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Wireless LANs

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| Draft Text for Hybrid Beamforming Protocol Design Details | | | | |
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Introduction

This submission proposes text based on the presentation [3] and builds on the introductory text agreed to in [4].

The material in **red** is new, the material in **green** is in [3] and has been accepted in the 802.11ay Draft D0.8 polled in the 11ay CC and is waiting for motion in the next 802.11ay F2F and the material in **black** is the 802.11ay Draft D0.8.

***Make the following changes on D0.8:***

*Insert the following Section as follows:*

# Hybrid Beamforming for SU-MIMO and MU-MIMO.

An EDMG STA is Hybrid Beamforming capable if either (or both) of the Hybrid Beamforming and SU MIMO Supported field or the Hybrid Beamforming and MU-MIMO Supported field in the STA’s EDMG Capabilities element is set to one. A Hybrid Beamforming capable STA shall be Hybrid Beamforming and SU-MIMO capable if the Hybrid Beamforming and SU MIMO supported field in the STA’s EDMG Capability element is set to one. A Hybrid Beamforming capable STA shall be Hybrid Beamforming and MU-MIMO capable if the Hybrid Beamforming and MU MIMO supported field in the STA’s EDMG Capability element is set to one. The Hybrid Beamforming capable STA may be Hybrid Beamforming and SU-MIMO capable, Hybrid Beamforming and MU-MIMO capable or both. A Hybrid Beamforming capable STA supports the Hybrid Beamforming protocol described in this sub-clause.

The Hybrid Beamforming protocol enables the determination of the baseband beamformer based on the antenna configuration selected in the SU-MIMO or MU-MIMO beamforming protocol. It supports digital baseband training and hybrid beamforming information feedback for subsequent Hybrid Beamforming transmission which is the transmission and reception of multiple spatial streams using a combination of analog beamforming and digital beamforming between a SU-MIMO capable initiator and an SU-MIMO capable responder or between an MU-MIMO capable initiator and one or more MU-MIMO capable responders. It can also be used to support the transmission of a single spatial stream using multiple DMG antennas with a combination of analog beamforming and digital beamforming between a SU-MIMO capable initiator and an SU-MIMO capable responder.

The analog beamformer may be selected during the SU-MIMO beamforming protocol (10.38.9.2.3) or MU-MIMO beamforming protocol (10.38.9.2.4) procedures which enable the determination of the antenna configuration for the simultaneous transmission of single or multiple spatial streams from the initiator to the responder(s) (or vice versa in the case of SU-MIMO).

The relationship between the transmitted signal, x, and received signal, Y, in Hybrid Beamforming transmission can be represented as:

The relationship between the transmitted signal, , and received signal, in Hybrid Beamforming transmission can be represented as:

***=***

where

= Channel between Tx and Rx antennas,

= Additive white noise

= Effective baseband channel, i.e., the channel based on combining the analog beamformer(s) and the actual channel,

= Ntx,A x Ntx Transmit Analog beamformer, = Nrx x Nrx,A Receive Analog beamformer

= Ntx x Nsts Transmit Baseband beamformer, = Nsts x Nrx Receive Baseband beamformer

= The transmitted Single User or Multi-user MIMO signal

= Subcarrier Index. For SC PPDU transmission, while for OFDM PPDU transmission, .

~~The Hybrid Beamforming protocol may be explicit or implicit.~~

In the ~~explicit~~ Hybrid beamforming protocol, the transmitter acquires hybrid beamforming information based on feedback from the receiver derived from the channel in the direction between the transmitter and receiver.

~~In the implicit Hybrid Beamforming Protocol, the transmitter acquires hybrid beamforming information directly from the channel in the direction between the receiver and the transmitter without the need for feedback. The initiator or responder may initiate an implicit hybrid beamforming protocol procedure if the Antenna Pattern Reciprocity subfield in the DMG STA Capability Information field of the responder and the Antenna Pattern Reciprocity subfield in the DMG STA Capability Information field of the initiator are both equal to 1.~~

The Hybrid Beamforming Protocol comprises the following phases

* Announcement Phase (~~for explicit and implicit HBF protocol,~~ optional if configuration has been previously set)
* Sounding Phase
* Feedback Phase ~~(for explicit HBF protocol only)~~

On completion of the HBF protocol, the HBF transmission may take place.

For EDMG SU PPDUs to which HBF is applied, isa digital beamforming steering matrix and is derived from the TXVECTOR parameter EXPANSION\_MAT. For EMDG MU PPDUs to which HBF is applied, isa digital beamforming steering matrix and is derived from the TXVECTOR parameter EXPANSION\_MAT. The digital beamforming steering matrices and digital DL-MU-MIMO steering matrices are implementation specific.

***Announcement Phase***

The HBF protocol announcement phase uses an announcement and optional announcement acknowledgement frame exchange to enable the initiator and responder(s) to set up their antenna configurations to the desired transmit and receive antenna sectors and to indicate the start of the HBF protocol.

Note that if the initiator and responder are already in the correct configuration and have previously set up their HBF protocol information, the announcement phase may be optional.

The parameters governing the HBF protocol such as feedback type and the HBF protocol feedback parameters shall be signaled during the sounding phase.

***Announcement Phase for SU-MIMO***

For SU-MIMO, the announcement and announcement acknowledgement for the HBF protocol may use

- a Grant frame as the announcement frame and Grant ACK frame as the announcement acknowledgement frame with control trailers for signaling the transmission configuration to be used.

- an RTS as the announcement and CTS as the announcement acknowledgement frame with control trailers for signaling the transmission configuration to be used.

The procedure is detailed in 10.36.11.4.3 SU-MIMO Channel access procedure.

***Announcement Phase for MU-MIMO***

For MU-MIMO, the announcement and announcement acknowledgement for the HBF protocol may use

- an RTS as the announcement frame and simultaneous DMG CTS as the announcement acknowledgement frame with control trailers for signaling the transmission configuration.

- a DMG CTS-to-self as the announcement frame with control trailers for signaling the transmission configuration.

The procedure is detailed in 10.36.11.4.4 MU-MIMO Channel access procedure.

***Sounding Phase***

The sounding phase of the HBF protocol sends TRN fields to or from the transmitter to measure the channel for HBF. The TRN fields may be sent during the BRP (10.38.3) or during Digital Beam Tracking (10.38.7).

The analog beam combination for which the digital precoders are computed should be the last analog combination decided between the two STAs. The type of feedback requested is indicated within the BRP frames. TRN fields to enable sounding are appended to the initiator or responder frames as required.

BRP sounding shall be used immediately after the HBF protocol announcement or when the feedback configuration may need to be changed. BRP or Digital Beam Tracking may be used when the transmission and feedback configurations are unchanged.

When Digital Beam Tracking within the header is requested, then TRN fields to enable sounding are appended to the initiator or responder frames based on the indications in the headers. The feedback for the digital beam tracking procedure should be the feedback negotiated in the most recent BRP sounding.

A transmitter that desires to use the HBF protocol shall initiate transmit beam refinement (see 10.38.3) or initiator transmit beam tracking (see 10.38.7).

The Digital BF Request field in the EDMG BRP Request element (see 9.4.2.255) shall be set to 1, to indicate that sounding for digital BF is requested.

For the EDMG SC mode, the DBF FBCK REQ field in the DMG Beam Refinement element (see 9.4.2.130) shall be set to zero to indicate MIMO Channel Measurement Feedback, and set to 1 to indicate Digital Beamforming Matrix Feedback.

For the EDMG OFDM mode, the DBF FBCK REQ field shall always be set to 1 to indicate Digital Beamforming Matrix Feedback.

For the EDMG SC mode, the number of taps requested during MIMO Channel Measurement or Digital Beamforming Matrix Feedback shall be set in the number of taps requested field in the DMG Beam Refinement element (see 9.4.2.130).

For the EDMG OFDM mode, the number of streams of compressed feedback requests during Digital Beamforming Matrix Feedback shall be set in the Digital BF Compressed Nc Index field in the EDMG BRP Request element (see 9.4.2.255).

***HBF Sounding with BRP frame(s)***

***SU-MIMO Sounding (for both Initiator and Responder)***

The initiator shall initiate the sounding phase a SIFS following reception of the Announcement ACK frame from the responder (the CTS or the Grant ACK frame). In the initiator sounding subphase, the initiator shall transmit EDMG BRP-TX packets to the responder. Each EDMG BRP-TX packet shall be separated by SIFS for the desired configuration. Each transmitted EDMG BRP-TX packet is used to train one or more transmit sectors based on the analog AWVs selected during the HBF Announcement Phase by the Grant/RTS frame. In each EDMG BRP-TX packet, the initiator shall include, for each selected transmit sector, TRN subfields in the TRN field of the PPDU for the responder to perform receive AWV training. For each EDMG BRP-TX packet, the TXVECTOR parameter EDMG\_TRN\_LEN shall be set to a value greater than zero, and the parameters RX\_TRN\_PER\_TX\_TRN and EDMG\_TRN\_M shall be set to the values of the L-TX-RX and EDMG TRN-Unit M subfields based on the desired configuration. The initiator may transmit each EDMG BRP-TX packet to train multiple TX DMG antennas simultaneously by using the TRN subfields defined in 30.9.2.2.6 and, therefore, reduce sounding time. The TX Antenna Mask field of each EDMG BRP-TX packet shall indicate the TX DMG antenna(s) which is being used by the initiator to transmit the EDMG BRP-TX packet. The BRP CDOWN field of each EDMG BRP-TX packet shall indicate the number of remaining EDMG BRP RX/TX packets to be transmitted by the initiator in the initiator HBF sounding subphase.

If indicated, the responder shall initiate the responder sounding subphase a SIFS following the reception of an EDMG BRP-TX packet with the BRP CDOWN field set to 0 from the initiator. Note that two-way sounding is announced in the Grant ACK/CTS (see 10.36.11.4.3). In the responder sounding subphase, the responder shall transmit EDMG BRP-TX packets to the initiator. Each EDMG BRP-TX packet shall be separated by SIFS. For each EDMG BRP-TX packet, the TXVECTOR parameter EDMG\_TRN\_LEN shall be set to a value greater than zero, and the parameters RX\_TRN\_PER\_TX\_TRN and EDMG\_TRN\_M shall be set to the values of the L-TX-RX and Requested EDMG TRN-Unit M based on the configuration, respectively. The responder may transmit each EDMG BRP-TX packet to train multiple TX DMG antennas simultaneously by using the TRN subfields defined in 30.9.2.2.6 and, therefore, reduce sounding time. The TX Antenna Mask field of each EDMG BRP-TX packet shall indicate the TX DMG antenna(s) which is being used by the responder to transmit the EDMG BRP-TX packet. The BRP CDOWN field of each EDMG BRP-TX packet shall indicate the number of remaining EDMG BRP RX/TX packets to be transmitted by the responder in the responder sounding subphase.

In the case that the sounding is for the initiator only or responder only, only the STA sounding its channel may send the BRP frame and associated TRN subfields.

***MU-MIMO Sounding (for Initiator)***

The initiator shall initiate the HBF sounding subphase a SIFS following the reception of the Announcement ACK frame(s) from the responder(s) if required or immediately following the transmission of the CTS-to-self from the initiator. In the HBF sounding subphase, the initiator shall transmit one or more EDMG BRP-TX packets to the remaining responders in the MU group. Each EDMG BRP-TX packet shall be separated by SIFS. Each transmitted EDMG BRP-TX packet is used to train one or more transmit sectors based on the analog AWVs selected during the HBF Announcement phase. In each EDMG BRP-TX packet, the initiator shall include, for each selected transmit sector, TRN subfields in the TRN field for the remaining responders to perform receive AWV sounding. For each EDMG BRP-TX packet, the TXVECTOR parameter EDMG\_TRN\_LEN shall be set to a value greater than zero. The parameters RX\_TRN\_PER\_TX\_TRN and EDMG\_TRN\_M shall be set in such a manner that the number of TRN subfields included in the TRN field used for receive AWV sounding is the maximum number of receive sectors across all the remaining responders based on the L-TX-RX subfields and the EDMG TRN-Unit M subfields in the feedback from all the remaining responders in the SISO phase. The initiator may transmit each EDMG BRP-TX packet to train multiple TX DMG antennas simultaneously using TRN subfields defined in 30.9.2.2.6 to reduce the sounding time. The TX Antenna Mask field of each EDMG BRP-TX packet shall indicate the TX DMG antenna(s) which is being used by the responder to transmit the EDMG BRP-TX packet. The BRP CDOWN field of each EDMG BRP-TX packet shall indicate the number of remaining EDMG BRP RX/TX packets to be transmitted by the initiator in the HBF sounding subphase.

***HBF Sounding with Tracking***

SU-/MU-MIMO tracking may take place after the establishment of a HBF link. The combination of an announcement with BRP sounding shall be used to establish the antenna configuration and feedback parameters for the HBF link.

The initiator shall transmit an EDMG frame with the DMG header and EDMG- header-A setting up an EDMG initiator transmit beam tracking (10.38.7) to the responder(s). The antenna configuration and feedback parameters used shall be based on the most recent BRP sounding parameters.

***10.38.9.2.5.3 Feedback Phase***

The feedback phase is used by the HBF protocol to feed back the HBF information to the transmitter for use in HBF transmission.





Figure 1: HBF Protocol and transmission procedure for SU-MIMO using BRP sounding

Figure xxx illustrates two examples of a frame exchange sequence using the SU-MIMO HBF protocol procedure.

**9.4.2.250.2 Beamforming field**

*Change 1st paragraph in [1] as follows*

The Beamforming Capability field is defined in Figure 23.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| B0 B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 B15 |
| Requested BRP SC Blocks | MU-MIMO Supported | SU-MIMO Supported | Grant Required | NoRSS Supported | Hybrid Beamforming and SU MIMO Supported | Hybrid Beamforming and MU MIMO Supported | Reserved |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |

**Figure 22 —Beamforming Capability field format**

*Insert after 6th paragraph in [1] as follows*

The Hybrid Beamforming and SU MIMO Supported field is set to one to indicate that the STA supports hybrid beamforming protocol during SU-MIMO transmission including the Hybrid beamforming protocol described in 10.38.9.2.5. The field is set to zero otherwise. Note that the SU-MIMO Supported shall be set to one.

The Hybrid Beamforming and MU-MIMO Supported field is set to one to indicate that the STA supports the hybrid beamforming protocol during MU-MIMO transmission including the Hybrid beamforming protocol described in 10.38.9.2.5. The field is set to zero otherwise. Note that the MU-MIMO Supported field shall be set to one.

10.36.11.4.3 SU-MIMO channel access procedure

*Change 1st paragraph in [1] as follows* An EDMG STA shall transmit a Grant frame with a control trailer to a peer EDMG STA to indicate the intent to transmit a MIMO PPDU or announce the start of an HBF protocol to the peer STA if the Grant Required field within the peer STA’s EDMG Capabilities element is one. Otherwise if the Grant Required field within the peer STA’s EDMG Capabilities is zero, the STA may transmit a Grant frame.

In the transmitted Grant frame, the value of the Allocation Duration field plus the Duration field of the Grant frame indicates the time offset from the PHY-TXEND.indication primitive of the Grant frame transmission when the EDMG STA intends to initiate access to the channel to transmit or initiate the start of the HBF protocol to the peer EDMG STA. For the transmitted Grant frame, the TXVECTOR parameter CONTROL\_TRAILER shall be set to Present and the parameter CT\_TYPE shall be set to GRANT\_RTS\_CTS2Self. The SISO/MIMO field shall be set to 1 and the SU/MU MIMO field shall be set to 0 to indicate that the following transmission or HBF protocol is performed in SU-MIMO. The control trailer also indicates the corresponding antenna configuration for the upcoming SU-MIMO transmission or HBF protocol.

If an EDMG STA that receives a Grant frame with a control trailer indicating a SU-MIMO transmission or an HBF protocol announcement to itself is able to perform the SU-MIMO reception or the HBF protocol at the target time indicated by the Grant frame, the STA shall configure its antennas according to the settings included in the control trailer of the received Grant frame within a time period determined by the value of the Allocation Duration field plus the value of the Duration field of the received Grant frame starting from the PHY-TXEND.indication primitive of the Grant frame transmission. The STA shall transmit a Grant Ack frame in response of the received Grant frame. For this transmitted Grant Ack frame, the TXVECTOR parameter CONTROL\_TRAILER shall be set to Present and the parameter CT\_TYPE shall be set to GRANT\_RTS\_CTS2Self.

If it uses SU-MIMO for the transmission of the reverse direction or desires to announce the HBF protocol in the reverse direction, the SISO/MIMO field shall be set to 1 and the SU/MU MIMO field shall be set to 0. The control trailer also indicates the corresponding antenna configuration for the upcoming SU-MIMO transmission in the reverse direction. If the STA intends to use SISO for the transmission in the reverse direction, the SISO/MIMO field shall be set to 0.

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An EDMG STA shall transmit an RTS frame with a control trailer to a peer EDMG STA to access the channel and establish a SU-MIMO TXOP or announce the start of an HBF protocol. This RTS frame should be transmitted using all SU-MIMO sectors, with a small delay between each sector. For the transmitted RTS frame, the TXVECTOR parameter CONTROL\_TRAILER shall be set to Present and the parameter CT\_TYPE shall be set to GRANT\_RTS\_CTS2Self. The SISO/MIMO field shall be set to 1 and the SU/MU MIMO field shall be set to 0 to indicate that the following transmission or HBF protocol is performed in SU-MIMO. The control trailer also indicates the corresponding antenna configuration for the upcoming SU-MIMO transmission or HBF protocol.

If an EDMG STA that receives an RTS frame with a control trailer indicating a SU-MIMO transmission or HBF protocol to itself is able to perform the SU-MIMO receiving or the HBF protocol, it shall configure its antennas according to the settings included in the control trailer of the received RTS frame. It shall also transmit a CTS frame with a control trailer in response of the received RTS frame. For this transmitted CTS frame, the TXVECTOR parameter CONTROL\_TRAILER shall be set to Present and the parameter CT\_TYPE shall be set to CTS\_DTS.

If it uses SU-MIMO for the transmission in the reverse direction or desires to announce the HBF protocol in the reverse direction, the SISO/MIMO field shall be set to 1, the SU/MU MIMO field shall be set to 0. The CTS frame should be transmitted using all SU-MIMO sectors, with a small delay between each sector. The control trailer also indicates the corresponding antenna configuration for the upcoming SU-MIMO transmission or HBF protocol in the reverse direction. If it uses SISO for the transmission of the reverse direction, the SISO/MIMO field shall be set to 0. The CTS frame should be sent using the SISO sector. Alternatively, if the EDMG STA is not able to perform the SU-MIMO transmission or the HBF protocol, it may transmit a DTS frame with a control trailer to the TXOP initiator to provide further information. The DTS frame should be sent using a SISO transmission.

10.36.11.4.4 MU-MIMO Channel Access Procedure

*Change 1st paragraph in [1] as follows*An EDMG STA is MU-MIMO capable if the MU-MIMO Supported field in the STA’s EDMG Capabilities element is one. An MU-MIMO TXOP is a TXOP where an MU-MIMO capable initiator and multiple MU-MIMO capable responders in an MU group exchange one or more EDMG MU PPDUs. The MU-MIMO channel access procedure describes how an MU-MIMO capable initiator and multiple MU-MIMO capable responders establish an MU-MIMO TXOP.

The MU-MIMO channel access procedure also describes how an MU-MIMO capable initiator with Hybrid Beamforming and MU MIMO Supported capability and multiple MU-MIMO capable responders with Hybrid Beamforming and MU MIMO Supported capability establish a HBF protocol.

Prior to the transmission of an EDMG MU PPDU to a set of responder STAs within an MU group, the initiator shall:

Include the MU group within the EDMG Group ID Set element and communicate the resulting element to the STAs in the BSS (see Section 10.38.9.2.4.1).

Perform MU-MIMO beamforming with the responders of the MU group (see Section 10.38.9.2.4).

An EDMG STA establishes an MU-MIMO TXOP by transmitting an RTS frame or a DMG CTS-to-self frame to the intended MU-MIMO group of responders. The EDMG STA shall transmit the RTS frame or DMG CTS-to-self frame with a control trailer to the group of responders to indicate the intent to transmit an EDMG MU PPDU. The RTS and DMG CTS-to-self frame shall be transmitted using the MU-MIMO antenna setting obtained through the last successful MU-MIMO beamforming training with the group of responders. For the transmitted RTS and DMG CTS-to-self frame, the TXVECTOR parameter CONTROL\_TRAILER shall be set to Present and the parameter CT\_TYPE shall be set to GRANT\_RTS\_CTS2self. In the control trailer, the SISO/MIMO field shall be set to 1, and the SU/MU MIMO field shall be set to 1 to indicate that the following PPDU transmitted by the initiator is an EDMG MU PPDU. For a MU-MIMO MPDU transmission and reception, the HBF protocol announcement field shall be set to zero. The EDMG Group ID field shall be set to the value that identifies the corresponding group of responders that are the intended destinations of the EDMG MU PPDU to be transmitted. The RA field of the RTS shall be set to the broadcast MAC address. After transmitting the RTS frame, the initiator shall configure its Rx antenna to quasi-omni receive pattern to receive the DMG CTS.

A STA that receives an RTS frame addressed to an MU group that the STA belongs to shall transmit a DMG CTS frame back to the initiator employing the most recent SISO antenna configuration used between the responder and the initiator. The DMG CTS frame shall be transmitted a SIFS interval following the reception of the RTS frame. The TA field of the DMG CTS shall be set to the broadcast MAC address and the Scrambler Initialization field in the PHY header shall be set to the same value as the Scrambler Initialization field of the PPDU that contained in the received RTS frame. For the STA addressed by the DMG CTS frame to successfully receive the frame, the difference in time between all the DMG CTS transmissions as measured at the receiving STA should be no more than ±30 ns. Following transmission of the DMG CTS, the responder shall then configure its antennas based on the antenna setting obtained during the last MU-MIMO beamforming training for the MU group. The MU-MIMO transmission or HBF protocol begins SIFS interval following the reception or expected reception of the DMG CTS frame by the initiator. This is shown in Figure 1.

A STA that receives a DMG CTS-to-self frame addressed to an MU group that the STA belongs to shall configure its antennas based on the antenna setting obtained during the last successful MU-MIMO beamforming training for the MU group. The MU-MIMO transmission or HBF protocol begins SIFS interval following the end of the DMG CTS-to-self frame transmission by the initiator. This is shown in Figure 2.

Section 10.3.2.10 describes the MU PPDU acknowledgement procedure.

The initiator may send a CF-End frame to one or more responders in an MU-MIMO TXOP to truncate the TXOP.

**30.2.2 TXVECTOR and RXVECTOR parameters**

*Add variables to Table 7 in [1] as follows:*

**Table 7 —1 TXVECTOR and RXVECTOR parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Condition | Value | TXVECTOR | RXVECTOR |
| EXPANSION\_MAT\_TYPE | EXPANSION\_MAT\_TYPE is COMPRESSED\_SV | Contains a set of compressed beamforming feedback matrices. Used in the EDMG OFDM mode only. | Y | N |
| EXPANSION\_MAT\_TYPE is NON\_COMPRESED\_SV | Contains a set of noncompressed beamforming feedback matrices. Used in the EDMG SC mode only | Y | N |
| EXPANSION\_MAT\_TYPE is CSI\_MATRICES | Contains a set of CSI matrices. Used in EDMG SC mode only | Y | N |
| EXPANSION\_MAT | EXPANSION\_MAT is present | Enumerated type:  COMPRESSED\_SV indicates that the EXPANSION\_MAT is a set of compressed beamforming feedback matrices  NON\_COMPRESSED\_SV indicates that EXPANSION\_MAT is a set of non-compressed beamforming feedback matrices  CSI\_MATRICES indicates that EXPANSION\_MAT is a set of channel state matrices | Y | N |
| Otherwise | Not present |  |  |

**References:**

1. Draft P802.11ay\_D0.8
2. 802.11-2016
3. 11-17-1689-00-00ay-Hybrid Beamforming Protocol Design Details
4. 11-17-1534-01-00ay-Comment Resolution on CIDs for Hybrid Beamforming - HBF Introduction