IEEE802.16t Direct Peer-to-Peer (DPP) Requirements

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# Definitions and Terms

**Air Interface Protocol (AIP):** A set of rules defining how two DPP SSs communicate with each other over the air.

**Air Interface Resource (AIR):** A two-dimensional entity with a frequency and a time range. Can be expressed in terms of slots.

**CTS Deferral:** A period after CTS reception during which a non-intended receiver willnot access the channel.

**CSMA/CA**: Carrier Sense Multiple Access with Collision Avoidance

**Direct Peer-to-Peer (DPP)**: Direct link between two SSs with no Base Station infrastructure in between nor required for operation.

**DPP PDU**: A Protocol Data Unit (PDU) used in DPP communication.

**DPP SS**: Each of the two SSs of the DPP link.

**DPP Channel**: A continuous frequency range or an aggregation of multiple non-adjacent frequency ranges used for communication between DPP SSs.

**DPP Sub-channel:** A partition of DPP channel in the frequency domain.

**DPP Sub-channel group**: An aggregation of one or more adjacent or non-adjacent DPP sub-channels. A DPP link operates over one subchannel group.

**Half Duplex (HD):** Communication in both directions is not done at the same time.

**Link Adaptation (LA):** A process by which a DPP SS is notified by its peer DPP SS, what MCS it can use for transmission.

**LA Hold Timer:** Link Adaptation Hold Timer is a timer which starts/restarts once a measurement report is received and resets once maximum duration time is reached which is configured in terms of seconds between 1 to 60 seconds.

**MAX RBC:** Maximum Random Backoff Count, a configuration parameter used to declare the transmission failure once the random backoff count exceeds the configured value.

**MAX CO:** Maximum Channel Occupancy, a configuration parameter defining the maximum duration of the burst in terms of the number of slots.

**Minimum Inter Burst Gap:** A minimum duration between consecutive transmission of a DPP SS in which it is not allowed to transmit.

**Non-Intended Receiver:** Any DPP SS other than the intended DPP SS receiver as identified by the destination Ethernet address in the burst.

**Paired DPP Channel:** Two distinct DPP channels are used, one for each direction.

**Paired DPP subchannel group:** Two distinct subchannel groups are used, one for each direction.

**Random Back-Off Duration:** A duration in which a DPP SS avoids channel access following an access attempt in which the channel was busy. The backoff is random so that if multiple DPP SSs are trying to access the channel at the same time, the probability of collision next time is minimized.

**Receive MCS**: The MCS used by the DPP SS for reception.

**Repetition Factor**: the number of PHY layer repetition used for a given MCS

**Robust MCS**: The highest MCS that can reliably be decoded by the peer DPP SS.

**RSSI Threshold:** The measured RSSI is compared with the configurable RSSI Threshold parameter for use by the CSMA mechanism to determine whether or not the channel is in use.

**Slot**: The minimal duration usage within a subchannel.

**Service Flow (SF):** A one direction virtual connection used to carry DPP PDUs meeting certain classification rules.

**Transmit MCS**: The MCS used by the DPP SS for transmission.

**Time To Live (TTL)**: Time before SDU expires.

**Unpaired DPP Channel:** the same DPP channel is used for communication in both directions.

**Unpaired DPP Sub-channel group**: The same subchannel group is used for both directions of communication between two DPP SSs.

# Abbreviations and acronyms

**CTS**: Clear to Send

**OTA:** Over the Air

**RTS**: Request to Send

**RX**: Receive, receiving, reception

**TX:** Transmit, transmitting, transmission

# General (DPP Should be a new clause 9 at same level as PHY

**this section General would be 9.1, and so on.**

## This document specifies the requirements for Direct Peer-to-Peer (DPP) communication between two DPP SSs, which is peer-to-peer operation without the use of base station infrastructure. A Relay Station, however, may be used in DPP mode for range extension. The two DPP SSs of a DPP link are peers (i.e., there is no master slave relationship) and the DPP Air Interface Protocol (AIP) is symmetrical. Minimal a priori configuration as described in this document is needed to establish link connectivity.

## DPP SSs communicate over a paired or unpaired DPP sub-channel group. When two distinct bands are used, the higher frequency band will be referred to as the “high band” and the lower frequency band will be referred to as the “low band”. When two distinct bands are used for TX and RX, the same subchannel group will be used in both bands.

## When two distinct bands are available, an optional frequency DPP frequency diversity mode may be implemented. In this mode, the same TX diversity or RX diversity or both are applied.

## A DPP link operates in Half Duplex (HD) mode with no strict framing, using a CSMA/CA access mechanism. A DPP SS shall only transmit when needed. The CSMA/CA mechanism is used to resolve contention between the two DPP SSs of the DPP link and resolve possible contention with DPP SSs of other in-range DPP links.

## A DPP SS employs the same PHY layer for transmit and receive. The PHY layer is identical to the uplink of the WirelessMAN-NB PHY

## Each DPP SS employs CSMA/CA before the start of a transmission. A DPP link may interfere with a nearby WirelessMAN-NB PtMP system if operated on the same frequency. Moreover, if operated on the same frequency, the DPP SSs may be starved due to high utilization activity in a nearby WirelessMAN-NB PtMP system. It is therefore required to use a dedicated frequency for DPP whenever it is in range of a WirelessMAN-NB PtMP system.

## A DPP SS employs various connectivity management messages with its peer for power control, MCS selection (this is also referred to as “Link Adaptation”) and automatic PHS rules establishment.

## The DPP PDU structure is described in section 5.6. It is optimized for the DPP requirements. The DPP PDU can be used to encapsulate one SDU, concatenate multiple SDUs, encapsulate a fragment of concatenated SDUs or concatenate fragments of multiple SDUs.

## A DPP link may employ multiple service flows in each direction. Each service flow carries SDUs which meet classification rules configured at the DPP SS at which the SDU is received. Each service flow has an associated traffic priority between 0 to 7 (the higher the number, the higher the priority). Higher priority SDUs are transmitted before lower priority SDUs.

## The TTL shall be configured per SF based on the maximum latency tolerated for the SF. When the SDU is received for transmission, a DPP SS shall tag the SDUs with TTL based on the SF requirement. DPP SS shall remove the SDUs from the transmission queue if the TTL expires. The end-to-end DPP Link latency will be considered when configuring the TTL value per service flow.

## Each DPP SS may automatically establish Packet Header Suppression (PHS) rules with its peer.

# DPP Air Interface Protocol (AIP) (9.2)

## The DPP SS shall generate bursts in accordance with Figure 1 below. The DPP burst consists of a Gain Adjustment, Synchronization, Control Message and one or more DPP PDU fields. The gain adjustment field is added in the beginning of every burst to support connectionless operation.

## The DPP SS shall use a SC-FDMA waveform for communication in both directions as described in the WirelessMAN-NB PHY specification section “8.6.4 Uplink”. The DPP SS shall generate Control Messages and Data DPP PDUs in accordance with the procedure described in the WirelessMAN-NB PHY specification document, section “8.6.8 Uplink transmitter”.

## In generating the Gain Adjustment and Synchronization fields of a burst, the DPP SS shall omit the channel coding and slot formation part of the procedure described in the WirelessMAN-NB PHY specification document, section “8.6.8 Uplink transmitter”. The DPP SS shall transmit the Gain Adjustment and Synchronization fields in the lowest subchannel of the subchannel group if more than one subchannel is used (aggregated) between a pair of radios operating in DPP mode.

## One transmission cycle constitutes one burst, and a burst can have multiple DPP PDUs. The DPP SS shall limit the number of DPP PDUs in a burst to not exceed 16.



Figure 1. Burst structure

## Burst Structure:

### **Gain Adjustment Period**: The DPP SS shall begin each burst by transmitting one slot worth of alternate 1’s and 0’s as a BPSK modulated signal for a receiver to adjust the gain.

### **Synchronization:** Following the Gain Adjustment Period,the DPP SS shall transmit a preamble to be used as a synchronization signal carrying a Gold sequence of length 63 as described in WirelessMAN-NB PHY specification document, refer to the section “*8.6.7 Downlink Preamble Transmission”.*

### **Control Message:** The DPP SS shall use the robust MCS when transmitting a control message (CTRL MSG). Table 4 describes the CTRL MSG structure. In the control message type field, the DPP SS shall indicate whether the CTRL MSG is used to convey information about DPP PDUs that follow the CTRL MSG in the burst or is used to indicate an RTS, CTS, or Ack message. The DPP SS shall set an ACK indication if any PDU within the burst requires an Ack. An ACK indication is set based on the presence of any DPP PDU which needs an ACK, and is not allowed for RTS and CTS messages. A non-intended DPP SS receiver shall use the ACK indication for ACK-based deferral as defined in section 6.4.3.

### **DPP PDU**: The DPP SS shall transmit DPP PDUs in accordance with 802.16t PHY specification document, section “*8.6.8* *Uplink transmitter” except for the Ranging section.*

The DPP SS shall limit the total duration of a burst to the value of a configurable Maximal Channel Occupancy (MAX CO) specified in terms of a number of slots.

## DPP PDU structure

1. The DPP SS shall begin each PDU with 4 bytes of header followed by a variable length payload and a 4-byte CRC as shown in Figure 2.



Figure 2. DPP PDU Structure

1. The DPP SS shall produce PDU headers in accordance with Figure 3 and Table 1.

 

Figure 3. DPP PDU Header Structure

Table 1 DPP PDU Header fields

|  |  |  |
| --- | --- | --- |
| 1. Syntax
 | Size(bits) | Notes |
| PDU header () { | --- | ---- |
| Header Type | 1 | 0: Management DPP PDU 1: Data DPP PDU |
| Encryption indication | 1 | 0: Off 1: On |
| PHS indication | 1 | 0: Off 1: On |
| Sub Header indication  | 1 | 0: Absent 1: Present |
| ACK Indication | 1 | 0: Off 1: ACK to be sent. |
| Length | 11 | 0 to 2047 Length in bytes of the DPP PDU including the header and the 4-Byte CRC. |
| If (PHS indication == 1) PHS index   | 8 | If PHS Indication is set to 0, PHS is turned off and there is no PHS index.PHS Index= 0, PDU is unsuppressed. PHS Index != 0 PDU is suppressed ,with PHS Index indicating the PHS rule used.  |
| HCS  | 8 | CRC8 for the above 3 bytes (as in Table 6-3) |
| } |  |  |

.

1. The DPP SS shall include the following fields in the header of each DPP PDU it transmits:
2. A Header Type, indicating the type of the DPP PDU:
3. The value 0 indicates it is a Management DPP PDU used to carry management messages mentioned below,
4. Association Messages, refer to Table 5Table 6 and Table 6
5. Measurement Report, refer to Table 7
6. Automatic PHS, refer to Table 9 and Table 10
7. The value 1 indicates it is a Data DPP PDU.
8. An Encryption indication. The value 0 indicates the data is not encrypted. The value 1 indicates the data is encrypted.
9. A PHS indication. The value 0 indicates PHS is disabled and the value 1 indicates PHS is enabled. The value of the PHS indication field is determined by the PHS configuration in the service flow associated with this PDU.
10. A Sub-Header Indication. The value 0 indicates there are no sub-headers and 1 indicates there are sub-headers present within the DPP PDU. The sub-header is present immediately after the DPP PDU header and then onwards to the beginning of the first SDU. Within the sub-header, the Sub-header type field describes the SDUs as either packed by value of 0 or fragmented by value of 1. The sub-header format is described in Table 2.
11. ACK Indication field (ACKI). The value 0 indicates that an ACK is not needed for the DPP PDU. The value 1 indicates that an ACK is needed.
12. A DPP PDU length field. The value can be from 0 to 2047 referring to the number of bytes comprising the DPP PDU.
13. A PHS Index field. If the PHS indication is 1 this field indicates the PHS index. Otherwise, it is 0. Refer to section 8.3 for PHS related details.
14. The HCS is computed in the same manner as described in Table 6-3 of 802.16-2017.

Table 2 Sub-Header format

|  |  |  |
| --- | --- | --- |
| 1. Syntax
 | Size(bits) | Notes |
| Sub header () { | --- | ---- |
| Sub header Type | 1 | 0: Packing 1: Fragmentation |
| Fragmentation state | 2 | Indicates the fragmentation state of the payload:00 = No fragmentation01 = Last fragment10 = First fragment11 = Continuing (middle) fragment |
| FSN | 8 | Sequence number of the current SDU fragment. The value shall increment by one (modulo 256) for each fragment.  |
| Length  | 11 | 0 to 2047 Length in bytes of the SDU including the Sub header. |
| Reserved | 2 |  |
| } |  |  |
| } |  |  |

1. The DPP SS shall pack SDUs mapped to the same service flow in a single DPP PDU subject to the limit of the Maximum Channel Occupancy. SDUs mapped to the same service flow will have the same PHS index value and ACK requirements. If the number of SDUs exceed the limit of the Maximum Channel Occupancy, the DPP SS shall send the remaining SDUs in the next burst. If the SDU needs to be fragmented, the DPP SS shall indicate “fragmentation” in the PDU Sub-header Type field. shall indicate fragmentation. Refer to Table 2 **.** for the sub header details.
2. The 4-byte DPP PDU CRC is computed in the same manner as described in 802.16 section 6.3.3.5 CRC calculation.

# Channel Access

## General

### The DPP SS shall support the following configurable channel/sub-channel access schemes:

## Half Duplex non-persistent CSMA with the same frequency used in both directions.

## Half Duplex non-persistent CSMA with a distinct frequency used in each direction. In this case, sensing is done on both transmit and receive frequencies.

## In addition to the above, the channel access procedure can be configured to use Request to Send (RTS) and Clear to Send (CTS) messages.

### The DPP SS shall support the division of a channel dedicated to DPP service into sub-channels, the same as is done in the WirelessMAN-NB PHY.

### The DPP SS shall limit each burst length to a multiple of the slot duration that is specified as an integer in a configurable Maximum Channel Occupancy (MAX CO) parameter. The MAX CO parameter will be configured by the user based on the application/deployment scenario. This feature helps to avoid excessive usage of the channel by one DPP SS.

### A configurable Minimum Inter Burst Gap between consecutive transmission by the same DPP SS shall disallow the advantage in channel access to a DPP SS who has just transmitted and would otherwise have an advantage relative to other DPP SS.

### When the DPP SS has data to transmit and the channel is free, it shall compute the total duration of the burst in slots, based on the length of the SDUs in the buffer and the MCS to be used for transmission. If the computed duration of the burst for all available SDUs to be transmitted is less than the Maximum Channel Occupancy parameter, then the DPP SS shall send all available SDUs immediately in the same burst; else when the computed burst duration exceeds the Maximum Channel Occupancy parameter, the DPP SS shall send the remaining SDUs in the next burst after the DPP SS performs carrier sense and determines the channel is free. The DPP SS shall use fragmentation necessary to ensure that the burst duration does not exceed the configured Maximum Channel Occupancy parameter.

### The DPP SS shall transmit higher priority SDUs first while lower priority SDUs are left in the queue and transmitted in the next burst. An SDU shall be discarded when its TTL expires .

### A DPP SS shall compute the RSSI of a signal of interest at the antenna connector. The RSSI measurement is vendor specific. One possible method to estimate RSSI is given by equation (8-151) described in 8.4.12.2.

### When the DPP terminal has an entirely new data burst ready to transmit, the terminal shall set the Random Backoff Count (RBC) to zero. When the DPP terminal has a data burst ready to transmit and RBC is zero, the terminal shall transmit the data immediately upon detecting that the measured RSSI on the transmit channel is less than the RSSI threshold . In case the DPP terminal with data to transmit senses that the transmit channel is busy as indicated by the measured RSSI being greater than the RSSI threshold, the terminal shall increment the RBC count, and select a Random Back-Off Duration based on the integer random function output with the range of values between one to MAX CO in terms of slots. When the DPP terminal has postponed transmission due to sensing that the measured RSSI is greater than the RSSI threshold, after waiting for the Random Back-Off Duration, the DPP terminal shall modify the burst by removing TTL expired SDUs and adding new SDUs received based on the priority since the previous attempt. The DPP terminal shall repeat the process of channel sensing and: - transmit if the measured RSSI is less than the RSSI threshold, or - increment the RBC and compute a new Random Back-Off time. In case the RBC exceeds the MAX RBC, the DPP terminal shall reset RBC to zero and send a vendor-specific indication to the operator.

### The DPP SS shall indicate to its peer the need to acknowledge error free receipt of one or more DPP PDUs in the burst by using the ACK Indication bit in the DPP PDU header shown in Table 1. The DPP SS shall set the Ack Indication bit to 1 in the CTRL MSG if the transmitted burst requires any of its DPP PDUs to be acknowledged.

### Upon detecting a burst, the DPP SS receiver shall decode all the PDUs in the burst and check whether the CRC passed or failed for each of the PDUs. The DPP SS receiver shall then update the ACK bit map value for the bit position corresponding to each of the PDUs to 1 for pass or 0 for fail. ACK bitmap LSB indicates the first DPP PDU and MSB last. In the received burst DPP SS shall check for ACK Indication bit in CTRL-MSG, if it is set to 1 then DPP SS shall transmit a CTRL MSG to the sender DPP SS with type ACK (value 3) along with the ACK bit map.

### When an ACK is required, the sending DPP SS shall wait for the ACK message for a configurable duration (this should be greater than or equal to the maximum round trip delay) before retransmitting the PDU if no ACK is received.

## Half Duplex CSMA

### This paragraph describes the behavior of DPP SSs using HD CSMA with the same band used for TX and RX as well as the case in which distinct bands are used for TX and RX.

### The DPP SS shall conform with the flowchart behavior shown in Figure 4 when initiating a transmission.

 

Figure 4. CSMA flowchart for transmitting radio

### Intended receiver behavior

1. The DPP SS shall determine that it is the intended receiver if it identifies its MAC address in an incoming CTRL MSG.
2. The intended DPP receive SS shall decode the DPP PDUs based on the MCS identified within the CTRL MSG.
3. If an ACK is required, the intended DPP receive SS shall perform the CSMA procedure to send the ACK. The DPP receive SS shall transmit ACK messages using Robust MCS.

### Non-Intended Receiver behavior

The DPP SS shall determine that it is a non-intended receiver if it does not identify its MAC address or Name in the incoming message. The DPP SS shall discard a message for which it is a non-intended receiver. If an ACK is required based on an ACK indication in the incoming CTRL MSG, a non-intended receiver shall avoid transmission within the ACK Deferral duration from the time the CTRL MSG was received as defined in 6.4.3.

## CSMA/CA with RTS, CTS

### The CSMA mechanism has the known problem of hidden nodes. This is optionally addressed by the exchange of RTS and CTS Messages between the two DPP SSs.

### If needed DPP SS shall be configured to transmit the CTRL-MSG indicating RTS with Control Message Type value 1 described in Table 4 and upon receiving the CTS, the burst with PDUs shall be transmitted as per the CTS.

### The access procedure described in this paragraph includes a RTS message transmitted by the DPP SS with SDU(s) queued to transmit, referred to as the “initiating DPP SS”, and a CTS response by the intended receiver. RTS and CTS are short messages that precede the data transmission. Upon having one or more SDUs queued to send and CSMA-sensing that the channel is clear, the DPP SS shall transmit a RTS message that specifies the requested number of bytes including the DPP PDU and SDU overheads. The intended DPP SS receiver specifies within the CTS message the allocated number of slots to be transmitted and the MCS to be used which is based on the measured CINR. Refer Table 4 for RTS/CTS message details.

### The initiating DPP SS shall conform with the flowchart behavior shown in Figure 5 when the need for the RTS is configured.

### Intended DPP SS Receiver behavior:

1. The intended DPP SS receiver shall detect its MAC address or Name in CTRL MSG as described in Table 4.
2. Upon receiving a RTS message, the intended DPP SS receiver shall convert the number of bytes that were requested in the CTRL MSG into the number of slots that it is allocating at the MCS which it determines based on the CINR measured in the received RTS message, plus the additional slots required to transmit the CTRL MSG, using the Robust MCS.
3. Upon CSMA-sensing that the channel is clear after receiving a RTS message, the intended DPP SS receiver shall transmit a CTS message identifying the number of slots it has allocated along with the MCS to be used in accordance with Table 4.
4. When the intended DPP receiver transmits a CTS message in response to a RTS message, the DPP SS receiver shall delay any subsequent transmission by the CTS Deferral time as defined in 6.4.2.
5. Upon receiving a message without errors, the intended DPP SS receiver shall decode the message and upon CSMA-sensing that the channel is clear, send an ACK to the sender if required per the CTRL MSG.

### Non-Intended DPP SS Receiver behavior

1. A DPP SS is considered to be a non-intended DPP SS receiver for a message it receives in which it does not recognize its MAC address or Name (see Table 4).
2. If a received CTRL MSG indicates RTS in the Control Message Type field, the non-intended DPP SS receiver shall avoid transmitting within the RTS Deferral duration from the time the CTRL MSG was received as defined in 6.4.1.
3. If a received CTRL MSG indicates CTS in the Control Message Type field, the non-intended DPP SS receiver shall avoid transmitting within the CTS Deferral duration from the time the CTRL MSG was received as defined in 6.4.2.
4. If CTRL MSG is received with an ACK Indication field requiring an ACK, then the non-intended DPP SS receiver will avoid transmitting within the ACK deferral duration from the time the CTRL MSG was received as defined in 6.4.3.

## Deferrals

### RTS Deferral: When the non-intended DPP SS receiver detects a CTRL MSG with indication of RTS in the Control Message Type field, it shall compute the deferral time by considering the number of bytes requested to compute the number of slots required considering robust MCS, plus twice the duration of the CTRL MSG, gain adjustment, synchronization signal, and maximum round trip duration.

### CTS Deferral:

1. When the non-intended DPP SS receiver detects a CTRL MSG with the indication of CTS in the Control Message Type field, it shall compute the CTS Deferral Time by considering the number of slots allocated in the CTS message plus the duration of the CTRL MSG, gain adjustment, synchronization signal, and maximum round trip duration.
2. When the intended DPP SS receiver sends a CTRL MSG with the indication of CTS in the Control Message Type field, it shall compute the CTS Deferral Time by considering the number of slots allocated in the CTS message plus the duration of the CTRL MSG, gain adjustment, synchronization signal, and maximum round trip duration.

### ACK Deferral: When a non-intended DPP SS receiver detects a CTRL MSG with the ACK indication ON, it shall compute the deferral time by considering the number of slots allocated in the current burst plus the duration of the CTRL MSG, gain adjustment, synchronization signal, and maximum round trip duration.

 

Figure 5. CSMA/CA RTS CTS flowchart for DPP SS initiating transmission

# DPP SS States

## Offline state

## The DPP SS when turned ON shall enter the Offline state by default.

## Each DPP SS shall have a unique MAC Address and public/private key pair that is configured during production.

## The DPP SS shall allow an X.509 certificate signed by a Certificate Authority to be installed during production or later by a Certificate Authority under customer responsibility. The purpose of the certificate is to protect the identity of the DPP SS and is used by the TLS authentication scheme for the DPP SSs to mutually authenticate each other.

## The DPP SS shall be configurable with the following operational parameters:

##  Frequency (one or two frequencies),

## Channel parameters (Subchannel bandwidth, subchannel bitmap and subchannel group)

## Service flows with their associated QoS profiles.

## Pairing mode as described in 7.1 subparagraph 5 below.

## Name (optional)

## Other DPP parameters identified in this document as “configurable”.

## Each DPP SS shall be configurable to identify which pairing mode it is to use. The DPP SS shall support the following two pairing modes:

1. Automatic Pairing: If configured for Automatic Pairing, a DPP SS shall identify its peer(s) using the preconfigured peer’s MAC address or a Name.
2. List Selection Pairing: If configured for List Selection Pairing, a DPP SS shall support a vendor specific display of the names of DPP SSs within its range with a Certificate Authority (CA) Issuer, identical to its configured peer CA name. The DPP SS names and their CA shall be extracted from the ASSOCIATE Request messages received. During list selection pairing shall allow the user to manually select the desired peer SS from the list of DPP SSs having matching CAs within range, using a vendor-specific process, to complete the association process. Refer to section 8.1 for the identity Filtering process description.

## If configured for the ‘Automatic’ pairing mode, the DPP SS shall be configurable with the following parameters of its peer DPP SS:

## MAC address of peer SS and an optional Name

## public key of its peer SS.

## If configured for the ‘List Selection’ pairing mode, the DPP SS shall be configurable with parameters of valid peer DPP SSs as follows:

## certificate authority name, as appears in the certificate Issuer Name field.

## Certificate authority root public key.

## When configured to use two distinct bands in ‘Automatic’ pairing mode, the DPP SS shall compare its own MAC address with the MAC address of its peer and use the higher band for TX and the lower band for RX if its MAC address is higher than the peer DPP SS’s MAC address; otherwise, it selects the lower band for TX and the higher band for RX.

## When configured to use two distinct bands in ‘List Selection’ pairing mode, the DPP SS shall operate on the lower band while in Online state and Association state. While in Operational state, the DPP shall compare its own MAC address with the MAC address of its peer and use the higher band for TX and the lower band for RX if its MAC address is higher than the peer DPP SS’s MAC address; otherwise, it selects the lower band for TX and the higher band for RX.

## The DPP SS shall switch to the Online state based on a vendor-specific manual trigger.

## Online state

1. The Online state is used when the DPP SS is not paired but is seeking its configured peer for pairing. While in the Online state, the DPP SS shall periodically transmit an ASSOCIATE Request message. The information included in the message depends on the DPP SS pairing mode as follows:
	1. When configured for Automatic Pairing mode, the ASSOCIATE Request message transmitted by a DPP SS shall indicate the transmitting DPP SS MAC address and optionally its Name (if configured to include its Name) .
	2. When configured for List Selection pairing mode, the ASSOCIATE Request message transmitted by a DPP SS shall indicate the transmitting DPP SS Name and the Certificate Authority name, as appear in its certificate. .

## Association state

## In the case of automatic pairing mode, the DPP SS shall enter the association state following the receipt of an ASSOCIATE Response or ASSOCIATE Request message from its peer. In the case of list selection pairing mode, the DPP SS shall enter the association state following the sending or receipt of an ASSOCIATE Response from a peer.

## The DPP SS shall perform the following activities during the Association state:

## Verify the DPP SS identity of its peer SS as described in section 8.1.

## Authenticate its peer SS as described in section 8.2.

## Automatically configure PHS as described in section 8.3.

## The DPP SS in the Association state shall receive and transmit internal control messages (non-traffic table 5 to 10) but does not transmit any user data until it reaches the Operational state.

## Operational state

## The DPP SS shall enter the Operational state automatically, following the completion of the activities described in the Association state with successful verification and authentication of its peer DPP SS.

## The DPP SS shall perform the following activities during the Operational state:

## Exchange data messages with its peer DPP SS.

## Perform continuous link adaptation to adjust MCS and repetitions based on the CINR at the peer DPP SS. Link adaptation is performed in each direction independent of the other direction. Refer to section 8.4 for the link adaptation process description.

## Perform continuous receive gain adjustments as needed to attempt to bring the signal level to the optimum level for demodulation (maximize level subject to no saturation of ADC) .

## Perform power control to minimize the TX power subject to the RSSI performance criteria. Refer to section 8.5 for the power control process description.

## Continuously adjust automatic PHS rules. Refer to section 8.3 for the automatic PHS process description.

## The DPP SS shall leave Operational state and return to Association state if its peer DPP SS does not respond/transmit any burst for the time duration which shall be provided in the configuration in terms of seconds.

# DPP link Connectivity Establishment and Maintenance Procedures

## Identity Filtering

### If configured to use the ‘Automatic’ pairing mode, a pair of DPP SS peers shall exchange their MAC addresses and Names using ASSOCIATE Request/Response messages. The DPP SS receiving an ASSOCIATE Request message shall compare the received MAC address or Name with the MAC address(es) or Name of its configured peer DPP SS and send an ASSOCIATE Response message to the sender of the ASSOCIATE Request message if a match is found. If there is no match, the DPP SS shall not respond to the ASSOCIATE request message and returns to Online state. The identity verification process is shown in Figure 6 below.

### If configured to use the ‘List Selection’ pairing mode, the DPP SS receiving an ASSOCIATE Request message shall compare the CA identified in the received ASSOCIATE Request message with its configured peer DPP SS(s) CA and if matched will add the SS’s name and MAC address, as appear in the ASSOCIATE Request message, to the list of candidate DPP SS peers.

### If configured to use the ‘List Selection’ pairing mode, the DPP SS shall include a vendor-specific function to display the list of candidate DPP SS peer Names to enable manual selection of the of the peer DPP SS. When a DPP SS is selected from the list, the DPP SS shall send an ASSOCIATE Response message to the selected DPP SS. Figure 7 shows the flow. If no DPP SS is selected, the DPP SS shall return to the Online state.



Figure 6. Association message flow Automatic Pairing

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Figure 7 Association message flow: List Selection Pairing

## Authentication

### Authentication and Key Management

1. Each DPP SS in the network shall include a unique private / public key pair.
2. Each DPP SS shall have an X.509 certificate, that includes the unique public key and has been signed by a trusted Certificate Authority (CA).
3. A DPP SS configured to use the ‘List Selection’ pairing mode shall have a configurable DPP SS Name.

### Each DPP SS shall support both client and server TLS v1.3. If TLS authentication fails, the DPP SS shall return to the Online state.

### At minimum, a DPP SS shall support the following TLS v1.3 cipher suites options:

1. Key exchange: Elliptic Curve Diffie-Hellman (ECDH) [RFC 4492] or ephemeral Elliptic Curve Diffie-Hellman (ECDHE)
2. Authentication: Elliptic Curve Digital Signature Algorithm (ECDSA)
3. Encryption: AES-128 or AES-256

### Message authentication: HMAC-SHA256, HMAC-SHA384 and HMAC-SHA512.

### Upon sending an ASSOCIATE Response, the DPP SS shall compare its own MAC address with the MAC address of its peer and shall operate as a mTLS (mutual TLS) server if its MAC address is higher than the peer DPP SS’s MAC address, otherwise, it shall operate as a mTLS client.

### Upon receiving an ASSOCIATE Response message, the receiving SS shall compare its own MAC address with the MAC address of its peer and shall operate as a mTLS server if its MAC address is higher than the peer DPP SS’s MAC address, otherwise, it shall operate as a mTLS client.

### When operating as a TLS server, if the DPP SS does not receive a ClientHello message within TBD msec after beginning operating as a TLS server started, it shall return to Online state.

### A DPP SS operating as mTLS server, shall include in the ServerHello optional fields: Certificate, CertificateRequest and CertificateVerify, to support mutual authentication.

### Upon receiving a certificate from another DPP SS, if configured to ‘Automatic’ pairing, the receiving SS shall authenticate the sending SS identity using its configured public key .

### Upon receiving a certificate from another DPP SS, if configured to ‘List Selection’ pairing, the receiving SS shall authenticate the issuing CA using its configured root CA public key and then authenticate the SS by the public key sent with the mTLS certificate.

## Automatic Packet Header Suppression

### A repetitive portion of the data in the SDU can be suppressed by the sender and restored by the receiver depending on known rules called PHS rules. PHS rules are used in reconstructing the packet correctly at the receiving end.

### PHS parameters include PHS field, PHS index, PHS mask and PHS size. All these parameters are specified during PHS rule creation.

1. **PHS Field (PHSF):** A string of bytes representing the portion of the SDU in which one or more bytes are to be suppressed. It’s a snapshot of the uncompressed SDU inclusive of suppressed and unsuppressed bytes. The most significant byte of the string corresponds to the first byte of the SDU.
2. **PHS Index (PHSI):** The PHS Index has a value between 1 and 255, which uniquely references the PHS rule used to suppress the SDU. If PHS is enabled, each DPP PDU header indicates the PHSI, which references the PHSF. If PHS is enabled and the SDU is not suppressed, the PHS Index is set to 0.
3. **PHS Mask (PHSM):** A bitmask indicating which bytes in the PHS field to suppress and which not to suppress. If a bit has the value 1 in the PHSM, the corresponding byte in the PHSF is supressed, otherwise, if a bit has the value 0 in the PHSM, the corresponding byte in the PHSF is not supressed.
4. **PHS Size (PHSS):** PHS Size is the total length in bytes spanning over entire data portion of the SDU for which the PHS rule is applied. The PHS size includes suppressed and unsuppressed bytes.
5. The value of PHSS is equivalent to number of bytes in the PHSF and number of valid bits in the PHSM.

Figure 8 demonstrates SDU suppression and restoration. Note that the PHSF and PHSS span the entire suppression field, included suppressed and unsuppressed bytes.



Figure 8 PHS Suppression and Restoration

### When PHS is enabled, the DPP SS transmitter shall automatically create a new PHS rule when a SDU is received with a new value for one pf the PHS fields for which the PHS mask indicates suppression is required. The DPP SS shall send its peer the PHS request message to specify the field values that can be suppressed in the SDU and the associated PHS index to identify the PHS rule.

### When PHS is enabled, a sending DPP SS shall trigger creation of a new PHS rule when any repetitive field value in the traffic is observed and the field values are not matching with any of the already existing PHS rule field values stored.

### A sending DPP SS shall apply PHS after creation of a PHS rule. Until a PHS rule is created, the SDU shall be transmitted unsuppressed with PHS index set to 0.

### When PHS is applied, the sending DPP SS shall include PHS index corresponding to the PHS rule used to suppress the SDU, in the DPP PDU header.

### A receiving DPP SS shall identify each PHS rule using a PHS Index (PHSI) as specified in DPP PDU header. A receiving DPP SS shall reconstruct the SDU using the PHS Mask, PHS size and PHS field values corresponding to the PHS rule, this operation is as shown if Figure 9.



Figure 9 DPP SS transmitter and Receiver Operation

### PHS rules are created with PHS message exchanges between two DPP SSs. In Figure 10 the DPP SS1 is initiating the creation of PHS rule by sending PHS request message to DPP SS2. The DPP SS2 shall create the PHS rule and respond with a PHS response message indicating the PHS index for this rule (this is referred to an the PHS response message as a “response code”). The DPP SS1 shall interpret the PHS Index response code as “Accept” response. In case the DPP SS2 identifies an error (if the PHS Index is already in use or any unacceptable parameters specified) in the PHS Request message then it shall response with response code 0 indicating a Reject. The DPP SS1 shall acknowledge the response by sending the PHS Ack message.



Figure 10 PHS creation message flow

### The Automatic PHS-related messages are described in section 10.1.4.

## Link Adaptation (LA)

### Link adaptation is the process of dynamic selection for transmission of the highest MCS and repetition rate that can support reliable communications subject to the CINR at the peer SS receiver.

### At the beginning of the LA process, the DPP SS shall transmit all packets with the Robust MCS. To initiate the LA process, when DPP SS enters the Association state, measurements shall be done on the ASSOCIATE Request message received, then DPP SS shall send an unsolicited Measurement Report message to its peer DPP SS. To reinitiate the LA process, the DPP SS shall send an unsolicited Measurement Report message to its peer DPP SS whenever it detects a significant change in CINR measurements indicating that the current MCS needs to be changed. DPP SS shall have the configurable range of CINR (minimum and maximum) for each MCS which shall be used to decide the MCS.

### Table 3 defines the values of combined MCS and repetition factor.

### After receiving a Measurement Report message, the DPP SS shall start/restart its LA hold timer and use the MCS as per the report until the timer expires or another Measurement Report message is received, whichever occurs first.

###

### In case the LA hold timer expires, the DPP SS shall use the Robust MCS for transmission until the LA process has reoccurred and determined that a different MCS should be applied.

### The Measurement Report message structure is described in section 10.1.3. Figure 11 shows the flow of the LA process.



Figure 11. Link Adaptation (LA) Procedure

Table 3 MCS table

|  |  |
| --- | --- |
| MCS | Value |
| QPSK 1/2 R128  | 0 |
| QPSK 1/2 R64 | 1 |
| QPSK 1/2 R32 | 2 |
| QPSK 1/2 R16 | 3 |
| QPSK 1/2 R8 | 4 |
| QPSK 1/2 R4 | 5 |
| QPSK 1/2 R2 | 6 |
| QPSK 1/2  | 7 |
| QPSK 3/4 | 8 |
| 16 QAM 1/2 | 9 |
| 16 QAM 3/4 | 10 |
| 64 QAM 3/4 | 11 |
| 64 QAM 5/6 | 12 |
| 256 QAM 7/8 | 13 |

## Power Control

### Power control is an optional DPP process. When power control is not enabled, the DPP SS shall transmit at a configurable fixed TX power (typically Max TX power).

### The objective of the power control is to minimize self-interference by reduction in TX power as much as possible subject to CINR and/or RSSI criteria at the peer DPP SS. The criteria is vendor specific. The receiving DPP SS sends a Measurement Report message (the same message type as used for LA) which includes the RSSI, so that the transmitting DPP SS can use this RSSI measurement to compare it with the target RSSI and do the delta power correction in the next transmission (if power control is enabled). The power control process (if present) must be designed to work synergistically with the LA process.

### The Measurement Report message structure is defined in section 10.1.3 .

# Relay Station

## General

### Relay station shall perform the channel access as per the procedure described in section 6.2. Relay station shall not do RTS CTS mechanism for relaying.

### The CTRL-MSG within the burst shall indicate if the burst is to be relayed using the Relay Option field as described in Table 4.

### A DPP SS shall be configured with one of three relay options as follows:

* + 1. Direct transmission only: when a relay station receives a CTRL-MSG with Relay Option field value of 0, it will not relay the burst.
		2. Relay: When a relay station receives a CTRL-MSG with Relay Option value of 1, it will relay the burst.
		3. Relay based on ACK failure: For this option, the ACK Indication field will be set to a value of 1 in the CTRL-MSG. When the relay station receives the CTRL-MSG with a Relay Option value of 2, it will decode the burst and wait for the ACK bit map to be received until the configurable wait time duration has passed. If the ACK bit map is not received, the relay station will relay the whole burst. If the ACK bit map is received, depending on the bitmap status, the relay station will relay only the PDUs in the burst whose bit status is zero. The ACK bitmap is present in the CTRL-MSG when the Control Message Type option value is 3.

### A relay station will relay the burst if required by the CTRL MSG. The relay station will change the relay status to 1 in CTRL-MSG when it does the relay transmission.

# Messages format

All data fields are little endian.

### Control Message (CTRL MSG)

Table 4 CTRL Message

|  |  |  |
| --- | --- | --- |
|  Syntax | Size(bits) | Notes |
| Control Message () { | --- | ---- |
| Control Message Type | 2 | This field indicates the type of CTRL MSG based on what description it is carrying.Value 0: DPP PDU,  1: RTS 2: CTS 3: ACK |
| Relay Status | 1 | 0: Original transmission, 1: Relay Transmission |
| Relay Option | 2 | Value 0: Direct transmission only, No Relay 1: Relay 2: Relay based on ACK failure |
| Sender ID | 48 | MAC address or Name |
| Receiver ID  | 48 | MAC address or Name |
| If (control message Type == 1) { |  |  |
| Requested Bytes | 16 | Total bytes to transmit including DPP PDU and SDU overheads. |
| Reserved |  3  |  |
| } |  |  |
| ElseIf (control message Type == 3) { |  |  |
| ACK Bit Map | 16 | LSB applies to first DPP PDU and MSB to last. Bit value 1 indicates ACK. Maximum number of DPP PDUs in burst shall not exceed 16. |
| Reserved | 3 |  |
| } else { |  |  |
| MCS | 4 | MCS includes the Repetition. Refer Table 3. |
| ACKI | 1 | ACK Indication. 0: disabled, 1: enabled |
| Number of Slots | 12 | Number of slots requested (for RTS) or allocated (for CTS/PDU) post CTRL MSG. |
| Reserved | 1 |  |
| AUTHI | 1 | Authentication. 0: Disabled 1: Valid CMAC/HMAC is present. |
| } |  |  |
| CRC | 8 | CRC for above bytes computed per 802.16 section 6.3.3.5 CRC calculation |
| CMAC/HMAC Digest | 128 | Message integrity code of the message. Must be last field in the message. If AUTHI is 0 then this field is not transmitted, when AUTHI is set to 1 this will be present after the CRC. |
|  } |  |  |

### Association Message (ASSOCIATE Request, ASSOCIATE Response)

Table 5 Associate Request

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| ASSOCIATE Request () { | --- | ---- |
| Message Type | 8 | Value: 1 |
| Initiator MAC addr | 48 | MAC address of initiating SS |
| Receiver MAC addr | 48 | MAC address of peer SS |
| SS name length | 8 |  |
| SS name |  | As appears in certificate.subjectName |
| CA name length | 8 |  |
| CA name  |  | As appears in certificate.issuerName |
|  } |  |  |

Table 6 Associate Response

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| ASSOCIATE\_Response () { | --- | ---- |
| Message Type | 8 | Value: 2 |
| Initiator MAC addr | 48 | MAC address of initiating SS |
| Receiver MAC addr | 48 | MAC address of peer SS |
|  } |  |  |

### Measurement Report Message

Table 7 Measurement report

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| Measurement\_report () { | --- | ---- |
| Message Type | 8 | Value: 3 |
|  CINR | 8 | Averaged CINR measurement report |
|  RSSI | 16 | Averaged RSSI measurement report |
| MCS | 4 | MCS includes Repetition. Refer Table 3. |
| Reserved | 4 |  |
|  } |  |  |
|  |  |  |

### Automatic PHS Message

Table 8 PHS Request

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| PHS Request () { | --- | ---- |
| Message Type | 8 | Value: 4 |
| PHSI | 8 | PHS Index, Identifies the PHS rule |
| PHS size | 8 | Size of the PHS Field |
| PHS Mask | 48 | Bitmask that determines which bytes of the PHSF that needs to be suppressed |
| PHS Field | 48  | Variable Field values 0 to 48 bits |
|  } |  |  |

Table 9 PHS Response

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| PHS Response () { | --- | ---- |
| Message Type | 8 | Value: 5 |
| Response | 8 | 0: Reject, 1 to 255 PHS Index |
|  } |  |  |

Table 10 PHS ACK

|  |  |  |
| --- | --- | --- |
| Syntax | Size(bit) | Notes |
| PHS\_Ack () { | --- | ---- |
| Message Type | 8 | Value: 6 |
|  } |  |  |