IEEE P802.11
Wireless LANs

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| Comment Resolutions on Clause 10.38.9.2.4 (Hybrid beamforming for SU-MIMO and MU-MIMO)  |
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Introduction

This submission proposes resolutions for the following 13 comments on Clause 10.38.9.2.4 (Hybrid beamforming for SU-MIMO and MU-MIMO):

1354, 1374, 1844, 1351, 2024, 2025, 2027, 1491, 1346, 1349, 1350, 1352, and 1489

Note that CID 1489 has some changes to Clause 10.38.7 (Beam Tracking).

Revisions:

- Rev 0: Initial version of document.

Interpretation of a Motion to Adopt

A motion to approve this submission means that the editing instructions and any changed or added material are actioned in the TGay Draft. This introduction is not part of the adopted material.

***Editing instructions formatted like this are intended to be copied into the TGay Draft (i.e. they are instructions to the 802.11 editor on how to merge the text with the baseline documents).***

***TGay Editor: Editing instructions preceded by “TGay Editor” are instructions to the TGay editor to modify existing material in the TGay draft. As a result of adopting the changes, the TGay editor will execute the instructions rather than copy them to the TGay Draft.***

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| --- | --- | --- | --- | --- | --- |
| **CID** | **Clause Number(C)** | **Page** | **Comment** | **Proposed Change** | **Resolution** |
| 1354 | 10.38.9.2.4.3.2.1 | 178.10 | "by SIFS" - language | replace by "by a SIFS" | RevisedAccept in PrincipleThe following lines were updated in the draft (pg.line): 177.33, 178.10, 178.32TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1354 |
| 1374 | 10.38.9.2.4 | 174.40 | Throughout this subclasue, replace beamforming with "beamforming training". Beamforming is not well defined | as in comment | revised1. The hybrid BF protocol defined not just beamforming training but beamforming training and feedback.2. Modify text to explicitly define beamforming3. In D1.0, in most cases, hybrid beamforming is followed by the word protocol unless we are discussing the scheme such as on line 175.41 and 176.1 TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1374 |
| 1844 | 10.38.9.2.4.1 | 176.01 | Spelling error | Change "EMDG" to "EDMG" | RevisedAccepted Comment. TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1844 |
| 1351 | 10.38.9.2.4.3.1 | 177.11 | "BRP sounding shall be used immediately after the hybrid beamforming protocol announcement or when the feedback configuration" | Feedback configuration has not beed defined yet. | RevisedAccepted in principle. Modified text to explicitly discuss antenna configuration and digital beamforming feedback. Feedback configuration defined in 11-18/0441r2.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1351 |
| 2024 | 10.38.9.2.4.1 | 175.19 | The equation is only valid for the SU case as in the MU case N\_sts at the receiver may be different than at the transmitter. Secondly the noise should be amplified with the analog beamforming matrix. | Please correct the equation | RevisedAgree with commenter. Equation is modified.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 2024 |
| 2025 | 10.38.9.2.4.3.2 | 178.07 | It is not clear what needs to be set up in order for the responder to initiate the responder sounding phase. | Please clarify | RevisedUpdated text to read the following " If the responder indicates that it will use SU-MIMO in the opposite direction (from the responder to the initiator) during the announcement phase,”TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 2025 |
| 2027 | 10.38.9.2.4.3.3 | 179.10 | MU MIMO tracking is not possible with what is currently defined. | Either define MU MIMO tracking procedure or remove from the sounding procedure. | RevisedAgree with commenterMU-MIMO is removed.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 2027 |
| 1491 | 10.38.9.2.4 | 174.40 | Hybrid beamforming is not defined. | Add a definition for hybrid beamforming. | RevisedHybrid beamforming definition explicitly stated.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1491 |
| 1346 | 10.38.9.2.4.1 | 175.31 | "0 Ôëñ i Ôëñ NDDC - 1." ND\_DC is undefined. N\_DC is the number of data subcarrier. I don't think we are interested in BF (of any type) which is limitted to the DC subcarriers. The set should be symetrical as in the PHY | Probably it is best to have "-N\_SR<=i<N\_SR" | RevisedAgree with commenter.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1346 |
| 1349 | 10.38.9.2.4.1 | 175.42 | EXAPANSSION\_MAT is not an enumerated type. It can take one of 3 forms but it is not an enumerated type. Anyway, what passes through the PHY-TXVECTOR interface should only be SV matrices. The calculation should happen at the PHY | fix text. | RejectAn enumerated type similar to that in HT is created but in this case, limited to compressed (OFDM), non-compressed (SC) and channel matrices (see page 232 line 1).  |
| 1350 | 10.38.9.2.4.3.1 | 177.04 | "The sounding phase of the hybrid beamforming protocol sends TRN fields to the transmitter..." -- The sounding phase is not entity that can send anything. | fix this paragraph to talk about entities like initiator and responder | RevisedModify specification text to include initiator and responder. TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1350 |
| 1352 | 10.38.9.2.4.3.1 | 177.11 | "When digital beam tracking is requested, the TRN fields to enable sounding are appended to the initiator's transmitted PPDUs. The feedback for the digital beam tracking procedure should be the feedback negotiated in the most recent BRP sounding." - It is not clear what is the entity doing all those actions | Fix with the subject as either the initiator or responder, do not use the passive form | RevisedChange specification text to non-passive form. Changed to active voice by making the initiator and responder perform the action. TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1352 |
| 1489 | 10.38.7 | 160.05 | Analog and baseband beams need to be defined. | Add definitions for "analog beam" and "baseband beam". | RevisedModified definition of analog beam to “AWVs of DMG antennas” and baseband beam to “transmit spatial mapping matrix” to harmonize with the rest of the specification.TGay editor to make the changes shown in 11-18/0715r0 under all headings that include CID 1489 |

*Changes to D1.0*

***TGay Editor: Please make the following change from Pg 174 line 40 D1.0. Note that this is equivalent to Section 10.39.9.2.4, pg 218 line 19 in D1.2. No changes have been made prior to this document within this section.***

# 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.~~ (#1374)

Hybrid beamforming is the transmission and reception of multiple spatial streams using a combination of analog beamforming (by determining appropriate AWVs) (#1489) and digital beamforming (by determining appropriate spatial mapping matrices) (#1489) between an 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 (#1491). The spatial mapping matrices are determined based on the DMG antenna configuration selected as a result of the SU-MIMO or MU-MIMO beamforming protocol.

The hybrid beamforming protocol supports digital baseband training and hybrid beamforming information feedback for subsequent hybrid beamforming transmission.

The hybrid beamforming protocol 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 an SU-MIMO capable initiator and an SU-MIMO capable responder. (#1374)

The ~~analog beamformer~~ AWVs of the DMG antennas (#1489) 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 (#2024):

$Y\_{i,j}=Q\_{Br,i,j}Q\_{Ar}H\_{i} Q\_{At}H\_{BB,i,j}Q\_{Bt,i}x\_{i}+Q\_{Br,i,j}Q\_{Ar,j}n\_{i,j} ; $$H\_{BB,i,j}$***=*** $Q\_{Ar,j}H\_{i,j} Q\_{At}$

where

$H\_{i,j}$ is the channel between the transmit DMG antennas and receive DMG antennas of the *jth* STA in an MU-MIMO transmission.

$n\_{i,j} $ is additive white noise at the receiver of the *jth* STA in an MU-MIMO transmission

$H\_{BB,i,j} $is the effective baseband channel at the receiver of the *jth* STA in an MU-MIMO transmission, i.e., the channel ~~based on combining the analog beamformer(s) and the actual channel~~ observed by the baseband processor of the receiver when including the effect of their DMG antennas at the transmitter and receiver (#1489)

$Q\_{At} $is the NTX,A X NTX ~~Transmit Analog beamformer~~ response of the DMG antennas of the transmitter (#1489)

$Q\_{Ar,j} $is the NRX,J X NRX,J,A ~~Receive Analog beamformer~~ response of the DMG antennas at the receiver of the *jth* STA in an MU-MIMO transmission (#1489)

$Q\_{Bt,i} $is the NTX X NSTS ~~Transmit Baseband beamformer~~ transmit spatial mapping matrix (#1489)

 $Q\_{Br,i,j} $is the NSTS,J X NRX,J ~~Receive Baseband beamformer~~ receive equalizer at the receiver of the *jth* STA in an MU-MIMO transmission (#1489)

$x\_{i} $ is the The transmitted Single User (SU) or Multi-user (MU) MIMO signal.

$i $is the subcarrier Index. For an EDMG SC mode PPDU transmission, $i=0;$for and EDMG OFDM mode PPDU transmission,$0-N\_{SR}\leq i\leq N\_{SR} ND\_{DC}-1$. (#1346)

***j*** = index of *jth* STA in an MU-MIMO transmission. For an SU-MIMO transmission, ***j*** *= 0*.

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

The Hybrid Beamforming Protocol comprises the following phases

* Announcement Phase (optional if configuration has been previously set)
* Sounding Phase
* Feedback Phase

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

For EDMG SU PPDUs to which HBF is applied, $Q\_{Bt,i}$ isa transmit spatial mapping matrix ~~digital beamforming steering~~ matrix and is derived from the TXVECTOR parameter EXPANSION\_MAT. with enumerated type NON\_COMPRESSED\_SV or CSI\_MATRICES. For ~~EMDG~~ EDMG (#1844) MU PPDUs to which HBF is applied, $Q\_{Bt,i}$ isa transmit spatial mapping matrix ~~digital beamforming steering~~ and is derived from the TXVECTOR parameter EXPANSION\_MAT with enumerated type COMPRESSED\_SV. The transmit spatial mapping matrices ~~digital beamforming steering~~ ~~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.

Prior to the start of hybrid beamforming training with 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 10.38.9.2.3.1).
* Perform MU-MIMO beamforming with the responders of the MU group (see 10.38.9.2.3).

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

***Sounding Phase (#1350) (#1352)***

~~The sounding phase of the HBF protocol sends TRN fields to 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). 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~~). (#1350)

In the sounding phase of the HBF protocol, the initiator (or responder) may send TRN fields to the responder (initiator) to measure the baseband channel. ~~The sounding phase of the HBF protocol sends TRN fields to 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). A transmitter (initiator or responder) that desires to ~~use the HBF protocol~~ sound the baseband channel shall initiate transmit beam refinement (see 10.38.3) or transmit beam tracking (see 10.38.7).

The ~~analog beam combination for which the digital precoders are~~ spatial mapping matrix, Q, for transmission that uses digital beamforming should be computed ~~should be~~ using the last analog combination decided between the two STAs (that is, on the current AWVs used by the STAs). (#1489)

The transmitter (initiator or responder) shall use BRP sounding ~~shall be used~~ immediately after the HBF protocol announcement or when the ~~feedback configuration~~ DMG antenna configuration or the Digital beamforming feedback may (#1351) need to be ~~changed~~ modified. The transmitter (initiator or responder) may use BRP or Digital Beam Tracking ~~may be used~~ when the transmission and ~~feedback configurations~~ DMG antenna configuration and the Digital beamforming feedback (#1351) are unchanged.

~~When transmit beam refinement is used, the TRN configuration and the type of feedback requested is indicated within the BRP frames. TRN fields to enable sounding are appended to the BRP frames~~.

For transmit beam refinement, the BRP frames indicate the TRN configuration and the type of feedback requested, and TRN fields are appended to the BRP frames to enable sounding.

~~When Digital Beam Tracking within the header is requested, then TRN fields to enable sounding are appended to the initiator 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.~~

For Digital Beam Tracking, TRN fields to enable sounding are appended to the initiator 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.

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).

***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 a SIFS (#1354) for the desired configuration. Each transmitted EDMG BRP-TX packet is used to train one or more transmit sectors based on the ~~analog~~ AWVs of the DMG antennas (#1489) 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 the responder indicates that it will use SU-MIMO in the opposite direction (from the responder to the initiator) during the announcement phase, ~~indicated~~ ~~during set up (see 10.36.11.4.3),~~ (#2025) 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 a SIFS (#1354). 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 a SIFS (#1354). Each transmitted EDMG BRP-TX packet is used to train one or more transmit sectors based on the ~~analog~~ AWVs of the DMG antennas (#1489) 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.

***Hybrid beamforming sounding with tracking***

SU-MIMO ~~and MU-MIMO~~ (#2027) 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.

***TGay Editor: Please make the following change from Pg. 160 line 5 in Section 10.38.7 of D1.0***

Beam tracking enables an initiator or responder to track ~~the change in its analog or baseband beams~~ changes in the AWVs of its DMG antennas and/or the spatial mapping matrix Q (defined in Clause 30) (#1489) without the need to perform a complete BRP procedure. Analog beam tracking allows DMG STAs to track ~~tracks~~ changes in the ~~analog beams~~ AWVs of its DMG antennas. Baseband beam tracking in SU or MU MIMO scenarios allows EDMG STAs to track ~~tracks~~ changes in the ~~baseband beamformer only in a hybrid beamforming transmission~~ spatial mapping matrix Q for transmissions that use digital beamforming (see Clause 30).

***TGay Editor: Please make the following change from Pg. 162 line 19 in Section 10.38.7 of D1.0***

In addition, a beam tracking initiator or beam tracking responder may request baseband beam tracking if at least one of the following conditions is met:

- The performance of the system is degraded in a hybrid beamforming transmission and the requestor would like to re-estimate the ~~baseband beams~~ spatial mapping matrix Q as part of the link adaptation procedure

- The requestor did not ~~request for baseband beam information~~ determine the spatial mapping matrix Q as part of the MIMO setup procedure. In this case, the ~~analog beams~~ AWVs of the DMG antennas at the transmitter and receiver have been identified, but ~~the information to establish the baseband beams~~ a procedure to determine the spatial mapping matrix Q is still needed.

**References:**

1. **IEEE P802.11ayTM/D1.0**

**Straw Poll**

Do you agree to accept comment resolutions for CIDs 1354, 1374, 1844, 1351, 2024, 2025, 2027, 1491, 1346, 1349, 1350, 1352, and 1489 as proposed in 11-18/0715r0?