Technical Documentation

IEEE 802.16t Direct Peer to Peer (DPP) vs Point to Multipoint (PtMP)

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This document is intended to provide the reader with a technical description of two operational modes included in the IEEE 802.16t standard – Direct Peer-to-Peer protocol and Point-to-Multipoint protocol. A comparison between the different operating modes will also be made.

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IEEE 802.16t Operational Modes

IEEE 802.16t offers two operational modes:

- Point to Multipoint mode (PtMP)
- Direct Peer to Peer mode (DPP)

IEEE 802.16t PtMP

1. This mode supports communication from a.) remotes to the office and b.) from the office to the remotes through the base station to which the remotes are connected. PtMP also facilitates remote to remote communication but all traffic in this case goes through the base station and as such, each packet is transmitted over the air twice.

2. IEEE 802.16t PtMP employs Time Division framing to separate in time the transmission from the base stations to the remotes (this is referred to as downlink) and the transmission from the remotes to the base stations (this is referred to as uplink). All base stations are synchronized in time. The transmission in the downlink and in the uplink direction can be done in the same frequency (this is referred to as Time Division Duplex or TDD) or in distinct frequencies (this is referred to as Half Duplex Frequency Division Duplex or HD-FDD).

3. Communication between base stations and remotes is done over an IEEE 802.16t subchannel group. This consists of multiple adjacent or non-adjacent subchannels. The subchannels may but are not necessarily aligned with the underlying Land Mobile Radio (LMR) channels. As an example, in the 900 MHz A-Block, a subchannel group may consist of a single 12.5 kHz sub-channel group, 10 x 12.5 kHz sub-channel group (this consists of the entire 125 kHz sub-band) or any subset of 12.5 kHz channels. As another example, in the 160 MHz band, the subchannel group may consist of a single 15 kHz or 7.5 kHz sub-channel group, 90/180 x 15/7.5 kHz subchannel group (this consists of the entire 1.35 MHz 160 MHz band) or any subset of 15/7.5 kHz channels in the band.

4. IEEE 802.16t PtMP is a scheduled air interface protocol. Any communication between the base station to its connected remotes in both directions is scheduled by the base station scheduler. The base station scheduler supports the following scheduling modes:
   i. **Standalone scheduling mode**: this mode is used when there is no BSC. The base station has a static configuration of the Air Interface Resources it owns, e.g., specific channels in the 900 MHz A-Block.

The base station allocates Air Interface Resources (AIRs), which it owns for communication with each remote in both directions.

ii. **Secondary scheduling mode**: this mode is used when there is a BSC. The BSC assigns AIRs to the base stations under its control dynamically. The base stations use the assigned AIRs and allocate them for communication with their connected remotes in both directions.

5. IEEE 802.16t PtMP is a connection-oriented air interface protocol, i.e., each remote establishes a connection to a base station and is connected to this base station unless a roaming condition is detected which triggers roaming to another base station. Information is exchanged between the remote and the base station when the connection is established (this is referred to as "Network Entry"). This includes:
   i. Synchronization of bit, frame, and frequency of the remote to the base station.
   ii. Service Flows (SF) creation. A Service Flow (SF) is a unidirectional entity with a Quality of Service (QOS) profile and classification parameters. The QOS profile includes various QOS parameters such as traffic priority. Each SF may have associated Packet Header Suppression (PHS) rules to suppress repetitive bit patterns within the Service Data Units (SDUs).
   iii. The Modulation and Coding Scheme (MCS) for this remote in the downlink and in the uplink direction.
   iv. Ranging parameters, i.e., one way propagation delay
   v. Transmit power of the remote

6. After the connection is established, the connection is maintained by the continuous exchange of signals and messages between remote and the base stations. The connection establishment and maintenance consume bandwidth which is an overhead component effecting the overall frequency utilization. Connectivity maintenance, however, helps maintain optimal usage of the network. Here are two examples:
   i. **Power control** messages are exchanged to optimize the transmit power of the Remotes, i.e., reduce the transmit power of the remotes without sacrificing performance. The power control objective is to optimize the UL RSSI value at the base station receiver, e.g., - 90 dBm

for a 12.5 kHz wide channel. As the path loss between a remote and the base station is reduced, the remote reduces its transmit power level such that its UL RSSI will meet the target value. This helps avoid saturating the receiver or operating in sub-optimal conditions. This also helps reduce self-interference in other base stations. With power control, the remote's transmit power is adjusted continuously as needed, e.g., in case there is a fade, in a case of temporary obstruction, or in general as the path loss to the base station changes.

ii. **Adaptive Modulation:** the Modulation and Coding Scheme (MCS) is selected dynamically, for each remote independent of the other remotes and in each direction, independent of the other direction. As such, frequency utilization is optimized for the instantaneous conditions in each direction at each remote. If static MCS configuration is used, it is necessary to configure the MCS in each direction for each remote considering the worst-case scenario which significantly reduces the frequency utilization of the network.

IEEE 802.16t DPP

1. This mode supports communication between DPP terminals with no base station infrastructure. If two remotes are in range of each other, they can use direct communication which does not require double transmission over the air as in the PtMP case. If, however, the two DPP terminals are not in range, a DPP relay is used in which case, double transmission is required.

2. DPP employs Carrier Sende Multiple Access with Collision Avoidance (CSMA/CA) for channel access and transmission of a DPP terminal is not scheduled by a central entity. CSMA/CA is mandated by FCC for unlicensed bands, e.g., Wi-Fi and IEEE 802.15.4. It is also used in licensed bands in low traffic load scenarios, e.g., ATCS. CSMA/CA is a simple channel access mechanism that helps avoid packet collision. Scenarios in which CSMA/CA may fail to avoid packet collisions include:
    iii. Two DPP terminals in range of each other will collide if they start to transmit within a time window smaller than the propagation delay between them.
    iv. The CSMA/CA mechanism requires all DPP terminals to be in range, i.e., hear each other. When this condition is not met, packets transmitted by DPP terminals who don't see each other may collide. The DPP air interface protocol offers a short RTS/CTS message exchange prior to the transmission of the data packet, to reduce the probability of collision. Note however that the use of RTS/CTS messages increases latency.
    v. CSMA/CA works best when the terminals are in proximity such that any transmission by a terminal is detected immediately by all other terminals. As the distance between the terminals increases, the propagation delay increases resulting in an increased probability of collision.

3. Given DPP terminal transmission is not scheduled by a central entity, minimum throughput and latency cannot be guaranteed. Also, a DPP terminal cannot be controlled by the BSC. To avoid interference between IEEE 802.16t DPP and PtMP, a distinct spectrum should be used for each of them. For example, in the 900 A-Block, it is proposed to assign one or two dedicated 12.5 kHz channels to DPP while the rest of the channels will be assigned to PtMP. The channels assigned to DPP will be removed from the AIRs under BSC management.

4. DPP supports the same subchannel and subchannel group infrastructure as described in paragraph 2c above.

5. Both IEEE 802.16t PtMP and DPP do not transmit and receive at the same time but unlike PtMP, DPP does not employ framing and there is no strict division of time between the transmitting and the receiving phase. The communication mechanism is referred to as Half Duplex with the transmission in both directions on the same frequency.

6. The DPP air interface protocol is connectionless, i.e., there is no connection establishment and maintenance. Each burst transmitted by a DPP terminal is processed by its peer with no previously acquired information. To enable decoding of the burst at the receiver, each burst carries a preamble sequence. This is used by the receiver to identify the beginning of the burst, to synchronize its frequency and bit rate and to set up the receiver gain. Additional information is included in the burst to inform the receiver about the MCS to be used, and information for pairing and authentication.

7. DPP may support power control and adaptive modulation. Due to the connectionless operation mode, this requires an RTS/CTS message exchange between the two DPP terminals prior to the transmission of data. This introduces significant latency and may not be effective in a mobility environment which requires fast adaptation to the channel conditions. Note that other connectionless systems, e.g., ATCS and head-of-train / end-of-train support a single modulation scheme while Positive Train Control (which is also connectionless) supports two MCSs, but the MCS is configured statically.

8. An association is established between two DPP terminals for pairing and authentication. A DPP terminal can establish associations with multiple DPP terminals to support any to any communication.

IEEE 802.16t PtMP vs DPP Comparison

The comparison includes the following:

1. Waveform
2. Duplexing and framing
3. Sub-channel group configuration
4. Modulation and Coding Schemes
5. MAC Layer
6. Repetition Combining
7. Quality of Service
8. Frequency utilization
9. End to end latency
10. Ease of deployments
11. Mobility

1. Waveform

1. PtMP employs OFDM with single subcarrier per subchannel in the downlink direction and SC-FDMA in the uplink direction.

2. DPP employs SC-FDMA (same as the PtMP uplink waveform) in both DL and UL.

3. The frequency utilization of the PtMP and DPP waveform is the same. Due to the use of the same waveform in both directions in DPP, the two DPP terminals in a DPP link behave the same so there is no need for a manual or automatic role assignment process

2. Duplexing and Framing

1. Both PtMP and DPP do not transmit and receive at the same time.

2. PtMP employs a configurable frame divided into a downlink subframe and an uplink subframe with a gap in between. Communication in both directions can be done at the same frequency (this is referred to as TDD) or in distinct frequencies (this is referred to as HD-FDD).

3. DPP employs Half Duplex communication. Transmission in both directions is done in the same frequency.

4. Operation in the same frequency in both directions is more efficient than using a distinct frequency in each direction. The use of distinct frequency in each direction however may be required by FCC or because of possible interference with legacy deployments.

5. The use of framing requires GPS synchronization at all base stations. Framing helps avoid interference between base stations and remotes because they never transmit at the same time. Framing is needed to support central scheduling. It allows for high utilization of the air interface resources and the ability to guarantee throughput and latency. On the other hand, framing increase latency.

3. Sub-channel group configuration

1. The band of operation is partitioned into subchannels, some of which are active and others which may be non-active[1]. Active adjacent and non-adjacent channels are grouped into subchannel groups.

2. In a PtMP system, a base station may operate over multiple subchannel groups while each remote operates just in one of the subchannel groups.

3. A DPP terminal operates over a single subchannel group. When two or more DPP terminals communicate with each other, all the DPP terminals operate over the same sub-channel group.

4. The total bandwidth span of operation for DPP is the same as for the PtMP remote and is determined by the hardware platform used. For example, the Ondas Networks Venus radios support the entire AAR-owned spectrum of 1.35 MHz in the 160 MHz band.

4. Modulation and Coding Schemes (MCSs)

1. PtMP and DPP support the same MCSs including QPSK ½, QPSK ¾, 16QAM ½, 16QAM ¾, 64QAM 2/3, 64QAM ¾ & 64QAM 5/6.

2. Both Convolutional Coding (CC) and Convolutional Turbo Coding (CTC) are supported.

[1] Non active subchannels are not available, typically because they are in use by another operator or application.

3. 256 QAM 7/8 is also required in the IEEE 802.16t standard.

5. MAC Layer

1. PtMP MAC layer employs a scheduled air interface protocol. In the Standalone scheduling mode, a scheduler at the base station is responsible for the allocation of the Air Interface Resources (AIRs) under its control in the uplink and in the downlink direction to its connected remotes. AIRs are high resolution 2-dimentional, frequency and time entities referred to as “slots”. In the frequency domain, the band is partitioned into sub-channels, so each slot is identified by the subchannel frequency, and its time offset from the beginning of the IEEE 802.16t frame. The PtMP base station scheduler assumes exclusive usage of all the AIRs under its control. As such, the scheduler can allocate 100% of the AIRs under its control to its connected remotes. To support the exclusivity assumption in a multisector environment, a partitioning of the AIRs is needed to avoid self-interference. This can be done statically, e.g., by frequency planning, i.e., by allocating a subset of the channels to each base station, making sure that two interfering sectors will not use the same channels.

2. Static partitioning of air interface resources does not consider the utilization of the AIRs at any point in time. If the AIRs in a sector are underutilized, i.e., when the traffic in either the downlink or the uplink direction is low, the underutilized AIRs can be moved to another sector in need. Such dynamic allocation of AIRs is realized by adding a Base Station Controller (BSC) and operating the PtMP base station in secondary scheduling mode as a slave to a BSC. Moreover, the BSC employs a Self-Interference-Matrix (SIM) to re-use the air interface resources as much as possible.

3. DPP employs a distributed CSMA/CA MAC layer. A DPP terminal performs channel sensing prior to transmission and defers its transmission if the channel is busy. Due to the propagation delay between DPP terminals, the detection of a transmission of one DPP terminal by a second DPP terminal may happen only after the second DPP terminal already transmitted a packet as well, resulting in a packet collision. The percentage of packet collisions increases with distance between DPP

terminals, with the number of DPP terminals operating in the same channel and as the traffic load increases.

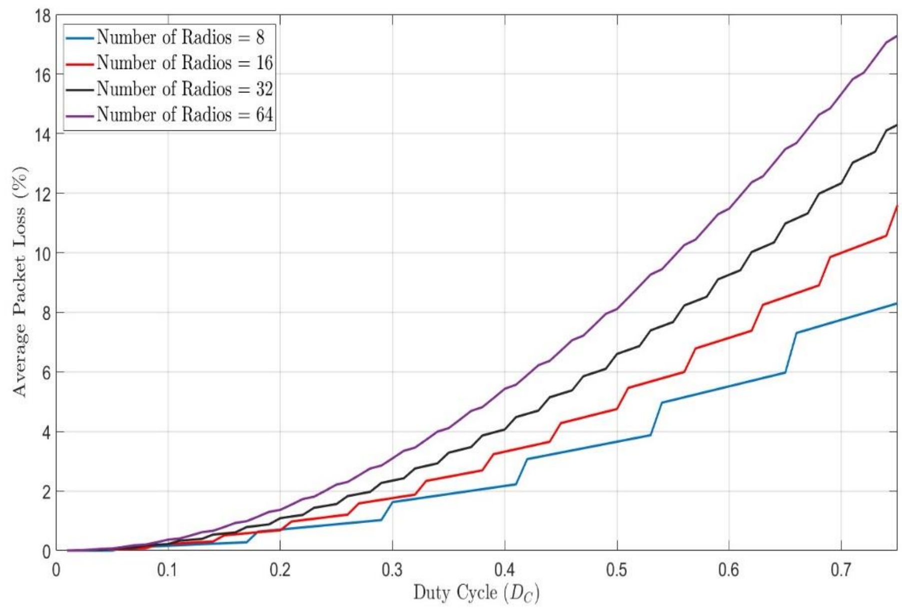

Figure 1 - DPP Duty Cycle Vs % Packet loss for various numbers of radios

6. Codeword Repetition/Combining

1. Codeword repetition/combining is a powerful time diversity scheme that can be used on top of Forward Error Correction to significantly improve robustness. Unlike message retransmission in which errored replicas of the message are dropped and the first error-free replica is selected, with codeword repetition, the power of all codeword repetitions is combined before decoding. As such, codeword repetition combining is equivalent to an increase in transmit power at the repetition rate. For example, 8 repetitions are equivalent to an increase in transmit power by 10 log 8 = 9 dB. In addition, repetition combining provides time diversity to help mitigate fades if at least one of the repetitions is communicated before or after the fade.

2. While codeword repetition combining offers significant improvement of wireless communication robustness, it reduces the offered throughput by the repetition rate. Repetition combining is therefore applicable to low packet/message rate applications which are common in railroad communication systems.

3. IEEE 802.16t requires both PtMP and DPP to support a repetition rate of up-to 128.

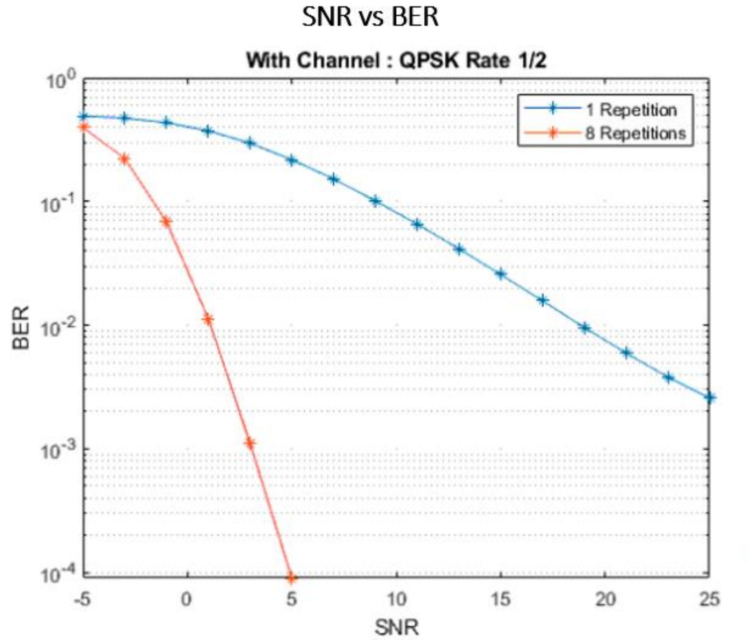

Figure 2 - Simulation results for Hilly Terrain model with 80 kmph

7. Quality of Service

1. Both PtMP and DPP can be configured with multiple Service Flows. Each Service Flow is a unidirectional flow of packets with common preconfigured attributes. The attributes are typically packet header field values, e.g., destination IP address. Each service flow has an associated QOS profile.

2. DPP cannot guarantee throughput or latency and therefore, the only DPP QOS parameter is priority.

3. Unlike DPP, PtMP central scheduler can guarantee throughput and latency per service flow and therefore, additional QOS parameters are available in the QOS profile. These include Minimum Sustained Rate (MSR) and Maximum latency.

8. Frequency Utilization

1. PtMP and DPP employ the same MCSs and therefore the PHY layer overhead is the same.

2. Over the air Protocol Data Unit (PDU) overhead is higher in DPP than in PtMP because of the need to carry information which is a-priori known in PtMP due to connectivity maintenance. This is partially offset by the connectivity messages overhead in PtMP. The extra per DPP burst overhead includes:
    i. DPP employs one slot worth of alternate 1 and 0 pattern to help the receiver in gain adjustments. This is not used in PtMP.
    ii. Both DPP and PtMP employ a 31-bit preamble sequence used for burst/frame sync and for synchronization. In DPP, this sequence is transmitted in every burst while in PtMP it is transmitted at a regular but configurable rate, e.g., in our current configuration, it is transmitted once every 5 frames with a frame duration of 100 ms.

3. The lack of framing in DPP gives it the flexibility to assign the air interface resources dynamically in the two directions compared with the static TDD frame partitioning into DLSF and ULSF.

4. A major overhead component in DPP is packet collisions at high load. This overhead does not exist in PtMP. RTS/CTS message exchange can be used to reduce collisions, but this results in overhead and latency. An ACK mechanism including retransmission can be used in DPP to help guarantee packet delivery. This mechanism, however, increases overhead.

5. Adaptive modulation may not be available in DPP, e.g., in high-speed mobility. In this case, a robust MCS must be configured to support the worst-case scenario. This significantly reduces frequency utilization.

6. DPP has an advantage over PtMP in peer-to-peer communication scenario when the two end points are in range of each other with no need for repeater. In this case, each packet is only transmitted over the air once while in the PtMP case, it is always transmitted twice. This advantage goes away if the two DPP terminals are not in range.

7.

8. The use of the BSC in the PtMP case, with the base stations operating in secondary mode further improves frequency utilization because the BSC has a view of the entire network, and it can optimize air interface resource utilization based on demand.

9. End to end Latency

1. When the end points are in range of each other (no hidden node), the nodes are in proximity and the load is low (these conditions are needed to avoid packet collisions), DPP has lower end to end latency than PtMP. Moreover, for a peer-to-peer communication scenario, the end-to-end latency is half relative to the PtMP scenario.

2. If, however, some of the end points are not all in range of each other, as the distance between the nodes increases and as the traffic load increases, packet collision increases. In this case, the DPP Ack mechanism and retransmission is used to guarantee delivery. The maximum latency will significantly increase in this case and will be higher than in the PtMP case.

3. PtMP end to end latency depends on the frame duration and the scheduling mode. If Semi Persistent Scheduling (SPS) is used, the latency is about 3 x frame duration, e.g., in the case of a single 12.5 kHz subchannel group and 50 ms frame duration, the end-to-end latency can be as low as 150 ms for packets that can be encapsulated in one 50 ms frame. The frame duration may be significantly lower as the subchannel group increases.

10. Ease of Deployment

1. DPP deployment is easier than PtMP because the CSMA/CA mechanism resolves interference scenarios by deferrals and makes it easier to coexist near other systems. PtMP system deployment requires extensive sites survey and proper frequency planning to avoid self-interference.

2. PtMP deployment is done in frequencies free of interference from other systems. Such interference may limit operation to low MCS and/or cause packet error rate.

11. Mobility

1. DPP is connectionless with each burst transmitted on its own. As such, DPP supports seamless handovers.

2. PtMP is connection oriented. Seamless handover requires the establishment of the new connection before the previous connection is terminated and the buffering of downlink packets.

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