16	17–20	21–29	30–37	38–43
Bit mapping	R_0	RNG	M_3–M_0	L_{10}–L_0	A_3–A_0	S_8–S_0	H_7–H_0	T_5–T_0
Field name	Reserved	Ranging	Rate	Frame Length	Channel Aggregation	Scrambler Seed	HCS	Tail

Figure 185—PHY header fields for TVWS-NB-OFDM

The Channel Aggregation field (A_3-A_0) is used for channel aggregation as described in 20.3.4. The total number of subchannels used for channel aggregation equals to the value of the Channel Aggregation field plus 1. If channel aggregation is not used, the Channel Aggregation field is set to 0.

The Scrambler Seed field (S_8-S_0) specifies the scrambling seed defined by the manufacturer.

The Header Check Sequence (HCS) field (H_7-H_0) is an 8-bit CRC taken over the PHY header (PHR) fields. The HCS shall be computed using the first 30 bits of the PHR using the polynomial $G_8(x) = x^8 + x^2 + x + 1$.The HCS is the remainder resulting from $[x^8(b_0x^{29} + b_1x^{28} + \ldots + b_{28}x + b_{29})]$ divided (modulo 2) by $G_8(x)$, where $b_0x^{29} + b_1x^{28} + \ldots + b_{28}x + b_{29}$ is the polynomial representing the first 30 bits of the PHR for which the checksum is to be computed. At the transmitter, the initial remainder shall be preset to all zeros.

The Tail bit field (T_5-T_0) is set to six continuous zeros for Viterbi decoder flushing.

20.3.1.4 PSDU field

The PSDU field carries the data of the PHY packet.

20.3.2 System parameters for TVWS-NB-OFDM

Table 213 shows system parameters for TVWS-NB-OFDM.

Table 213—System parameters for TVWS-NB-OFDM

Parameter	Value
Nominal bandwidth (kHz)	380.95
Subcarrier spacing (kHz)	0.99206 (=125/126)
Total Number of subcarriers – N_{ST}	384
Number of pilot subcarriers per TVWS-NB-OFDM symbol – N_{SP}	32
Number of data subcarriers per TVWS-NB-OFDM symbol – N_{SD}	352
Effective symbol duration – T_{FFT} (μs)	1008
Cyclic prefix interval duration – T_{CP} (μs)	Mandatory 1/32 (31.5 μs) Optional 1/16 (63.0 μs), 1/8 (126.0 μs)

Table 213—System parameters for TVWS-NB-OFDM *(continued)*

Parameter	Value
T_{SYM} (μs)	Mandatory 1039.5 Optional 1071.0, 1134.0 (T_{FFT}+T_{CP})
STF duration	1 symbol
LTF duration	1 symbol

20.3.3 Modulation and coding parameters for TVWS-NB-OFDM

The modulation and coding schemes with supported data rates for TVWS-NB-OFDM and corresponding MCS-related parameters are shown in the Table 214, where CC above stands for inner convolutional coding.

Table 214—Data rates for TVWS-NB-OFDM

MCS index	Modulation	CC coding rate	Data rate (kb/s)	CC coded bits per subcarrier (N_{BPSC})	CC coded bits per OFDM symbol (N_{CPBS})	RS encoded data bits per OFDM symbol (N_{DBPS})
MCS0	BPSK	1/2	156	1	352	176
MCS1	BPSK	3/4	234	1	352	264
MCS2	QPSK	1/2	312	2	704	352
MCS3	QPSK	3/4	468	2	704	528
MCS4	16-QAM	1/2	624	4	1408	704
MCS5	16-QAM	3/4	936	4	1408	1056
MCS6	64-QAM	1/2	936	6	2112	1056
MCS7	64-QAM	3/4	1404	6	2112	1584
MCS8	64-QAM	7/8	1638	6	2112	1848

20.3.3.1 Reference modulator diagram

The reference modulator diagram is shown in Figure 186.

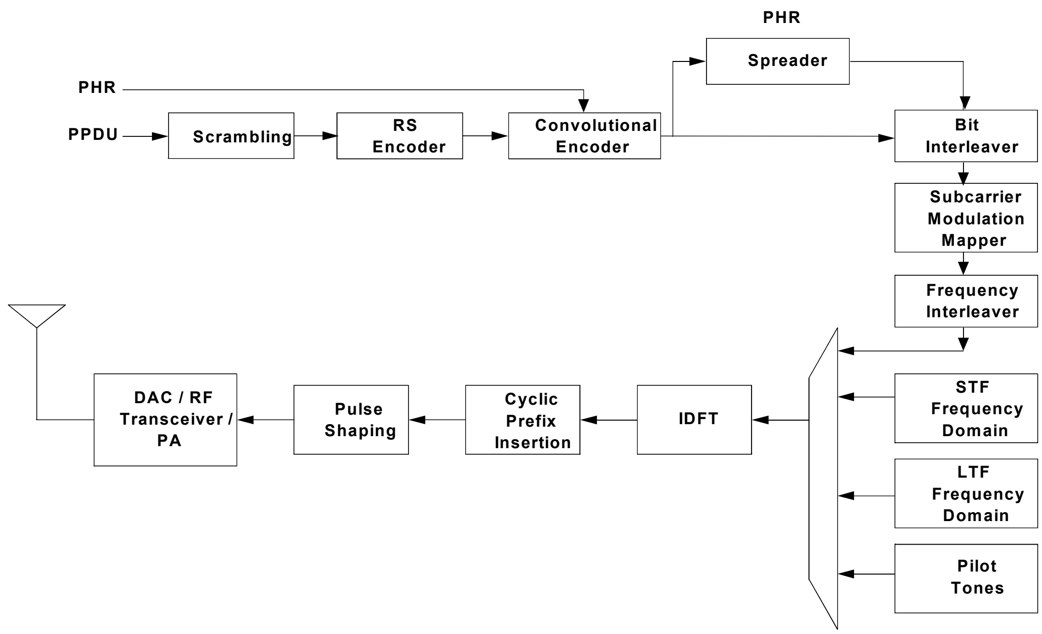

Figure 186—Reference modulator diagram for TVWS-NB-OFDM

Subclauses 20.3.3.2 through 20.3.3.13 describe the blocks in the reference modulator diagram.

20.3.3.2 Scrambler and scrambler seed

The input to the scrambler is the data bits followed by tail bits and then pad bits. The scrambler uses a PN9 sequence that is generated by the generator shown in Figure 102. The PN9 scrambler is initialized by the scrambling seed specified by 9 bits in the PHR. The leftmost value of the scrambling seed is placed into the leftmost delay element in Figure 102. The PN9 generator is clocked using the seed as the starting point and enabled after the first clock cycle.

20.3.3.3 Outer encoding

Reed Solomon (RS) encoding (204, 188) shall be used for the outer encoder. The RS encoding is applied with an RS (255, 239) coder as a shortened code. To generate the shortened code, 51 bytes of zeros shall be prepended to each 188-byte input data before RS (255,239) encoding, and the first 51 bytes of zeros shall be removed after the encoding. A root of the primitive polynomial for the RS encoder is:

$$p(x) = 1 + x^2 + x^3 + x^4 + x^8.$$

The polynomial generator *g(x)* shall be the following equation:

$$G(x) = (x - \lambda^0)(x - \lambda^1)(x - \lambda^2)(x - \lambda^3)\ldots(x - \lambda^{15}),$$

where λ is 02Hex.

20.3.3.4 Inner encoding

A recursive and systematic convolutional encoder of coding rate R = 1/2, 3/4, or 7/8 encodes the RS encoded data bits, 6 tail bits, and pad bits. The convolutional encoder shall use the generator polynomials g_0 = 171 and g_1 = 133, of rate R = 1/2, with feedback connection of g_0 as shown in Figure 187.

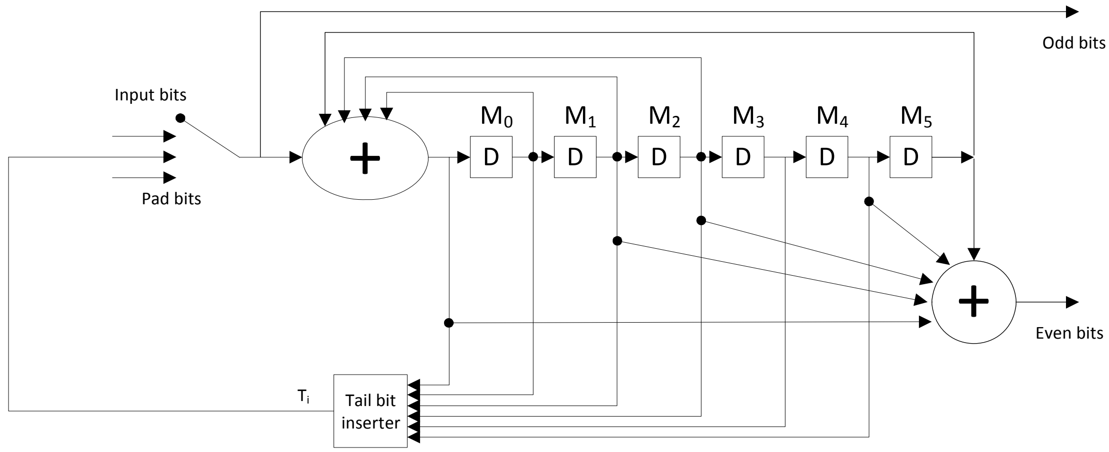

Figure 187—Recursive and systematic convolution encoder for TVWS-NB-OFDM

The value of the tail bits are dependent on the memory state shown in Figure 187 and shall be set as shown in Table 215.

Table 215—Tail bit pattern for the recursive and systematic encoder for TVWS-NB-OFDM

Memory state (M0–M5)	Tail bits (T0–T5)	Memory state (M0–M5)	Tail bits (T0–T5)	Memory state (M0–M5)	Tail bits (T0–T5)	Memory state (M0–M5)	Tail bits (T0–T5)
000000	000000	010000	110010	100000	111001	110000	001011
000001	100001	010001	010010	100001	011001	110001	101011
000010	010000	010010	100010	100010	101001	110010	011011
000011	110000	010011	000010	100011	001001	110011	111011
000100	001000	010100	111010	100100	110001	110100	000011
000101	101000	010101	011010	100101	010001	110101	100011
000110	011000	010110	101010	100110	100001	110110	010011
000111	111000	010111	001010	100111	000001	110111	110011
001000	100100	011000	010110	101000	011101	111000	101111
001001	000100	011001	110110	101001	111101	111001	001111
001010	110100	011010	000110	101010	001101	111010	111111
001011	010100	011011	100110	101011	101101	111011	011111
001100	101100	011100	01111=	101100	010101	111100	100111
001101	001100	011101	111110	101101	110101	111101	000111
001110	111100	011110	001110	101110	000101	111110	110111
001111	011100	011111	101110	101111	100101	111111	010111

Puncturing enables a higher data rate by omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy “zero” metric into the convolutional decoder at the receive side in place of the omitted bits. The puncturing patterns are illustrated in Figure 188, Figure 189, and Figure 190 for the rates 2/3, 3/4, and 7/8, respectively.

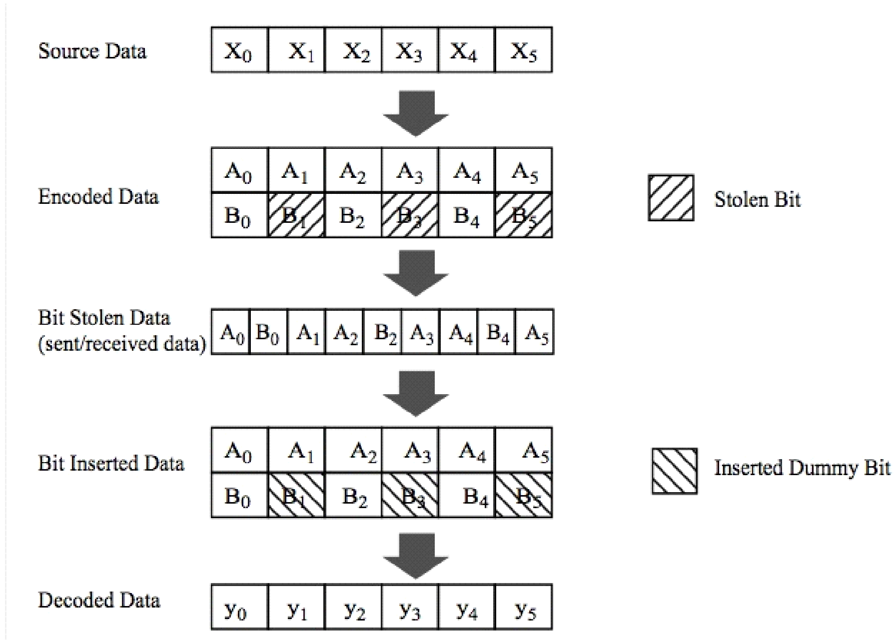

Figure 188—R=2/3 puncturing pattern for TVWS-NB-OFDM

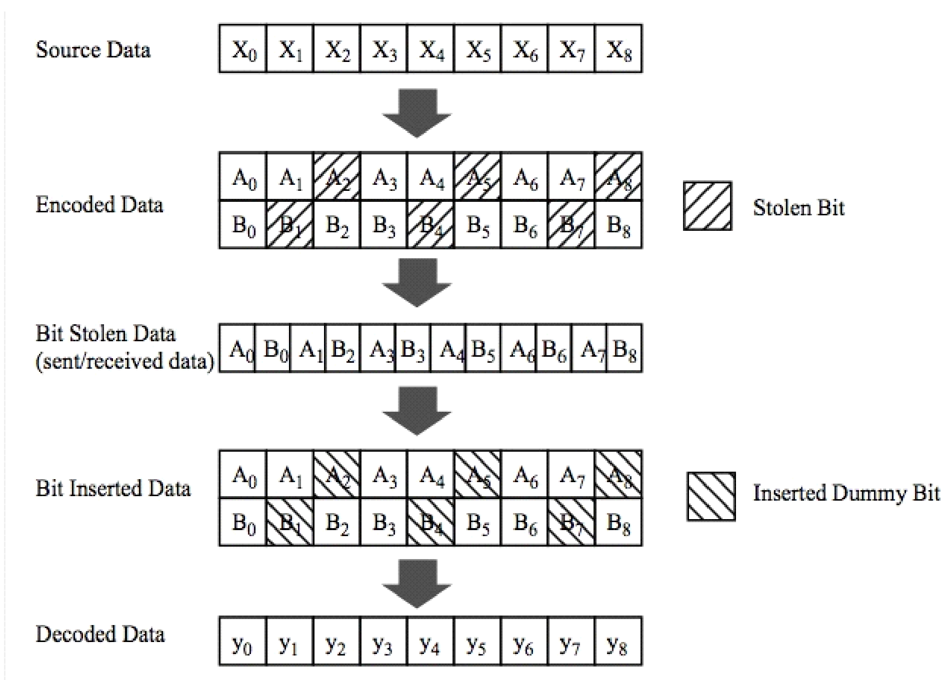

Figure 189—R=3/4 puncturing pattern for TVWS-NB-OFDM

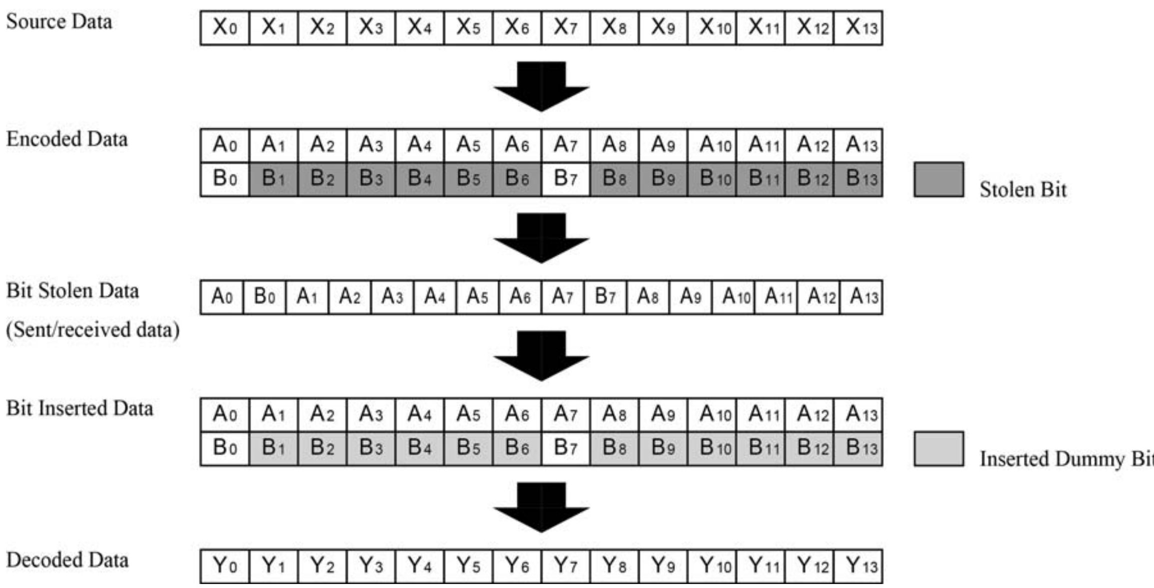

Figure 190—R=7/8 puncturing pattern for TVWS-NB-OFDM

20.3.3.5 Pad bit insertion

The number of pad bits input to the convolutional encoder, N_{PAD}, shall be computed with the following equations:

N_{RS} = ceiling (L_{PSDU}/(188×8))

$L_{RS} = L_{PSDU}+N_{RS}\times16\times8$

N_{SYS} = ceiling ((L_{RS}+6)/N_{DBPS})

$N_{DATA} = N_{SYS}\times N_{DBPS}$

$N_{PAD} = N_{DATA}$-(×L_{RS}+6)

L_{PSDU} is the number of PSDU bits, which is equal to the content of the Frame Length field in Figure 185, and N_{DBPS} is shown in Table 214.

The function ceiling (.) returns the smallest integer value greater than or equal to its argument value. The pad bits are set to zeros.

20.3.3.6 Spreader

The spreader only applies to the PHR. The 44 PHR bits are encoded using the rate–1/2 recursive convolutional code as described in 20.3.3.4 to create an 88-bit sequence (d_0, d_1, d_2, ... d_{87}). The 88-bit sequence is spread by using a spreading sequence [1111] to generate the 352-bit sequence (d_0, d_0, d_0, d_0, d_1, d_1, d_1, d_1, d_2, d_2, d_2, d_2, …, d_{87}, d_{87}, d_{87}, d_{87}). The 352-bit sequence is then interleaved as described in 20.3.3.7 and mapped using BPSK as described in 20.3.3.8. The resulting values are interleaved in the frequency domain as described in 20.3.3.9; pilots are inserted as described in 20.3.3.10 and then modulated as an TVWS-NB-OFDM symbol.

20.3.3.7 Bit interleaving

All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of encoded bits in a single TVWS-NB-OFDM symbol, N_{CBPS}. The interleaver is defined by a two-step permutation.

The first permutation is defined by the rule:

$$i = (N_{CBPS}/44)\ (k \bmod 44) + \mathrm{floor}(k/44),\ k = 0,1,\ldots,\ N_{CBPS} - 1$$

Here, k shall be the index of the coded bit before the first permutation; and i shall be the index after the first and before the second permutation. The function floor (.) denotes the largest integer not exceeding the parameter. The second permutation is defined by the rule:

$$j = s \cdot \mathrm{floor}(i/s) + (i + N_{CBPS} - \mathrm{floor}(44 \cdot i/\ N_{CBPS})) \bmod \mathrm{s},\ i = 0,1,\ldots\ N_{CBPS} - 1$$

where j is the index after the second permutation, just prior to mapping. The value of s is determined by the number of coded bits per subcarrier, N_{BPSC}, according to:

$$s = \max(N_{BPSC}/2,1)$$

where N_{BPSC} is shown in Table 214. The deinterleaver, which performs the inverse relation, is also defined by these two corresponding permutations.

20.3.3.8 Subcarrier mapping

The TVWS-NB-OFDM subcarriers shall be modulated by using BPSK, QPSK, 16-QAM, or 64-QAM modulation. The encoded and interleaved binary serial input data shall be parsed into N_{BPSC} bits per symbol and mapped onto I- and Q-channel data. The conversion shall be performed according to Gray-coded constellation mapping, illustrated in Figure 191, with the input bit, b_0, being the earliest in the stream. The output values, d, are formed by multiplying the resulting (I+jQ) values by a normalization factor K_{MOD}, as described in the following equation:

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

The normalization factor, K_{MOD}, depends on the base modulation mode, as prescribed in Table 216.

Table 216—Modulation-dependent normalization factor K_{MOD} for TVWS-NB-OFDM

Modulation	K_{MOD}
BPSK	1
QPSK	$1/\sqrt{2}$
16-QAM	$1/\sqrt{10}$
64-QAM	$1/\sqrt{42}$

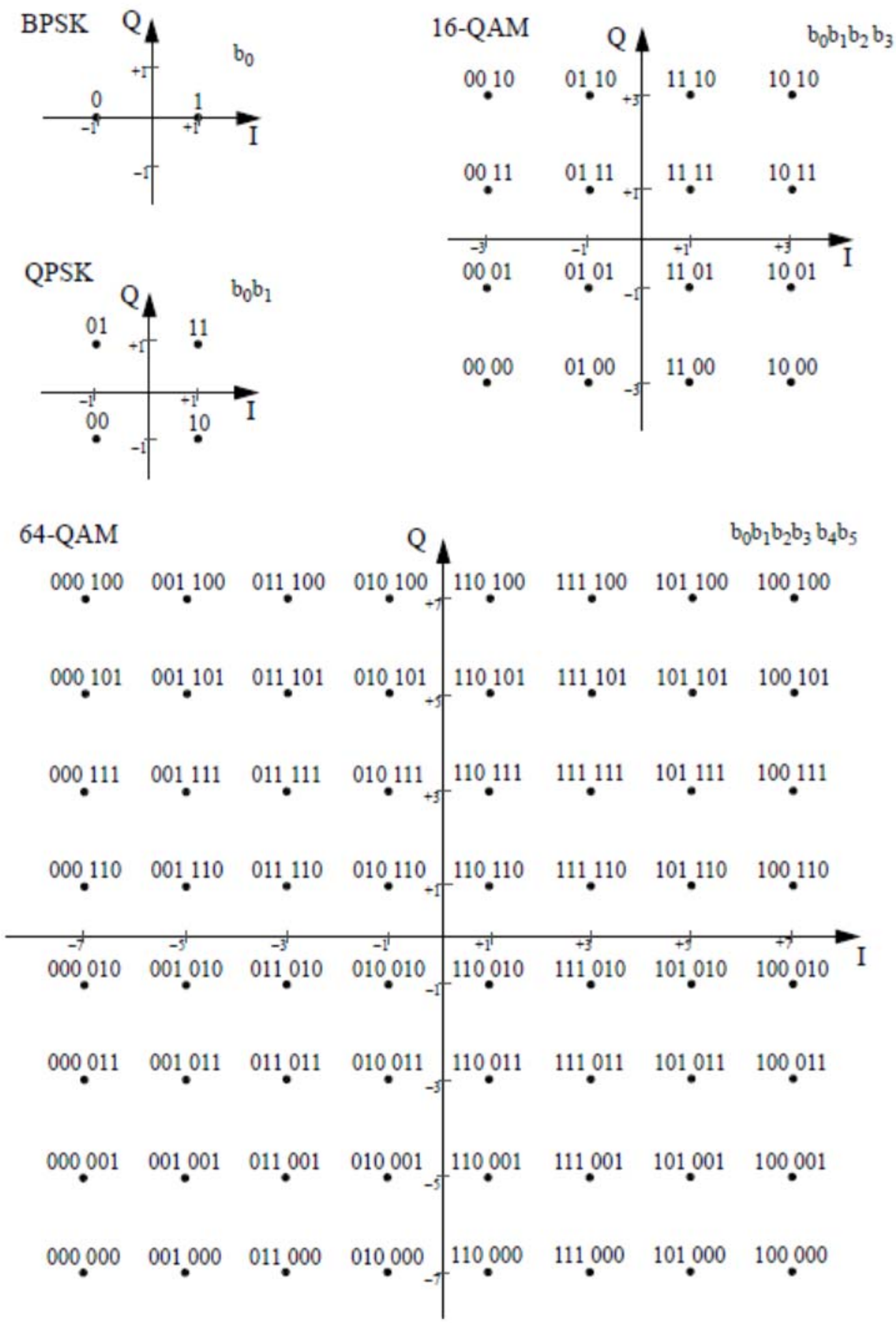

Figure 191—Constellation mapping for TVWS-NB-OFDM

20.3.3.9 Frequency interleaving

Random interleaver is used for frequency interleaving. The permutation rule for the frequency interleaving is specified as follows.

The index of an input bit before interleaving is represented by i; J, the index of an output bit after interleaving shall be represented as follows:

$J=Z(i)$ for $i = 0,1,..., 352-1$

where Z=[63 14 12 286 337 221 227 93 57 47 121 176 299 173 236 54 165 188 126 83 6 46 174 259 136 183 142 274 127 265 287 89 234 62 250 311 180 156 58 124 209 15 228 101 312 206 80 185 186 329 78 116 278 113 21 200 179 144 153 216 205 140 235 193 310 184 82 130 257 315 102 44 98 325 143 158 91 215 103 30 304 262 32 23 53 306 302 294 178 117 297 86 197 192 115 59 199 17 168 146 120 246 114 296 194 233 18 109 284 247 65 238 190 129 303 321 240 336 40 348 352 74 159 277 244 100 39 288 4 331 154 316 118 290 214 211 150 338 340 152 242 322 218 31 335 162 323 50 177 13 347 61 29 230 266 289 226 60 182 171 320 342 87 252 134 345 110 45 269 258 324 56 318 122 261 276 191 20 64 19 249 10 241 212 151 231 333 232 72 256 351 84 88 155 219 139 270 349 131 161 279 217 237 309 224 255 26 99 301 202 138 220 37 326 125 67 170 22 36 108 51 107 334 327 263 253 272 264 137 1 207 160 123 189 7 285 97 27 201 198 187 346 341 350 104 85 229 213 3 68 319 2 75 343 167 195 34 69 268 112 119 141 196 106 203 292 260 24 172 66 282 25 166 9 95 223 332 35 239 267 90 81 254 164 281 248 5 291 280 55 79 181 73 317 283 132 208 344 307 222 133 8 149 300 169 225 49 48 314 76 105 71 148 41 111 70 147 38 175 42 33 305 308 313 16 273 135 243 204 210 163 298 328 11 94 43 251 157 339 293 145 295 330 128 271 77 96 92 245 275 28 52].

Figure 192 shows the distribution of interleaving for input bits before interleaving versus output bits after interleaving.

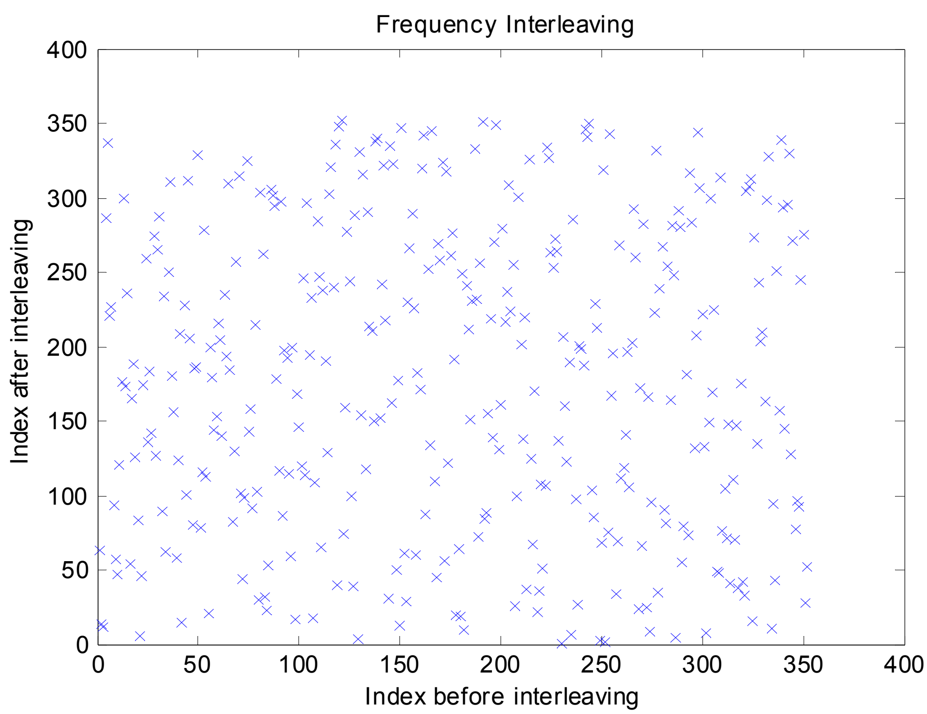

Figure 192—Illustration of frequency interleaving mapping for TVWS-NB-OFDM

20.3.3.10 Pilot tones

Figure 193 shows the pilot symbol pattern of TVWS-NB-OFDM. As shown in the figure, the pilot symbol is inserted into a frame once every 12 subcarriers in the frequency direction and once every 4 symbols in the symbol or time direction.

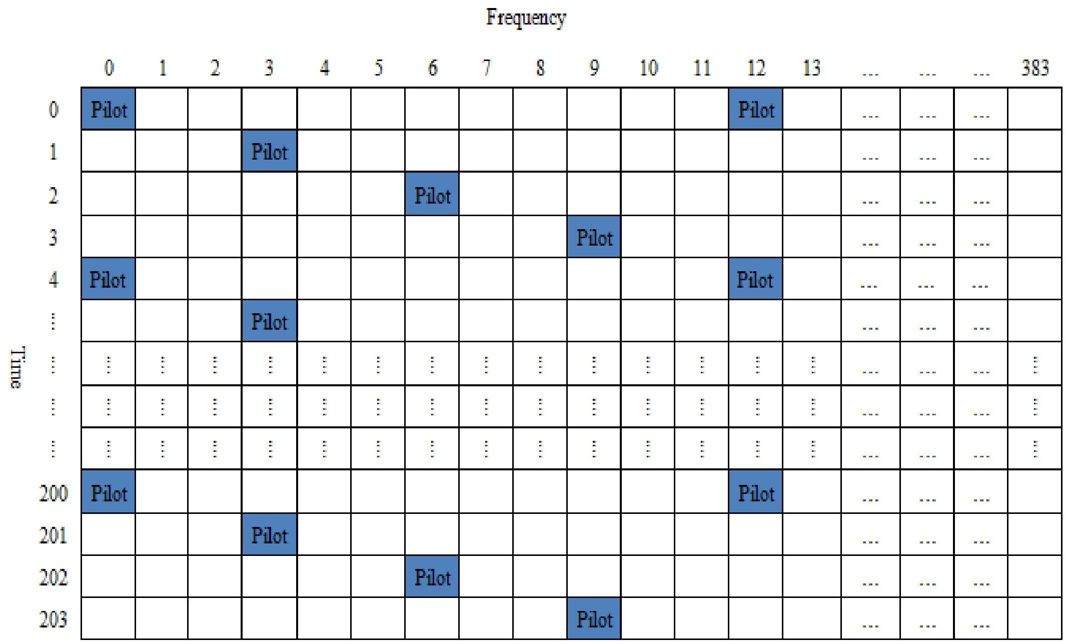

Figure 193—Pattern of pilot subcarriers allocated in TVWS-NB-OFDM symbol

20.3.3.11 Cyclic prefix

A cyclic prefix shall be prepended to each TVWS-NB-OFDM symbol. For the STF, the CP is defined in 20.3.1.1.3. For the LTF, the CP is defined in 20.3.1.2.3. For the rest of the TVWS-NB-OFDM symbols, by default, the duration of the cyclic prefix (31.5 μs) shall be 1/32 of the base TVWS-NB-OFDM symbol (1008 μs). Optionally, the cyclic prefix of duration 63 μs which is 1/16 of the base TVWS-NB-OFDM symbol, or the cyclic prefix of duration 126 μs which is 1/8 of the base TVWS-NB-OFDM symbol can be selected.

20.3.3.12 Pulse shaping

Time domain windowing shall be applied during TVWS-NB-OFDM signal generation in order to smooth the transition between two consecutive TVWS-NB-OFDM symbols. This can reduce spectral leakage for both cases when combined with and without implementing any digital pulse shaping filter in TVWS-NB-OFDM. When time domain windowing is applied for pulse shaping, a windowing function *w(t)*, as exemplified in the following equation, shall be utilized after insertion of cyclic prefix.

$$w(t) = \begin{cases} \sin^2\left(\frac{\pi}{2}(0.5 + t/T_{TR})\right) & -T_{TR}/2 < t < T_{TR}/2 \\ 1 & T_{TR}/2 \le t < T - T_{TR}/2 \\ \sin^2\left(\frac{\pi}{2}(0.5 - (t-T)/T_{TR})\right) & (T - T_{TR})/2 \le t < T + T_{TR}/2 \end{cases}$$

where T_{TR}, the windowing duration, is the duration of the transition from the minimum to maximum value of the windowing function and vice versa

The continuous pulse shaped waveform is expressed as follows:

$$s(t) = w(t)\frac{1}{\sqrt{N_{ST}}}\sum_{n=0}^{N_{ST}-1} S_n e^{j2\pi n\Delta f(t - T_{CP})}$$

The parameter Δf, which denotes sub-carrier spacing, and N_{ST} are described in Table 213. S_n is defined as data, pilot, or training symbols. The binding requirements are the spectral mask and modulation accuracy requirements. Note that, in the receiver, shifting the time by more than T_{CP} for application of DFT helps to avoid inter-symbol interference caused by the superposition of the extended TVWS-NB-OFDM symbols and inter-carrier interference caused by the windowing.

20.3.3.13 PIB attribute values for *phySymbolsPerOctet*

The number of symbols per octet depends on the MCS mode applied and is computed as follows:

$$phySymbolsPerOctet = 8 \times n/k \times 1/N_{dbps}$$

where

n=204, and k=188

20.3.4 Channel aggregation for TVWS-NB-OFDM

The use of channel aggregation is controlled by the *phyTvwsChannelAggregation* PIB described in Table 71. When channel aggregation is enabled at least one of the bandwidths, 6 MHz or 8 MHz, shall be supported. The maximum number of aggregated channels depends on the availability of channel bandwidth. Table 217 shows the channel aggregation parameters.

Table 217—Channel aggregation parameters for TVWS-NB-OFDM

Maximal bandwidth on channel aggregation use	6 MHz	8 MHz
Maximal number of subchannels available for aggregation	11	16
Channel spacing	400.79365 kHz (= 125/126 kHz × 404)	
Guard band for each side of channel	795.63495 kHz	793.6508 kHz

20.3.5 TVWS-NB-OFDM RF requirements

20.3.5.1 Operating frequency range

The TVWS-NB-OFDM PHY operates in the bands indicated in Table 4ab.

20.3.5.2 Transmit power spectral density (PSD) mask

The TVWS-NB-OFDM PHY transmit PSD mask shall conform with local regulations.

20.3.5.3 Receiver sensitivity

The sensitivity requirements, as described in 8.1.7, for each MCS mode are shown in Table 218.

Table 218—TVWS-NB-OFDM PHY sensitivity requirements

MCS Mode	Sensitivity
0	–97 dBm
1	–96 dBm
2	–94 dBm
3	–92 dBm
4	–89 dBm
5	–85 dBm
6	–81 dBm
7	–80 dBm
8	–78 dBm

20.3.5.4 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as given in 8.2.1.

20.3.5.5 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as given in 8.2.2.

20.3.5.6 Error-vector magnitude (EVM) definition

The relative constellation RMS error averaged over subcarriers, symbols, and packets shall not exceed the values shown in Table 219.

Table 219—TVWS-NB-OFDM PHY EVM requirements

MCS mode	RMS error
0	–3 dB
1	–5 dB
2	–8 dB
3	–11 dB
4	–14 dB
5	–17 dB
6	–20 dB
7	–23 dB
8	–26 dB

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signal into a stream of complex samples. The sampled signal shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Detect the start of packet.
b) Detect the transition from STF to LTF, and establish fine timing (with one sample resolution).
c) Estimate the coarse and fine frequency offsets.
d) De-rotate the packet according to estimated frequency offset.
e) Estimate the complex channel response coefficients for each of the subcarriers.
f) For each data TVWS-NB-OFDM symbol, transform the symbol into subcarrier received values, and divide each subcarrier value with the estimated channel response coefficient.
g) For each data-carrying subcarrier, find the closest constellation point, and compute the squared Euclidean distance from it.
h) Compute the RMS average of all errors in a packet. It is given by:

$$RMS_{error} = 20\log_{10}\left(\frac{1}{N_F}\sum_{i=1}^{N_F}\sqrt{\frac{\sum_{j=1}^{N_{SYM}}\sum_{k\in U_D}\Delta(i,j,k)^2}{352\times N_{SYM}\times P_0}}\right)$$

with

$$\Delta(i,j,k)^2 = [I(i,j,k) - I_0(i,j,k)]^2 + [Q(i,j,k) - Q_0(i,j,k)]^2$$

where

N_{SYM}	is the number of TVWS-NB-OFDM symbols in the packet
N_F	is the number of packets used for the measurement
U_D	is the index set of data tones
$[I_0((i,j,k), Q_0(i,j,k))]$	denotes the ideal symbol point of the *i*th packet, *j*th TVWS-NB-OFDM symbol of the packet, and *k*th subcarrier of the TVWS-NB-OFDM symbol in the complex plane
$[I((i,j,k), Q(i,j,k))]$	denotes the observed point of the *i*th packet, *j*th TVWS-NB-OFDM symbol of the packet, and *k*th tone of the TVWS-NB-OFDM symbol in the complex plane
P_0	is the average power of the constellation

The test shall be performed over at least $N_F = 20$ packets. The payload of the packets under test shall contain $N_{SYM} = 16$ TVWS-NB-OFDM symbols. Random data shall be used for the payload.

20.3.5.7 Transmit center frequency and symbol tolerance

The transmit center frequency tolerance shall be ±20 ppm maximum. The symbol clock frequency tolerance shall also be ±20 ppm maximum. The transmit center frequency and the symbol clock frequency shall be derived from the same reference oscillator.

Annex A

(informative)

Bibliography

Insert the following new references into Annex A in alphabetic order:

[B.x1] Chang, S.-Y., and C. Seibert, "15-13-0166-03-004m-tg-15-4m-coexistence-assurance-document-cad.pdf,"[6] IEEE 802.15™ documents, 2013.

[B.x2] Lu, L., K. Mizutani, C.-S. Sum, F. Kojima, and H. Harada, "15-13-0565-02-004m-tvws-nb-ofdm-frame-example.doc,"[6] IEEE 802.15 documents, 2013.

[B.x3] Seibert, C., "15-13-0131-01-004m-example-encoding-for-tvws-fsk-phy.pdf,"[6] IEEE 802.15 documents, 2013.

[B.x4] Shin, C., B.H. Kim, S. Choi, and S.-Y. Chang, "15-13-0287-01-004m-tvws-ofdm-frame-example.doc,"[6] IEEE 802.15 documents, 2013.

[6] This IEEE document is available at https://mentor.ieee.org/802.15/documents.

Annex D

(informative)

Protocol implementation conformance statement (PICS) proforma[7]

NOTE—Subclause D.2 is reproduced here to assist the reader in understanding the abbreviations and special symbols in this annex. No changes are made to D.2.

D.2 Abbreviations and special symbols

Notations for requirement status:

M Mandatory
O Optional
O.n Optional, but support of at least one of the group of options labeled O.n is required.
N/A Not applicable
X Prohibited
"item": Conditional, status dependent upon the support marked for the "item"

For example, FD1: O.1 indicates that the status is optional but at least one of the features described in FD1 and FD2 is required to be implemented, if this implementation is to follow the standard to which this PICS proforma is part.

D.7 PICS proforma tables

D.7.1 Functional device types

Insert the following new row at the end of Table D.1:

Table D.1—Functional device types

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
FD11	TVWS PHY device	8.1	O.3			

[7]Copyright release for PICS proformas: Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

D.7.2 Major capabilities for the PHY

D.7.2.2 Radio frequency (RF)

Insert the following new rows at the end of Table D.3:

Table D.3—Radio frequency (RF)

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
RF20	TVWS-PHYs					
RF20.1	TVWS-FSK	20.1	FD10: O.12			
RF20.2	TVWS-OFDM	20.2	FD10: O.12			
RF20.3	TVWS-NB-OFDM	20.3	FD10: O.12			
RF20.4	Support at least one of the given bands	Table 4ab	FD10: M			
RF20.5	TVWS Ranging	Annex T	FD10:O			
RF21	TVWS-FSK options					
RF21.1	Support for at least one of the modes	20.1.2 Table 201	RF20.1: M			
RF21.2	TVWS-FSK FEC and Interleaving	20.1.2.2	RF20.1: O			
RF21.3	TVWS-FSK data whitening	20.1.2.3	RF20.1: O			
RF21.4	TVWS-FSK spreading	20.1.2.4	RF20.1: O			
RF22	TVWS-OFDM operating modes					
RF22.1	Support for MCS0, MCS1, and MCS2 modes	20.2.2 Table 205	RF20.2: M			
RF22.2	Support for MCS3, MCS4, and MCS5 modes	20.2.2 Table 205	RF20.2: O			
RF23	TVWS-NB-OFDM operating modes					
RF23.1	Support for at least one of the modes	20.3.3 Table 214	RF20.3: M			

D.7.3 Major capabilities for the MAC sublayer

D.7.3.1 MAC sublayer functions

Insert the following new rows at the end of Table D.5:

Table D.5—MAC sublayer functions

Item number	Item description	Reference	Status	Support		
				N/A	Yes	No
MLF31	Beacon only period	5.1.1.1.3	FD10: O			
MLF32	Ranging	5.1.8	FD10: O			
MLF33	TVWS power saving capability	5.1.15	FD10: O			
MLF34	Information elements	5.2.2	FD10: O MLF32:M MLF33:M			

Insert the following new annex (Annex T) after Annex S:

Annex T

(informative)

Ranging considerations for operation in TVWS

T.1 Introduction

This annex describes a ranging mechanism for a TVWS WPAN. The geolocation requirements for TVWS specify that the accuracy of a geolocation capability to determine its geographical coordinates is ± 50 m for Mode II fixed and personal/portable devices. Mode I devices may also require location capability. It may be possible to provide a geolocation capability by incorporating a GPS receiver on a device. However, the GPS service may not always be available in some situations, such as when the receiver is inside a building or urban canyon, or is under attack through jamming or spoofing. Moreover, battery-powered Mode I devices may not be equipped with GPS receiver. Therefore, it is advisable to provide optional RF localization for TVWS WPANs.

T.2 General

The ranging mechanism for TVWS WPAN PHYs is basically the same as that of the UWB PHY, shown in Annex E. Similar to the UWB PHY, a TVWS WPAN frame with the ranging bit set in the PHR is called a ranging frame (RFRAME). The critical instant in this RFRAME is the start of the PHR for both TVWS-FSK, TVWS-OFDM, and TVWS-NB-OFDM PHYs, known as the ranging marker (RMARKER). In the two-way ranging technique, ranging counter values in the ranging originator are captured upon RMARKER departure and arrival, while ranging counter values in the ranging responder are captured upon RMARKER arrival and departure. In this ranging counter operation, the exact timing of RMARKER for any RFRAME transmission can be easily determined. However, the timing of the RMARKER arrival at the receiver that determines the ranging performance is susceptible to noise, signal bandwidth, and operation clock frequency tolerance. As a result, a major issue in TVWS WPAN based ranging is how to obtain the accurate arrival time of TVWS-FSK, TVWS-OFDM, and TVWS-NB-OFDM signals.

The technique for achieving appropriate accuracy of this signal arrival time is outside the scope of this standard, but it is helpful to discuss a typical approach for TVWS WPAN PHYs, e.g., TVWS-FSK, TVWS-OFDM, and TVWS-NB-OFDM PHYs. In the following, the symbol transition timing (STT) estimation for the TVWS-FSK PHY and the time of arrival (ToA) estimation for the TVWS-OFDM and TVWS-NB-OFDM PHYs are briefly described.

T.3 Estimation for TVWS-FSK PHY

Generally, the FSK system has not been used for accurate ranging due to its narrowband characteristics. However, the accuracy of ± 50 m in TVWS enables FSK-based ranging to assist a geolocation capability of TVWS devices. Unlike the UWB and OFDM PHYs that exploit a correlation property of the preamble sequence, the timing of the RMARKER arrival in an FSK system can be obtained from STT estimation during the preamble, whose sequence is multiple repetitions of "01010101."

One approach for STT estimation is to use the phase difference vector of the received FSK signal. The phase of the FSK signal is reversed in every symbol during the preamble. Therefore, the phase difference vector between the received signal and its delayed signal shows a phase transition, from which the symbol transition time can be estimated. The TVWS-FSK PHY WPAN allows applications to specify the length of the preamble (between 4 to 1000 bytes); this feature can be used to enhance the ranging performance by increasing the number of preamble symbols involved in STT estimation.

T.4 ToA estimation for TVWS-OFDM PHYs

The conventional autocorrelation-based schemes can be used for ToA estimation in the TVWS-OFDM and TVWS-NB-OFDM PHYs since the STF and LTF sequences in the SHR show a good autocorrelation property.