IEEE P802.15
Wireless Personal Area Networks

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Abstract	[Preliminary Draft of TG4m Merged Proposals]
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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
IEEE Computer Society

Approved 00 Month 2013

IEEE-SA Standards Board

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 802.15.4g-2012, 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.

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

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

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~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
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 coordinator on their dedicated channels at 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 coordinators in the cluster and has access to the geolocation database (GDB) server to provide TVWS channel availability information to the other coordinators that have associated with the SPC. The SPC in the TMCTP supports association with other coordinators in the cluster using multiple channels. Other devices gradually connect and form a multi-cluster network structure, each possibly using a different channel allocated by the SPC. An example is shown in Figure 1. The use of TMCTP can increase the coverage area with controlled message latency, with reduced collisions between coordinators, and allows independent operation of each cluster simultaneously. Each parent PAN coordinator including the SPC may communicate with its child PAN coordinators using a dedicated channel during the dedicated beacon slot (DBS) assigned to them in the beacon only period (BOP), as shown with an asterisk (*) in Figure 1.

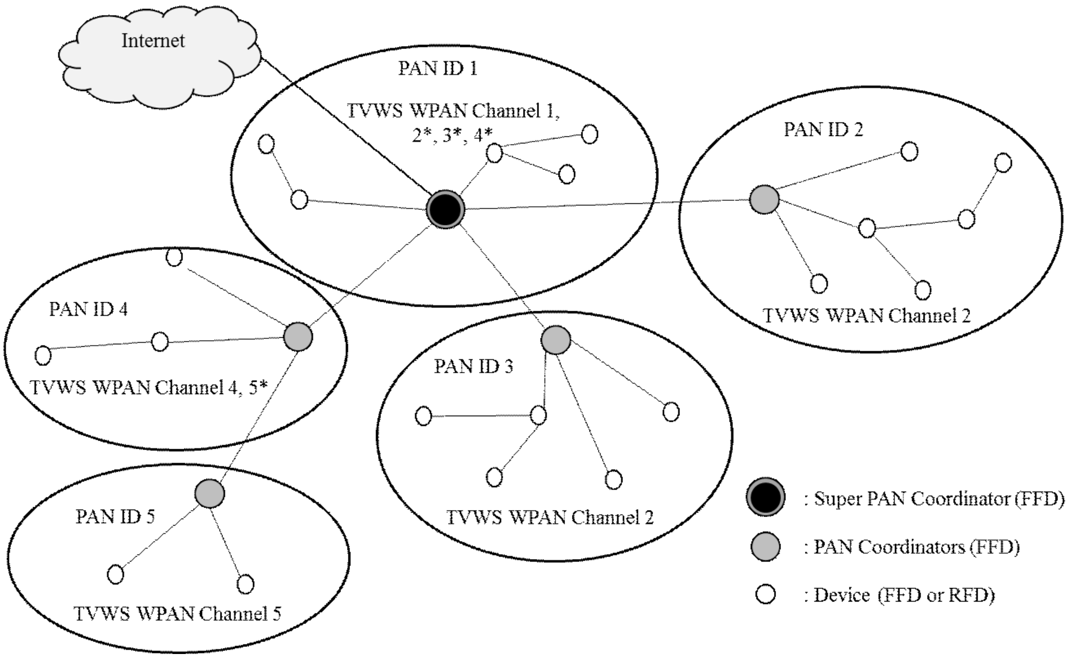

Figure 1 - Example of TVWS multichannel cluster PAN

4.5 Functional Overview

4.5.1 Superframe Structure

Insert the following new subclause (4.5.1.5) after 4.5.1.4:

4.5.1.1 Superframe Usage for TVWS

4.5.1.5.1 TVWS Multichannel Cluster Tree PAN (TMCTP) Superframe

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 2: TMCTP superframe extension. The BOP is composed of one or more DBSs. A DBS is used to communicate beacons between the parent PAN coordinator and the child PAN coordinator. More information on the TMCTP superframe structure can be found in 5.1.1.1a.

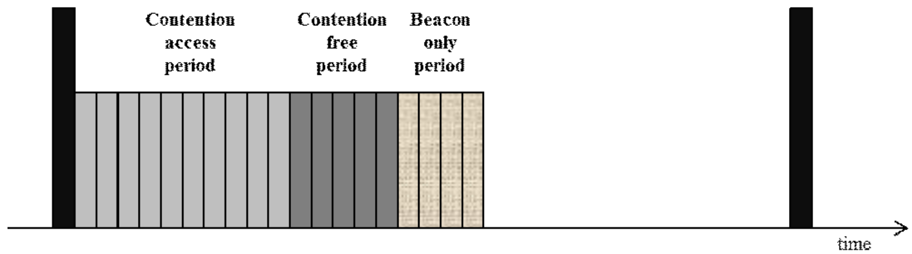

Figure 2 - TMCTP superframe extension

4.5.1.5.2 Generalized GTS Usage

In a TVWS PAN allocated GTS may be configured for direct peer-to-peer communication. When a frame is transmitted in a GTS with a valid destination address, implicit addressing based on the GTS direction parameter is not used.

Add overview paragraph for GTS features to support TVWS operation

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 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 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

4.5.5.1 Low-energy Mechanisms

Add overview paragraph for new LE mechanism

4.5.7 Overview of TVWS Operation

This clause provides an overview of operation of 802.15.4 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. Examples based on the requirements known at the time of this writing are given in Annex Q.

5. MAC protocol

5.1 MAC functional description

Insert after paragraph 2 the following paragraph:

A device operating in TVWS may be an independent device or a dependent device. An independent device is a device capable of obtaining permission from a regulatory-specific entity to operate within the TVWS in the corresponding regulatory domain, while a dependent device is a device that may only operate under the control of an independent device.

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 Beacon Only Period (BOP) and the structure of the superframe is described in Superframe use for TMCTP operation.

5.1.1.1.1 Contention access period (CAP)

5.1.1.1.2 Contention Free Period (CFP)

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 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 beacon sent by the 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 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

Add after the last paragraph of 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 1.

- 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 parent PAN coordinator (including the SPC) and the 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 3, according to the macBeaconOrder, the macsuperframeOrder and the macTMCTPExtendedOrder as shown in the Figure 3.

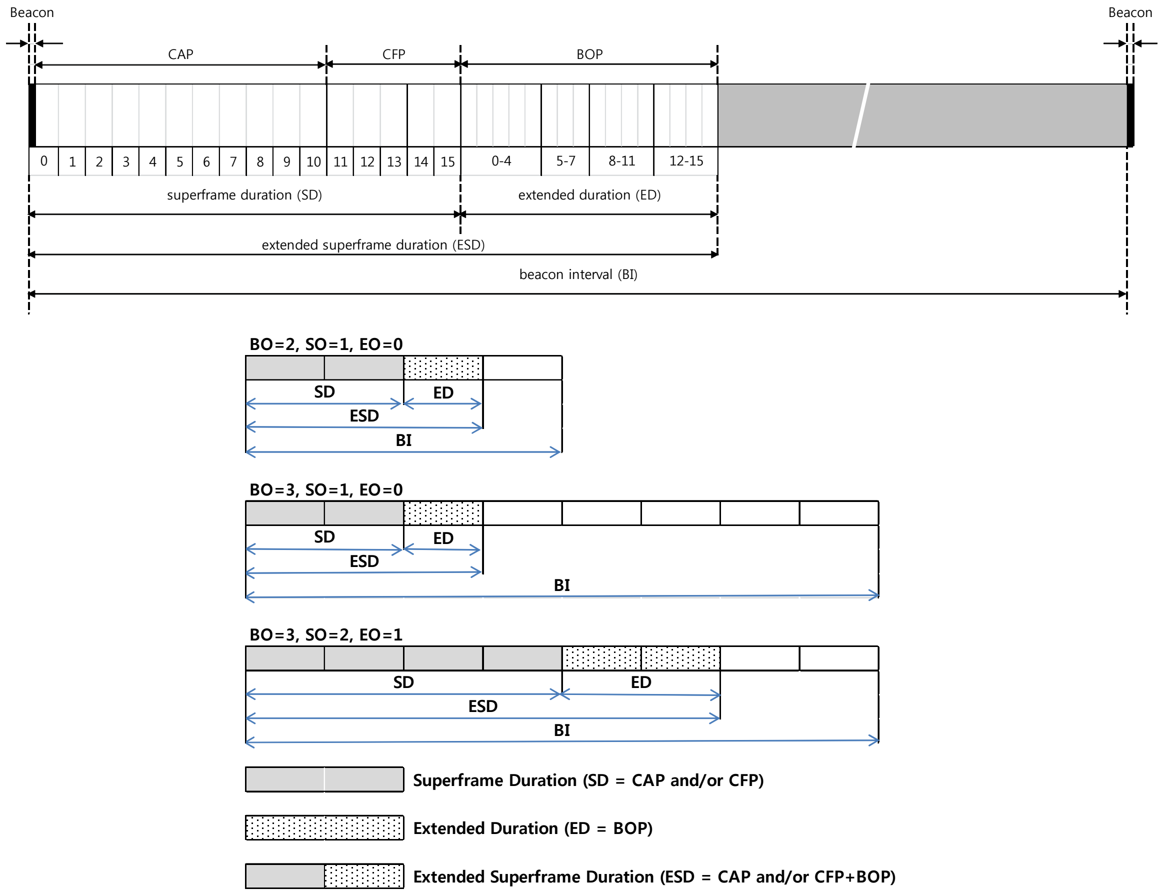

Figure 3 - An exanpme of the TMCTP superframe structure

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 following text 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. A device may carry out neighbor discovery after association with its coordinator, at appropriate time upon receiving MLME-

NBR.Request primitive from next higher layer. A coordinator device shall carry out neighbor discovery in the active portion of its incoming superframe on beacon-enabled PAN.

In Figure 5 - Message sequence chart for neighbor discovery, upon receiving MLME-NBR.Request primitive from next higher layer, at appropriate time a device broadcasts neighbor discovery request command and starts a timer that will expire after [TBD]. If a recipient device of the neighbor discovery request command associated with the same coordinator as the requester, it sends neighbor discovery response command to the requester device. After the timer expires, the requester MAC issues MLME-NBR.Confirm primitive to next higher layer.

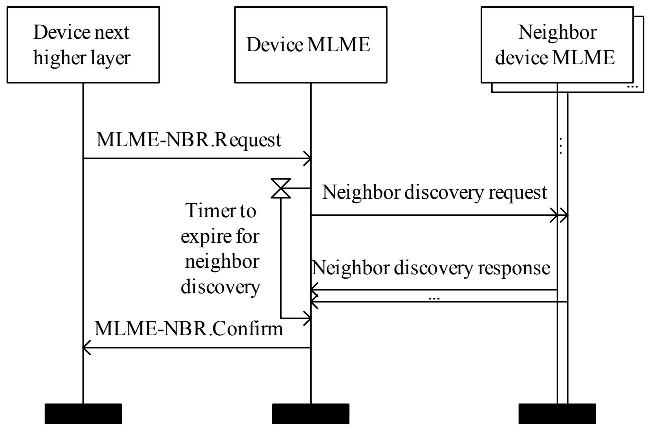

Figure 4 - Message sequence chart for neighbour discovery

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 appropriate time, without probing the receiver status of the neighbor device.

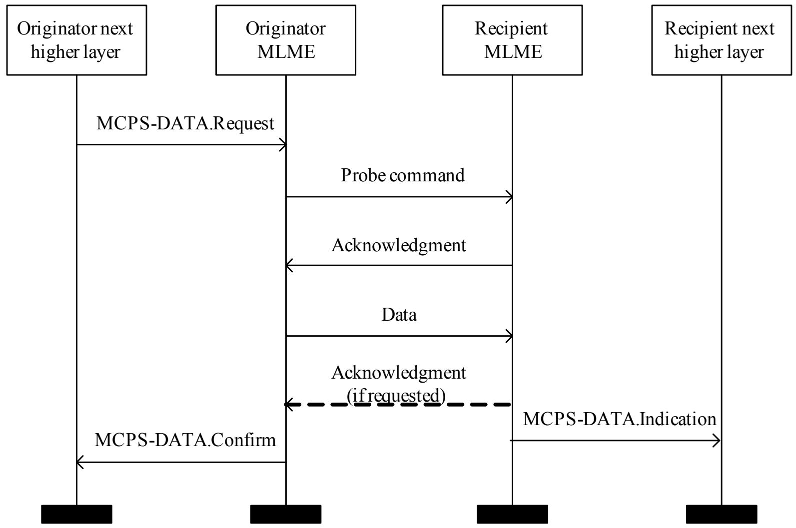

Figure 5 - Message sequence chart for probe-mode direct data transfer

If the receiver status of the neighbor device is unknown, it sends Probe command to the destination device and starts timer with duration of [TBD]. 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 appropriate time.

On receiving a Probe command, a destination device shall send acknowledgement and enable its receiver for at most [TBD] 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 detected unreachable, the data frame may remain in transaction queue until another request from higher layer 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 5.

5.1.6.7.3 Polling-mode direct data transfer

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

On receiving a data request command, a device shall send 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 has no 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 [TBD] to receive the corresponding data from the neighbor device. If the polling device does not receive a data frame from the neighbor device within [TBD] 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 6.

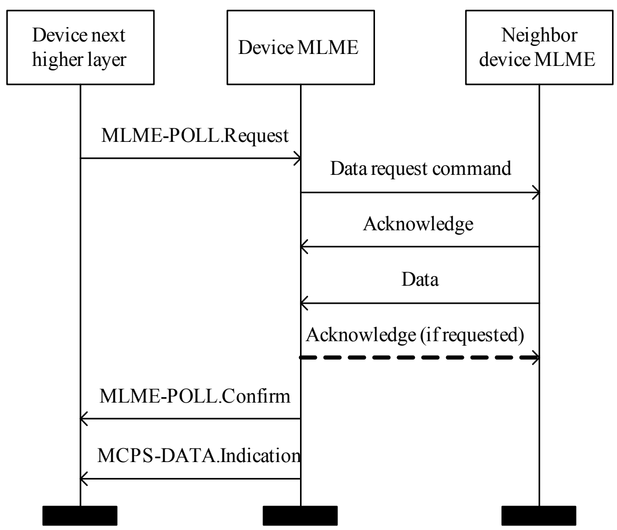

Figure 6 - Message sequence chart for polling-mode direct data transfer

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 at appropriate time, [TBD]. The AR field of the data frame shall be set to indicate no acknowledgement requested. Figure 7 shows message sequence of broadcast-mode direct data transfer.

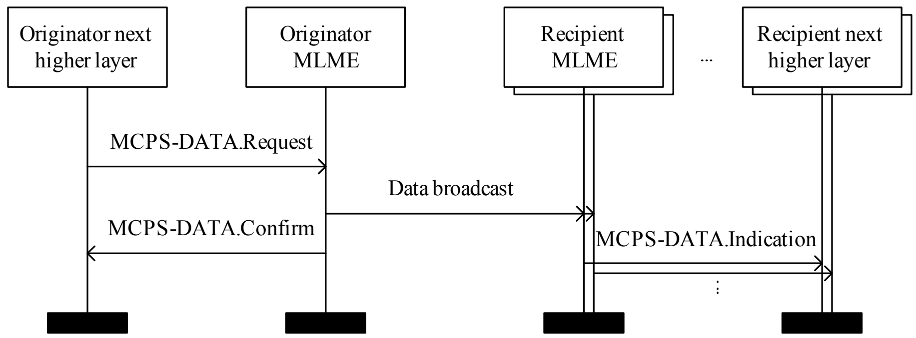

Figure 7 - Message sequence chart for broadcast-mode direct data transfer

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 8 shows message sequence of Multicast-mode direct data transfer.

A device may subscribe 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 [insert normative reference to RAC document]

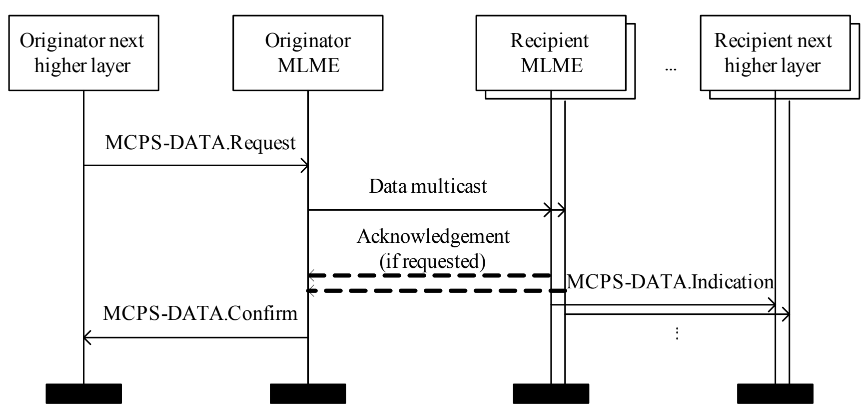

Figure 8 - Message sequence chart for multicast-mode direct data transfer

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 imitated 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 (Ranging request IE) 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 (Ranging request IE) is received by an RDEV that supports IEs, the receive Timestamp is captured and a Ranging response IE (Ranging response IE) 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.

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

In step A, the SPC obtains the list of available TVWS channels from the Geolocation 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 child PAN coordinator completes the scan procedure over all PHY channels and association procedures with the SPC, and is waiting the beacon of the SPC.

In step B the SPC transmits an enhanced beacon containing a TMCTP Extended Superframe Specificiation IE (xref). Upon successful reception of the beacon from the SPC, the child PAN coordinator may request a DBS allocation sending a DBS request (xref) 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 child PAN coordinator in its beacon. The 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 child PAN coordinator on the allocated channel, the SPC switches into its own dedicated channel.

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

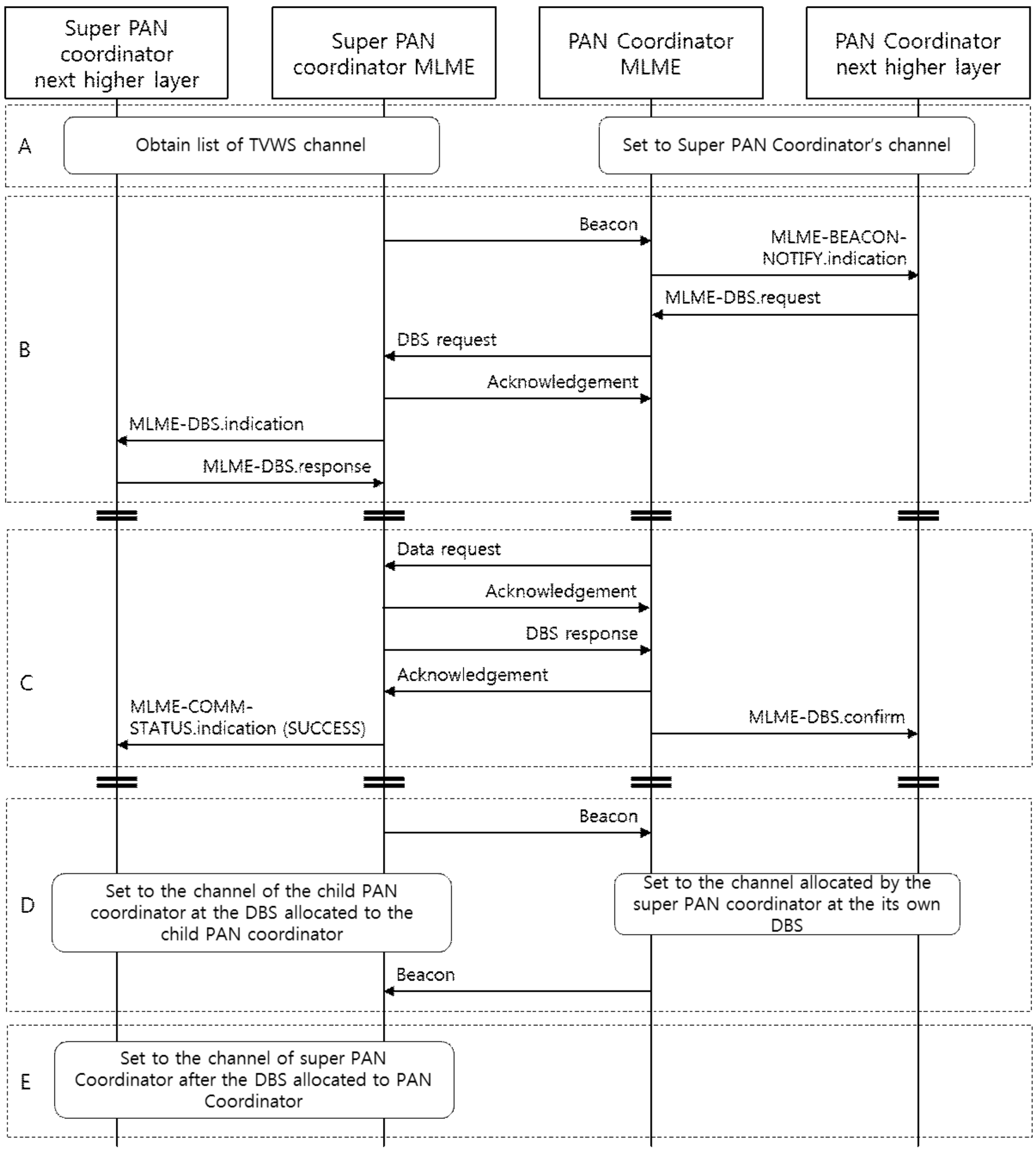

Figure 9 - Example message sequence between SPC and PAN coordinator

Figure 10 provides another example for TMCTP formation between the PAN coordinators, one is the parent PAN coordinator and the other is the child PAN Coordinator.

In step A, the child PAN coordinator performs a scan and association with the parent PAN coordinator, and is waiting for the beacon of the parent PAN coordinator.

In step B, the parent PAN coordinator sends an enhanced beacon containing an Extended Superframe Specification IE (TMCTP Extended Superframe Specification IE). Upon successful reception of the beacon from the parent PAN coordinator, the child PAN coordinator requests a channel and a slot by using the DBS request sent to the parent PAN coordinator. Upon receiving the DBS request, the 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 parent PAN coordinator sends a beacon. The parent PAN coordinator switches into the channel allocated to the child PAN coordinator and receives the beacon frame from the child PAN coordinator.

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

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

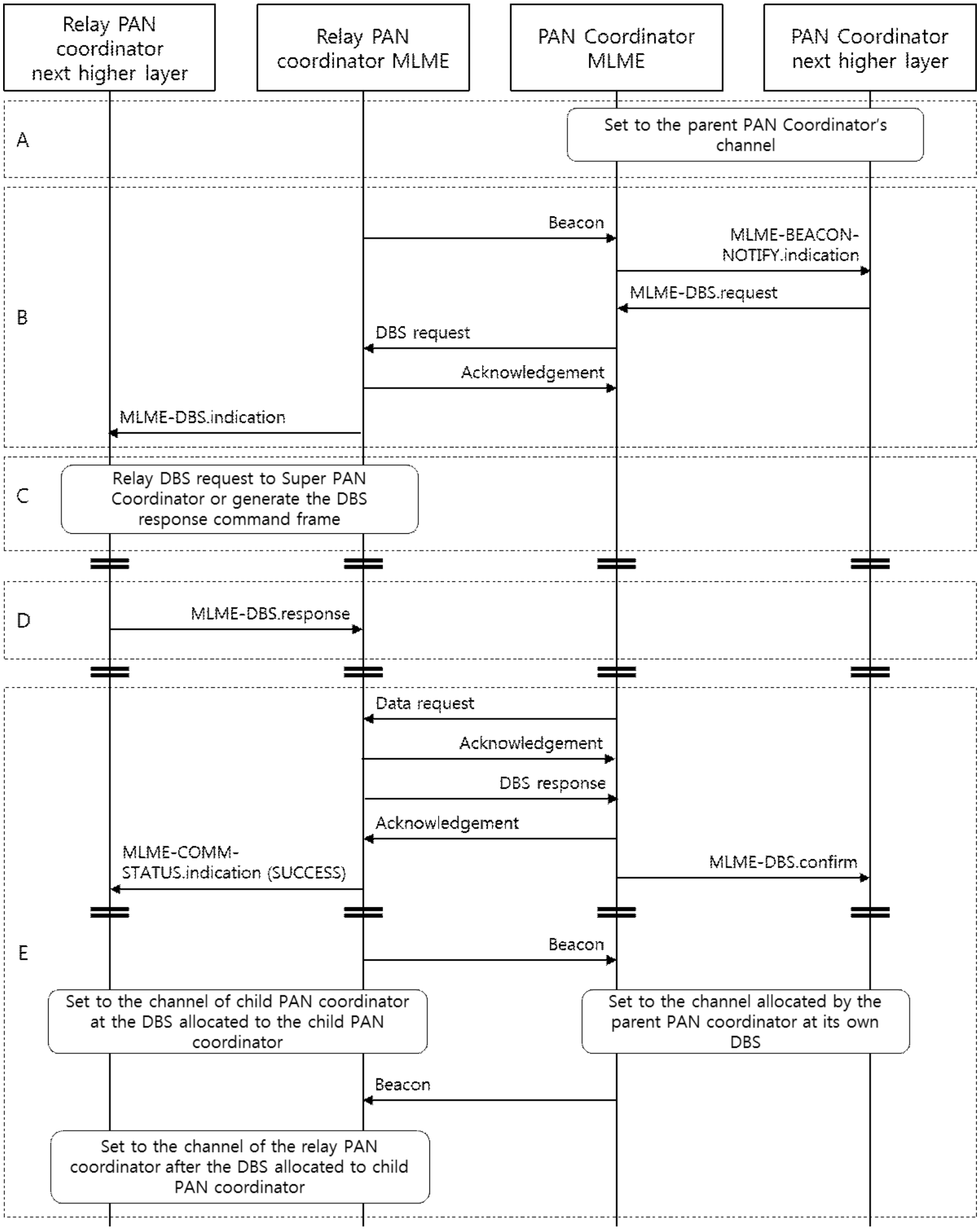

Figure 10 - Example message sequence between TMCTP PAN coordinator

Figure 11 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, and switches into the dedicated channel of the child PAN coordinator 2, 3, and 4 at their DBS. Similarly the PAN coordinator 4 operates on the dedicated channel, which is channel 4, and switches into the dedicated channel of the child PAN coordinator 5 at its DBS.

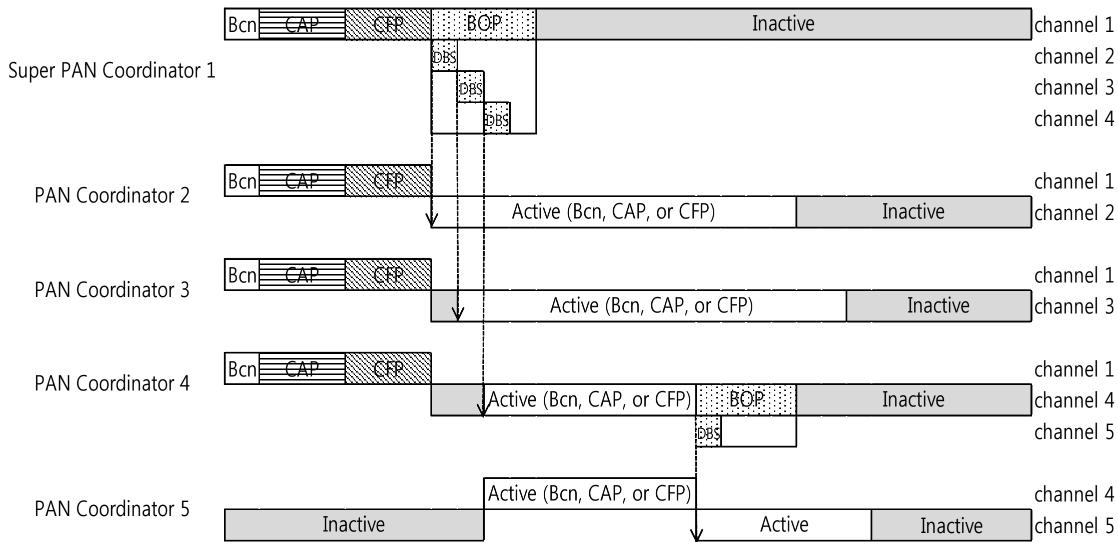

Figure 11 - Example TMCTP BOP allocation

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 followed by a channel listening period at *macTVWSPSPollingInterval*, for total duration *macTVWSPSPollingDuration* or until receiving an acknowledgement frame, whichever occurs first.

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.

When generating the TVWSPS ID, 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, and transmits the data requested by the initiating device at indicated rendezvous time.

Two illustrative examples of the TVWSPS protocol is given in Figure 12. In the first example the initiating device 1 has pending data to transmit to the responding device. In the second, Initiating device 2 is requesting data from the responding device.

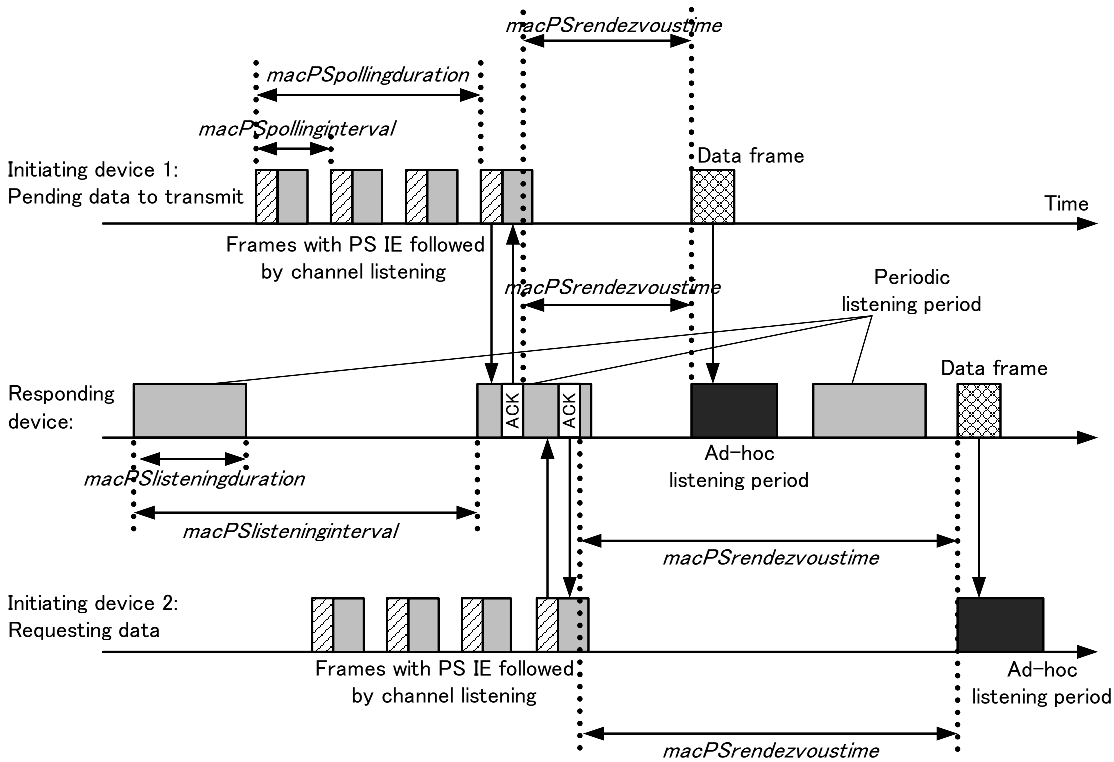

Figure 12 - TVWS power saving example

5.2 MAC frame formats

5.2.2 Format of individual frame types

5.2.2.1 Beacon frame format

5.2.2.1.1a Information elements (IEs) field

5.2.4.1 Header information elements

5.2.4.4 MLME information elements

Table 1—

Sub-ID Value	Content Length	Name	Description
			PHY Parameter Change IE defined in PHY Parameter Change IE
TBA	12	PS IE	TVWS Power Saving IE, defined in TVWS Power Saving (TVWSPS) IE.
TBA	variable	TVWS PHY Operating Mode Description IE	Description of a specific TVWS PHY operating mode, defined in 5.2.4.31.
TBA	variable	TVWS device capabilities IE	IE used to exchange TVWS PHY specific device capabilities, defined in TVWS device capabilities IE.
TBA			
TBA			TVWS device location IE, defined in TVWS device location IE
TBA			TVWS channel information query request/ response IE, defined in TVWS channel information query request/response IE
TBA			Network Channel Control IE defined in Network Channel Control IE
TBA			Channel Timing Management IE, defined in Channel Timing Management IE
TBA			

Table 1—

			Ranging request IE, defined in Ranging request IE
			Ranging response IE, defined in Ranging response IE
			TMCTP Extended Superframe Specification IE, defined in TMCTP Extended Superframe Specification IE

ID values are assigned by the Working Group 15 Assigned Numbering Authority prior to submitting draft for publication.

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 13.

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

Figure 13 - 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 Starting and maintaining TVWS Multichannel Cluster Tree PANs (TMCTP)) 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 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 16: TVWS PHY operating mode description IE content.

TVWS PHY Operating Mode Description

Figure 14—TVWS PHY operating mode description IE content

The TVWS PHY operating mode description field shall be encoded as shown in Table 2. The specific parameters are encoded depending the PHY type indicated.

Table 2—TVWS PHY operating mode description field encoding

Bit Number	Description
0:7	TVWS Band ID
8:15	TVWS Channel ID The TVWS Channel ID allocated by the TVWS database (see annex Q.zzz)[a]
16:23	PHY Channel ID The channel identification for the 802.15.4 TVWS PHY channel as defined in 8.1.2.
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

26:31	FSK Operating Parameters: when PHY Type Selector is set to 0.	
	Bit Number	
	26	FEC Enabled
	27	Interleaving enabled
	28	Spreading enabled
	29:30	FSK Operating Mode [symbol rate, channel spacing – xref to PHY clause]
	31	Reserved
	OFDM Operating Parameters when PHY Type selector is set to 1	
	26:28	Modulation order: TBD
	29:31	Reserved
	NB-OFDM	
	26:28	Modulation order: TBD
	29:31	

[a] We may reduce the TVWS Channel ID and PHY Channel ID to a single field depending on how the PHY channel assignments are specified. The field size can also be adjusted when we have complete PHY specifications.

Note: The content of this table is illustrative: the actual parameters included and thus bit field sizes will be determined when the PHY specifications are complete enough to complete the parameters that should be signaled.

5.2.4.32 TVWS device capabilities IE

The following 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 15.

Note: the details of this IE will be change when the PHY specification is completed

Octets: 1	2	2	Variable
TVWS PHY type	TVWS supported bands	TVWS supported PHY features	TVWS channels supported

Figure 15 -TVWS device capabilities IE

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

Table 3—TVWS PHY Type Field Values

Value	Description
1	TVWS FSK PHY
2	TVWS OFDM
3	TVWS NB-OFDM
4-255	Reserved

The TVWS supported bands field is a bitmap indicating the supported TVWS bands. A value of one indicates that the band is supported, and zero indicates the band is not supported. The supported TVWS bands supported shall be encoded as shown in Table 4. The device shall indicate as supported only those TVWS bands that are implemented and defined for the indicated PHY type [add cross reference to TVWS PHY clause].

Table 4—TVWS PHY Bands Supported Field Encoding

Bit number	Description
0	TVWS Band USA
1	TVWS Band UK
2	TVWS Band Japan
3	TVWS Band Canada
4	TVWS Band Korea
5 - 31	Reserved

The TVWS supported features field indicates the supported PHY features of a TVWS PHY. The field shall be encoded as shown in Table 5.

Table 5—TVWS PHY Features Supported Field Encoding

Bit #	Description
0	To be completed when the TVWS PHYs are further defined
1	
…	

The Channels Supported field is a set of channel maps that shall be formatted as described in Figure 16.

The Channels Supported field content depends on the value of the TVWS Bands Supported field. For each defined TVWS band, the channel numbering is given in 8.1.2. For each band indicated as supported, a corresponding channel bit map shall be constructed, having the format as shown in Figure 48nm. The first bit field of each map, as shown in Table 4z, 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 are supported and the channel map is 1 octet. 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 TVWS Bands Supported field, the corresponding channel maps are concatenated in order, such that the channel maps occur in the order of the bands given in Table 4, i.e. channel map corresponding to the band indicated by bit 0 of the TVWS Bands Supported field is transmitted first.

Octets: 1/TBD	1/TBD	...	1/TBD
Channel Map for band 1	Channel Map for band 2		Channel Map for band n

Figure 16 -TVWS channels supported bitmap encoding

5.2.4.33 TVWS Enabling IEs

5.2.4.33.1 TVWS device category field

The device category field is 1 octet and shall be set to one of the non reserved values shown in Table 6.

Bit #	
0	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. (FCC mode I)
2	Not fixed, independent: device location may change after initial contact; has access to channel availability database (FCC mode2)
3 - 255	TBD or reserved

Table 6—Device category

5.2.4.33.2 TVWS device identification IE

The device identification may contain 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 17.

Octets: 1	Variable
ID type	Device ID

Figure 17 -TVWS device identification IE content

The ID Type field shall be set to one of the non-reserved values in Table 7.

Table 7—ID Type field values

ID type value	Description
0	US specific regulator assigned ID (FCC 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 ID types indicated as regulator assigned, the Device ID is comprised of two fields, formatted as shown in Figure 18.

Octets: 1	Variable
Device Category	ID string

Figure 18 -Regulator assigned ID format

adddevice example category table

The ID string field is a counted string as shown in Figure 19.

Octets: 1	Variable
Length	Array of octets

Figure 19 -Counted string field

The length field specifies the number of octets that follow 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 IE contains a list of geo-location coordinates. Each location list entry is 16 octets, encoded as shown in Table 8. The encoding is based on RFC 6225. The field contents are as described in RFC 6225.

Octets: 1	Variable
Number of locations in list	List of locations

Figure 20 -

Table 8—Device location field content 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 21.

Octets: 1	1	1	Variable
Channel Map ID	Status	Number of Channels	Channel Descriptions List

Figure 21 -Channel information query IE

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

The 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 9.

Table 9—Channel information query status values

Sta-tus	Description
0	Channel list requested
1	Available channel list for verified for a device location
	Available channel list for verified for multiple device location
2	Request not successful due to device ID not verified
3	Request not successful due to device location is out of the geographic coordinate
4	Request not successful due to one or more parameters have invalid values
5	Request not successful for another reason
7-255	Reserved

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

When the status field indicates a response with available channel list for verified device location, the number of channels and channel descriptions 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 channel descriptions that follow in the channel descriptions list. Each entry in the channel descriptions list contains the specific information on available channels as shown in Figure 22.

Octets: 2	1	Variable
TVWS Channel ID	Maximum TX Power	Spectrum Mask Descriptor

Figure 22 -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" (as might be used for contact verification).

The Spectrum Mask Descriptor field contents is TBD (TBD: require updates on describing spectrum mask description).

5.2.4.33.5 Network Channel Control IE

The Network Channel Control IE provides a description of a particular PHY channel and shall be formatted as shown in Figure 23.

Octets: 2	Variable
PHY Channel ID	Spectrum Mask Descriptor

Figure 23 -Available TVWS Channel description

The Spectrum Mask Descriptor field contents is TBD (TBD: require updates on describing spectrum mask description).

5.2.4.33.6 TVWS channel information source description

Channel Data Source Inforomation 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 24.

Octets: 1	16	0/8	0/4	0/1	Variable
Source Info	Location	Address of Known source	Known source Chan-nel Description	Number of channel descriptions	Channel Descriptions

Figure 24 -Channel information source description IE content

The Source info field is a bit map, encoded as shown in Table 10.

Bit #	Description

0	Indication that this device is a channel info source, and thus channel description fields are present
1	Indication of known Channel Info source address field included
2	Indication that known Source Channel descriptions field present
3-7	Reserved

Table 10—Source info field encoding

The location field is formatted as shown in Table 8.

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 a device known to the transmitting device to be a source of channel availability data.

The known source channel description field is present when indicated by the source info field and contains the channel description for contacting the known source described in the address of known source field.

Number of channel descriptions indicates how many Chanel Descriptions are contained in the channel Descriptions field. This field is present only when the source info field indicates that this device is a channel data source. Channel descriptions field is present when the Number of channel descriptions field is present and not zero; each channel description is formatted as shown in Figure 22.

5.2.4.33.7 Channel Timing Management IE

The content of the Channel Timing Management IE shall be formatted as shown in Figure 25.

Octets: 1	1	Variable	Variable
Reason/Result Code	Device Class	Device Identification	Channel Timing Information

Figure 25 -Channel Timing Management IE Content

The Reason/Result Code 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 Reason/Result Code field values are defined in the Table 11.

Table 11—Reason/Result code field values

Reason/Result Code 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 timeslots 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 12.

Table 12—Channel Timing Information field encoding

TBD

Table 13—Timing Management IE Reason/Result Code field values

TBD

5.2.4.33.8 Channel map verification IE

The channel map 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 26.

Octets: 1	1
Channel Map ID	Valid time

Figure 26 -Channel map veriication IE content

The Channel map ID field contains the ID for the channel map ID as described in TVWS channel information query request/response IE.

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 The ranging exchange with Information Elements.

The ranging request IE content is 1 octet and encoded as shown in Figure 27.

Octets: 1		
Bit #: 0	1:7	
Ranging method	Ranging message sequence number	

Figure 27 -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 The ranging exchange with Information Elements.

5.2.4.34.2 Ranging response IE

The Ranging response IE is encoded as shown in Figure 28.

Octets: 1		0/4	4
Bits: 0	1:7		
Ranging method	Ranging message sequence number	Request RX Timestamp	Response TX Time-stamp

Figure 28 -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 The ranging exchange with Information Elements.

The Request RX Timestamp 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 shall be set to the TBD time, in the responders time reference , when response packet is transmitted.

5.2.4.35 TMCTP Extended Superframe Specification IE

The Extended superframe Specification IE shall be formatted as illustrated in Figure 29.

Bits: 0-3	4	5	6	7
Beacon Only Period Order	Reserved	Dedicated Beacon Slot Allocation Capability	Channel Allocation Capability	Channel Allocation Relay Capability

Figure 29 -Format of the Extended Superframe 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 Superframe use for TMCTP operation.

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

5.3 MAC command frames

Insert into Table 5 new rows:

Table 5—MAC command frame frames

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

Note: Identifier values will be assigned by the 802.15 WG assigned numbering authority

Note: This is an existing Table in the base standard.

5.3.4 Data request command

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.

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 30.

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

Figure 30 -TMCTP DBS Request Command Frame

5.3.14.1 MHR Fields

TBD

5.3.14.2 DBS Request information field

The DBS Request information field shall be encoded as shown in Figure 31.

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

Figure 31 -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 descendant PAN coordinators. It may be set as 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 32.

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

Figure 32 -TMCTP DBS response command format

5.3.15.1 MHR Fields

TBD

5.3.15.2 DBS Response information field

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

Figure 33 -

Note: the specification of channel IDs may take a different form as the TVWS PHYs are more completely defined.

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

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

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

5.3.16 Neighbor discovery request command

The neighbor discovery request command is broadcasted by a device to discover neighbor devices that are associated with the same PAN coordinator or coordinator on a beacon-enabled PAN.

The neighbor discovery request command shall be formatted as illustrated in Figure 34.

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

MHR				MAC Payload	

Figure 34 -Neighbor discovery request 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.

5.3.17 Neighbor discovery response command

The neighbor discovery response command is sent to a device that is discovering neighbors and associated with the same PAN coordinator or coordinator of this device, as described in Direct device-to-device data transfer.

The neighbor discovery request command shall be formatted as illustrated in Figure 35.

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

Figure 35 -Neighbor discovery response command format

5.3.17.1 MHR fields

Both the Frame Pending field and the AR field shall be set to zero. The PAN ID Compression field shall be set to one. Both source and destination addresses shall be present.

5.3.17.2 Capability information field

Capability information is described in 5.3.1.2.

5.3.18 Probe command

The probe command is sent to a neighbor device, if the device has data pending for the neighbor device and its status is unknown, as described in Probe-mode direct data transfer.

The probe command shall be formatted as illustrated in Figure 36.

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 36 -Probe discovery command format

5.3.18.1 MHR fields

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

5.5 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 Geolocation 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 geolocation to be reported to the GDB. The GDB then provides available channels and relevant operating information. Upon receiving permission from the GDB, the independent device may start a network and enabling other devices.

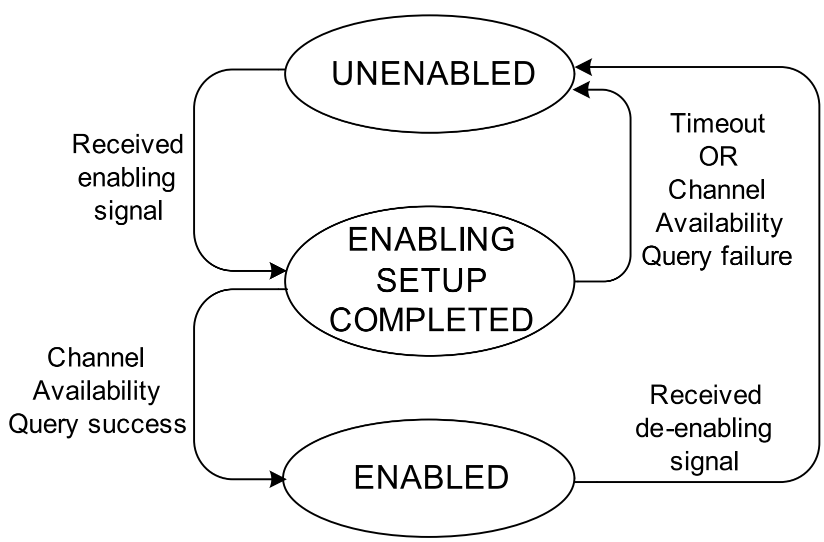

Figure 37 - State transition of a dependent device

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 that transmissions 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 (i.e. a beacon) from an independent device, the state transitions to ENABLING STEUP COMPLETED. From the ENBLING SETUP COMPLETED state, the dependent device will initiate a channel availability query (CAQ) as required by the particular regulatory domain in which it is operating. IEs are provided (xref) for the query and delivery of channel availability information. Upon successfully completed CAQ the state transitions to

ENABLED. In this state, the dependent device is able to conduct data communications. If a de-enabling signal is received, the state of the dependent device transitions to UNENABLED.

5.5.12 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 (xref).

(TBD: require more details on the CTM procedure will be provided in clause 5)

5.5.13 Network Channel Control (NCC)

Network Channel Control facilitates the assessment of available PHY channel available to be occupied. NCC is used by employing the NCC IE as in (xref).

(TBD: require more details on the NCC procedure)

6. MAC services

6.2 MAC management service

Insert the following new rows into Table 8:

Table 8—MAC command frame frames

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

Note: This is an existing Table in the base standard.

6.2.2 Association primitives

[will need parameters for new GTS options]

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

[may need new parameters]

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

5.1.12.1 MLME-BEACON-NOTIFY.indication

Insert Insert the following new parameters at the end of the list in 6.2.3.1 (before the closing parenthesis):

PeriodicListeningInterval
PeriodicListeningDuration
RendezvousTime
TransactionTime

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	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.

6.2.6 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

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~~.~~ <u>or a neighbor device directly.</u>

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~~.~~ <u>Or a neighbor device directly.</u>

The semantics of this primitive are:

```
MLME-POLL.request (
                    CoordAddrMode,
                    CoordPANId,
                    CoordAddress,
                    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 Polling-mode direct data transfer, 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:

~~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 coor-dinator or the neighbor device to which the poll is intended.

This is an existing Table in the base standard

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

[make ranging primitives not PHY specific]

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

6.2.23 TMCTP DBS allocation primitives

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

6.2.23.1 MLME-DBS.request

The MLME-DBS.request primitive is used when a child PAN coordinator requests the allocation of a DBS and a channel to a 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 14.

On receipt of the MLME-DBS.request primitive, the MLME generates a DBS request command, as defined in DBS request command frame, 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 child PAN coordinator requesting DBS allocation shares a key with the parent PAN coordinator, then security may be specified.

Table 14—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	See [xref]	Number of BOP slots being requested for the DBS.
NumberOfDescendents	PHY Channel ID	See 8.1.2	Value to set the The Number of the Descendant field in the DBS request: indicates 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	As defined in Table 48		
KeyIdMode			
KeySource			
KeyIndex			

6.2.23.2 MLME-DBS.indication

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

The semantics of this primitive are:

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

The primitive parameters are defined in Table 15.

Table 15—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.
DBSLength	Integer	See [xref]	Value of the DBSLength field of the the received TMCTP DBS Request
RequestType	Enumeration	ALLOCATION, DEALLOCATION	Indicaes if the received request is for an allocation or deallocation of TMCTP DBS.
NumberOfDescendents	PHY Channel ID	See 8.1.2	Value to of the Number of the Descendant field in the received DBS request: indicates 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	As defined in Table 48		
KeyIdMode			
KeySource			
KeyIndex			

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

6.2.23.3 MLME-DBS.response

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

The semantics of this primitive are:

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

The primitive parameters are defined in Table 16.

Table 16—MLME-DBS.response Parameters

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

EndingChNum	PHY Channel ID	See 8.1.2	The highest channel number, which is assigned by the parent PAN coordinator
SecurityLevel	As defined in Table 48		
KeyIdMode			
KeySource			
KeyIndex			

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

6.2.23.4 MLME-DBS.confirm

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

The semantics of this primitive are:

```
MLME-DBS.confirm    (
                        RequesterCoordAddr,
                        DBSStartingSlot,
                        DBSLength,
                        ChannelNumber,
                        ChannelPage,
                        StartingChNum,
                        EndingChNum,
                        status
)
```

The primitive parameters are defined in Table 17.

Table 17—MLME-DBS.confirm parameters

Name	Type	Valid range	Description
RequesterCoor-dAddr	Integer	0x0000-0xffff	The short device address of the (original) source requester PAN coordinator.
DBSStartingSlot	Integer	See [xref]	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 parent PAN coordinator
EndingChNum	PHY Channel ID	See 8.1.2	The highest channel number, which is assigned by the parent PAN coordinator
Status	Enumeration	SUCCESS, (TBD), NO_ACK, DENIED, UNAVAILABLE_KEY, UNSUPPORTED_SECU-RITY, INVALID_PARAMETER	The status of the attempt of the allocation of a DBS and a channel.

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

6.2.24 Primitives for neighbor discovery

These primitives are used for neighbor device discovery.

6.2.24.1 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 18.

Table 18—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 CoordAd-drMode parameter	the address of the coor-dinator that this device associated with

On receipt of the MLME-NBR.Request primitive, the MLME starts the neighbor discovery process as described in Direct device-to-device data transfer.

6.2.24.2 MLME-NBR.Confirm primitive

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

The semantics of this primitive are

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

The primitive parameter is described in Table 19.

Table 19—MLME-NBR.Confirm parameters

Name	Type	Valid range	Description
CoordAddrMode	Enumeration	SHORT_ADDRESS, EXTENDED_ADDRESS	The addressing mode of the coordinator that this device associated with.

The MLME-NBR.Confirm primitive is generated by MLME and issued to its next higher layer in response to an MLME-NBR.Request primitive.

6.3 MAC data service

6.3.12 MCPS-Data.request

Insert 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.

This is an exsiting Table in the base standard

6.3.13 MCPS-DATA.confirm

Add new parameters

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:

[description of where the new parameters come from]

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.
PeriodicListeningDura-tion	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.

This is an exsiting Table in the base standard

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**
macTVWSPSListeningDura-tion	Integer	0 - 16777215	Time in milliseconds time between the start and the end of a periodic listening period when TVWS PS is enabled.	TBD
macTVWSPSListeningInterval	Integer	0 - 16777215	Time in milliseconds between the start of a periodic listening duration to the start of the sub-sequent periodic listening dura-tion when TVWS PS is enabled.	TBD
macTVWSPSPollingDuration	Integer	0 - 16777215	Time in milliseconds that the ini-tiating device repeats the polling operation when TVWSPS is enabled when TVWS PS is enabled.	TBD
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.	TBD

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.	TBD
macTVWSPSTransDuration	Integer	0 - 65535	Time in milliseconds needed complete the transaction between the initiating and responding devices when TVWS PS is enabled.	TBD
macTVWSPSenable	Boolean	TRUE, FALSE	Indicates that TVWS PS is enabled.	FALSE

This is an exsiting Table in the base standard

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_1–R_0	PC	FCS	DW	L_{10}–L_0
Field name	Reserved	Parity Check	FCS Type	Data Whitening	Frame Length

Figure 113—Format of the PHR for TVWS-FSK

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.

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.

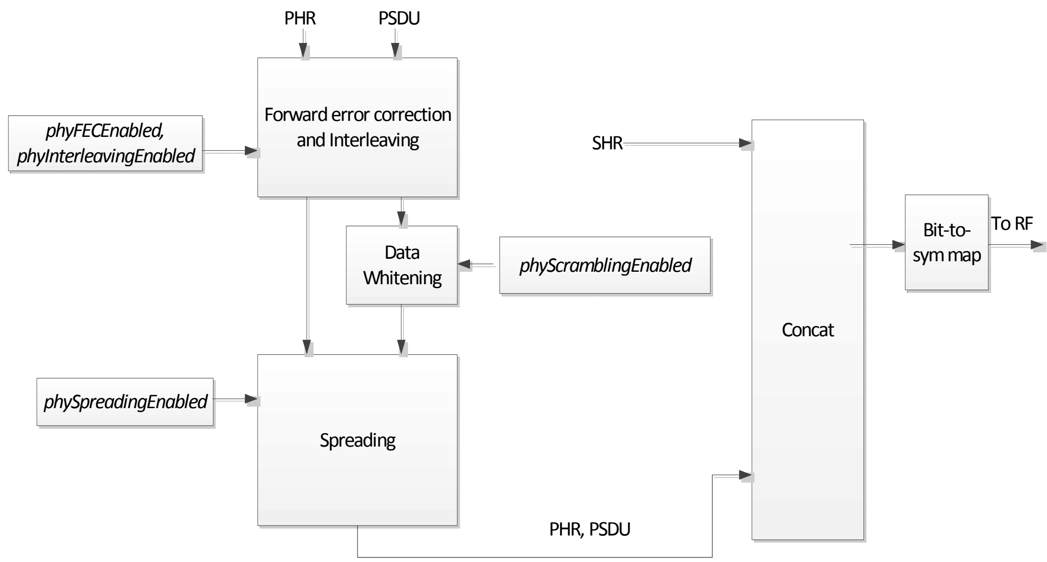

Figure 114—Reference modulator diagram

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).

20.1.2.2 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 *phyScramblingEnabled*, as defined in 9.3. The data whitening algorithm shall be as defined in 19.2.3.

20.1.4 2RF requirements for TVWS-FSK

20.1.4.1 Clock accuracy

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

20.1.4.2 Channel switch time

The channel switch time shall be as given in 19.2.4.4.

20.1.4.3 Receiver sensitivity

The receiver sensitivity shall be as given in 18.1.5.7.

20.1.4.4 Tx-to-Rx turnaround time

The TX-to-RX turnaround time shall be as given in 18.1.5.9.

20.1.4.5 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.

TThe 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 127 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.

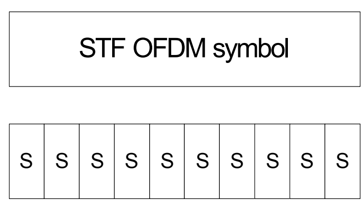

Figure 116—Structure of STF OFDM symbol

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 should be a multiplication by TBD, which is approximately TBD dB.

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 TBD

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

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.

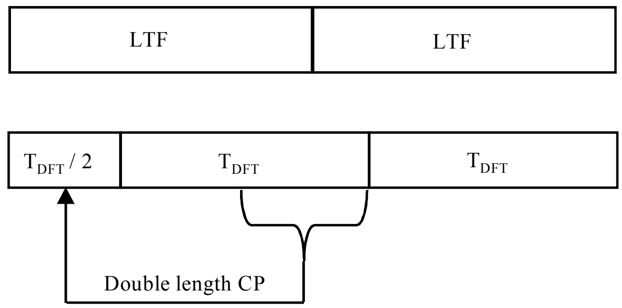

Figure 117—Structure of LTF for TVWS-OFDM

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	**0-5**	**6-7**	**8–18**	**19–27**	**28–43**	**44–49**
Bit mapping	R_5–R_0	RA_1–RA_0	L_{10}–L_0	S_8–S_0	H_{15}–H_0	T_5–T_0
Field name	Reserved	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 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 PHY

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 rate 1/2)	390.625	
MCS1 (kb/s) (QPSK rate 1/2)	781.250	
MCS2 (kb/s) (16-QAM rate 1/2)	1562.5	
MCS3 (kb/s) (BPSK rate 1/2)		1562.5
MCS4 (kb/s) (QPSK rate 1/2)		3125
MCS5 (kb/s) (16-QAM rate 1/2)		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.

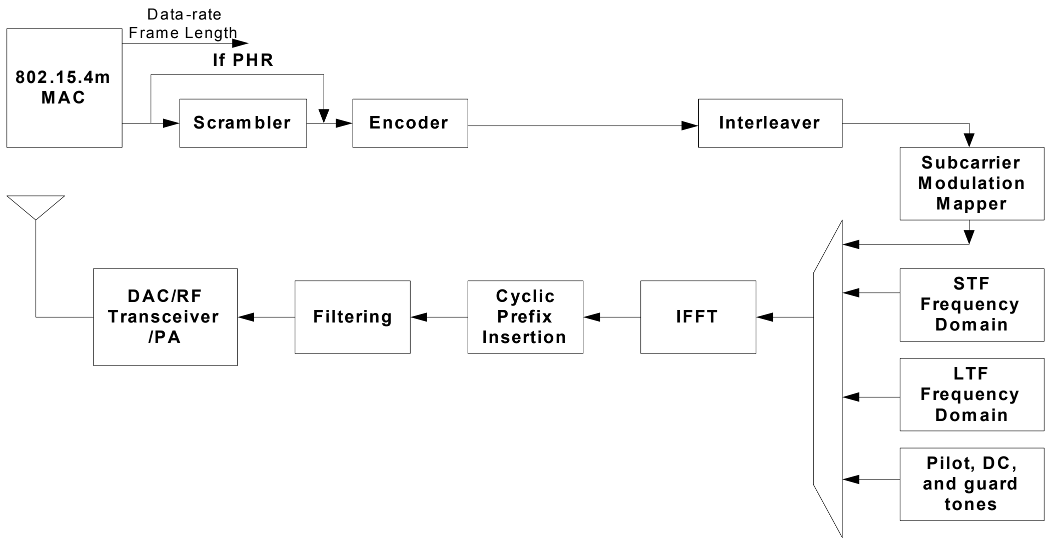

Figure 119—Reference modulator diagram for TVWS-OFDM

20.2.3.2 Bit-to-symbol mapping

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

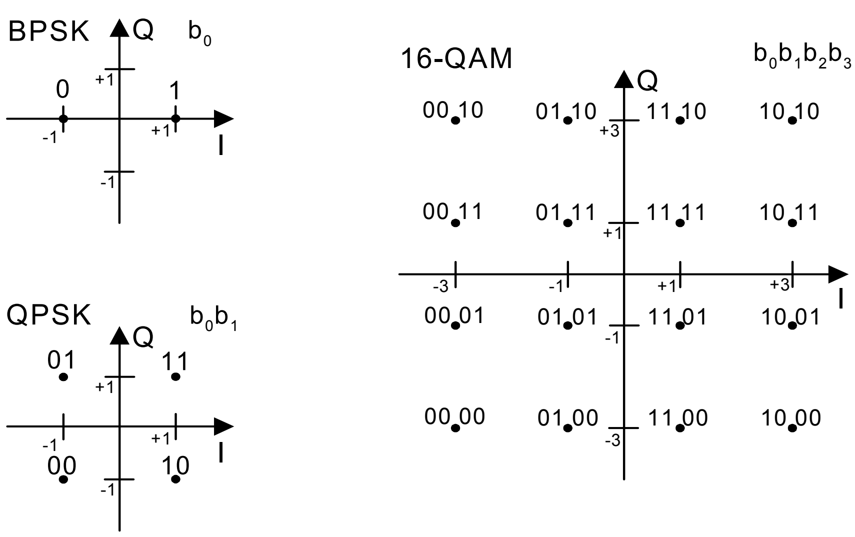

Figure 120—Bit-to-symbol mapping for TVWS-OFDM

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 PHY

Parameter	Mandatory Modes	Optional Modes
MCS0 (BPSK rate 1/2)	8 bits/octet * 1/50 symbol/bits	
MCS1 (QPSK rate 1/2)	8 bits/octet * 1/100 symbol/bits	
MCS2 (16-QAM rate 1/2)	8 bits/octet * 1/200 symbol/bits	
MCS3 (BPSK rate 1/2)		8 bits/octet * 1/50 symbol/bits
MCS4 (QPSK rate 1/2)		8 bits/octet * 1/100 symbol/bits
MCS5 (16-QAM rate 1/2)		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.

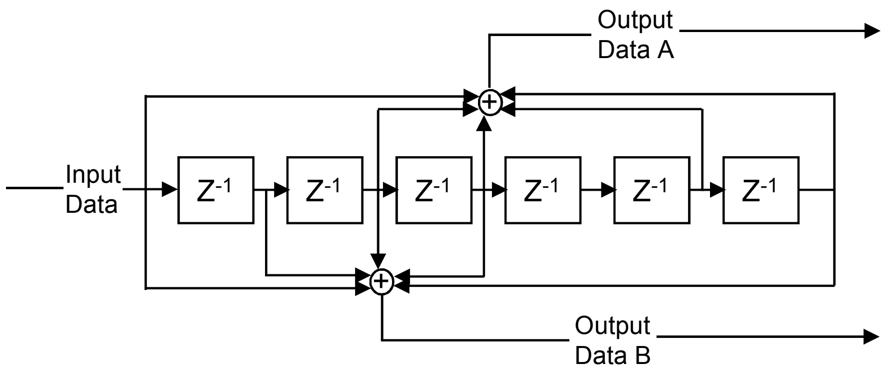

Figure 121—Rate 1/2 convolutional encoder

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:

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

where

N_{cbps} is the number of coded bits per symbol,

i is0, 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 are defined as shown in Table 140.

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

	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.

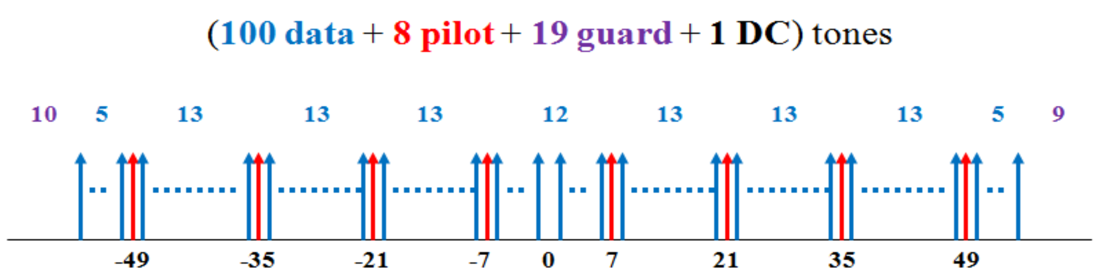

Figure 122—Pilot tones for TVWS-OFDM

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.

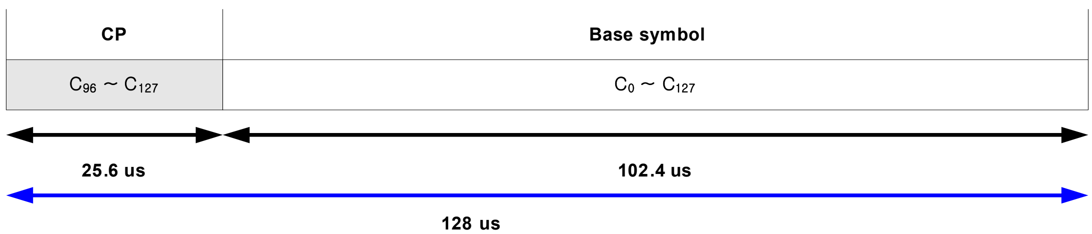

Figure 123—Cyclic prefix (CP)

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:

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

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

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

$$N_{PAD} = N_{DATA} - (8 \times \text{LENGTH} + 6) \quad (1)$$

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 137. The PN9 scrambler is initialized by the scrambling seed specified by 9 bits in the PHR, as shown in Figure 131. The leftmost value of the scrambling seed is placed into the leftmost delay element in Figure 124.

The PN generator is defined by the schematic in Figure 124.

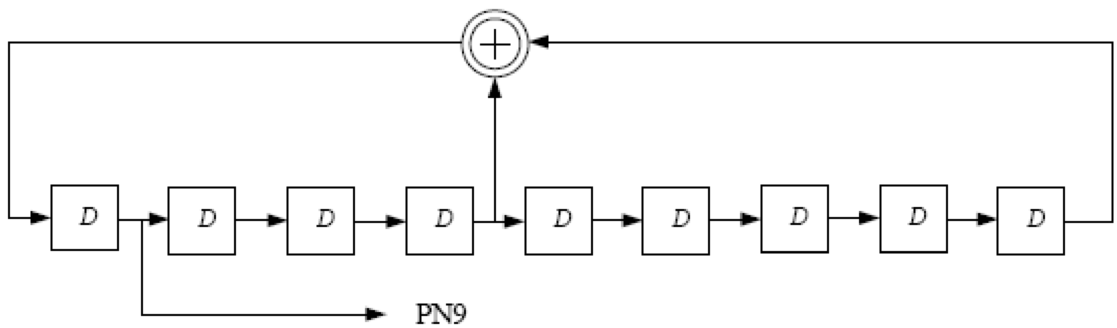

Figure 124—Schematic of the PN9 sequence generator

The PN9 generator shall be reinitialized to the seed after each packet (either transmit or receive). The PN9 generator is clocked using the seed as the starting point and enabled after the first clock cycle. For example, for the seed in the PN9 generator of all ones as “111111111,” the first 30 bits out of the PN9 generator, once it is enabled, would be as follows:

PN9 = 0_0, 0_1, 0_2, 0_3, 1_4, 1_5, 1_6, 1_7, 0_8, 1_9, 1_{10} , 1_{11} , 0_{12} , 0_{13} , 0_{14} , 0_{15} , 1_{16} , 0_{17} , 1_{18} , 1_{19} , 0_{20} , 0_{21} , 1_{22} , 1_{23} , 0_{24} ,1_{25} , 1_{26} , 0_{27} , 1_{28} , 1_{29} .

The scrambled bits are found using an XOR operation of each of the input bits with the PN9 sequence:

$$E_n = R_n \oplus PN9_n$$

After scrambling, the tail bits are reset to all zeros.

20.2.3.11 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 125. 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.

<table>
<tr><td colspan="6"></td><td colspan="2">Octets</td></tr>
<tr><td colspan="6"></td><td></td><td>Variable</td></tr>
<tr><td colspan="6">SHR</td><td rowspan="2">PHR</td><td rowspan="2">PSDU</td></tr>
<tr><td>STF</td><td>STF</td><td>STF</td><td>STF</td><td>STF</td><td>STF</td></tr>
</table>

Figure 125—Format of the TVWS-FSK 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 following Figure 126.

Figure 126—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
N is 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 127.

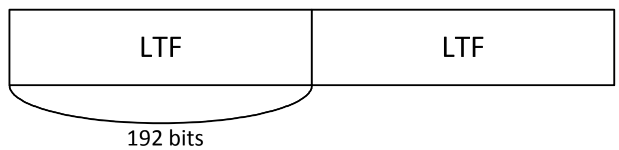

Figure 127—LTF Format

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
N   is 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(*Nactive/Nltf*)

where
Nactive is the number of used subcarriers in rest of the OFDM packet for the particular DFT option,
Nltf is the number of subcarriers used in the LTF.

20.3.1.3 PHR

Figure 128 shows PHR format, which is composed of 40 bits for controlling the TVWS-NB-OFDM PHY.

Bit string index	**0-3**	**4-7**	**8–9**	**10-20**	**21–24**	**25**	**26–33**	**34–39**
Bit mapping	R_3–R_0	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	Rate	FEC Type	Frame length	Channel aggregation	Reserved	HCS	Tail

Figure 128—PHY header fields for TVWS-NB-OFDM

20.3.1.4 PSDU field

TBD.

20.3.2 System parameters for TVBS-NB-OFDM

Table 142 shows system parameters for TVBS-NB-OFDM.

Table 142—System parameters for TVWS-OFDM PHY

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)	

Table 142—System parameters for TVWS-OFDM PHY *(continued)*

Parameter	Mode #1	Mode #2
Symbol interval - T_{SYM} (µs)	Mandatory 1039.5 Optional 1071.0, 1134.0 (T_{FFT}+T_{GF})	
STF duration (T_{SHR})	TBD	
LTF duration (T_{SHR})	TBD	

20.3.3 Modulation and coding parameters for TVBS-NB-OFDM

The modulation and coding schemes with supported data rates for TVBS-NB-OFDM and corresponding MCS-related parameters are shown in the Table 143.

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

TBD.

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.

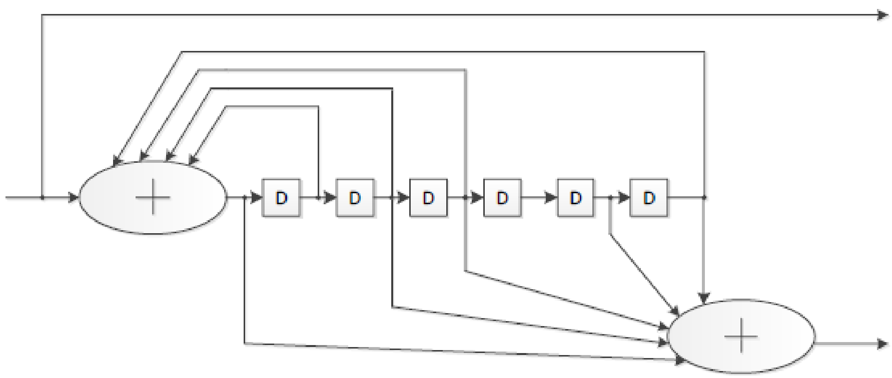

Figure 129—Recursive and systematic convolution encoder

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.

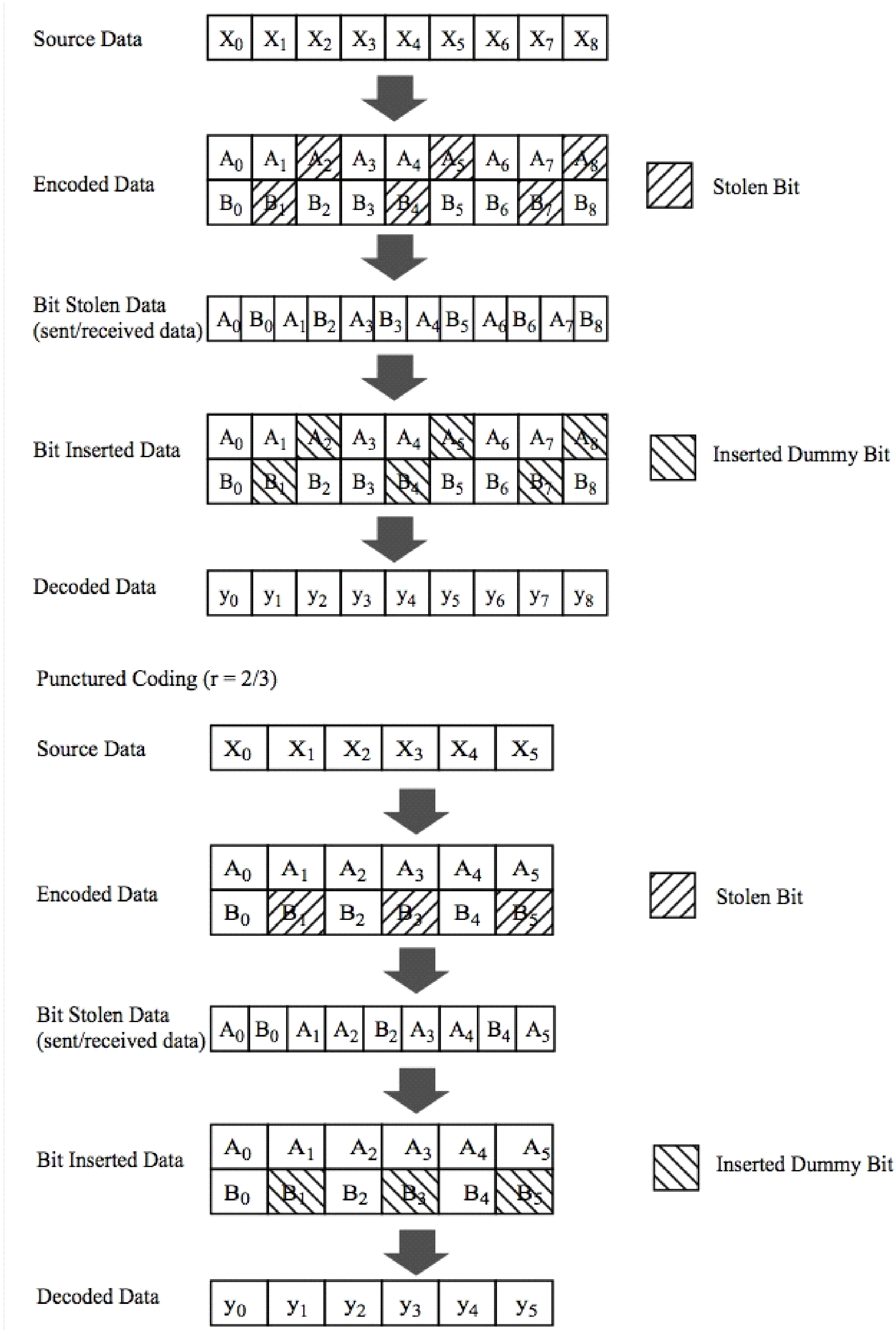

Figure 130—Puncturing pattern

20.3.3.2.3 Pad bit Insertion

TBD.

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 144.

Table 144—Modulation-dependent normalization factor K_{MOD}

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

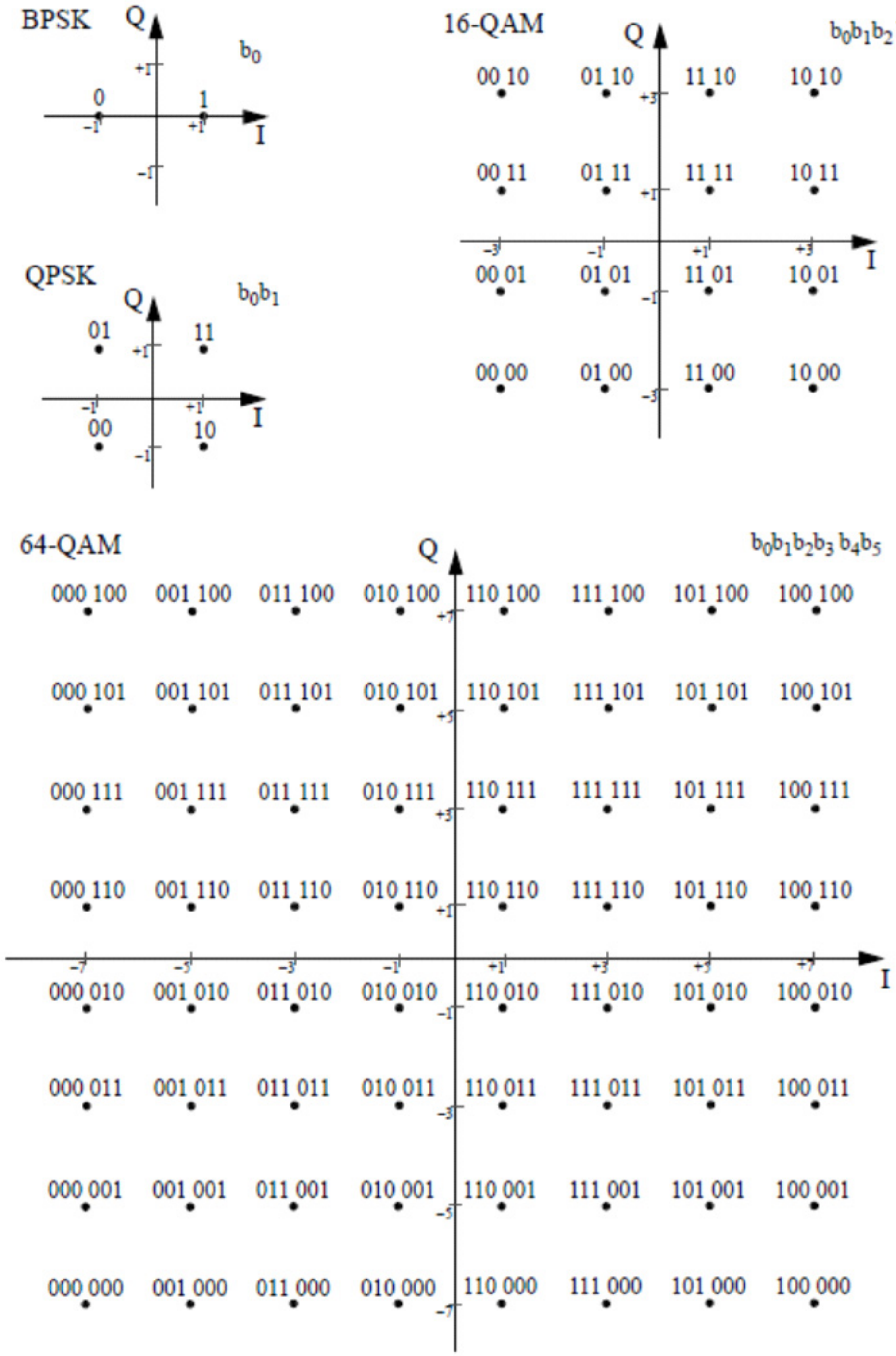

Figure 131—BPSK, QPSK, 16-QAM, and 64-QAM constellation mapping

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:

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

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

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

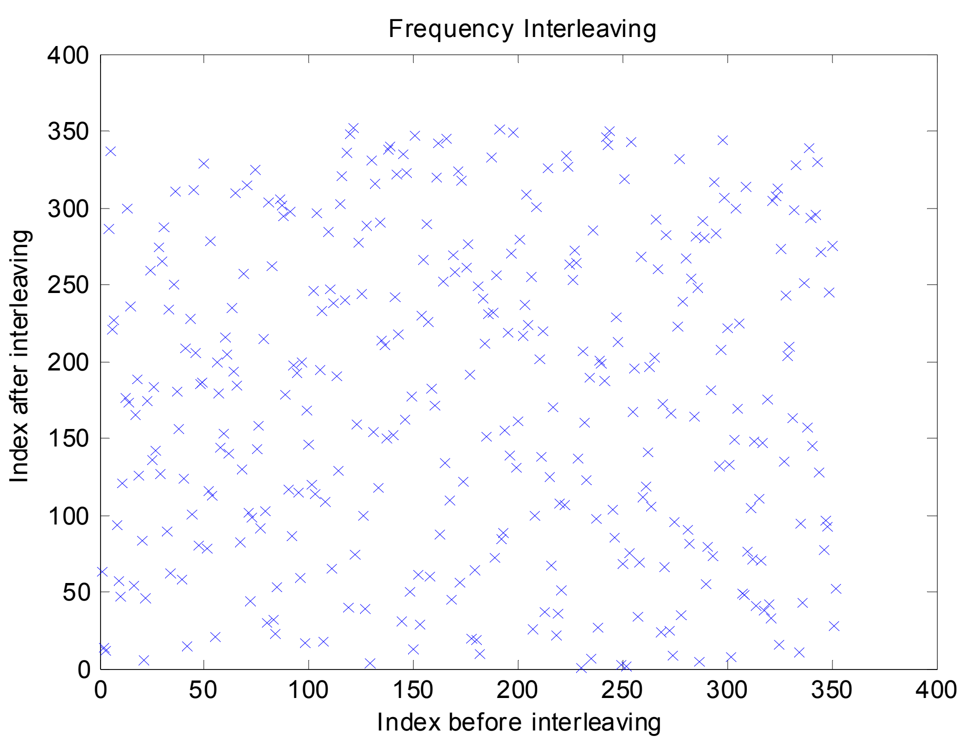

Figure 132—Illustration of frequency interleaving mapping

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.

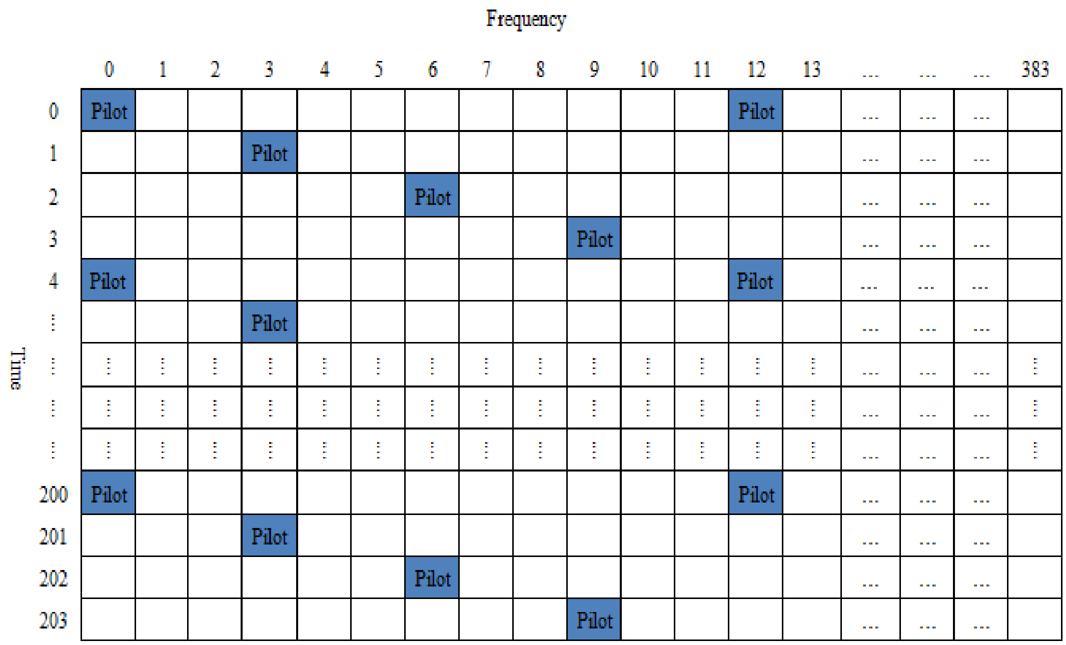

Figure 133—Pattern of pilot subcarriers allocated in OFDM symbol

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 20.3.4 Channel aggregation

Table 145 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 145—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 PHY RF requirement

20.3.5.1 Operating frequency range

The TVWS-NB-OFDM PHY operates in the following bands:

TBD.

20.3.5.2 Transmit power spectral density (PSD) mask

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

20.3.5.3 Pulse shaping

TBD.

Annex Q Considerations for operation in TVWS

[provide overview and specific information on how the MAC features provided are used to enable operation in the TVWS bands under known regulations at the time of publication with appropriate caveats about regulatory changes]

Q.1 Introduction

Overview of the TVWS operational differences

Q.2 Enabling access to TVWS channels

Description of typical requirements for enabling access and how this can be achieved with this standard.

Q.3 Considerations in non-beacon PANs

Description of how 4TV peer-to-peer networks might work.

Q.4 Band sharing

Description of the requirements for vacating the band when told to defer to protected users, and how the dynamic band switching can be achieved using the PHY parameter change mechanisms.

Q.5 Other