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Wireless Personal Area Networks

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IEEE Standard for
Local and metropolitan area networks—

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

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

Sponsor

LAN/MAN Standards Committee
of the
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Approved 00 Month 2013

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Abstract: In this amendment to IEEE Std 802.15.4-2011, outdoor low-data-rate, wireless, TV White Space network requirements are addressed. Alternate PHYs are defined as well as only those 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-2013, IEEE Standard for Local and metropolitan area networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)—Amendment X: TV White Space Between 54 MHz and 862 MHz Physical Layer.

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

The alternate PHYs support principally outdoor, low-data-rate, wireless, TV White Space network (TVWS) 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.

Contents

IEEE Standard for
Local and metropolitan area networks—

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

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

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

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.[1]

[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 reference alphabetically into Clause 2:

3. Definitions, acronyms, and abbreviations

3.1 Definitions

Insert the following definitions alphabetically into 3.1:

TVWS Multichannel Cluster Tree PAN (TMCTP): A PAN operating in a TVWS band employing a Super PAN coordinator to form a multi-channel cluster tree topology.

Super PAN Coordinator: The PAN coordinator of a TVWS Multichannel Cluster Tree PAN which was access to the TVWS geolocation database and provides synchronization services for the TVWS Multichannel Cluster Tree PAN.

TVWS Channel: Spectrum unit allocation as defined by the TV bands channel availability database.

3.2 Acronyms and abbreviations

Insert the following acronyms alphabetically into 3.2:

BOP	Beacon Only Period
DBS	Dedicated Beacon Slot
GDB	Geolocation DataBase
ICI	Inter Carrier Interference
SPC	Super PAN coordinator
TMCTP	TVWS Multichannel Cluster Tree PAN
TVWS	TeleVision White Space

4. General description

4.2 Components of the IEEE 802.15.4 WPAN

Insert the following 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

4.3.1 STAR network formation

4.3.2 Peer to peer network formation

Insert the following new paragraphs after the last paragraph of 4.3.2:

A TVWS multichannel cluster tree PAN (TMCTP) is a form of a cluster tree network where the SPC is the overall PAN coordinator providing synchronization services to other PAN coordinators in the cluster and has access to the geo-location database (GDB) server to provide TVWS channel availability information to the other PAN coordinators. Each PAN coordinator uses a different channel allocated by the SPC. An example is shown in Figure 2a. The use of TMCTP can increase the coverage area with controlled message latency and reduced collisions between coordinators, and allows independent operations of each cluster simultaneously. Each TMCTP-parent PAN coordinator including the SPC may communicate with its TMCTP-child PAN coordinators during the active portion of the TMCTP-parent PAN coordinator and receives beacon frames of TMCTP-child PAN coordinators on a dedicated channel during the dedicated beacon slots (DBS) assigned to them in the beacon only period (BOP), as shown with an asterisk (*) in Figure 2a.

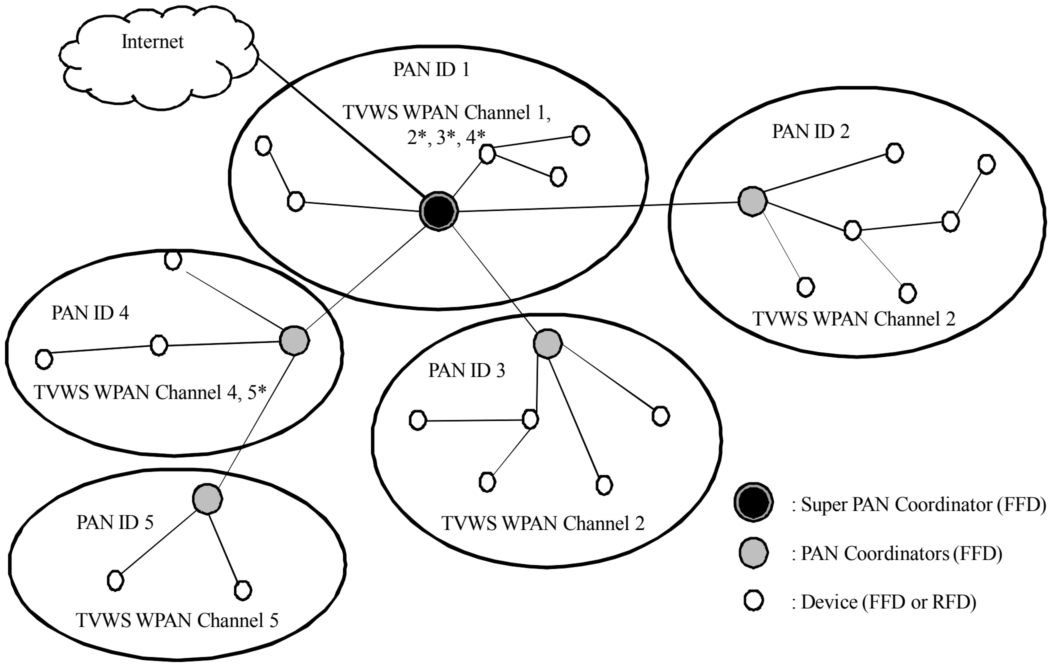

Figure 2a - Example of TVWS multichannel cluster tree PAN

4.5 Functional overview

4.5.1 Superframe structure

Insert the following new subclause (4.5.1.5) after 4.5.1.4:

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

This standard allows the optional use of a superframe structure in a TVWS multichannel cluster tree PAN (TMCTP) that is extended by the addition of a beacon only period (BOP) to the active portion of the superframe. The format of the TMCTP superframe is defined by the SPC. 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 the BOP is illustrated in Figure 5a. The BOP is composed of one or more DBSs. A DBS is used to communicate beacons between the TMCTP-parent PAN coordinator and the TMCTP-child PAN coordinator. More information on the TMCTP superframe structure can be found in 5.1.1.1.3.

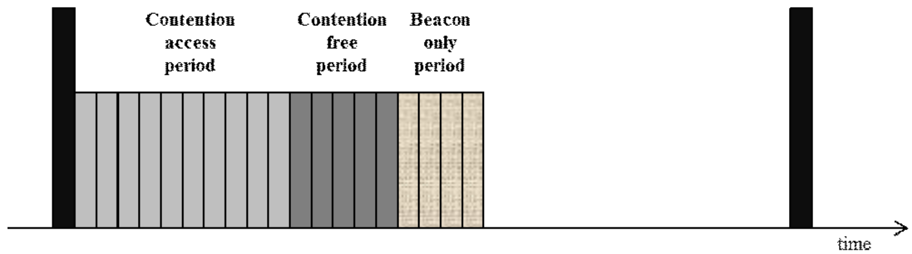

Figure 5a - TMCTP superframe extension

4.5.2 Data transfer model

Insert new subclause at the end of 4.5.2:

4.5.2.4 Direct device-to-device data transfer

Direct device-to-device data transfer enables data transfer in a GTS between two or more neighbor devices directly on a beacon-enabled PAN. Neighbor devices are peer devices associated with the same coordinator or PAN coordinator on a beacon-enabled PAN.

Direct device-to-device data transfer has four operation modes: (a) Probe-mode direct data transfer; (b) Polling-mode direct data transfer; (c) Broadcast-mode direct data transfer; and (d) Multicast-mode direct data transfer. With Probe-mode direct data transfer, a device transfers unicast data directly to a neighbor device. If the status of the neighbor device is unknown, then before sending data to a neighbor device, it probes status of the neighbor device. With Polling-mode direct data transfer, a device polls a neighbor device for data. With Broadcast-mode direct data transfer, a device directly broadcasts data to all its neighbor devices, while with Multicast-mode direct data transfer, a device sends data directly to a list of its neighbor devices.

Neighbor discovery may be needed for direct device-to-device data transfer.

4.5.5 Power consumption considerations

Insert new subclause 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.

In this standard, a low energy mechanism that is capable to reduce energy consumption and at the same time holds the characteristics to be compliant to regulatory requirements is specified.

Insert new subclause at the end of 4.5:

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 differs from the use of other license exempt and licensed band operation defined in this standard in having additional requirements for determining which TVWS frequency allocations are available for use at a given time and geographic location. In this standard it is assumed devices will depend on a TVWS channel availability database method for determination of available TVWS spectrum. Access based on sensing alone is not assume in this standard, but is not excluded either.

In this standard, 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 Internet, and so must depend upon another device for acquiring channel availability information.

Due to the dependence on regional regulatory variations, this standard provides methods that may be used for meeting the requirements of regional regulations without 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 in 5.1.1.1 after the first paragraph the following text:

For TVWS operation, when operating as a TMCTP the superframe structure 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.

5.1.1.1.1 Contention access period (CAP)

5.1.1.1.2 Contention free period (CFP)

Insert new subclause following 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. The CAP and CFP comprise the first 16 slots of the superframe as described in 5.1.1.1, 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 allocated to each TMCTP-child PAN coordinator. All DBSs shall be located within the BOP and occupy contiguous slots. The BOP therefore grows and/or shrinks depending on the total length of all of the combined DBSs. BOP slots are allocated to a DBS according to the length of the beacon sent by the TMCTP-child coordinator which will occupy the DBS.

No beacon transmissions within the BOP shall use a CSMA-CA mechanism to access the dedicated channel. A TMCTP-child PAN coordinator transmitting in the BOP shall ensure that its beacon transmission is complete one IFS period, as described in 5.1.1.3, before the end of its DBS.

5.1.1.7 LE Functional description

Add to end of bullet list in 5.1.1.7:

- *macTVWSPSenabled*

Insert new subclause following 5.1.1.7:

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 5a.

- 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 contention access period (CAP), as described in 5.1.1.1.1, which is used to communicate command frames and/or data.
- The contention free period (CFP), as described in 5.1.1.1.2, which is composed of guaranteed time slots (GTSs). No transmissions within the CFP shall use a CSMA-CA mechanism to access the channel.

- The beacon only period (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 the TMCTP-parent PAN coordinator (including the SPC) and the TMCTP-child PAN coordinator in a TMCTP.

The SD and BI of the TMCTP superframe are 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:

$$ED = aBaseSuperframeDuration \times 2^{macTMCTPExtendedOrder}$$

$$= aBaseSlotDuration \times (aNumSuprframeSlots \times 2^{macTMCTPExtendedOrder})$$

for $0 \leq macTMCTPExtendedOrder \leq (macBeaconOrder\text{-}macSuperframeOrder) \leq macBeaconOrder \leq 14$

The ED of each TMCTP superframe shall be divided into $aNumSuprframeSlots \times 2^{macTMCTPExtendedOrder}$ equally spaced slots of duration *aBaseSlotDuration* and is composed of beacon only period (BOP). The BOP consists of DBSs. Each DBS is composed of one or more base slots, which are *aBaseSlotDuration* in length. The extended duration of the active portion of each TMCTP superframe includes 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 11ha, according to the *macBeaconOrder*, the *macsuperframeOrder* and the *macTMCTPExtendedOrder* as shown in the Figure 11ha.

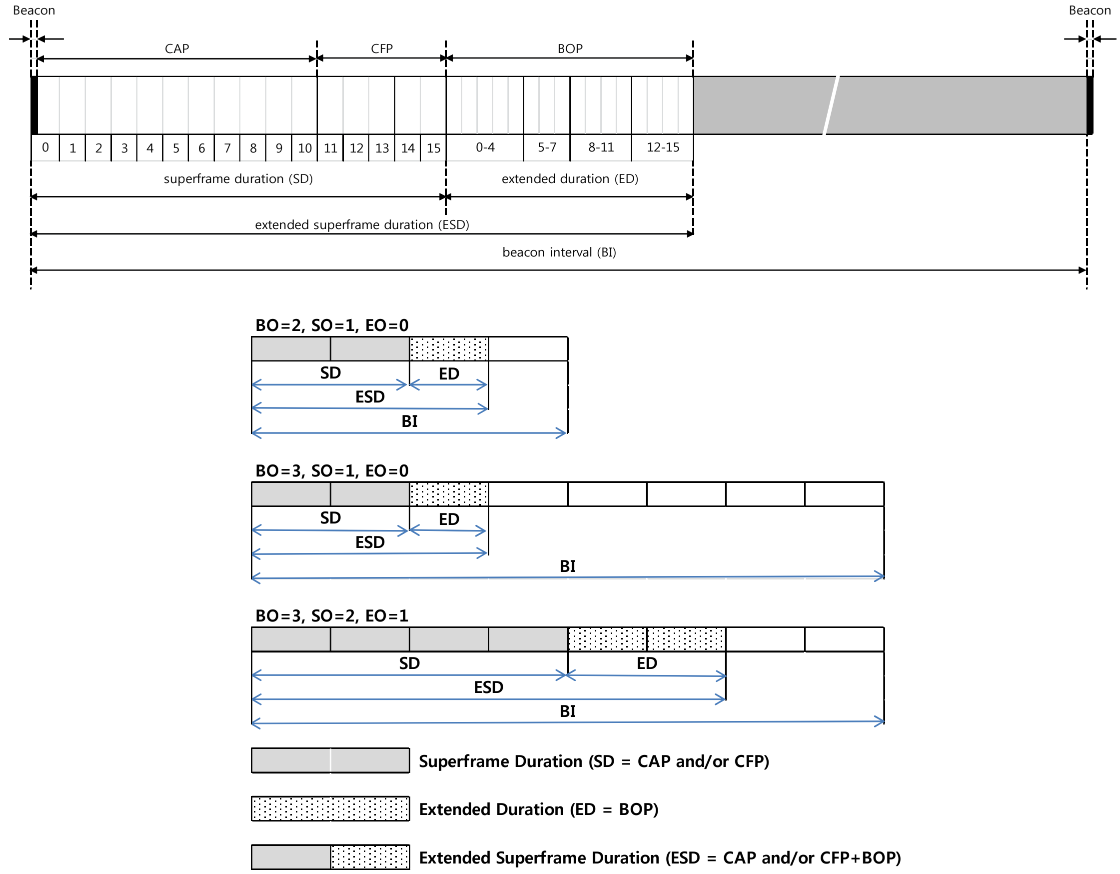

Figure 11ha - An example of the TMCTP superframe structure

5.1.2 Starting and maintaining PANs

5.1.3 Association and disassociation

5.1.4 Synchronization

5.1.5 Transaction handling

5.1.6 Transmission, reception and acknowledgement

Add new subclause at the end of section 5.1.6 Transmission, reception, and acknowledgement

5.1.6.7 Direct device-to-device data transfer

5.1.6.7.1 Neighbor discovery

Neighbor discovery may be required for direct device-to-device data transfer.

Neighbor discovery is to discover one-hop neighbor devices and to be discovered by neighbor devices. In this amendment, a one-hop neighbor device is a device in communication range and has the same coordinator.

A device may discover a one-hop neighbor device by receiving beacon frame broadcast by the neighbor device, if it broadcasts beacon regularly. It may also discover a one-hop neighbor device by receiving Neighbor Discovery command broadcast by it.

One the other hand, a device can be discovered by its one-hop neighbor devices through beacon if it broadcasts beacon regularly, or by broadcasting the Neighbor Discovery command if necessary.

A Neighbor Discovery command can be broadcast if a device wants to be discovered by its one-hop neighbor devices. It can be broadcast by a device that does not broadcast beacon regularly, or by a device broadcasting beacon regularly when necessary. A Neighbor Discovery command can be broadcast by a device after association with its coordinator, at the appropriate time upon receiving MLME-NBR.Request primitive from the next higher layer. A Neighbor Discovery command requires no acknowledgement. Figure 22ca shows the message sequence chart for neighbor discovery by broadcasting Neighbor Discovery command.

A Neighbor Discovery command can only be broadcast by a device in the active portion of its incoming superframe, if the device is a coordinator.

Upon receiving a Neighbor Discovery command, a device ignores it if the source device is not associated with the same coordinator. Otherwise, it adds the source device into its neighbor list if the source device is not included. If the device is not listed in the Address List field of Neighbor Discovery command, it means that the device is not discovered by the source device as one-hop neighbor device. In this case, if necessary, it may broadcast a Neighbor Discovery command at appropriate time for being discovered by the source device.

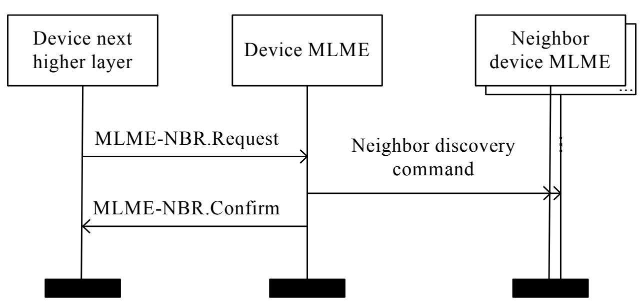

Figure 22ca - Message sequence chart for neighbor discovery by broadcasting neighbor discovery command

5.1.6.7.2 Probe-mode direct data transfer

In Probe-mode direct data transfer, if a device has data for a neighbor device and it knows that the receiver status of the neighbor device is “on”, the device sends data to the destination device at the appropriate time, without probing the receiver status of the neighbor device.

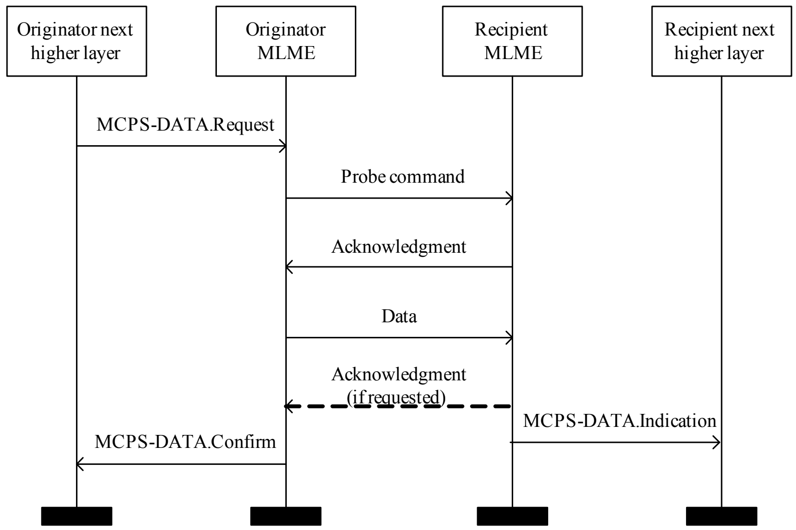

Figure 22cb - Message sequence chart for probe-mode direct data transfer

If the receiver status of the neighbor device is unknown, it sends a Probe command to the destination device and starts a timer with duration of *macACKWaitDuration*. If it receives no acknowledgement of the Probe command from the neighbor destination device before expiration of the timer, the destination device is concluded unreachable at this moment. If before expiration of the timer, it receives acknowledgement of the Probe command from the neighbor destination device, it sends the data to the neighbor device at the appropriate time.

On receiving a Probe command, a destination device shall send acknowledgement and enable its receiver for at most *macMaxFrameTotalWaitTime* to receive data from the source device. If it receives data before expiration of the timer, it acknowledges receipt of the data if it is required.

If the destination device is unreachable, the data frame may remain in the transaction queue until another request from the higher layer is received or *macTransactionPersistenceTime* is reached. If *macTransactionPersistenceTime* is reached, the transaction information will be discarded, and the MAC sublayer will issue a failure confirmation to the next higher layer.

The message sequence of Probe-mode direct data transfer is shown in Figure 22cb.

5.1.6.7.3 Polling-mode direct data transfer

With Polling-mode direct data transfer, when a device's MAC sublayer receives the MLME-POLL.request primitive from next higher layer, it sends a data request command to a target neighbor device at the appropriate time and starts a timer with duration of *macACKWaitDuration*.

On receiving a data request command, a device shall send an acknowledgement to confirm successful reception of the command and indicate whether it has data pending for the polling neighbor.

If before sending the acknowledgement of data request command, the polled device is able to determine that it has data pending for the polling device, it sets the Frame Pending field of the acknowledgement to one. If it is able to determine that it has no data pending for the polling device, it sets the Frame Pending field of the acknowledgement to zero. If it does not have enough time to determine whether it has data pending for the polling device, it sets the Frame Pending field to one.

If before expiration of the timer, the polling device receives no acknowledgement of the data request command, it concludes that the neighbor device is not reachable at this moment. The polling device MAC sublayer shall issue a failure confirmation to next higher layer.

If before expiration of the timer, the polling device receives acknowledgement with the Frame Pending field set to zero, it concludes that there is no data pending at the neighbor device.

If before expiration of the timer, the polling device receives acknowledgement with the Frame Pending field set to one, it shall enable it receiver for at most *macMaxFrameTotalWaitTime* to receive the corresponding data from the neighbor device. If the polling device does not receive a data frame from the neighbor device within *macMaxFrameTotalWaitTime* or if the polling device receives a data frame from the neighbor device with a zero length payload, it shall conclude that there are no data pending at the neighbor device. If the polling device does receive a data frame from the neighbor device, it shall send an acknowledgment frame, if requested, thus confirming receipt of the data frame.

If the Frame Pending field of the data frame received is one, then the neighbor device has more data pending. In this case it may extract the data by sending a new data request command to the neighbor device.

The message sequence of Polling-mode direct data transfer is shown in Figure 22cc.

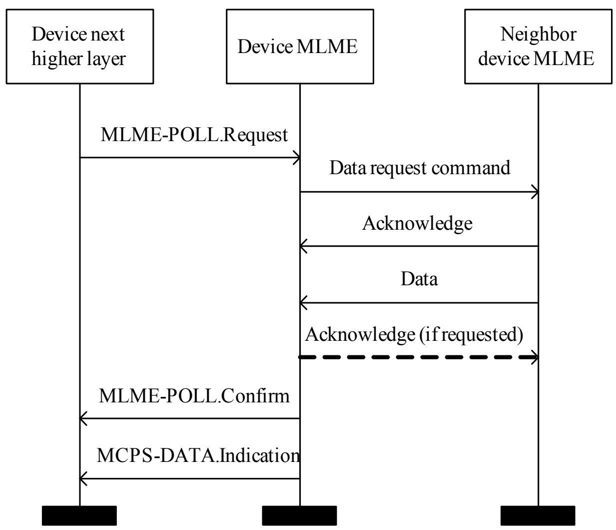

Figure 22cc - Message sequence chart for polling-mode direct data transfer

5.1.6.7.4 Broadcast-mode direct data transfer

In Broadcast-mode direct data transfer, upon receiving higher layer MCPS-DATA.Request primitive with address of broadcast, the device broadcasts the data frame. The AR field of the data frame shall be set to indicate no acknowledgement requested. Figure 22cd shows message sequence of broadcast-mode direct data transfer.

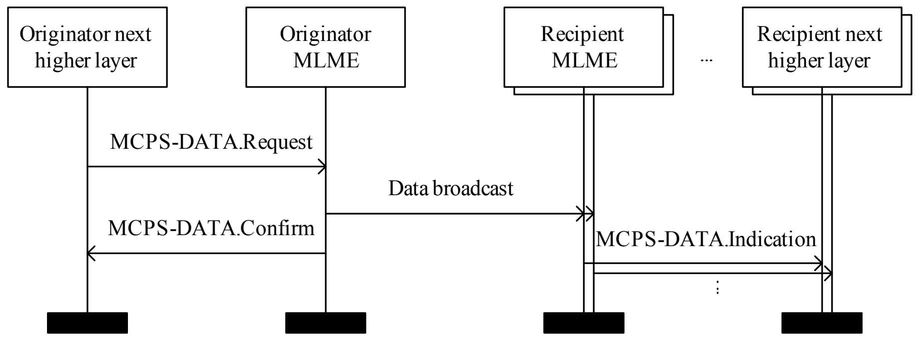

Figure 22cd - Message sequence chart for broadcast-mode direct data transfer

5.1.6.7.5 Multicast-mode direct data transfer

A device multicast a data frame to a subset of its neighbor devices upon receiving higher layer MCPS-DATA.Request primitive with a multicast address. Figure 22ce shows message sequence of Multicast-mode direct data transfer.

A device may subscribe to a multicast group by enabling reception of data frames destined for corresponding multicast address. Note: The form of an EUI-64 Multicast address is given in Registration Authority Committee (RAC).

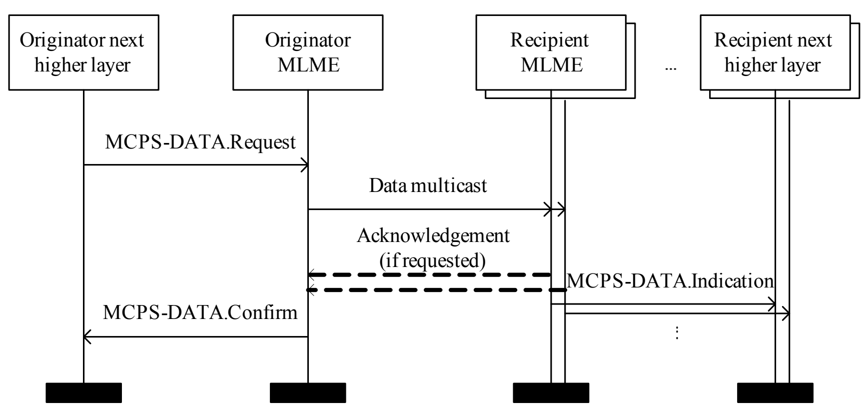

Figure 22ce - Message sequence chart for multicast-mode direct data transfer

5.1.7 GTS allocation and management

5.1.8 Ranging

Insert new subclause following 5.1.8.4:

5.1.8.5 The ranging exchange with Information Elements

In an RDEV that supports IEs, the range exchange may be performed by the MAC as part of the data/acknowledgement process.

This process is initiated upon receipt an MCPS-DATA.request with the Ranging parameter set to a supported ranging mode, and the *UseRangingIE* parameter set to TRUE. The MAC sublayer will generate a Ranging request IE (see 5.2.4.34.1) and include it in the data or multipurpose frame sent. The Ranging method field shall be set according to the RangingMethod parameter of the request. The Range message sequence number field shall be incremented with each MCPS-DATA.request with ranging enabled. The AR field of the FCF shall be set to request acknowledgment. The Timestamp parameter will be included in the generated MCPS-DATA.confirm.

When a data or multipurpose frame containing a Ranging request IE (see 5.2.4.34.1) is received by an RDEV that supports IEs, the receive Timestamp is captured and a Ranging response IE (see 5.2.4.34.2) is included in the Acknowledgement. The Response TX-timestamp field of the Ranging response IE is set to the local time reference when the Acknowledgement is transmitted. If the Ranging method field of the received Ranging Request IE indicates a two-way ranging request, the Request RX-timestamp field is set to the Timestamp captured when the packet containing the request was received.

Upon receipt of the Acknowldgement by the originating device, the Timestamp parameters of the MCPS-DATA.confirm are set according to the contents of the Ranging response IE.

Insert new subclauses 5.1.14 and 5.1.15 following 5.1.13:

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

This subclause specifies the procedures for TMCTP formation.

5.1.14.1 Network formation using TMCTP

Figure 34ta 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 geo-location database (GDB) through the Internet. The protocol used to access the GDB over the internet is outside the scope of this standard. Alternately, the SPC may obtain the list of available TVWS channels from another device (Fixed, Mode II or Mode I Device). The SPC maps the TVWS channels to corresponding PHY channels and 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.

In Step B, the SPC transmits an enhanced beacon containing a TMCTP Extended Superframe Specification IE as in 5.2.4.35. Upon successful reception of the beacon from the SPC, the TMCTP-child PAN coordinator may request a DBS allocation sending a DBS request, as in 5.3.14, to the SPC. Upon receiving the DBS request, the SPC will allocate a DBS slot and channel, and generate a DBS response to report the slot and channel allocated (the request is successful in this example).

In Step C, of the example, 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.

In Step D, the SPC sends its own beacon frame. The SPC switches into the channel allocated to the PAN coordinator and receives the beacon frame from the PAN coordinator.

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 into its own dedicated channel.

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

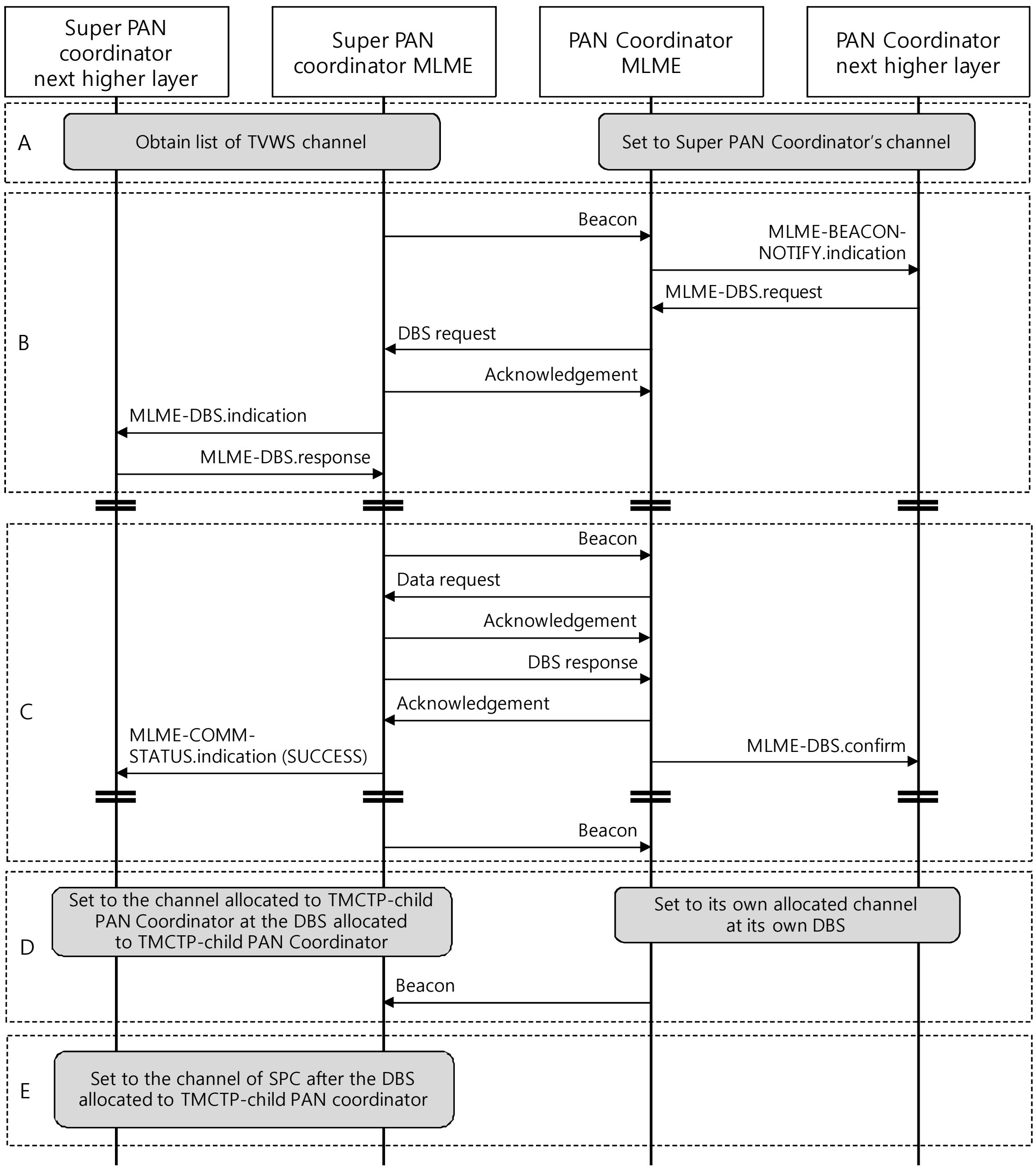

Figure 34ta - Example message sequence between SPC and TMCTP-child PAN coordinator

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

In Step A, the TMCTP-child PAN coordinator performs a scan procedure and is waiting 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 directly generates the DBS response frame reporting the slot and a channel allocated, or it or sends the DBS request command frame to the SPC and then receives the DBS response command frame from the SPC.

In Step C, the TMCTP-parent PAN coordinator sends a beacon. The TMCTP-parent PAN coordinator switches into 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 into 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 into 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.

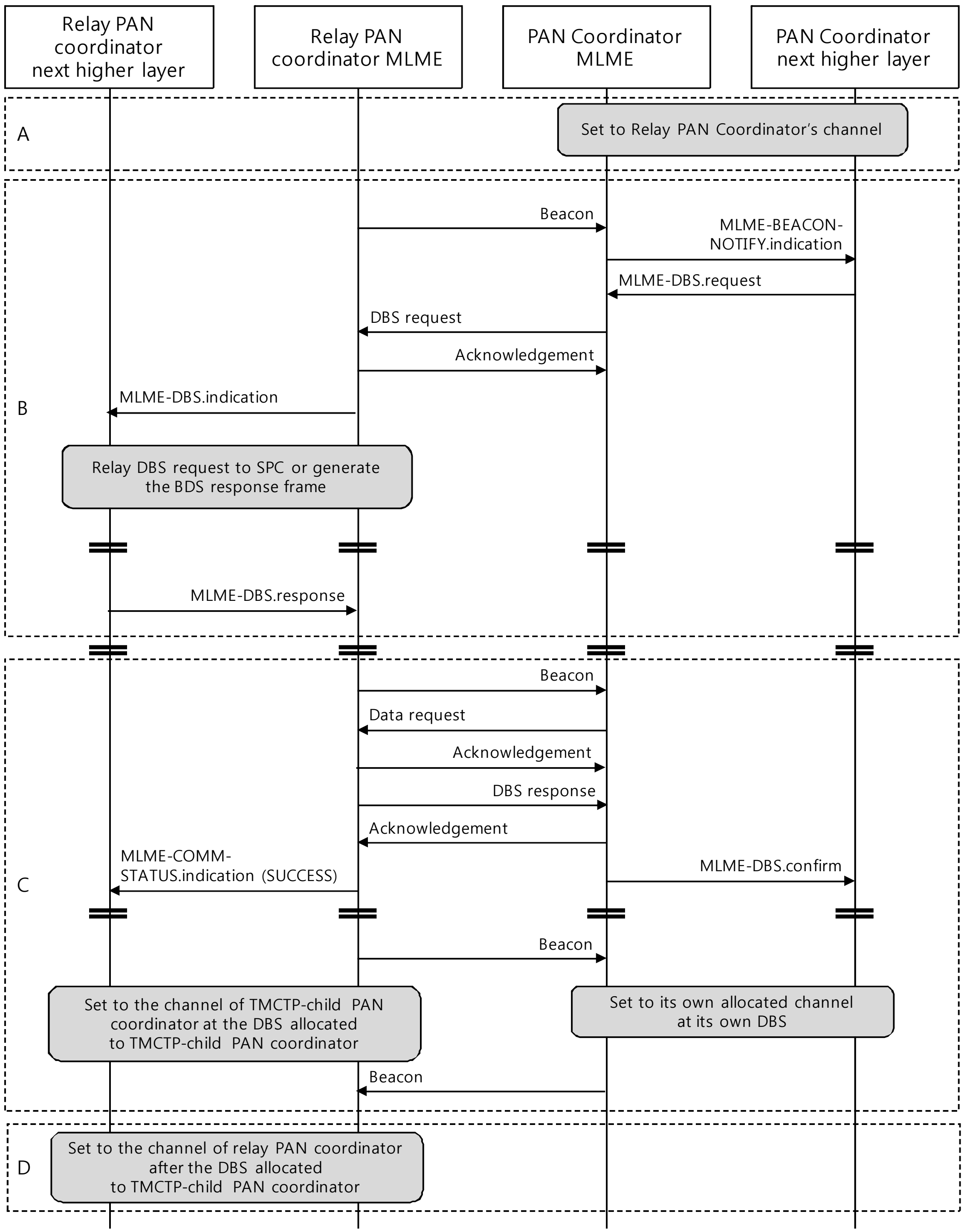

Figure 34tb - Example message sequence between TMCTP PAN coordinator

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

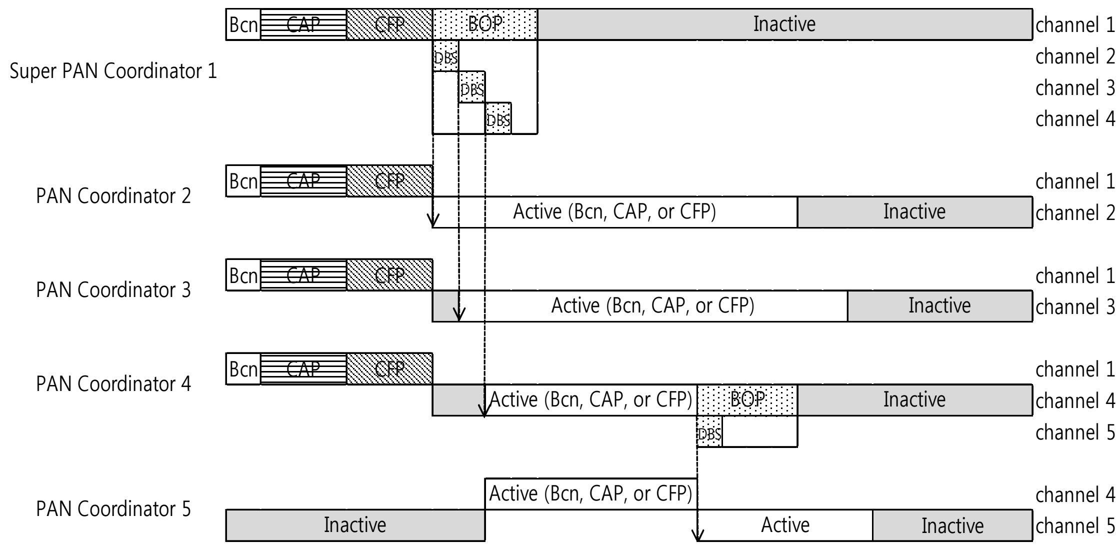

Figure 34tc - Example TMCTP BOP allocation

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.

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 at *macTVWSPSPollingInterval*, for total duration *macTVWSPSPollingDuration* or until receiving an acknowledgement 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*.

The value of *macTVWSPSPollingInterval* should be less than or equal to *macTVWSPSListeningDuration* and *macTVWSPSPollingDuration* should be more than or equals to *macTVWSPSListeningInterval*. The TVWSPS IE may be included in an enhanced beacon, data or multi-purpose frame.

An initiating or responding device may also indicate the required time for completing the transaction in the transaction duration field of the generated TVWSPS IE (see 5.2.4.30).

When generating the TVWSPS IE, the Rendezvous time field shall be set to the value of *macTVWSPSRendezvousTime* and the Transaction duration field shall be set to the value of *macTVWSPSTransDuration*.

Upon receiving a frame with a TVWSPS IE, the responding device switches on 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 indicated Rendezvous time.

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

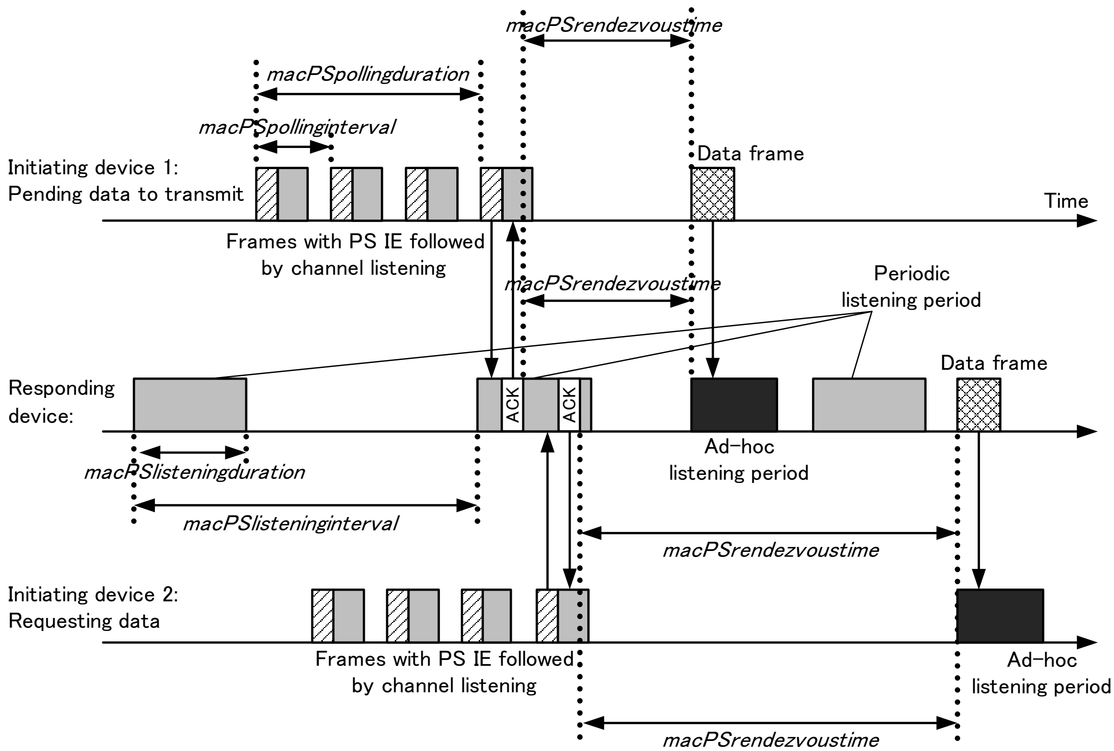

Figure 34td - TVWS power saving mechanism

5.2 MAC frame formats

5.2.2 Format of individual frame types

5.2.2.1 Beacon frame format

5.2.2.1.1 Information elements (IEs) field

5.2.4.1 Header information elements

5.2.4.4 MLME information elements

Add the following rows in Table 4d:

Table 4d - Sub-ID allocation for short format

Sub-ID Value	Content Length	Name	Description

Table 4d - Sub-ID allocation for short format

TBA	variable	PHY Parameter Change IE	Description on PHY parameter change for devices, as defined in 5.2.4.29
TBA	12	TVWSPS IE	Description on parameters for TVWS power saving mechanism, as defined in 5.2.4.30
TBA	variable	TVWS PHY Operating Mode Description IE	Description on a specific TVWS PHY operating mode, as defined in 5.2.4.31
TBA	variable	TVWS Device Capabilities IE	Description on TVWS PHY-specific device capabilities, defined in 5.2.4.32
TBA	1	TVWS Device Category IE	Description on the device regulatory category, as defined in 5.2.4.33.1
TBA	variable	TVWS Device Identification IE	Description on the device assigned identification, as defined in 5.2.4.33.2
TBA	variable	TVWS Device Location IE	Description on location of device, as defined in 5.2.4.33.3
TBA	variable	TVWS Channel Information Query/Response IE	Description on the query and response protocol for channel information, as defined in 5.2.4.33.4
TBA	variable	TVWS Channel Information Source Description IE	Description on channel information source for channel enabling, as defined in 5.2.4.33.5
TBA	variable	Channel Timing Management IE	Description on the information for management in timing schedule for channel, as defined in 5.2.4.33.6
TBA	2	Channel List Verification IE	Description on list of verified channel, as defined in 5.2.4.33.7
TBA	1	Ranging Request IE	Description on request for device ranging, as defined in 5.2.4.34.1
TBA	variable	Ranging Response IE	Description on response for device ranging, as defined in 5.2.4.34.2
TBA	variable	TMCTP Specification IE	Description on information for TMCTP protocols, as defined in 5.2.4.35

Insert new subclauses at the end of 5.2.4:

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 48no.

Octets: 1	3	3	3	2
PS Control	Periodic Listening Period	Periodic Listening Duration	Rendezvous Time	Maximum Transaction Duration

Figure 48no - TVWSPS IE content

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. A value of 1 indicates that an initiating device has pending data to be transmitted to the responding data. A value of 2 indicates that an initiating device is requesting data from the responding device. All other values are reserved.

The Periodic Listening Interval field is the time between the start of a periodic listening duration to the start of the subsequent periodic listening duration (see 5.1.15) in milliseconds, with a range of from 0 to 16777215 milliseconds. 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 of 0 to 16777215 milliseconds. 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 acknowledgement 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 of from 0 to 16777215 milliseconds.

The Transaction Duration field is the time needed complete the transaction between the initiating and responding devices. When generated this field is set to the value of *macTVWSPSTransDuration*, with a valid range of from 0 to 65535 milliseconds.

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 (5.2.4.29) to signal dynamically a change in operating channel, band or other PHY operating parameter when the resulting change will be to a configuration defined by the 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 48np.

TVWS PHY Operating Mode Description

Figure 48np - TVWS PHY operating mode description IE content

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

Table 4ia - TVWS PHY Operating Mode Description field

Bit Number	Description
0:7	Band ID. The band ID described in Table 4ic.
8:15	TVWS Channel ID. The TVWS Channel ID allocated by the TVWS database.
16:23	PHY Channel ID. The channel identification for the 802.15.4 TVWS PHY channel as defined in 8.1.2.6.
24:25	PHY Type Selector: 0 = TVWS FSK PHY (20.1) 1 = TVWS OFDM PHY (20.2) 2 = TVWS NB-OFDM PHY (20.3) 3 = Reserved

	Bit Number	Description
26:39	FSK Operating Parameters: when PHY Type Selector is set to 0	
	26	FEC 0 = not enabled 1 = enabled
	27	Interleaving 0 = not enabled 1 = enabled
	28	Spreading 0 = not enabled 1 = enabled
	29	Whitening 0 = not enabled 1 = enabled
	30:32	FSK Mode as in Table 133.
	33	Modulation index option: When Mode = 1, 2 or 3: 0 = modulation index is 0.5 1 = modulation index is 1.0 When Mode = 4 or 5, shall be set to zero.
	34	SFD Length 0 = 16 bit SFD 1 = 24 bit SFD
	35:39	Reserved
	OFDM Operating Parameters: when PHY Type selector is set to 1	
	26:27	Modulation 0 = BPSK, 1 = QPSK, 2 = 16-QAM, 3 =Reserved
	28:30	MCS Mode 0-5 as given in Table 137 6-7 Reserved
	31:39	Reserved
	NB-OFDM Operating Parameters: when PHY Type selector is set to 2	
	26:29	MCS Mode 0-8 as given in Table 143 9-15 Reserved
	30	Channel aggregation 0 = not enabled 1 = enabled
	31:39	Reserved

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. The IE content shall be as shown in Figure 48nq.

Octets: 1	2	1	Variable
TVWS PHY Type	Supported Bands	TVWS Supported PHY Features	TVWS Supported Channels

Figure 48nq - 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 4ib.

Table 4ib - TVWS PHY Type field

Value	Description

1	TVWS FSK PHY
2	TVWS OFDM
3	TVWS NB-OFDM
4-255	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 4ic. The device shall indicate only those bands that are implemented and defined for the indicated PHY type.

Table 4ic - 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	169.400-169.475 MHz
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	1427-1518 MHz
18	2400-2483.5 MHz
19 - 31	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 4id, Table 4ie and Table 4if accordingly.

Table 4id - TVWS FSK PHY Supported Features field

Bit number	Description
0	24-bit SFD length supported
1	FEC supported
2	Interleaving supported
3	Spreading factor 2 supported
4	Spreading factor 4 supported
5	Spreading factor 8 supported
6	Spreading factor 16 supported
7	Data whitening supported

Table 4ie - TVWS OFDM PHY Supported Features field

Bit number	Description
0	MCS3 supported
1	MCS4 supported
2	MCS5 supported
3:7	Reserved

Table 4if - 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	Reserved

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

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 8.1.2.6. 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 48nr. Each channel bit map will be encoded as shown in Table 4ig. 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 8.1.2.6 are supported and the channel list is 1 octet, with bits 1-7. If the first bit field is set to zero (*i.e.* not all channels in that band are supported), then the subsequent 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. 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 4ic, *i.e.* channel list corresponding to the band indicated by bit 0 of the Supported Bands field is transmitted first.

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

Figure 48nr - TVWS Supported Channels bitmap

Table 4ig - Channel list format

Bit position	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

5.2.4.33 TVWS enabling IEs

5.2.4.33.1 TVWS device category IE

The Device Category field is 1 octet and shall be set to one of the non-reserved values shown in Table 4ih.

Bit #	Description
0	Fixed device: device at a fixed location will not change after initial contact.
1	Not fixed, dependent device: device location may change after initial contact; operates without direct internet access to a database, depends on another device for channel availability information. (*e.g.* FCC mode I)
2	Not fixed, independent: device location may change after initial contact; has access to channel availability database (*e.g.* FCC mode II)
3 - 255	reserved

Table 4ih - Device Category

5.2.4.33.2 TVWS device identification IE

The Device Identification IE contains one of several types if identification, including a regulator assigned device approval identification, a manufactures 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 48ns.

Octets: 1	Variable
ID Type	Device ID

Figure 48ns - TVWS Device Identification IE content

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

Table 4ii - ID Type field values

ID type 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	Manufactures serial number
6	General (implementation specific value)
7 - 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 48nt.

Octets: 1	Variable
Device Category	ID String

Figure 48nt - Regulator assigned ID format

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

Octets: 1	Variable
Length	Array of Octets

Figure 48nu - Counted 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 Device Location IE contains a list of geo-location coordinates, as shown in Figure 48nv. Each location list entry is 16 octets, encoded as shown in Table 4ij. The encoding is based on RFC 6225. The field contents are as described in RFC 6225.

Octets: 1	Variable
Number of Locations	Device Locations List

Figure 48nv - TVWS Device location list IE

Table 4ij - Device location list element encoding

Bit #	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 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 48nw.

Octets: 1	1	1	Variable
Channel List ID	Channel Info Status	Number of Channels	Channel Description List

Figure 48nw - Channel Information Query 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. It shall be set to one of the values in Table 4ik.

Table 4ik - Channel Information Query Status values

Channel Info Status	Description
0	Channel list requested
1	Available channel list for verified for a device location
2	Available channel list for verified for multiple device location
3	Request not successful due to device ID not verified
4	Request not successful due to device location is out of the geographic coordinate
5	Request not successful due to one or more parameters have invalid values
6	Request not successful for another reason
7-255	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 location, the Number of Channels and Channel Description List fields are included in the IE. For other status values these fields are not present.

The Number of Channels field contains the number of channels that follow in the Channel Descriptions List field. Each entry in the Channel Description List field contains the specific information on available channels as shown in Figure 48nx.

Octets: 2	1	Variable
TVWS Channel ID	Maximum TX Power	Valid Time

Figure 48nx - Available TVWS channel description

The TVWS Channel ID field contains a channel ID appropriate to the TVWS PHY in use as described in 8.1.2. The Maximum TX Power field contains the maximum allowed transmit power, in 0.5 dBm, authorized for the channel. The Valid Time field contains the time, in minutes from the time of transmission, that channel is available; a valid time of zero indicates, until further notice (*e.g.* as might be used for contact verification).

5.2.4.33.5 TVWS channel information source description IE

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 is formatted as shown in Figure 48ny.

Octets: 1	16	0/8	0/4	0/1	Variable
Source Info	Channel Info Source Location	Address of Known source	Known Source Channel Description	Number of Channels	Channel Description List

Figure 48ny - Channel Information Source Description IE content

The Source Info field is a bitmap, encoded as shown in Table 4il.

Bit #	Description
0	Indication that this device is a source of channel info, and thus channel description fields are present
1	Indication that Address of Known Source field present
2	Indication that Known Source Channel Descriptions field present
3-7	Reserved

Table 4il - Source info field encoding

The Channel Info Source Location field is the location of the device acting as the source of channel availability data, and shall be formatted as shown in Table 4ij.

The Address of Known Source field is present when indicated by the Source Info field. When present, it contains the 64-bit extended address of the device acting as the source of channel availability data.

The Known Source Channel Description field is present when indicated by the Source Info field. When present, it contains the descriptions for contacting the device described in the Address of Known Source field.

The Number of Channel field indicates number of channels contained in the Channel Description List field. This field is present only when the Source Info field indicates that this device is a channel data source. The Channel Description List field is present when the number of channel descriptions field is present and not zero; each channel description is formatted as shown in Figure 48nx.

5.2.4.33.6 Channel timing management IE

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

Octets: 1	Variable
CTM Control	Channel Timing Information

Figure 48nz - Channel Timing Management IE content

The CTM Control field indicates the reason for transmitting a query request for channel schedule information. It also indicates the result of a query as successful or not, and the reason, when the query is not successful. The CTM Control field values are defined in the Table 4im.

Table 4im - CTM Control field values

Field values	Description
0	Request for channel timing information from a local server
1	Request for channel timing information from an independent device
2	Success with full channel timing information on the requested channels
3	Success with additional time slots added on the requested channels
4	Success with time slots deleted from the list of last query on the requested channels
5	Success with no channel timing changes from last query
6	Request declined by an independent device with unspecified reason
7	Request declined by an independent device because of no capability for providing channel timing information on WPAN channels
8	Request declined by a local server because of unspecified reason
9	Request declined by a local server because of no capability for providing channel timing information on WPAN channels
10	Unknown reason
11	Timeout
12-255	Reserved

Channel Timing Information field shall be encoded as shown Table 4in.

Table 4in - Channel Timing Information field encoding

Name	Length	Value
Channel number	1	The Channel Number field is set to the number of the channel.
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.
Channel Availability Offset Time	2	The Channel Availability Offset Time field indicates the offset of channel availability time with respect to the time that the Channel timing information field is received.
Channel Availability Duration	2	

5.2.4.33.7 Channel list verification IE

The Channel List Verification IE can be used to periodical send verification that the current channel is still valid for operation. The IE contents are shown in Figure 48naa.

Octets: 1	1
Channel List ID	Valid Time

Figure 48naa - Channel List Verification IE content

The Channel List ID field contains the ID for the Channel List ID as described in 5.2.4.33.4.

The Valid Time field contains the time, in minutes from the time of transmission that the channel availability data is expected to remain valid.

5.2.4.34 Ranging support IEs

5.2.4.34.1 Ranging request IE

The Ranging request IE is used by an device to initiate the transfer of ranging measurements between devices. In a ranging capable device, the presence of a Ranging request IE signals the receiving MAC entity that the receive timestamp should be captured and returned to the requesting device. This IE is used in the ranging exchange described in 5.1.8.5.

The ranging request IE content is 1 octet and encoded as shown in Figure 48nab.

Octets: 1	
Bit #: 0	**1:7**
Ranging Method	Ranging Message Sequence Number

Figure 48nab - Ranging request IE content

The Ranging Method field shall be set to 0 to indicate one-way ranging and set to 1 to indicate two-way ranging. The Ranging Message Sequence Number shall be set as described in 5.1.8.5.

5.2.4.34.2 Ranging response IE

The Ranging response IE is encoded as shown in Figure 48nac.

Octets: 1		0/4	4
Bits: 0	**1:7**		
Ranging Method	Ranging Message Sequence Number	Request RX Timestamp	Response TX Timestamp

Figure 48nac - Ranging response IE content

The Ranging Method field shall be set to 0 to indicate one-way ranging and set to 1 to indicate two-way ranging. The Ranging Message Sequence Number shall be set as described in 5.1.8.5.

The Request RX Timestamp field shall be present when the ranging method field is set to two-way ranging and shall contain the time, in the responding device time reference, that the request was received. The field shall be omitted when the ranging method field is set to one-way ranging.

The Response TX Timestamp field shall be set to the TX time, in the responder's time reference, when response packet is transmitted.

5.2.4.35 TMCTP specification IE

The TMCTP specification IE shall be formatted as illustrated in Figure 48nad.

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 48nad - TMCTP specification IE

The Beacon Only Period Order field specifies the length of the extended duration. The relationship between the extended order 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 the 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 the 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 the 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 ID 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 coordinator.

5.3 MAC command frames

Insert the following rows into Table 5:

Table 5 - MAC Command frames

Command frame frame identifier	Command frame name	RFD		Subclause
		Tx	Rx	
TBA	DBS request			5.3.14
TBA	DBS response			5.3.15
TBA	Neighbor discovery request			5.3.16
TBA	Probe			5.3.17

5.3.4 Data request command frame

Change first paragraph of 5.3.4 as indicated:

The data request command is sent by a device to request data from the PAN coordinator, ~~or~~ a coordinator, or a neighbor device.

Add after last sentence of 5.3.4:

All TVWS devices shall be capable of transmitting and receiving this command except that a non-TVWS RFD is not required to be capable of receiving it.

Insert new subclauses following 5.3.13:

5.3.14 DBS request command frame

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 59de.

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

Figure 59de - 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. Each PAN coordinator shall have a unique PAN identifier in a SPC domain and the 16-bit short address for its 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 59df.

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

Figure 59df - DBS Request information field encoding

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 frame

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 59dg.

Octets: 11-25	1	8
MHR Fields	Command Frame Identifier	DBS Response Information

Figure 59dg -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 the 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 59dh.

Octets:2	1	1	1	1	1	1
Requester Short Address	Allocated DBS Starting Slot	Allocated DBS Length	Allocated PHY Channel ID	Allocated PHY Channel Page	Starting PHY Channel ID	Ending PHY Channel ID

Figure 59dh -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.

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

The Allocated PHY Channel Page field, if present, shall contain the channel page that the coordinator intends to use for all future communications. This field may be omitted if the new channel page is the same as the previous channel page.

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

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

5.3.16 Neighbor discovery command frame

The neighbor discovery request command is broadcast by a device for being discovered by neighbor devices that are associated with the same PAN coordinator or coordinator on a beacon-enabled PAN, if necessary.

The neighbor discovery command shall be formatted as illustrated in Figure 59di.

Octets: 2	1	Variable	0/5/6/10/14	1	2	2	Variable
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Command Frame Identifier	CoordAddress	Neighbor device number	Address list
MHR				MAC Payload			

Figure 59di - Neighbor Discovery command

5.3.16.1 MHR fields

The Frame Pending field shall be set to zero and ignored upon reception, and the AR field shall be set to zero. The PAN ID compression field shall be set to one, and the Destination PAN identifier shall be the same of the source PAN identifier. Both source and destination addresses shall be present. The destination address shall be set to 0xffff.

5.3.16.2 CoordAddress field

The CoordAddress field shall be set to the short address of the coordinator that the device associated with.

5.3.16.3 Neighbor device number field

This field is the number of current neighbor devices of the device.

5.3.16.4 Address list field

This field is the list of short addresses of the current neighbor devices of the device.

5.3.17 Probe command frame

The probe command is sent to a neighbor device, when the device has data pending for the neighbor device and its status is unknown, as described in 5.1.6.7.2.

The probe command shall be formatted as illustrated in Figure 59dj.

Octets: 2	1	Variable	0/5/6/10/14	1
Frame Control	Sequence Number	Addressing Fields	Auxiliary Security Header	Command Frame Identifier
MHR				MAC Payload

Figure 59dj -Probe Command format

5.3.17.1 MHR fields

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

Insert new subclause at the end of clause 5:

5.4 TVWS access procedures

In certain regulatory domains, an independent device operating in TVWS is required to communicate with a database for primary systems to obtain permission and radio resource information, prior to starting communications. A database for primary system is typically, but not limited to a Geo-location Database (GDB). When a GDB is employed as the database, an independent device shall first communicate with the GDB to obtain permission to operate in TVWS. The communication between the independent device and the GDB is not in the scope of this standard. In this case, the independent device determines its geo-location 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 enabling other devices. Figure 59dk shows the state transition diagram of the enabling procedure for a dependent device.

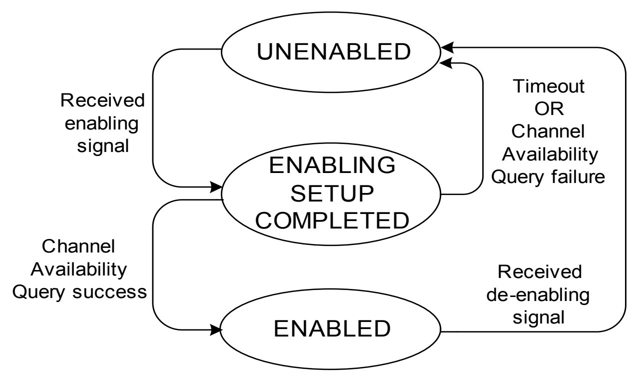

Figure 59dk -State transition of a dependent device

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 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. Information required for possible deployment of peer-to-peer link is exchanged in the IE as specified in 5.2.4.33.5. Upon successfully completed CAQ the state transitions to ENABLED. In this state, the dependent device is able to conduct data communications. Channel availability update may be facilitated using IE as specified in 5.2.4.33.7. If a de-enabling signal is received (*i.e.* by using the IE as specified in 5.2.4.33.7), the state of the dependent device transitions to UNENABLED.

5.4.12 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 PAN coordinator that is capable of database access as indicated in the enabling signal. The PAN coordinator that is capable of database access shall be able to access the database and obtain the channel time information on TV channels. The PAN coordinator may respond to a request by sending the CTM IE with Reason Result Code set to Request Declined, to indicate that it has no capability to provide schedule information on WPAN channels.

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

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 Reason Result code field value CTM element in a query response to Successful with no channel schedule changes from the last query and ignore the CTM IE.

6. MAC services

6.2 MAC management service

Insert the following new rows into Table 8:

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

Name	Request	Indication	Response	Confirm
MLME-DBS	X	X	X	X
MLME-NBR	X			X

6.2.2 Association primitives

6.2.2.1 MLME-ASSOCIATE.request

6.2.2.2 MLME-ASSOCIATE.indication

6.2.2.3 MLME-ASSOCIATE.response

6.2.2.4 MLME-ASSOCIATE.confirm

6.2.3 Disassociation primitives

6.2.3.1 MLME-DISASSOCIATE.request

6.2.3.2 MLME-DISASSOCIATE.indication

6.2.3.3 MLME-DISASSOCIATE.response

6.2.3.4 MLME-DISASSOCIATE.confirm

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
TransactionTime
DeviceCategory
DeviceIDType
DeviceID
NumberofLocations
DeviceLocationsList
ChannelListID
ChannelInfoStatus
NumberofChannels
ChannelDescriptionList
SourceInfo
ChannelInfoSourceLocation
AddressofKnownSource
KnownSourceChannelDescription
CTMControl
ChannelTimingInformation
ChannelVerificationValidTime

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 16777215	Time, in ms of the Periodic listening interval field of a received TVWSPS IE. See 5.2.4.30.

PeriodicListeningDuration	Integer	0 to 16777215	Time, in ms of the Periodic listening duration field of a received TVWSPS IE. See 5.2.4.30.
RendezvousTime	Integer	0 to 16777215	Time, in ms of the Rendezvous time field of a received TVWSPS IE. See 5.2.4.30.
TransactionDuration	Integer	0 to 65535	Time, in ms of the Transaction duration field of a received TVWSPS IE. See 5.2.4.30.
DeviceCategory	Enumeration	See Table 4ih	See Table 4ih.
DeviceIDType	Enumeration	See Table 4ii	See Table 4ii.
DeviceID	Set of octets	See Figure 48nt and Figure 48nu	See Figure 48nt and Figure 48nu.
NumberofLocations	Integer	0-255	The number of locations in the list of geo-location coordinates.
DeviceLocationsList	Set of octets	See Table 4ij	See Table 4ij.
ChannelListID	Integer	0-255	Provide information on received channel information. See description in Figure 48nw.
ChannelInfoStatus	Enumeration	See Table 4ik.	Indication on whether the channel information query is a request or a response, and in the case of a response, the nature of the response. See description in Table 4ik.
NumberofChannels	Integer	0-255	The number of TVWS channels.
ChannelDescriptionList	Set of octets	See Figure 48nx.	Description on each TVWS channel. See Figure 48nx.
SourceInfo	Enumeration	See Table 4il.	See Table 4il.
ChannelInfoSourceLocation	Octet strings	See Table 4ij	Indication of the location of the device acting as the source of channel availability data.
AddressofKnownSource	Device address	Extended IEEE address	When present, indication of device acting as the source of channel availability data.
KnownSourceChannelDescription	Octet strings	See Figure 48ny.	See Figure 48ny.
CTMControl	Enumeration	See Table 4im.	See Table 4im.
ChannelTimingInformation	Sets of octets	See Table 4in.	See Table 4in.
ChannelVerificationValidTime	Integer	0-255	Indication of time, in minutes from the time of transmission that the channel availability data is expected to remain valid.

6.2.6 GTS management primitives

6.2.6.1 MLME-GTS.request

6.2.6.2 MLME-GTS.confirm

6.2.6.3 MLME-GTS.indication

6.2.9 Primitives for specifying the receiver enable time

6.2.9.1 MLME-RX-ENABLE.request

6.2.9.2 MLME-RX-ENABLE.confirm

6.2.10 Primitives for channel scanning

6.2.10.1 MLME-SCAN.request

6.2.10.2 MLME-SCAN.confirm

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
DeviceLocationsList
ChannelListID
ChannelInfoStatus
NumberofChannels
ChannelDescriptionList
SourceInfo
ChannelInfoSourceLocation
AddressofKnownSource
KnownSourceChannelDescription
CTMControl
ChannelTimingInformation
ChannelVerificationValidTime

The primitive parameters are defined in Table 34.

Table 34 - MLME-START.request parameters

DeviceCategory	Enumeration	See Table 41h	See Table 41h.
DeviceIDType	Enumeration	See Table 41i	See Table 41i.
DeviceID	Set of octets	See Figure 48nt and Figure 48nu	See Figure 48nt and Figure 48nu.
NumberofLocations	Integer	0-255	The number of locations in the list of geo-location coordinates.
DeviceLocationsList	Set of octets	See Table 41j	See Table 41j.

ChannelListID	Integer	0-255	Provide information on received channel information. See description in Figure 48nw.
ChannelInfoStatus	Enumeration	See Table 4ik.	Indication on whether the channel information query is a request or a response, and in the case of a response, the nature of the response. See description in Table 4ik.
NumberofChannels	Integer	0-255	The number of TVWS channels.
ChannelDescription-List	Set of octets	See Figure 48nx.	Description on each TVWS channel. See Figure 48nx.
SourceInfo	Enumeration	See Table 4il.	See Table 4il.
ChannelInfoSourceLocation	Octet strings	See Table 4ij	Indication of the location of the device acting as the source of channel availability data.
AddressofKnown-Source	Device address	Extended IEEE address	When present, indication of device acting as the source of channel availability data.
KnownSourceChannel-Description	Octet strings	See Figure 48ny.	See Figure 48ny.
CTMControl	Enumeration	See Table 4im.	See Table 4im.
ChannelTimingInformation	Sets of octets	See Table 4in.	See Table 4in.
ChannelVerification-ValidTime	Integer	0-255	Indication of time, in minutes from the time of transmission that the channel availability data is expected to remain valid.

6.2.12.2 MLME-START.confirm

6.2.14 Primitives for requesting data from a coordinator

Change the 6.2.14 as indicated:

These primitives are used to request data from a coordinator~~.~~ or a neighbor device directly.

6.2.14.1 MLME-POLL.request

Change 6.2.14.1 as indicated:

The MLME-POLL.request primitive prompts the device to request data from the coordinator~~.~~ Or a neighbor device directly.

The semantics of this primitive are:

MLME-POLL.request (
~~Coord~~AddrMode,
~~Coord~~PANId,
~~Coord~~Address,
SecurityLevel,
KeyIdMode,
KeySource,
KeyIndex
)

The primitive parameters are defined in Table 38.

On receipt of the MLME-POLL.request primitive, the MLME requests data from the coordinator, as described in 5.1.6.3, or from a neighbor device as described in 5.1.6.7.3, depending on the address parameters. If the poll is directed to the PAN coordinator, the data request command may be generated without any destination address information present. Otherwise, the data request command is always generated with the destination address information in the ~~Coord~~PANId and ~~Coord~~Address parameters.

6.2.14.2 MLME-POLL.confirm

Change the first sentence of 6.2.14.2 as indicated:

The MLME-POLL.confirm primitive reports the results of a request to poll the coordinator or a neighbor device for data.

Change first 3 rows of Table 38 as indicated:

Table 38 - MLME-POLL.confirm parameters

~~Coord~~AddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the coordinator or the neighbor device to which the poll is intended.
~~Coord~~PANId	Integer	0x0000-0xfffe	The PAN identifier of the coordinator or the neighbor device to which the poll is intended.
~~Coord~~Address	Device Address	As specified by the CoordAddrMode	The address of the coordinator or the neighbor device to which the poll is intended.

6.2.17 Primitives for ranging calibration ~~(for UWB PHYs)~~

6.2.18 Primitives for beacon generation

6.2.19 Primitives for TSCH

6.2.19.3 MLME-SET-LINK.request

6.2.19.4 MLME-SET_LINK.confirm

6.2.22 TMCTP DBS allocation primitives

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

6.2.22.1 MLME-DBS.request

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

The semantics of this primitive are:

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

The primitive parameters are defined in Table 44za.

On receipt of the MLME-DBS.request primitive, the MLME generates a DBS request command, as defined in 5.3.14, with the DBS characteristics field set to 1 (request allocation).

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.

Table 44za - 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		

6.2.22.2 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 44zb.

Table 44zb - MLME-DBS.indication 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.
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.
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 the MLME-DBS.indication primitive, the TMCTP-parent PAN coordinator determines whether to accept or reject the DBS allocation request using an algorithm outside the scope of this standard.

6.2.22.3 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,
                            ChannelPage,
                            StartingChNum,
                            EndingChNum,
                            SecurityLevel,
                            KeyIdMode,
                            KeySource,
                            KeyIndex
                            )
```

The primitive parameters are defined in Table 44zc.

Table 44zc -MLME-DBS.response Parameters

Name	Type	Valid range	Description
CoordAddress	Device Short address	0x0000,Äì0xffff	The short address of the Coordinator that sent TMCTP DBS Request
RequesterCoordAddr	Device Short address	0x0000,Äì0xffff	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
DBSLength	Integer	0x00-0xff	The size, in BOP slots, of the allocated DBS.
ChannelNumber	PHY Channel ID	See 8.1.2	The channel number that the coordinator intends to use for all future communications
ChannelPage	Integer	See 8.1.2	The channel page that the coordinator intends to use for all future communications.
StartingChNum	PHY Channel ID	See 8.1.2	The lowest channel number, which is assigned by the TMCTP-parent PAN coordinator
EndingChNum	PHY Channel ID	See 8.1.2	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 the 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.

6.2.22.4 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,
                          ChannelPage,
                          StartingChNum,
                          EndingChNum,
                          status
                          )
```

The primitive parameters are defined in Table 44zd.

Table 44zd -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	The channel number that the coordinator intends to use for all future communications
ChannelPage	Integer	See 8.1.2	The channel page that the coordinator intends to use for all future communications.
StartingfChNum	PHY Channel ID	See 8.1.2	The lowest channel number, which is assigned by the TMCTP-parent PAN coordinator
EndingChNum	PHY Channel ID	See 8.1.2	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.

6.2.23 Primitives for neighbor discovery

These primitives are used for neighbor device discovery.

6.2.23.1 MLME-NBR.Request primitive

The MLME-NBR.Request primitive prompts the device to discover neighbor devices.

The semantics of this primitive are:

```
MLME-NBR.Request        (
                        CoordAddrMode,
                        CoordPANId,
                        CoordAddress
                        )
```

The primitive parameters are defined in Table 44ze.

Table 44ze -MLME-NBR.Request Parameters

Name	Type	Valid range	Description
CoordAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the coordinator that this device associated with.
CoordPANId	Integer	0x0000 - 0xffff	The identifier of the PAN that this device associated with.
CoordAddress	Device address	As specified by the CoordAddrMode parameter	the address of the coordinator that this device associated with

On receipt of the MLME-NBR.Request primitive, the MLME starts the neighbor discovery process as described in 5.1.6.7.1.

6.2.23.2 MLME-NBR.Confirm primitive

The MLME-NBR.Confirm primitive reports results of neighbor discovery by neighbor discover command.

The semantics of this primitive are

```
MLME-NBR.Confirm        (
                        status
                        )
```

The primitive parameter is described in Table 44zf.

Table 44zf -MLME-NBR.Confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS, FAILURE	The results of broadcasting neighbor discovery command.

The MLME-NBR.Confirm primitive is generated by MLME and issued to its next higher layer in response to an MLME-NBR.Request primitive. If the neighbor discovery command is broadcast successfully, then the status parameter shall be set as SUCCESS, otherwise, the status parameter shall be set as FAILAURE.

6.3 MAC data service

6.3.12 MCPS-Data.request

Insert the following new parameters at the end of the list in 6.3.1 (before the closing parenthesis):

UseRangingIE

Insert the following new rows at the end of Table 46:

Table 46 - MCPS-DATA.request parameters

Name	Type	Valid range	Description
UseRangingIE	Boolean	TRUE, FALSE	Set TRUE to indicate that a ranging request IE should be included in the generated MPDU.

6.3.13 MCPS-DATA.confirm

6.3.14 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
TransactionTime
UseRangingIE

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 16777215	Value of the Periodic listening interval field of a received TVWSPS IE.
PeriodicListeningDuration	Integer	0 to 16777215	Value of the Periodic listening duration field of a received TVWSPS IE.
RendezvousTime	Integer	0 to 16777215	Value of the Rendezvous time field of a received TVWSPS IE.
TransactionDuration	Integer	0 to 65535	Value of the Transaction duration field of a received TVWSPS IE.

6.4 MAC constants and PIB attributes

Insert the following rows to the end of Table 52:

Table 52 - MAC PIB attributes

Attribute	Type	Range	Description	Default
macTVWSPSListeningDuration	Integer	0 - 16777215	Time in milliseconds time between the start and the end of a periodic listening period when TVWS PS is enabled.	0
macTVWSPSListeningInterval	Integer	0 - 16777215	Time in milliseconds between the start of a periodic listening duration to the start of the subsequent periodic listening duration when TVWS PS is enabled.	0

macTVWSPSPollingDuration	Integer	0 - 16777215	Time in milliseconds that the initiating device repeats the polling operation when TVWSPS is enabled when TVWS PS is enabled.	0
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 acknowledgement 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
macTVWSPSenable	Boolean	TRUE, FALSE	Indicates that TVWS PS is enabled.	FALSE

8. General PHY requirements

8.1 General requirements and definitions

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

— **TVWS FSK PHY:** multi-rate and multi-regional frequency shift keying (FSK) PHY operating 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 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 (OFDM) PHY operating multiple over-the-air data rates in support of various applications in TVWS, as defined in 20.3.

Modify the following subclause (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:

$$ChanCenterFreq = ChanCenterFreq_0 + NumChan \times ChanSpacing$$

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:

$$ChanCenterFreq_0 = macStartBandEdge + ChanSpacing/2$$

where

$$TotalNumChan = floor((macEndBandEdge - macStartBandEdge)/ChanSpacing)$$

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

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

20. TVWS PHYs

Three PHYs are specified: a 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.

20.1 TVWS-FSK

20.1.1 PPDU format for TVWS-FSK

The TVWS-FSK PPDU shall support the format shown in Figure 112.

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 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 upon reception.

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

Figure 112—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 131. The SFD length is controlled by the PIB attribute *phyTVWSSFDLength,* as defined in 9.3.

Devices that do not support the FEC (see 20.1.2.4) shall support the SFD associated with uncoded (PHR + PSDU). Devices that support FEC (see 20.1.2.4) shall support both SFD values shown in Table 131.

20.1.1.3 PHR

The format of the PHR is shown in Figure 113. All multi-bit fields are unsigned integers and shall be processed MSB first.

The Parity Check (PC) field provides error detection. Its value is the modulo-2 addition of all bits in the PHR other than the Parity Check.

Table 131—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

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 113—Format of the PHR for TVWS-FSK

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

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 132 shows the relationship between the contents of the FCS Type field and the length of the transmitted FCS.

Table 132—Relationship between FCS Type field and transmitted FCS length

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 not be applied to the SHR or PHR.

The Frame Length field (L_{10}–L_0) specifies the total number of octets contained in the PSDU (prior to FEC encoding, if enabled). The most significant bit (leftmost) shall be transmitted first.

20.1.1.4 PSDU field

The PSDU field carries the 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 as needed to meet regulatory requirements in the band of operation. Table 133 shows the modulation and channel parameters for the operating modes of the TVWS-FSK PHY.

Table 133—TVWS-FSK modulation and channel parameters[a]

Freq. Band (MHz)	Param	Mode #1	Mode #2	Mode #3	Mode #4	Mode #5
All available TVWS bands	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 or 1.0	0.5 or 1.0	0.5 or 1.0	0.5	0.33
	Channel spacing (kHz)	100 if h=0.5 200 if h=1.0	200 if h=0.5 400 if h=1.0	400 if h=0.5 600 if h=1.0	600	600

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

20.1.2.1 Reference modulator diagram

The functional block diagram in Figure 114 is provided as a reference for specifying the TVWS-FSK data flow processing functions.

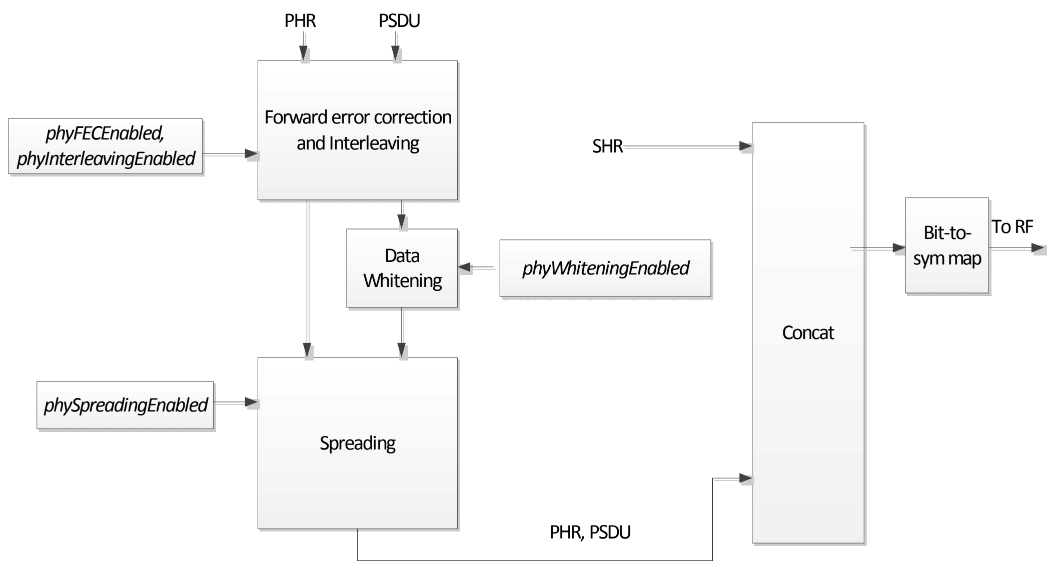

Figure 114—Reference modulator diagram

20.1.2.2 Bit-to-symbol mapping

The symbol encoding is shown in Table 134, where the frequency deviation, f_{dev}, is equal to (symbol rate x modulation index)/2 for 2-level Filtered FSK and is equal to (3 x symbol rate x modulation index) / 2 for 4-level Filtered FSK. For 4-level Filtered FSK modulation, two bits shall be mapped to four frequency deviation levels for the PHR and PSDU. The SHR shall be encoded in the lowest ($-f_{dev}$) and the highest ($+f_{dev}$) frequency deviations.

Table 134—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	$+f_{dev}$
Symbol (binary)	Frequency deviation

20.1.2.3 Modulation quality

The modulation quality shall be as given in 18.1.2.3.

20.1.2.4 Forward error correction (FEC)

FEC support is optional. The use of FEC is controlled by the PIB attribute *phyFECEnabled*, as defined in 9.3. The FEC scheme shall be according to sub-clause 19.2.2.4 for the case when the PHR is 2-octet long.

20.1.2.5 Code-symbol interleaving

Interleaving support is optional. The use of interleaving is controlled by the PIB attribute *phyInterleavingEnabled*, as defined in 9.3. Interleaving shall be according to sub-clause 19.2.2.5 for the case when the PHR is 2-octet long.

20.1.2.6 Spreading

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

20.1.3 Data whitening

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

20.1.4 TVWS-FSK RF requirements

20.1.4.1 Operating frequency range

The TVWS-FSK PHY operates in the bands indicated in 5.2.4.32.

20.1.4.2 Clock accuracy

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

20.1.4.3 Channel switch time

The channel switch time shall be as given in 19.2.4.4.

20.1.4.4 Receiver sensitivity

The receiver sensitivity shall be as given in 18.1.5.7.

20.1.4.5 Tx-to-Rx turnaround time

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

20.1.4.6 Rx-to-Tx turnaround time

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

20.2 TVWS-OFDM PHY

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

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

20.2.1 PPDU format for TVWS-OFDM

The TVWS-OFDM PPDU shall be formatted as illustrated in Figure 115.

Number of OFDM Symbols					
Variable (1-4)	**2**	**1**	**Variable**	**6 bits**	**Variable**
STF	LTF	As defined in 20.2.1.3	PSDU	TAIL	PAD
SHR		PHR	PHY payload		

Figure 115—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 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.

The DATA field is composed of the PSDU, tail bits, and pad bits, as described in 20.2.3.4. The PPDU Tail Bit field (TAIL) is described in 20.2.3.8. The method for adding pad bits (PAD) is described in 20.2.3.9.

20.2.1.1 Short training field (STF)

Subclauses 20.2.1.1.1through 20.2.1.1.4 describe the STF.

20.2.1.1.1 Frequency domain STF

The frequency domain representation of the STF is defined by Table 135.

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:

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

Table 135—Frequency domain representation of STF

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

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 = IDFT(STF_freq)

The CP is then prepended to the OFDM symbol.

20.2.1.1.3 Time domain STF repetition

The STF is repeated eight times per STF symbol and the CP is also 1/4 symbol. Therefore, there are 10 repetitions of 1/8 STF symbol in each STF OFDM symbol. The number of STF OFDM symbols varies from 1 to 4 as shown in Figure 115.

Figure 116 shows the STF structure. Each "s" in the figure represents one time-domain repetition of a subsequence of TVWS-OFDM.

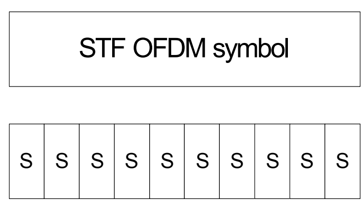

Figure 116—Structure of STF OFDM symbol

20.2.1.1.4 STF power boosting

Power boosting shall be applied to the STF 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 136 shows the frequency domain representation of the LTF.

20.2.1.2.2 Time domain LTF generation

The time domain LTF is obtained as follows:

LTF_time = IDFT(LTF_freq)

Table 136—Frequency domain representation of LTF

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
-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

A 1/2 symbol CP is prepended to two consecutive copies of the base symbol as shown in Figure 117. For more details, see 20.2.3.8.

The time-domain LTF structure is shown in Figure 117, where T_{DFT} is the duration of the base symbol.

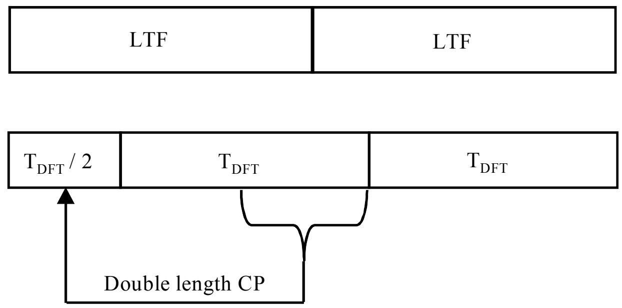

Figure 117—Structure of LTF for TVWS-OFDM

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 118. 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 118—PHY header fields for TVWS-OFDM

The PHR occupies one OFDM symbol. The PHR shall be transmitted using the lowest supported modulation and coding scheme (MCS) level, as described in Table 137. It is sent to the convolutional encoder starting from the leftmost bit in Figure 131 to the rightmost bit.

The Ranging (RNG) field is set to “1” to indicate that this particular frame is intended for ranging.If the frame is not intended for ranging the Ranging (RNG) field 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 $G_{16}(x) = x^{16} + x^{12} + x^5 + 1$.

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 20.2.3.8.

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 Data rates for TVWS-OFDM

All devices shall support all BPSK, QPSK and 16-QAM (Quadrature Amplitude Modulation) and coding scheme levels (MCS0-2). All 4 times overclock modes (MCS3-5) are optional.

The various data rates are shown in Table 137. The nominal bandwidth is calculated by multiplying {the number of active tones + 1 for the DC tone} by {the subcarrier spacing}.

Table 137—Data Rates for TVWS-OFDM

Parameter	Mandatory Modes	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 (kb/s) (BPSK)	390.625	-
MCS1 (kb/s) (QPSK)	781.250	-
MCS2 (kb/s) (16-QAM)	1562.5	-
MCS3 (kb/s) (BPSK)	-	1562.5
MCS4 (kb/s) (QPSK)	-	3125
MCS5 (kb/s) (16-QAM)	-	6250

20.2.3 Modulation and coding for TVWS-OFDM

20.2.3.1 Reference modulator diagram

The reference modulator diagram is shown in Figure 119.

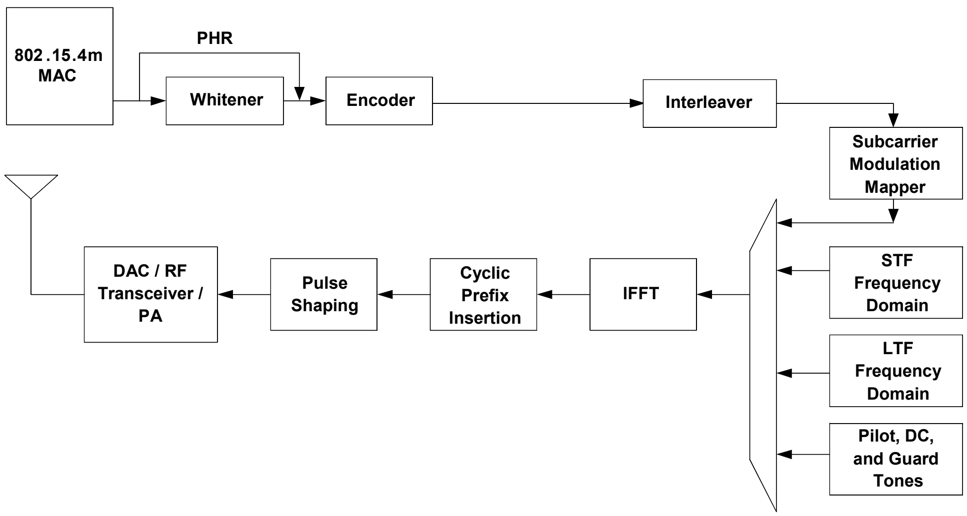

Figure 119—Reference modulator diagram for TVWS-OFDM

20.2.3.2 Bit-to-symbol mapping

Figure 120 shows the bit-to-symbol mapping for BPSK, QPSK, and 16-QAM.

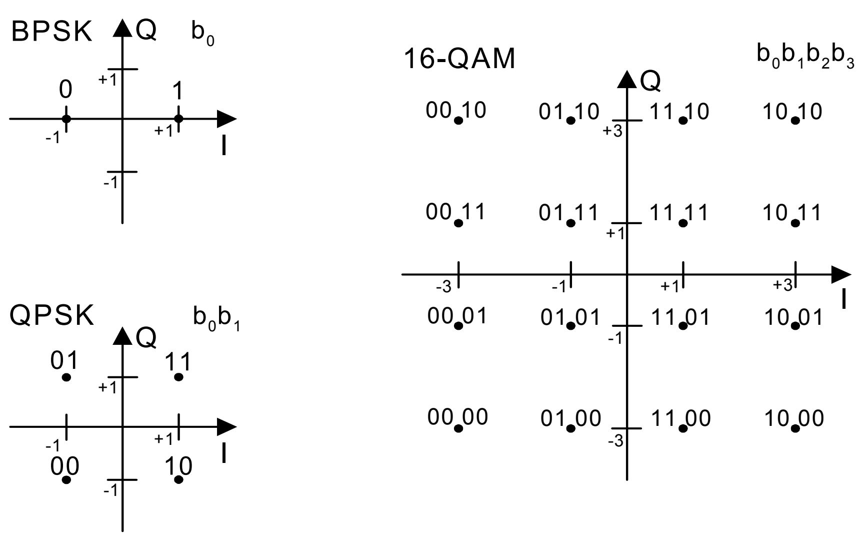

Figure 120—Bit-to-symbol mapping for TVWS-OFDM

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 138. The purpose of the normalization factor is to achieve the same average power for all mappings.

Table 138—Modulation-dependent normalization factor K_{MOD}

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

20.2.3.3 PIB attribute values for *phySymbolsPerOctet*

The number of symbols per octet depends on both the MCS level and the OFDM option, as represented in Table 139.

Table 139—*phySymbolsPerOctet* values for TVWS-OFDM

Parameter	Mandatory Modes	Optional Modes
MCS0 (BPSK)	8 bits/octet * 1/50 symbol/bits	
MCS1 (QPSK)	8 bits/octet * 1/100 symbol/bits	
MCS2 (16-QAM)	8 bits/octet * 1/200 symbol/bits	
MCS3 (BPSK)		8 bits/octet * 1/50 symbol/bits
MCS4 (QPSK)		8 bits/octet * 1/100 symbol/bits
MCS5 (16-QAM)		8 bits/octet * 1/200 symbol/bits

20.2.3.4 Forward error correction (FEC)

The DATA field shall be coded with a convolutional encoder of coding rate R = 1/2, corresponding to the desired data rate. 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 121. 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.

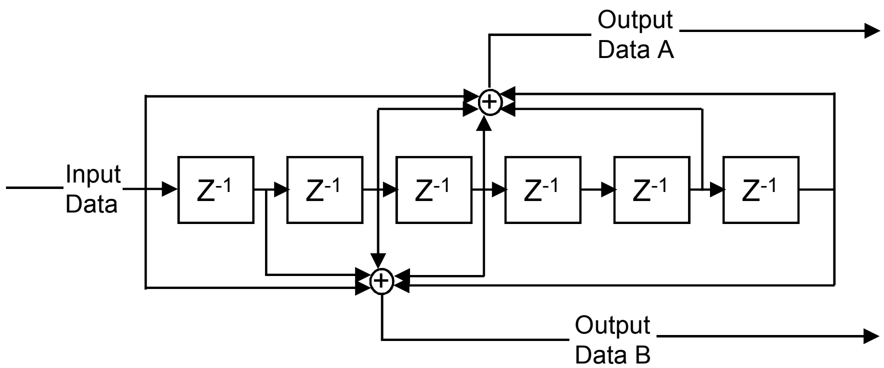

Figure 121—Rate 1/2 convolutional encoder

20.2.3.5 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), and

N_{row} is 20.

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

20.2.3.6 Pilot tones / null tones

The numbers of pilot and null tones for TVWS-OFDM are defined as shown in Table 140.

Table 140—Number of pilot and null tones for TVWS-OFDM

	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 by Figure 122.

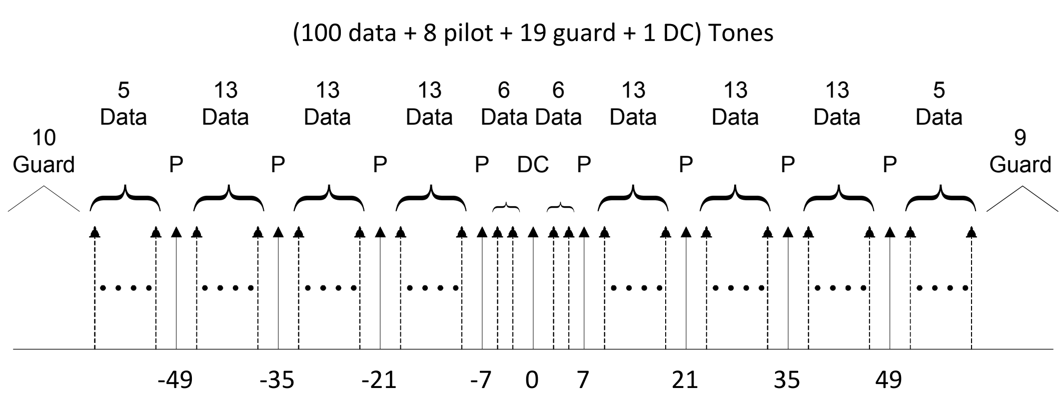

Figure 122—Pilot tones for TVWS-OFDM

The data carried on the pilot tones shall be determined by a pseudo-noise sequence PN9 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. Table 141 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 for one every pilot subcarrier.

Table 141—Mapping from PN9 sequence to pilot BPSK symbols

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

20.2.3.7 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 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). The CP is a replication of the last 25.6 µs of the base symbol. The CP is illustrated in Figure 123.

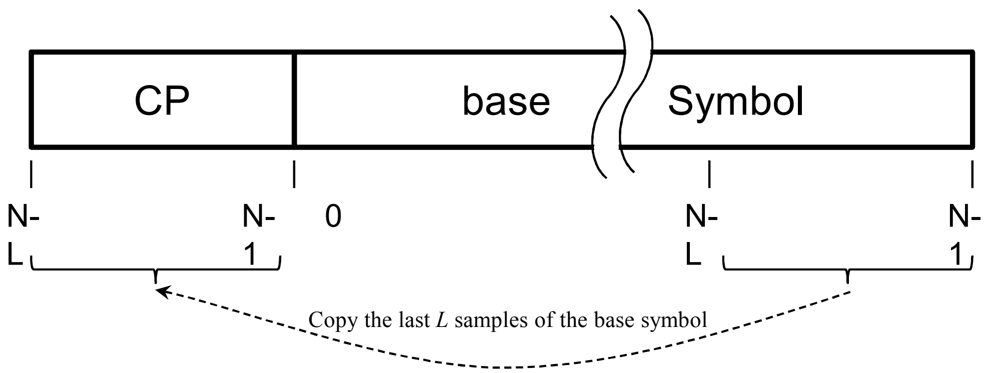

Figure 123—Cyclic prefix (CP)

20.2.3.8 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.

20.2.3.9 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 OFDM symbol. At least six bits are appended to the message, in order to accommodate the tail bits, as described in 20.2.3.8. The number of OFDM symbols, N_{SYM}, the number of bits in the DATA field, N_{DATA}, and the number of pad bits, N_{PAD}, are computed from the length, in octets, of the PSDU (LENGTH is equal to the content of the Frame Length field in Figure 118) as follows:

$$N_{dbps} = N_{cbps} \times codingrate(R)$$

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

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

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

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 of the PHR, the number of bits in the DATA field shall be set to 50 as in 20.2.1.3

20.2.3.10 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 shown in Figure 102. The PN9 scrambler is initialized by the scrambling seed specified by 9 bits in the PHR, as shown in Figure 102. The leftmost value of the scrambling seed is placed into the leftmost delay element in Figure 102.

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 5.2.4.32.

20.2.4.2 Pulse shaping

Pulse shaping is applied at the transmitter. The pulse shaping method is as needed to meet regulatory requirements in the band of operation.

20.3 TVWS-NB-OFDM

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 9.620 ksymbol/s, 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 124. 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 b_0 first to b_{n-1} last, without regard to their content or structure.

						Octets	
							Variable
SHR						PHR	PSDU
STF	STF	STF	STF	STF	STF		

Figure 124—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 Time domain STF generation

The short training field sequence is generated based on Zadoff Chu Sequence with length N=96. H is a prime number H=19, k=0, 1, …, N-1. The short training field sequence S(k) in the time domain can be calculated as below:

$$S(k) = e^{jH\pi k^{2/N}}$$

20.3.1.1.2 Time domain STF repetition

There are 4 repetitions of STF in the time domain as shown in the Figure 125.

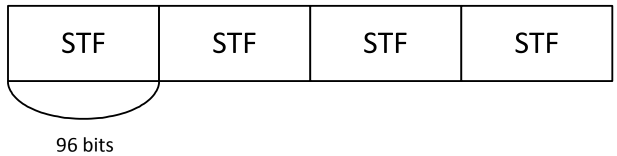

Figure 125—STF Format

The STF sequence, STF(n), is indexed by n=0, 1, 2, …, N_{ST}-1, where N_{ST} is the Number of effective subcarriers. STF(n) consists of 4 repetitions of S(k) and can be represented as:

STF(n)=S(MOD(n, N))for n=0, 1, …, 4*N-1

where

Nis 96,

MOD(n, N)is the modulo-N operation for any input n.

20.3.1.1.3 Frequency domain STF

The STF for the TVWS-NB-OFDM in frequency domain can be calculated from time domain STF sequence f(n) based on the discrete Fourier transform (DFT) and represented as F(m), where m=0, 1, …, N_{ST}-1.

$$F(m) = \frac{1}{\sqrt{N_{ST}}} \sum_{n=0}^{N_{ST}-1} f(n) e^{-j2\pi mn/(N_{ST}-1)}$$

where the k values numbered from 0 to N_{ST}/2-1 correspond to tones numbered from 0 to N_{ST}/2-1 and the k values numbered from N_{ST}/2 to N_{ST}-1 correspond to tones numbered from - N_{ST}/2 to -1, respectively.

Similarly, given frequency domain STF, the time domain STF can be generated as follows:

STF_time = IDFT(STF_freq)

The CP is then prepended to the OFDM symbol.

20.3.1.1.4 STF normalization

The STF uses a lesser number of tones than the DATA field. 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 DATA field, the normalization value is as follows:

sqrt(*Nactive/Nstf*)

where

Nactive is the number of used subcarriers in rest of the OFDM packet for the particular DFT option, *Nstf* 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 Time domain LTF generation

Long Training Sequence is generated based on Zadoff Chu Sequence with length N=192. H is a prime number, H=53, k=0, 1, …, N-1. The long training field sequence L in time domain can be calculated as below:

$$L(k) = e^{jH\pi k^{2/N}}$$

20.3.1.2.2 Time domain LTF repetition

The LTF shall be repeated for 2 times in the time domain as shown in Figure 126.

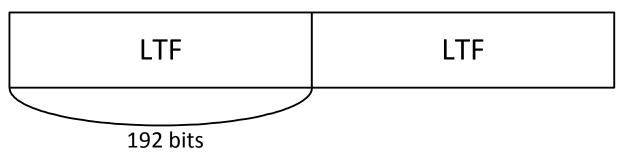

Figure 126—LTF Format

Given a LTF sequence, f(n), indexed by n=0, 1, 2, …, N_{ST}-1. It is the 2 repetition of L(k). It can be represented as:

LTF(n)=L(MOD(n, N)) for n=0, 1, …, 2*N-1

where

Nis 192,

MOD(n, N)is the modulo-N operation for any input n.

20.3.1.2.3 Frequency domain LTF

The LTF for the TVWS-NB-OFDM in the frequency domain can be calculated from time domain LTF sequence f(n) based on the discrete Fourier transform (DFT) and represented as F(m), where m=0, 1, …, N_{ST}-1.

$$F(m) = \frac{1}{\sqrt{N_{ST}}} \sum_{n=0}^{N_{ST}-1} f(n) e^{-j2\pi mn/(N_{ST}-1)}$$

where the k values numbered from 0 to N_{ST}/2-1 correspond to tones numbered from 0 to N_{ST}/2-1 and the k values numbered from N_{ST}/2 to N_{ST}-1 correspond to tones numbered from - N_{ST}/2 to -1, respectively.

Similarly, given frequency domain LTF, the time domain LTF can be generated as follows:

LTF_time = IDFT(LTF_freq)

The CP is then prepended to the OFDM symbol.

20.3.1.2.4 LTF normalization

The LTF uses a lesser number of tones than the DATA field. 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 DATA field, the normalization value is as follows:

sqrt(N_{active}/N_{ltf})

where

N_{active} is the number of used subcarriers in rest of the OFDM packet for the particular DFT option,

N_{ltf} is the number of subcarriers used in the LTF.

20.3.1.3 PHR

Figure 127 shows PHR format, which is composed of 40 bits for controlling the TVWS-NB-OFDM PHY.

Bit string index	**0-2**	**3**	**4-7**	**8–9**	**10-20**	**21–24**	**25**	**26–33**	**34–39**
Bit mapping	R_2–R_0	RNG	M_3–M_0	F_1–F_0	L_{10}–L_0	A_3–A_0	R	H_7–H_0	T_5–T_0
Field name	Reserved	Ranging	Rate	FEC type	Frame length	Channel aggregation	Reserved	HCS	Tail

Figure 127—PHY header fields for TVWS-NB-OFDM

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

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 142 shows system parameters for TVWS-NB-OFDM.

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 143.

Table 142—System parameters for TVWS-NB-OFDM

Parameter	Mode #1	Mode #2
Nominal bandwidth (kHz)	380.95	
Subcarrier spacing (kHz)	0.99206 =125/126)	
Number of subcarriers, total - N_{ST}	384	
Number of pilot subcarriers per - N_{SP}	32	
Number of data subcarriers per - N_{SD}	352	
Effective symbol duration - T_{FFT} (µs)	1008	
Guard interval duration - T_{GF} (µs)	Mandatory 1/32 (31.5 µs) Optional 1/16 (63.0 µs), 1/8 (126.0 µs)	
Symbol interval - T_{SYM} (µs)	Mandatory 1039.5 Optional 1071.0, 1134.0 (T_{FFT}+T_{GF})	
STF duration (T_{SHR})	1 symbol	
LTF duration (T_{SHR})	1 symbol	

Table 143—Data rates for TVWS-NB-OFDM

MCS Index	Modulation	CC coding rate	Data Rate (Kbps)	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	2	1408	704
MCS5	16-QAM	3/4	936	4	1408	1056
MCS6	64-QAM	1/2	1248	4	2112	1408
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 128.

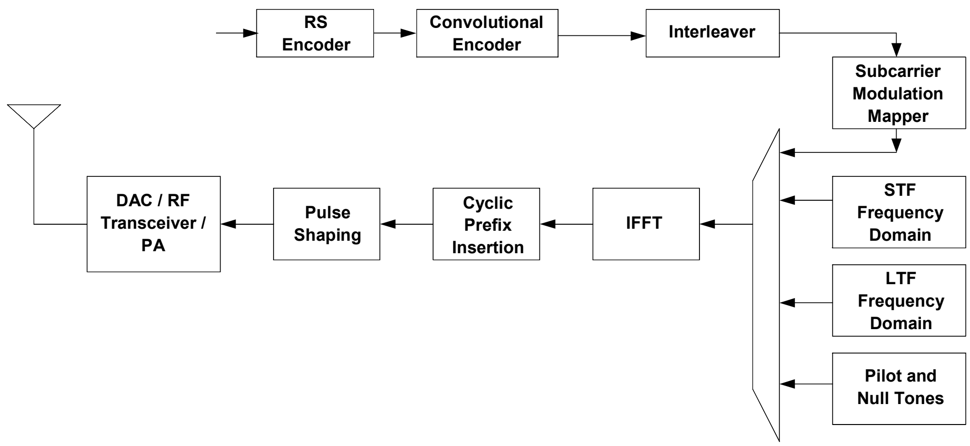

Figure 128—Reference modulator diagram for TVWS-NB-OFDM

20.3.3.2 Forward error correction (FEC)

Subclauses 20.3.3.2.1 through 20.3.3.2.3 describe outer encoding, inner encoding, and pad bit insertion.

20.3.3.2.1 Outer encoding

Reed Solomon (RS) encoding (204, 188) shall be used for outer encode. The RS encoding is applied with a RS (255, 239) coder as a shorten code. 51 byte 00 HEX shall be subsequently to 188 byte input data before encoding, and 51 byte data shall be removed after 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.

20.3.3.2.2 Inner encoding

A recursive and systematic convolutional encoder of coding rate R = 1/2, 2/3, 3/4, 7/8 encodes the RS encoded data bits, 6 tail bits, and pad bits. The convolutional encoder shall use the generator polynomials g_1 = 171 and g_1 = 133, of rate R = 1/2, with feedback connection of g_0 as shown in Figure 129.

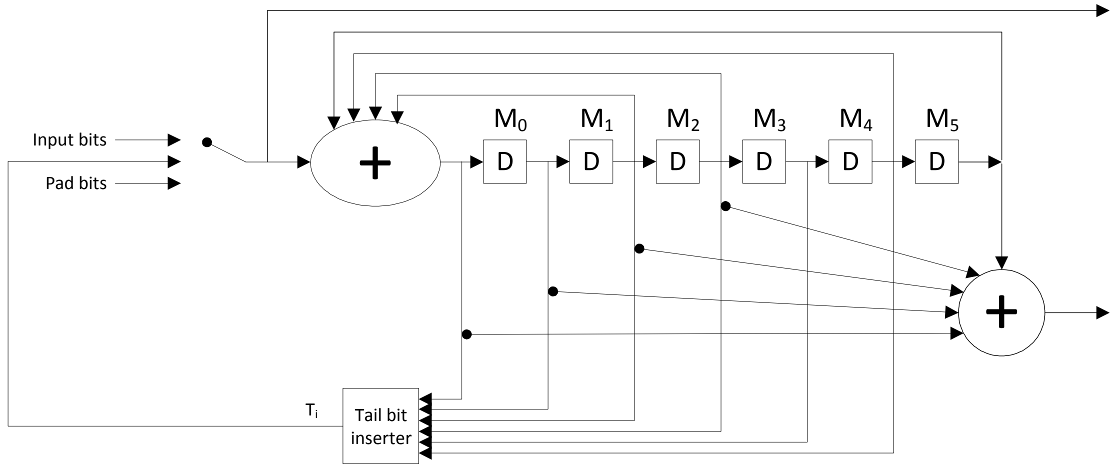

Figure 129—Recursive and systematic convolution encoder

The value of the tail bits are dependent on the memory state shown in Figure 129 and shall be set as shown in Table 144.

Table 144— 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	100001	100000	111011	110000	011010
000001	111001	010001	011000	100001	000010	110001	100011
000010	001011	010010	101010	100010	110000	110010	010001
000011	110010	010011	010011	100011	001001	110011	101000
000100	010110	010100	110111	100100	101101	110100	001100
000101	101111	010101	001110	100101	010100	110101	110101

Table 144— 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)
000110	011101	010110	111100	100110	100110	110110	000111
000111	100100	010111	000101	100111	011111	110111	111110
001000	101100	011000	001101	101000	010111	111000	110110
001001	010101	011001	110100	101001	101110	111001	001111
001010	100111	011010	000110	101010	011100	111010	111101
001011	011110	011011	111111	101011	100101	111011	000100
001100	111010	011100	011011	101100	000001	111100	100000
001101	000011	011101	100010	101101	111000	111101	011001
001110	110001	011110	010000	101110	001010	111110	101011
001111	001000	011111	101001	101111	110011	111111	010010

Puncturing enables 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 on the receive side in place of the omitted bits. The puncturing patterns are illustrated in Figure 130.

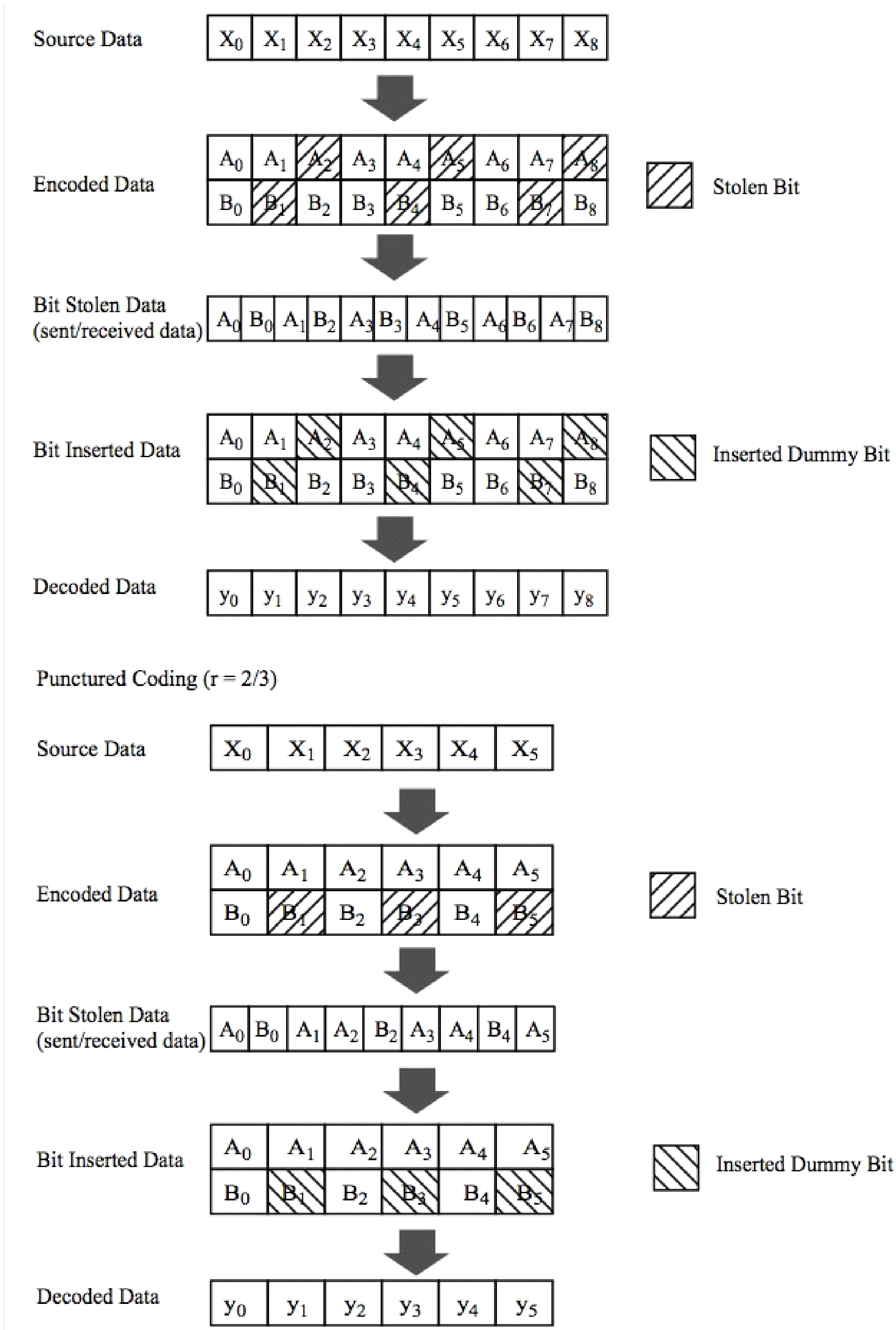

Figure 130—Puncturing pattern

20.3.3.2.3 Pad bit insertion

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

$$N_{RS} = \text{ceiling}\ (L_{PSDU}/(188*8))$$

$$L_{RS} = L_{PSDU}+N_{RS}*16*8$$

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

$$N_{DATA} = N_{SYS}*N_{DBPS}$$

$$N_{PAD} = N_{DATA}-8*L_{RS}+6$$

L_{PSDU} is the number of PSDU bits, which is equal to the content of the Frame Length field in Figure 127, and N_{DBPS} is shown in Table 143.

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

20.3.3.3 Bit interleaving and mapping

20.3.3.3.1 Bit interleaving

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

The first permutation is defined by the rule:

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

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

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

The value of s is determined by the number of coded bits per subcarrier, N_{BPSC}, according to:

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

The deinterleaver, which performs the inverse relation, is also defined by two corresponding permutations.

20.3.3.3.2 Subcarrier mapping

The OFDM subcarriers shall be modulated by using BPSK, QPSK, 16-QAM, or 64-QAM modulation. The encoded and interleaved binary serial input data has $\mathbf{N_{BPSC}}$ bits per symbol and mapped onto I- and Q-channel data. The conversion shall be performed according to Gray-coded constellation mappings, illustrated in Figure 131, with the input bit, b0, being the earliest in the stream. The output values, d, are formed by multiplying the resulting (I+jQ) value by a normalization factor K_{MOD}, as described in the following Equation:

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

The normalization factor, K_{MOD}, depends on the base modulation mode, as prescribed in Table 145.

Table 145—Modulation-dependent normalization factor K_{MOD}

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

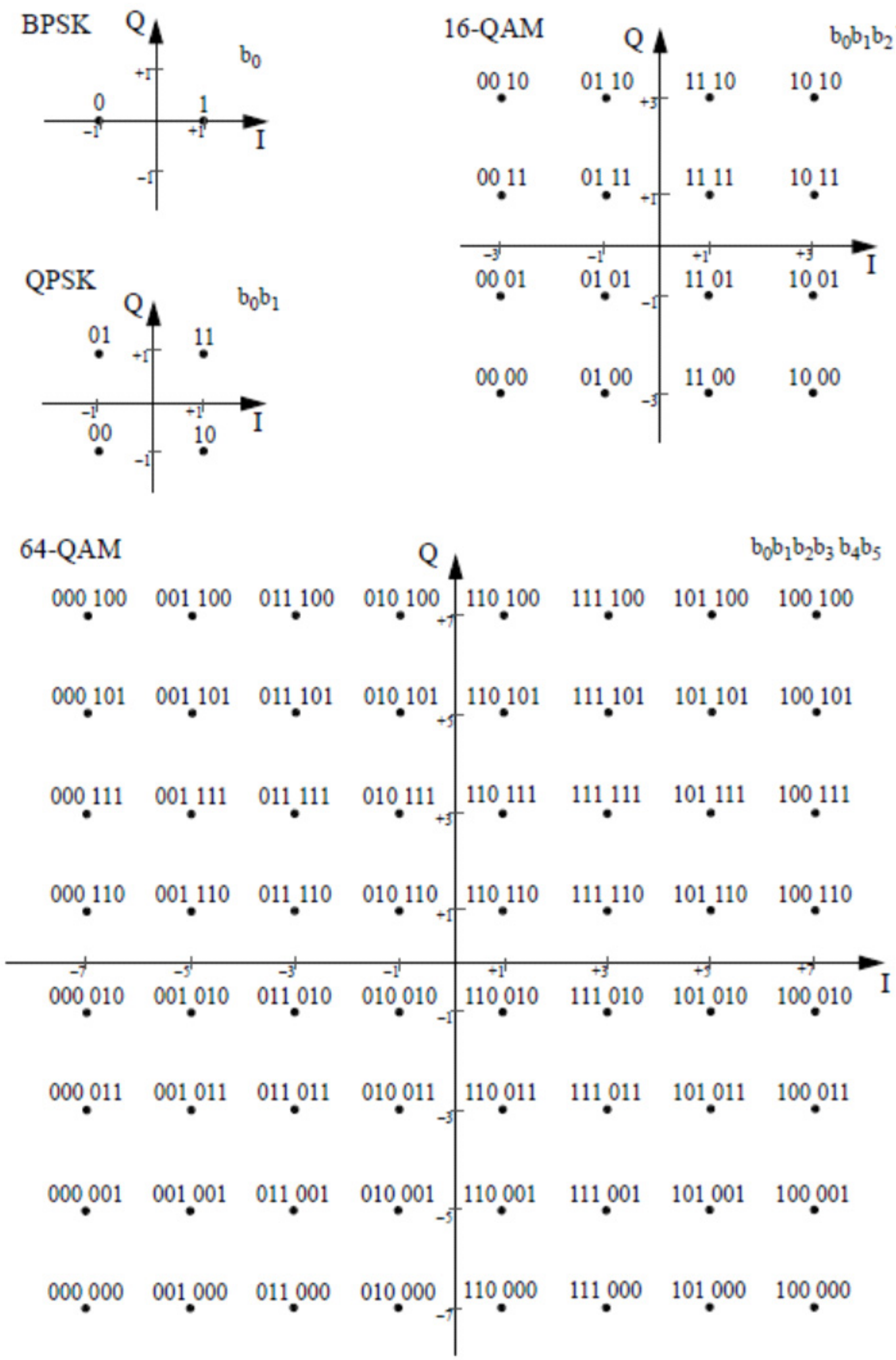

Figure 131—BPSK, QPSK, 16-QAM, and 64-QAM constellation mapping

20.3.3.4 Frequency interleaving

The frequency interleaving follows the following rule. The index of input bit before interleaving and J(k) represents the index of output bit after interleaving shall be represented as:

$J{=}Z(i)$for $k = 0,1,\ldots, 352-1$

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 132 shows the distribution of interleaving for input bits before interleaving against output bits after interleaving.

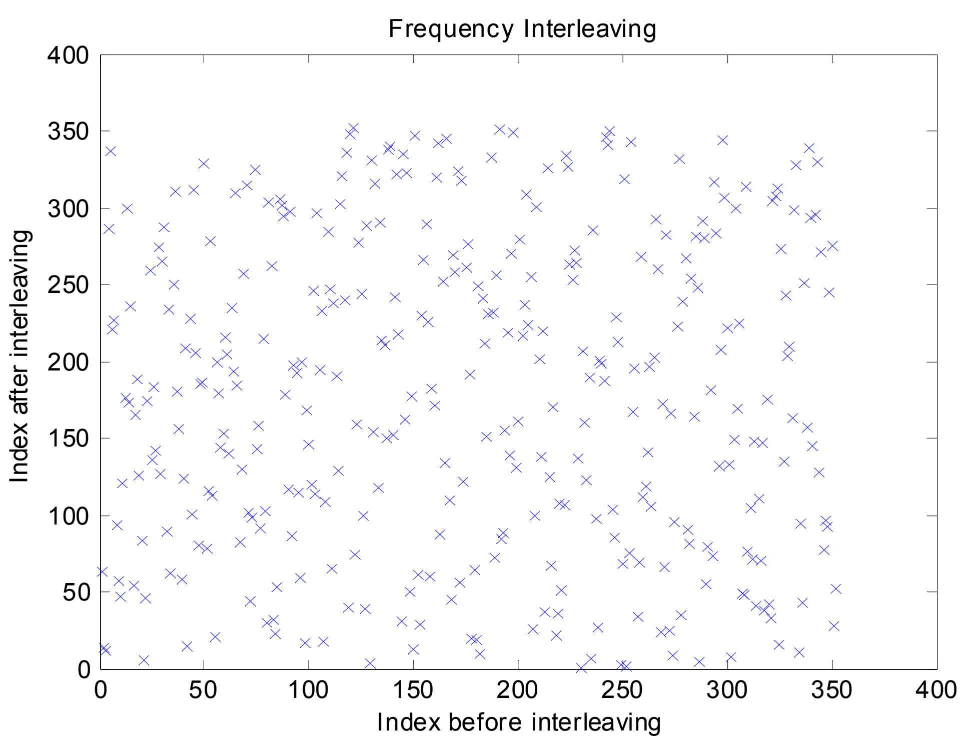

Figure 132—Illustration of frequency interleaving mapping

20.3.3.5 Pilot tones/null tones

Figure 133 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 carriers in the frequency direction, and once every 4 symbols in the symbol direction.

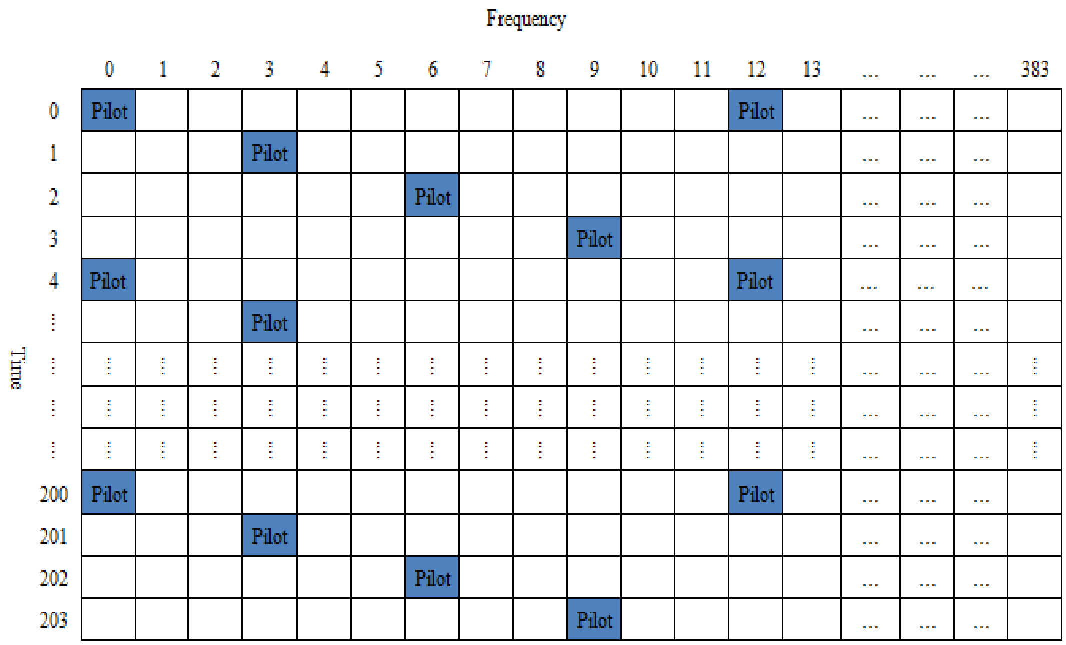

Figure 133—Pattern of pilot subcarriers allocated in NB-OFDM symbol

20.3.3.6 Cyclic prefix

A cyclic prefix shall be prepended to each OFDM symbol. By default, the duration of the cyclic prefix (31.5µs) shall be 1/32 of the OFDM symbol (1008µs). Optionally, the cyclic prefix of duration 63µs which is 1/16 of the OFDM symbol, or the cyclic prefix of duration 126µs which is 1/8 of the OFDM symbol or can be selected.

20.3.4 Channel aggregation

Table 146 shows channel aggregation parameters. For several regional supports, Modes 1 or 2, i.e, either of bandwidths, 6 MHz or 8 MHz, shall be supported. According to the channel bandwidth, maximal aggregated channel depends on the available channel bandwidth..

Table 146—Channel aggregation parameters

Maximal bandwidth on channel aggregation use	6 MHz	8 MHz
Number of maximal aggregated channels	11	16
Channel spacing	400 kHz	
Guard band for each side of channel	800 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 5.2.4.32.

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 Pulse shaping

Time domain windowing shall be applied during OFDM signal generation in order to smooth the transition between two consecutive OFDM symbols. This can reduce spectral leakage combined with or without any implementation of 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.

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

The continuous pulse shaped waveform is expressed as:

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

The parameter Δf, which denotes sub-carrier spacing, and N_{ST} are described in Table 142. 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_{GF} for application of DFT helps to avoid ISI caused by the superposition of the extended OFDM symbols and inter carrier interference (ICI) caused by the windowing.

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

Annex S

(informative)

Ranging considerations for operation in TVWS

S.1 Introduction

This annex describes a ranging mechanism for TVWS WPAN standard. The geo-location requirements for TVWS specify that accuracy of a geo-location capability to determine its geographical coordinates is +/- 50 meters for Mode II fixed and personal/portable devices. Mode I device may also require location capability. In order to incorporate these requirements, exploiting GPS receiver for TBVDs will be a solution. However, GPS is not 100 % available such as indoors, urban canyons and GPS jamming/spoofing attack environments. Moreover, battery-powered Mode I devices may not equip with GPS receiver. Therefore, it is well motivated to provide optional RF localization in TVWS WPAN standard.

S.2 General

The ranging mechanism for TVWS WPAN PHYs is basically same as that of UWB PHY, shown in Annex E of IEEE Std 802.15.4-2011. Similar to 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 PHR for both FSK and OFDM PHYs, called 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 at 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 achieved. However, the timing of RMARKER arrival at the receiver that determines the ranging performance is susceptible to noise, signal bandwidth, and operation clock. As a result, a main issue in TVWS WPAN based ranging is how to obtain the accurate arrival time of FSK and OFDM signals.

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

S.3 ToA estimation for OFDM PHY

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

S.4 Estimation for FSK PHY

Generally, the FSK system has not been used for accurate ranging due to its narrowband characteristics. However, the accuracy of +/- 50 meters in TVWS enables FSK-based ranging to assist a geo-location capability of TVBDs. Different from the UWB and OFDM PHYs that exploit a correlation property of preamble sequence, the timing of RMARKER arrival in FSK system can be obtained from STT estimation during preamble, whose sequence is multiple repetitions of “01010101.”

One of approaches for STT estimation is to use the phase difference vector of the received FSK signal. The phase of FSK signal is increasing and decreasing according to time and experiences changeover at every symbol duration during preamble. Therefore, the phase difference vector between the received signal and its delayed signal shows phase transition, from which symbol transition time can be estimated. Since the TVWS WPAN FSK PHY allows the applications to specify preambles 4-1000 long, large number of preambles involved in STT estimation enables ranging performance enhancement due to suppressed noise.

