**3GPP TSG RAN WG1 Meeting #104-e R1-210xxxx**

**E-meeting, January 25th – February 5th, 2021**

**Agenda Item: 8.1.4**

**Source: Moderator (Huawei, HiSilicon)**

**Title: Summary of CSI enhancements for MTRP and FDD (Round 1)**

**Document for: Discussion and Decision**

***Proposal 1: For PS codebook enhancements utilization DL/UL reciprocity of angle and/or delay, support codebook structure W=W1W2 WfH whereas***

* ***W1 is a free selection matrix, with identity matrix as special configuration***
  + ***FFS polarization-common/specific selection***
* ***Wf is a DFT based compression matrix in which N3 = NCQISubband\*R and Mv>=1***
  + ***Mv=1 is supported,***
  + ***Mv=2 is agreed as working assumption*** 
    - ***Mv=2 and other candidates of Mv, if needed, are to be decided in RAN1 104bis-e***
  + ***FFS other candidate values of R, mechanism of Configured/indicated to the UE and/or mechanism of selected/reported by UE for Wf***
* ***FFS other signaling/CSI reporting mechanism for trade-off among signaling overhead, UE complexity and performance gain***

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| Huawei (Moderator) | Thanks for all informative discussion, which are always helpful and grateful.  Configuring/indicating Mv=2 to the UE, performance gain with a proper UE implementation may be optimized to be equivalent to (or no worse than) the case of Mv=1 (as W1W2 structure), at a small expense of UE complexity. Also from gNB vendors/companies, some gNB flexibility still prefer in Rel-17, at least from specification point of view.  Therefore based on the latest discussion, it seems that current text of Proposal 1, as the majority view, seems to be a compromise among companies’ preference. Of cause, any other possible compromise is always welcome. |
| Samsung | We appreciate the good discussion among companies thus far. This is very helpful. We summarize our latest view.   * Based on the results comparing W1W2 and W2W2Wf, we can see that it is an even split, i.e. 3 (ZTE, QCM, Samsung) vs 3 (Nokia, E///, Fraunhofer). * The main argument from the proponents of Wf is to provide robustness against scenarios when the delay reciprocity is either weak or doesn’t exist. If delay reciprocity is weak or doesn’t exist, then what is the point of specifying R17 CB? We already have a codebook (from R16) for such scenarios. The R17 CB should not penalize the scenarios when the channel reciprocity is strong (this is part of the WID). * Finally, if R17 codebook has to be based on W1W2Wf CB structure, then there should be a way to turn OFF the Wf component, i.e., use W1W2 CB instead, when doing so is beneficial. |
| NTT DOCOMO | We support FL’s proposal.  The main motivation here is, as pointed out by some companies as well, we also think that the UE should be provided with sufficient opportunities to correct delay misalignments between UL channel (estimated at the gNB) and the DL channel observed at the UE.  As per our view, one important factor to note here is that, even though the reciprocity of angle(s) and delay(s) in the actual propagation channel stays sufficiently, due to the difference in effective antenna-spacing in two bands (due to the same physical spacing but different wavelengths), the estimated channel based on UL RS does not align exactly with the angle(s) and delay(s) of the DL channel. This is why there should be sufficient relaxation for the UE to select SD and FD bases based on what it observes in the DL |
| LG | We also support FL’s proposal.  As we can see in simulation result in QC’s Tdoc, Alt3-0 provides performance benefit than Alt1 in large CSI reporting overhead region. We think this means gNB can have flexibility in configuration between CSI reporting overhead and PMI accuracy. gNB can also provide performance of Alt1 based on Alt3-0 with Mv=1. And, if gNB wants to acquire more accurate PMI, then Mv>1 can be configured to a UE by increasing CSI reporting overhead. |
| Lenovo/MotM | Support the FL proposal. Agree with NTT Docomo’s comment. Also, even if we ignore the hardware impairments/estimation errors, channel reciprocity would depend on the temporal correlation of the channel since UL and DL channels are estimated in different slots. There could be certain instants wherein the DL channel deviates from UL channel due to instantaneous variations of the channel in time, therefore supporting *M*>1 can be useful (this may require more dynamic selection of *M* value, which can be discussed) |

***Proposal 2: For PS codebook enhancements utilization DL/UL reciprocity of angle and/or delay, down-select one codebook structure W=W1W2 WfH from***

* ***Alt 3-0, i.e. W1 ∈ N^{PCSI-RS × K1} (K1 ≤ PCSI-RS ) is a port selection matrix with one SD-FD/SD pair per port***
* ***Alt 5, i.e. W1∈ N^{PSD-FD × K2} (K2 ≤ PSD-FD=Of PCSI-RS) is a SD-FD basis selection matrix with multi-SD-FD/SD pairs per port***
* ***Note that PCSI-RS is the number of CSI-RS ports.***

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| Huawei (Moderator) | If there is no strong preference over Alt 5, I will propose to agree with Alt 3-0 since some companies share strong opinion over Alt 3-0 already. |
| Lenovo/MotM | Support Alt 3-0 |

***Proposal 6: For CSI measurement associated to a reporting setting CSI-ReportConfig for NCJT, the UE can be configured with Ks ≥ 2 NZP CSI-RS resources in a CSI-RS resource set for CMR and N ≥ 1 NZP CSI-RS resource pairs whereas each pair is used for a NCJT measurement hypothesis, support at least one CMR pairing mechanism by down-selecting from following in RAN1 104e:***

* ***Alt.1: Configure UE with N NZP CSI-RS resource pairs within a CMR resource set explicitly, whereas the first Ks-2N CMRs are for single-TRP measurement hypotheses and the remaining 2N CMRs in consecutive N CMR pairs are for N NCJT hypotheses.*** 
  + ***Note: Ks-2N ≥ 0 and the first Ks-2N CMRs in the set are for single-TRP measurement hypotheses***
  + ***QC/ZTE/DOCOMO***
* ***Alt.2: N CMR pairs are RRC configured and/or indicated (by MAC-CE) explicitly by a bitmap.*** 
  + ***Note: the first CMRs in the set are for single-TRP measurement hypotheses.***
  + ***Nokia***
* ***Alt.3: Configure UE with two CMR groups with Ks = K1+K2 (≥ 2N) CMRs, whereas each CMR group corresponds to one out of two TRPs. N CMR pairs are [explicitly/implicitly] determined from two CMR groups***
  + ***E.g. N NZP CSI-RS resource within a group can be explicitly/implicitly determined for NCJT measurement hypothesis with one-to-one mapping with the N NZP CSI-RS resource in the other group***
  + ***FFS K1=K2  or different K1/K2.***
  + ***Note that each CMR in each CMR group can also be used for single-TRP measurement hypotheses***
  + ***Vivo/CATT/Oppo/NEC/Intel/DOCOMO***
* ***Alt.4: N ≥ 1 NZP CSI-RS resource pairs are determined and reported by UE***
  + ***Futurewei***
* ***Alt.5: N= Ks(Ks-1)/2 pairs for all possible pairing from the set***
  + ***Ericsson***
* ***FFS maximal values of N and Ks***

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| Huawei (Moderator) | Some text update based on comments so far:  @Vivo @DC: Update accordingly for Alt 3 by certain merge to increase the chance of your preference.  @Vivo: I don’t understand the meaning of “at least” since it seems to be more difficult to have 3 groups in the set.  @DC: A note is added into Alt 1 based on my understanding, with small redundancy of RRC signalling (i.e. two CMRs with pointers may point to the same TRP/CSI-RS resource configuration) for better flexibility.  @Nokia: Update accordingly. Will you be ok with Alt 1 since some details using a bitmap or other RRC/MAC-CE signalling design can be decided in RAN2?  @Lenovo: OK both are FFS  @QC: A note is added since DC colleagues ask a question. I intends to make each Alt as clear as possible, if it is ok to you. With regarding Alt 3/5 to be applicable to FR1 only, I will leave proponent companies to answer. For Alt 4, I add a few words in my own understanding. |
| ZTE | We support the proposal even though we think proposal 3-5 may not work in FR2.  As we explained before, UE has to decide receive beams in advance. For MTRP, UE just use one receive beam, but for MTRP UE needs two receive beam. So, one resource cannot be configured for both STRP and MTRP. Anyway, let’s have further discuss. |
| NTT DOCOMO | We support Proposal 6 in principle to list all the options. And we prefer Alt.1 and Alt.3.  In Alt.1, the CMR for NCJT is not used for single-TRP measurement hypotheses, while in Alt.3, the CMR for NCJT can be used for single-TRP measurement hypotheses. Better to align them on this point.  For Alt.2, not understand how a bitmap can indicate multiple CMR pairs for NCJT. Better to clarify it.  For Alt.4, there is no assumption on CMR pairs, thus cannot understand how UE can determine the reported N pairs.  For Alt.5, the CMR pairs are redundant and not preferred. |
| CATT | Proposal 6 is supported, and Alt 3 is preferred.  Compared with Alt 1, as pointed out by NTT DOCOMO, any CMR in the resource set can be used for single-TRP CSI reporting in Alt 3.  Furthermore, up to K1\*K2 CMR pairs can be used for multi-TRP hypotheses, and higher flexibility in NC-JT CSI reporting can be achieved with Alt 3.  It’s also noted that, CMR pairing is only allowed between two CMR groups. Therefore, lower overhead is expected compared with Alt 5. |
| MediaTek | We are fine with Proposal 6. We support Alt. 3 for FR1 and FR2. We can accept Alt.1 but for FR2 only and should be UE capability. In FR1, the same CMR can be used for both single-TRP measurement hypotheses and all other participated NCJT measurement hypotheses. In FR2, if a UE, up to its implementation, uses the same spatial filter to receive a Tx beam regardless whether there are other Tx beams at the same time, then the same CMR can still be used for both single-TRP measurement hypotheses and all other participated NCJT measurement hypotheses. Alt. 1 can be considered as optimization for different hypotheses. |
| LG | We support the proposal for further discussion, and prefer Alt3.  Regarding FR2 issue commented by ZTE, we think one CMR can be configured for both STRP and MTRP if one-to-one mapping between CMRs in different CMR groups is assumed. |
| Lenovo/MotM | We support Alt 3, however we prefer to remove the example in the sub-bullet. Also, implying that all CMRs in the CMR groups can be used for STRP is too restrictive, we suggest relaxing this constraint until it is discussed in detail. We thereby propose modifying Alt.3 as follows   * ***Alt.3: Configure UE with two CMR groups with Ks = K1+K2 (≥ 2N) CMRs, whereas each CMR group corresponds to one out of two TRPs. N CMR pairs are [explicitly/implicitly] determined from two CMR groups***   + ***FFS K1=K2  or different K1/K2.***   ***Note that CMRs in one or more CMR groups can also be used for single-TRP measurement hypotheses*** |
| QC | Can we add a note to Alt1 (similar to the note in Alt3):   * + ***Note: Network can reuse CMRs of single-TRP hypotheses for NCJT hypotheses at least in FR1 (by configuring the same CSI-RS resource ID of any of the first Ks-2N CMRs for any of the remaining 2N CMRs in the resource set)*** |
| Ericsson | We are fine to clarify all the alternatives and then do a down-selection next week. We have some comments/clarifications on a few alternatives.  **Regarding Alt 1**  How would Alt 1 work when Ks = 3. If Ks =3, then N can at mast be one. Then, 1 CMR is used for single TRP measurement hypothesis, and 2 CMRs are used for NC-JT hypothesis. In this case, Alt 1 seems to only provide CMR for 1 TRP in case of a single-TRP hypothesis. Hence, measuring a 2nd single-TRP hypothesis seems to require at least Ks = 4. Does Alt 1 require imposing constraints/limitations on the values of Ks and N?  Also, regarding the note suggested by QC for Alt 1, it seems configuring same CSI-RS resource ID first in first Ks-2N CMRs and then in the remaining 2N CMRs seems to add to unnecessary signaling overhead.  **Regarding Alt 2**  We would like to understand Alt 2 better. Is Alt 2 a further optimization of Alt 1? The only difference of Alt 2 as compared to Alt 1 is that the *N* CMR pairs can by indicated via a MAC CE. Is this understanding correct?  **Regarding Alt 3**  For Alt 3, the one-to-one mapping between the two groups does not make sense. Does this mean that when one beam from TRP1 is selected, there is a corresponding beam from TRP2 that would be selected? Shouldn’t the beams from TRP1 and TRP2 be selected independently? We support the deletion of the example as proposed by Lenevo/MotM. In addition, we suggest deleting [explicitly/implicitly] since what is meant by these terms is unclear in Alt 3. We suggest the following revision to Alt 3:  Revised Alt 3:   * ***Alt.3: Configure UE with two CMR groups with Ks = K1+K2 (≥ 2N) CMRs, whereas each CMR group corresponds to one out of two TRPs. N CMR pairs are determined from two CMR groups***   + ***FFS K1=K2  or different K1/K2.***   + ***Note that each CMR in each CMR group can also be used for single-TRP measurement hypotheses***   **Regarding Alt 4**  For Alt 3, does the UE freely select the *N* NZP CSI-RS resource pairs to measure? How is N determined by the UE? Is it signaled to the UE by the network? or does the UE measure all possible pairs in which case Alt 4 will be similar to Alt 5?  **Regarding Alt 5**  For Alt 5, we prefer to add a note that CMRs used for NC-JT can be reused for single-TRP CSI. In our understanding, Alt 5 can be used with FR1 and FR2. For FR2, the best beam per TRP would be determined via beam reports, and the best beam will be used per TRP. |

***Proposal 8: For a CSI report associated with a Multi-TRP/panel NCJT measurement hypothesis configured by single CSI reporting setting, the UE can be configured to report:***

* ***Up to [one or two] (can be 0) CSIs associated with single-TRP measurement hypotheses and one CSI associated with NCJT measurement hypothesis***
  + ***FFS omission of CSI associated with NCJT measurement hypothesis***
* ***One CSI associated with the best one among NCJT and single-TRP measurement hypotheses***
  + ***FFS how to report recommended measurement hypothesis associated with that CSI report***

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| Company | Comments |
| Huawei (Moderator) | Yes (10): Vivo, Nokia/NSB, Futurewei, Lenovo/MotM, NEC, DOCOMO, Intel, Spreadtrum  No: QC/ZTE/MTK (up to one only), CATT/Ericsson (up to 2), CATT (ok Alt 3 only), Ericsson (ok with the first bullet only)  @Vivo: Yes, basically the first sub-bullet refer to Alt 1 (up to 1) and 3 (up to 2).  @LG: “or” has been sorted captured. If there is NCJT measurement only in a report, it means 0 in the best sub-bullet. If there is Single-TRP measurement only in a report, we can use Rel-15/16 measurement framework.  @ Ericsson: Word updating accordingly but still keep the second sub-bullet at the moment since some companies may have some interest. |
| ZTE | This MTRP CSI enhancement is mainly for single-DCI based SDM scheme. However, for single-DCI MTRP, there is no TRP index (e.g. CORESETPoolInex) at all, it is impossible to distinguish TRP, then it is not easy for UE to feedback two CSI for single TRP 0 and TRP1 respectively in one CSI reporting. Thus, in the first bullet, we cannot agree value two.  For progress, we suggest putting the whole fist bullet as FFS:  ***Proposal 8: For a CSI report associated with a Multi-TRP/panel NCJT measurement hypothesis configured by single CSI reporting setting, the UE can be configured to report:***   * ***FFS: Up to [one or two] (can be 0) CSIs associated with single-TRP measurement hypotheses and one CSI associated with NCJT measurement hypothesis***   + ***FFS omission of CSI associated with NCJT measurement hypothesis*** * ***One CSI associated with the best one among NCJT and single-TRP measurement hypotheses***   + ***FFS how to report recommended measurement hypothesis associated with that CSI report*** |
| NTT DOCOMO | Generally fine with the proposal 8. |
| CATT | Support Proposal 8.  In our opinion, distinguishing of TRP is not needed, because each CMR is associated with a TRP. Furthermore, CRI or something like that can be used to identify the CMR recommended by the UE. |
| MediaTek | We still prefer to have at most one best single-TRP hypothesis reported with the best NCJT measurement hypothesis. Proposal 8 can be revised as  ***Proposal 8: For a CSI report associated with a Multi-TRP/panel NCJT measurement hypothesis configured by single CSI reporting setting, the UE can be configured to report:***   * ***X CSIs associated with single-TRP measurement hypotheses and one CSI associated with NCJT measurement hypothesis***   + ***Alt. 1: X = 0, 1***   + ***Alt. 2: X = 0, 1, 2***   + ***FFS omission of CSI associated with NCJT measurement hypothesis*** * ***One CSI associated with the best one among NCJT and single-TRP measurement hypotheses***   + ***FFS how to report recommended measurement hypothesis associated with that CSI report***   Then, we support Alt. 1. |
| LG | We have similar view with ZTE. It seems that Alt3 can provide benefits only when a UE can differentiate TRPs for CMRs. So, it is not clear how to report two CSIs associated with single-TRP measurement hypotheses. |
| Lenovo/MotM | @moderator: we prefer “up to two CSI s associated with single-TRP measurement hypotheses” |
| QC | Support MediaTek’s update. One question: Why X=0 is needed? If no single-TRP report is needed, why such hypotheses are configured? Hence, suggest the following:   * + ***Alt. 1: X = 1***   + ***Alt. 2: X=0, 1***   + ***Alt. 3: X = 0, 1, 2*** |
| Ericsson | Is the intention of the proposal to support both the first sub-bullet and the second sub-bullet via configuration? We are a bit concerned about specifying too many options for NC-JT. So, we suggest to downselect between the first sub-bullet and the second sub-bullet. If down selection between the two options is difficult, then a fall back option is to only report NC-JT CSI and not report single-TRP CSI. We have added this as a third option  ***Proposal 8: For a CSI report associated with a Multi-TRP/panel NCJT measurement hypothesis configured by single CSI reporting setting, downselect between the following two options:***   * ***Option 1: the UE can be configured to report X CSIs associated with single-TRP measurement hypotheses and one CSI associated with NCJT measurement hypothesis***   + ***Alt. 1: X = 0, 1***   + ***Alt. 2: X = 0, 1, 2***   + ***FFS omission of CSI associated with NCJT measurement hypothesis*** * ***Option 2: One CSI associated with the best one among NCJT and single-TRP measurement hypotheses***   + ***FFS how to report recommended measurement hypothesis associated with that CSI report*** * ***Option 3: One CSI associated with the best NCJT CSI*** |

# Appendix

# Section 5 Proposals for Online/Offline Discussion from V43

***Proposal 1: For PS codebook enhancements utilization DL/UL reciprocity of angle and/or delay, support codebook structure W=W1W2 WfH whereas***

* ***W1 is a free selection matrix, with identity matrix as special configuration***
  + ***FFS polarization-common/specific selection***
* ***Wf is a DFT based compression matrix in which N3 = NCQISubband\*R and Mv>=1***
  + ***Mv=1 is supported,***
  + ***Mv=2 is agreed as working assumption*** 
    - ***Mv=2 and other candidates of Mv, if needed, are to be decided in RAN1 104bis-e***
  + ***FFS other candidate values of R, mechanism of Configured/indicated to the UE and/or mechanism of selected/reported by UE for Wf***
* ***FFS other signaling/CSI reporting mechanism for trade-off among signaling overhead, UE complexity and performance gain***

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| Company | Comments |
| Huawei (Moderator) | It seems that there is the majority view here.  Yes (15): Vivo, Nokia/NSB, Futurewei, Oppo, Lenovo/MoM, Spreadrum, Intel, LG, MTK, Apple, Ericsson, Huawei, HiSi,[QC]  No (3): CATT, ZTE, Samsung   * Oppo: The same FFS point from the last meeting is added to clarify polarization related discussion, which will be addressed in FL summary in P4. * MTK: a FFS is added to ensure that it is still feasible to optimize UCI design * QC/Fraunhofer/Ericsson: it seems that we have opposite preference. How about we consider Mv=2 as WA as a compromise for now? Depending on gNB implementation, the gNB can configure Mv=1 or 2 or other values like other CB parameters. |
| CATT | Companies argued that introduction of Wf improves robustness. But if there is uncertainty about the SD/FD basis at gNB, gNB could transmit beamformed CSI-RS with more FD component to let UE select the right FD component via port selection. This is the reason that W1 is port selection matrix. Though the downlink CSI-RS overhead is slightly increased, but it is well justified by the reduction of CSI reporting overhead. If more than one FD component are indicated/reported, the number of non-zero coefficients (or the bitmap to indicate position of non-zero coefficients) increases proportionally with the number of FD component.  As explained by Ericsson, the best FD component may be different for different SD beams. With Alt 1, gNB could find the best combination of SD beam and FD component for each cluster and transmit reference signal over a CSI-RS port accordingly. But if Wf is introduced in the codebook structure, the FD component has to be common to all SD beams unless FD component is indicated/reported in an SD-beam-specific manner. That would also significantly increase the feedback overehad and UE complexity.  We think Wf should not be in the codebook structure. |
| Intel | In our view codebook structure W1W2 is equivalent to W1W2Wf with Mv = 1.  There is only one difference: For W1W2 it is up to UE how to do averaging in FD while for W1W2Wf UE should do summation across PMI subbands. So, any kind of CSI-RS precoding is supported with W1W2Wf including DFT-based and SVD based.  Our preference is to support Wf in codebook structure since it makes UE behaviour clear and predictive for the gNB.  Thus, we support the proposal from FL. |
| Fraunhofer IIS,  Fraunhofer HHI | @Samsung: The main intention to support M>1 is to allow some flexibility to the UE to correct the misaligned FD-components as the channel is only partially reciprocal. If the channel is perfectly reciprocal (although it is not), M = 1 is sufficient.  Your results show that for M>1 there is a performance loss compared to the case of M=1.  It seems that for M=1 EVD-based beamforming is used and for M>1 DFT-based beamforming is used at the gNB. Is this correct? So, if for any reason EVD-based beamforming is better than DFT-based beamforming, why would the gNB not use EVD-based beamforming also for M>1?  If at all, if eigen beamforming is used for both Alt1 and Alt 3-0, can you please explain why does the performance reduces drastically when M >1? And if for any reason M>1 is worse than M=1, why would the UE not simply ignore all FD components, except the FD component zero? In such a case, the performance for the case M>1 would not be worse than the case of M =1. Can you please explain? |
| Qualcomm | @Intel, no matter W1W2 or W1W2Wf, how UE calculates the PMI is implementation, we are unsure of “it makes UE behaviour clear and predictive for the gNB”. The difference is single-tap PMI (WB) or multi-tap PMI. UE can find the best single or multi-tap to calculate PMI, or just do WB SVD or subband SVD using Mv DFT bases for compression (similar to R16 eType II). Besides, we agree SVD can be used as FD precoding, but the additional FD vectors have to be DFT.  @Fraunhofer, regarding non-idea reciprocal case, it does not seem the right place for Rel-17 FDD CSI which exploits spatial-delay reciprocity.  Although we see minor gain of M > 1, it costs additional UE complexity and CSI payload, so we prefer to remain our position on previous Proposal 1, i.e., FFS M > 1. |
| Fraunhofer IIS,  Fraunhofer HHI | @QC  We did not quite understand your comment! Can you please elaborate it?  As we mentioned earlier, the intention of using UE side delays (i.e., Wf with M>1) is to correct the mis-aligned delays. If the delays are perfectly reciprocal, then we should care less as UE only selects the coefficients associated with the DC component.  QC: Although we see minor gain of M > 1, it costs additional UE complexity and CSI payload, so we prefer to remain our position on previous Proposal 1, i.e., FFS M > 1.  The number of ports used in your simulation results are 32 and 16 for Alt 1 and Alt 3-0, respectively. Obviously, as the number of ports for Alt 1 (32 ports) is larger than Alt 3-0 (16 ports), the gain observed is not significant for M >1. Differently, if the number of ports is equal for both alternatives (obviously it needs additional UE complexity although it is minor), one can see a significant performance improvement by using M > 1 delays at the UE. Re CSI payload, although Alt 3-0 required few more bits than Alt 1, the feedback overhead is still less than the Rel. 16 Reg. codebook with a significant improvement in the performance. |
| Samsung | @Fraunhofer, as mentioned previously, it is clear why “Mv > 1 and DFT Wf” will be worse than “Alt1”. I don’t need to repeat myself, this is due to DFT vs ideal (eigenvector) FD beamforming. Re reciprocity, the underlined assumption is that there is enough reciprocity in the channel; otherwise, there is no need for R17 CB, we already have R16 CBs that will work as good as R17 CB.  The comment beamforming for Mv=1 and Mv>1, we used the same (eigen) for both cases.  Finally, regarding performance loss with Mv>1, as explained, this is due to DFT based FD compression (when Mv>1) as opposed to eigenvector based FD compression) when Mv=1.  @Intel: we have the same view as QCM, i.e., Alt3-0 with Mv=1 (DC component) is one way of implementing Alt1. In terms of UE implementation, Alt1 is preferred.  Finally, below is the **summary of SLS results** from companies comparing W1W2 and W1W2Wf. We can see that there is not enough SLS results comparing the two codebook structures. Among the companies having results, it is 3 vs 3. Since this item is about codebook design, we should make decisions based on the evaluation results (like in R15/16). This is also the intention behind agreeing to an EVM in the beginning of the WI.   |  |  | | --- | --- | | **Observation (based on SLS)** | **Number of companies** | | W1W2 is better | 3 | | W1W2Wf is better | 3 | | No results comparing W1W2 vs W1W2Wf | 18 | |  |  | |
| Ericsson | We address comments from QC and CATT below. We agree somewhat with Intel that if M=1 only is supported, then we could equally well use W1W2 codebook only. Hence. Alt.3-0 with M=1 only is not really an interesting combination.  **Regarding CATT’s comment on beam-specific indication of FD bases:**  When having multiple FD bases, say M=2, it is true that UE uses 2 adjacent FD components that are common for all SD beams. However, this is reasonable because gNB has precoded CSI-RS ports by using the a window method (discussed below), such that the dominant taps for different SD beams are all aligned within a size-2 window after CSI-RS precoding. Beam-specific indication is not needed. The CSI-RS precoding for M>1 is in essence the same as for M=1. With M=1, all the taps (or equivalently all the windows with size 1) are aligned; while with M>1, all the widows with size M are aligned.  **Regarding UE complexity and reporting overhead:**  For M=2 configuration, UE complexity is almost the same, so is the PMI reporting overhead, since the number of SD-FD pairs that gNB needs to process is the same. For example, precoding P ports with M=1 and precoding P/2 ports with M=2 give the same number of candidate SD-FD pairs to the UE, so the dimension of SVD is the same. The latter may introduce some performance loss, as adjacent FD bases are selected pair-wisely using a window method, but we show that the performance loss due to this can be quite small. In real world, where perfect delay reciprocity does not hold (see measurements from Fraunhofer), the latter with M=2 is a more robust configuration.  **Further elaboration regarding delay uncertainty and benefit of M=2 adjacent bases:**  Delay uncertainty needs to be taken care of by both ends when M >1 is configured/indicated. At the UE side, the UE uses a wider FD window, say with M=2 adjacent DFT vectors, for compressing the DL channel. At the gNB side, the gNB needs to precode CSI-RS accordingly. First, gNB finds a FD window with size M that captures the highest energy (Nokia also suggested using an even larger window which is also possible). Then, gNB precodes CSI-RS based on the first FD basis of this window. Figure 2 of Nokia’s tdoc shows a nice illustration of the CSI-RS precoding scheme with M>1, the only difference to our thinking is that *we don’t fix the number of FD windows per SD beam*, i.e., the SD beam and FD windows are jointly found, since the number of dominant taps varies from beam to beam. Another minor difference is that we set the window size to M.  One should also note that when M>1 is configured, UE can also capture all the taps within a window of size M to improve PMI calculation. One may argue that the dominant taps within a beam can have any delay, thus restriction of selecting *adjacent* taps within a window introduces loss. This is true, but the loss is small. We find that even if we allow free selection of SD and FD basis (DFT-based) during CSI-RS precoding, it ends up that adjacent taps (FD bases) within a beam are often selected. One explanation is that each tap has certain width due to finite time domain resolution, which is not as narrow as a dirac pulse, therefore multiple *adjacent* taps can be used. It is also possible that two taps that are close to each other merge into one wide tap.  Below we show two cases exemplifying that adjacent FD bases are used by UE. For the case with and , SD and FD basis are jointly and freely selected in oversampled DFT bases for CSI-RS precoding, the indices of selected SD basis and the corresponding FD basis are shown in the table. Note that the selected SD-FD pairs listed in the table are ordered by their indices, not by the captured power. It is observed that for a given SD beam index, adjacent FD bases are often selected. Then, the selected bases with and are also shown. gNB chooses CSI-RS precoder from the same oversampled DFT bases but the selection is based on a window of size 2. The UE will use adjacent DFT bases in FD to compress the DL channel. In this case, when gNB precodes with FD basis #1, UE can capture both the tap corresponding to FD basis #1 and the tap corresponding to FD basis #2. In addition, the angle-delay power spectrum is also shown for the azimuth cut. For both examples, we see quite good channel reconstruction with by using half of the CSI-RS ports. |
| Nokia/NSB | Support FL’s proposal.  We share similar views as Intel and Ericsson: both eigenvector-based, DFT-based or any other kind of precoding in the FD is possible with this proposal, at least for , but also for . The FD-precoded channel measured on a CSI-RS port is unlikely to be frequency-flat even with eigenvector-based precoding, so reporting of additional FD components can improve the accuracy also for eigenvector-based FD precoding.  We also think the codebook structure W1W2 is equivalent to W1W2Wf with Mv = 1. This structure shows how the precoder matrix is obtained from the reported quantities, so the structure W1W2Wf with Mv = 1 simply says that, for each layer, the same W2 combination coefficients for the selected ports/SD-FD based are applied to all PMI subbands (Wf is all-1 vector), which is the same assumption used with W1W2 and wideband PMI reporting.  So, because Alt1 and Alt3-0 with can support the same UE and gNB implementation, performance should be the same for these two configurations.  @CATT: regarding you comment: “With Alt 1, gNB could find the best combination of SD beam and FD component for each cluster and transmit reference signal over a CSI-RS port accordingly. But if Wf is introduced in the codebook structure, the FD component has to be common to all SD beams unless FD component is indicated/reported in an SD-beam-specific manner”. We don’t think this is the case. gNB can freely select the pairing of SD-FD precoding bases, regardless of the presence of . Whether a UE should know how many SD beams and FD components a gNB has used depends on other design choices for W1, such as polarisation common/specific reporting etc.  Similarly to Ericsson’s description, we also don’t fix the number of FD windows per SD beam as the number of dominant taps varies from beam to beam. Fig 2 in our tdoc illustrates an example for a single SD beam with three FD windows, other beams may have different number of windows |
| Samsung2 | @Ericsson:   * Thanks for the nice explanation. The beamforming operation is gNB implementation, which, in practice, UE is unaware of. Restricting FD basis for beamforming to be a common window among SD beams seems restrictive/artificial. In reality, FD basis will be different for different SD beams. * Then, this common window-based FD beamforming will lead to “less channel flattening” implying the resultant beamformed channel will have some frequency selectivity; hence we will need Wf with M>1. The need for Wf is not then entirely due to the “weak channel reciprocity” as mentioned in your comment, but it is also due to this restricted way to FD beamforming.   @Nokia:   * As mentioned, we don’t think W1W1 and W1W2Wf are identical in terms of codebook design and implementation. Their performance, however, I agree, can be the same. |
| Fraunhofer IIS,  Fraunhofer HHI | @Samsung: We sincerely apologize that you have to repeat yourself ☺  But it is still not clear why M>1 is worse compared to M=1 in your case. Let’s assume the gNB uses the same scheme for beamforming CSI-RS for M=1 and M>1 (in this case there is no difference of the beamformed CSI-RS for M=1 and M>1). Further, assume that the UE simply ignores the FD components (the UE does not care about the value of M) other than the DC component when calculating the precoder coefficients so that the same scheme is used at the UE when calculating the precoder coefficients. In this case, the performance would not depend on the configured value of M. So, in this case, the performance for M>1 would at least not worse than for M=1. However, it seems that use different schemes when calculating the precoder coefficients for M=1 and for M>1, right? If this is the case, it would be good to understand what is the difference between the two schemes. |
| Samsung3 | No need to apologize ☺  Yes, the beamforming scheme is the same (eigen beamforming). But, the number of beamfored ports is less when Mv>1. Is it not a key point in having the Wf component in the codebook? Are you assuming that the number of beamforming ports remains the same? Based on E/// and Nokia comments, I think, they also reduce number of beamformed ports when Mv>1.  If everything else remains the same (as in your comment), then I agree, the performance will be close, but then why we are increasing UE complexity and increasing PMI overhead, if there is not much performance benefits. |
| Sony | We support the FL´s proposal for the sake of progress, but we think that Mv>1 is needed to handle real-world channels, where in UL/DL reciprocity vanishes rapidly with the UL/DL duplex distance. |
| Lenovo/MotM | A few bullet points on our views on this proposal are as follows   * We agree with Samsung, Ericsson, Nokia that W1W2 and W1W2Wf at M=1 are the same, at least in performance. If M=1 only is supported, W1W2 codebook structure suffices * Regarding the support for M=1 and/or M=2, in our view the channel reciprocity is a statistical characteristic, i.e. the strength of the channel reciprocity would vary across time, due to temporal fluctuations of the channel between SRS and CSI-RS transmission. In that regard, two configurations should be supported for reciprocity codebook with M=1 and M=2, with dynamic selection between both. * We support free, polarization-common W1 selection |
| Fraunhofer IIS  Fraunhofer HHI | @Samsung: Thanks a lot for your reply.  When more ports (and hence beams) are spent for M=1 over the case of M>1 at the gNB for beamforming CSI-RS, there is an increase of the spatial resolution of the channel at the UE side. Obviously, this leads to a better estimate of the channel and hence PMI. However, more ports are spent for M=1 over M>1.  When the R17 CB only supports M=1, it would mean that the channel is assumed to be always reciprocal, especially when eigenvector-based beamforming is used for CSI-RS. This is regardless of the number of ports used at the gNB. There is no possibility to correct misaligned delays in the case of less-reciprocal channels.  The intention of Wf (ALT3-0) is to increase the robustness of the R17 CB in case of real-world channels which are less reciprocal than the 3GPP channels. Here, the UE has the ability to correct some misaligned delays. We think that M=2, as proposed by Ericsson, is a good compromise. In the case of identical number of ports for CSI-RS for ALT3-0 and ALT1, the PMI overhead is slightly increased for ALT3-0 over ALT1. However, the feedback overhead is still much less compared to the R16 CB. |

***Proposal 2: For PS codebook enhancements utilization DL/UL reciprocity of angle and/or delay, down-select one codebook structure W=W1W2 WfH from***

* ***Alt 3-0, i.e. W1 ∈ N^{PCSI-RS × K1} (K1 ≤ PCSI-RS ) is a port selection matrix with one SD-FD/SD pair per port***
* ***Alt 5, i.e. W1∈ N^{PSD-FD × K2} (K2 ≤ PSD-FD=Of PCSI-RS) is a SD-FD basis selection matrix with multi-SD-FD/SD pairs per port***
* ***Note that PCSI-RS is the number of CSI-RS ports.***

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| Company | Comments |
| Huawei (Moderator) | To clarify the intention here, I prefer to make a decision as we have agreed last meeting. There are potential impact of UCI design, from the UE perspective, if Alt 3-0 or Alt 5 cannot be clarified,  I am sorry that my original text may not be crystal clear here. So perhaps you may share your view/reasons here for further down-selection.  Here is what I have known so far based on comments.  Alt 3-0: Vivo, Lenovo/MoM, Intel, LGE, MTK, QC, Apple, Ericsson  Alt 5: Nokia/NSB |
| Intel | We support Alt 3-0 as it is captured above in the comment from the Moderator. |
| Ericsson | We support the Proposal. |
| Nokia/NSB | Support |
| Sony | We support Alt 3-0. For compatibility with P3, Option 4, the bullet title should perhaps be changed to Alt 3-0/Alt 3-1, to also support multi-SD-FD/SD pairs per port, if needed, with the CB structure of Alt 3-0. We do not think that supporting multi-SD-FD/SD pairs per port should restrict CB structure to that of Alt 5. |
| Lenovo/MotM | We support Alt 3-0. Company views in tdocs reveal that Alt 3-0 has significantly more support than Alt 5 |

***Proposal 6: For CSI measurement associated to a reporting setting CSI-ReportConfig for NCJT, the UE can be configured with Ks ≥ 2 NZP CSI-RS resources in a CSI-RS resource set for CMR and N ≥ 1 NZP CSI-RS resource pairs whereas each pair is used for a NCJT measurement hypothesis, by down-selection one or a combination of following CMR pairing mechanisms:***

* ***Alt.1: Configure UE with N NZP CSI-RS resource pairs within a CMR resource set explicitly, whereas the first Ks-2N CMRs are for single-TRP measurement hypotheses and the remaining 2N CMRs in consecutive N CMR pairs are for N NCJT hypotheses.*** 
  + ***QC/ZTE***
* ***Alt.2: N CMR pairs are RRC configured and/or indicated (by MAC-CE) explicitly by a bitmap***
  + ***Nokia***
* ***Alt.3: Configure UE with two CMR groups with Ks = K1+K2, whereas each CMR group corresponds to one out of two TRPs. N CMR pairs are explicitly/implicitly determined from two CMR groups, i.e. N=K1K2***
  + ***Vivo/CATT/Oppo/NEC/Intel***
* ***Alt.4: N ≥ 1 NZP CSI-RS resource pairs are determined by UE***
  + ***Futurewei***
* ***Alt.5: N= Ks(Ks-1)/2 pairs for all possible pairing from the set***
  + ***Ericsson***
* ***FFS maximal values of N and Ks***

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| Company | Comments |
| Huawei (Moderator) | From Feature lead perspective, all Alts can work with/extend to support single-TRP hypotheses so that it depends on further clarification from proponent companies.  All different solutions can be related to how to determine N CMR pairs from a given CMR set, so that NCJT reports can be conditioned/selected from those N pairs. It may not be fully decided by RAN2 since it can be related to UCI/CRI reporting/UE complexity design thereafter.  The plan is to stabilize all possible solutions this week and further down-selection next week. |
| Intel | In our view the most flexible alternative is Alt. 1. Also, in Alt. 1 gNB controls the CMR pairs for NCJT and CMR for STRP which is also good. The drawback of this alternative is higher configuration overhead comparing to other alternatives.  For Alt. 3 and Alt. 5, it seems that they are designed for particular use cases. For Alt. 3 it is assumed that there are 2 TRP with multiple beams for each TRP. For Alt. 5 it is assumed that there are Ks TRPs.  In our view for most of the use cases Ks = 2 is enough. Ks = 2 also allow to support deployments with >2 TRP in coordination set by configuring multiple category 1 CSI reports for NCJT. Such approach has more flexibility for scheduler since all the CSI reports are available at the gNB and gNB can allocate resources considering the CSI report and traffic load of a TRPs.  If majority of companies want to support Ks > 2, in our view Alt. 1 is the best candidate for CMR configuration due to flexibility. |
| vivo | In our view, the CMR used for NCJT hypothesis measurement can reused for STRP hypothesis measurement to save UE measurements at least for FR1. With regard to ZTE’s comment for FR2, it can be FFS.  Besides, all of the options discussed in MTRP MB enhancement are based on group-based CMR configuration, where CMRs per group correspond to one TRP. Therefore, an aligned CMR configuration between these two AIs are highly preferred.  Thus, we support Alt.3 with a modification that CMRs between two configured groups are one-to-one mapping to reduce candidate CMR pairs.   * ***Alt.3: At least configure UE with two CMR groups among Ks* ≥ *2N CMRs, whereas each CMR group corresponds to one out of two TRPs. N CMR pairs are explicitly/implicitly determined from two CMR groups. A CMR in each*** ***CMR group can also be used for single-TRP CSI.*** |
| NTT DOCOMO | Regarding the main bullet, we’d like to clarify following points.   * Whether the *N* NZP CSI-RS resource pairs used for NCJT measurement hypothesis can be used for single-TRP measurement hypothesis or not. * Whether *Ks-2N* should be larger than 0 or can be equal to 0.   For Alt.3, we also think that the modification on CMR pairing is needed to reduce the CMR pairs. For the two CMR groups with N NZP CSI-RS resource per group for NCJT measurement hypothesis, N CMR pairs can be determined based on one-to-one mapping between the two groups.   * ***Alt.3’: Configure UE with two CMR groups with Ks = K1+K2, whereas each CMR group corresponds to one out of two TRPs, and N NZP CSI-RS resource within a group can be explicitly/implicitly determined for NCJT measurement hypothesis with one-to-one mapping with the N NZP CSI-RS resource in the other group.***    + ***Support K1=K2. FFS different K1, K2.***   We can further discuss Alt.1 and Alt.3’. Other alternatives can be deleted. |
| Nokia/NSB | In our view the alternative allowing the most flexible configurations and minimal spec change is Alt 2. For example, for a UE capable of 4 simultaneous CSI calculations, the network can configure a CMR resource set with 4 CMRs (for example CMR 0,2 for TRP 0 and CMR 1,3 for TRP 1) and a 4-bit NCJT bitmap selecting CMR pair: (CMR 2, CMR 3). The same CSI Reporting Setting can be used to configure 4 STRP measurements (1 CSI in the report) or 2 STRP measurements (on CMR 0 and 1) and 1 NCJT measurement on (CMR 2, CMR 3) in case of 2 or 3 CSIs in the report.  We can further clarify Alt 2 as follows:   * ***Alt.2: N CMR pairs are RRC configured and/or indicated (by MAC-CE) explicitly by a bitmap. The first CMRs are for single-TRP measurement hypotheses.*** |
| Lenovo/MotM | In our view CMR for NCJT hypothesis can be reused for STRP, where Alt3 suffices for CMR group pairing. We do not agree with the restriction *K*1=*K*2 for Alt3, for instance, the case with *K*1=1 and *K*2=*Ks*-1 can be useful to support a scenario with a primary (fixed) TRP connected to the UE, where the second TRP changes more dynamically, e.g., a HetNet setup |
| QC | Support the proposal to list all the options first.   * We support Alt1. Reusing CMR for single-TRP hypotheses for a NCJT hypothesis is possible in Alt1. Network has full flexibility to reuse the same CSI-RS resource ID or not in the resource set (which can decide based on FR1 versus FR2, scheduling considerations, etc.). This alternative is the most flexible and can address various scenarios. Furthermore, CPU/resource/port occupation are naturally taken care of by this Alt. * We think at least in the case of Alt3 and Alt5, a separate solution is required for FR2 as mentioned before and pointed out by ZTE (unless if additional flexibility/structure are added to those, which would make them more complicated). Hence, we suggest to make it clear that Alt3 and Alt5 are considered for FR1 only (at least in their current formats). * Alt2 can work if the bitmap can also control the single-TRP hypotheses (and not just NCJT hypotheses), but requires more specification efforts. Basically bitmap should have length ***Ks +Ks(Ks-1)/2*** bits. With this Alt, CPU/resource/port occupation should be defined properly. * We are not sure what Alt4 means. |
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