**3GPP TSG RAN WG1 Meeting #103-e R1-200xxxx**

**E-meeting,** **October 26th – November 13th, 2020**

**Agenda Item: 8.1.4**

**Source: Huawei, HiSilicon**

**Title: Summary of CSI enhancements for MTRP and FDD**

**Document for: Discussion and Decision**

# Introduction

*Enhancement on CSI measurement and reporting:*

*a. Evaluate and, if needed, specify CSI reporting for DL multi-TRP and/or multi-panel transmission to enable more dynamic channel/interference hypotheses for NCJT, targeting both FR1 and FR2*

*b. Evaluate and, if needed, specify Type II port selection codebook enhancement (based on Rel.15/16 Type II port selection) where information related to angle(s) and delay(s) are estimated at the gNB based on SRS by utilizing DL/UL reciprocity of angle and delay, and the remaining DL CSI is reported by the UE, mainly targeting FDD FR1 to achieve better trade-off among UE complexity, performance and reporting overhead*

Based on agreed evaluation assumptions in RAN1 102e, companies have provided SLS results and/or preferred designs for CSI reporting for DL Multi-TRP/panel transmission and Type II PS codebook enhancements, which can be found in Reference and Appendix.

* In general for RAN1 103e, the highest priority is to start from sections 2.1 and 3.1 to confirm “Evaluate and, if needed, specify” firstly for both sub-objectives 4a/4b asap. Moreover, some high level RAN1 decisions, e.g. basic FDD CSI codebook design framework or basic common understanding of resource configurations for Multi-TRP transmission hypotheses, etc, shall be clarified in RAN1 103e.
* Moreover, some detailed design, alternatives, discussion points etc shall be summarized and clarified in some proposals to facilitate further technical analysis in next RAN1 meetings, e.g. if further SLS evaluations or technical comparisons among alternatives may be needed in future meetings.

# Summary of CSI enhancement for FDD

## Summary of Evaluation for Rel-17 PS Codebook enhancement

Eleven companies have shown their simulation results, taking into account DL/UL reciprocity of angle and delay. According to agreed EVM assumptions in RAN1#102e, simulation performance of all companies can be summarized in Figure 1 with Rel-16 eType II PS as the baseline under high traffic load (70%~80% resource utilization) with following notes:

* Companies’ contributions can have more simulation results for more extensive study, taking into account variations of the number of ports, ranks, traffic loading, etc. The purpose of summary is mainly for a quick overview of SLS results to identify performance variations at high level. It is encouraged to check companies’ contributions for more evaluation results.
* For the sake of overview, following Figure 1 has included results (if available) with *common simulation settings, i.e. 70% RU, mean UPT, Rel-16 eType II PS as the baseline, SRS error and calibration error modelling* according to the agreements of RAN1#102e.
* In terms of CSI-RS overhead in following figure, two simulation results are provided by Qualcomm, whereas “Qualcomm” and “Qualcomm2” are with and without counting CSI-RS overhead respectively. Moreover simulation performances demonstrated by Nokia/Nokia Shanghai Bell and ZTE have included corresponding CSI-RS overhead in SLS results.
* In terms of beamforming bases in following figure, Samsung, ZTE, CATT, Ericsson, Fraunhofer IIS/HHI and Intel have considered DFT-based CSI-RS beamforming, and remaining companies have considered SVD-based CSI-RS beamforming. Even for the same beamforming bases type, different companies have different gNB implementation on beamforming bases selection. Taking DFT bases as an example, CATT and Ericsson select beamforming bases separately in spatial domain and frequency domain, on the other hand SD-FD pairs are jointly selected in Fraunhofer and Samsung’s simulation.
* In terms of CSI-RS ports number in following figure, Ericsson have provided simulation results with 8 and 16 ports, shown in "Ericsson” and “Ericsson2” respectively.
* In terms of value of **R**, Ericsson have used **R**=1. ZTE, OPPO and Huawei/HiSi have used **R**=4. Qualcomm, vivo and Intel have used **R**=8.
* In terms of UE behaviour, Fraunhofer firstly calculates covariance matrix over each frequency unit (PRB or subband), and then summarizes covariance matrices across all frequency units, and finally selects *n*-th dominant eigenvector of the summation as the precoder for *n*-th layer. However, ZTE, vivo, Nokia/Nokia Shanghai Bell, Ericsson and Huawei/HiSi firstly summarizes all frequency units to obtain WB-like effective channel, and then selects the *n*-th dominant eigenvector of the covariance matrix over the effective matrix as the precoder for *n*-th layer.

**(a) low payload**

**(b) high payload**

**Figure 1 Summary of Simulation Results**

In addition, four companies, Samsung, OPPO, Ericsson and Intel also provide the simulation performance of R16 regular Type II as reference. Rel-17 eType II PS achieves similar performance-overhead trade-off as R16 regular Type II in Samsung and Intel’s simulation. OPPO shows that Rel-17 eType II PS can provide significant gain compared with R16 regular Type II. Ericsson shows that both Rel-17 eType II PS and Rel-16 eType II PS are generally worse than R16 regular Type II.

Last but not least, companies, OPPO, CATT, Ericsson and Huawei/HiSi, also have found that both SRS channel estimation error and gNB DL/UL calibration error have marginal impact on SLS results of Rel-17 Type II PS codebook enhancement.

***Observation 1:*** *The majority of companies can show up moderate performance gain of Rel-17 Type II PS codebook enhancement, compared to Rel-16 eType II PS, assuming high traffic load and same CSI payload.*

***Observation 2:*** *It seems that different gNB implementation over beamformed CSI-RS ports/resources or design details may lead to different achievable performance gain.*

Based on companies’ evaluation results and proposals, some of which may have certain preference of codebook design details without evaluation results, generally there are two possibilities to address “Evaluate and, if needed, specify Type II port selection codebook enhancement” in RAN1 103e as following table:

**Table 1 Summary of Companies’ Views**

|  |  |
| --- | --- |
| **Views** | **Companies** |
| Rel-17 Type II PS codebook enhancement is supported (14).  | CATT, ZTE, vivo, Futurewei, OPPO, Nokia/Nokia Shanghai Bell, Huawei/HiSi, DOCOMO, LG Electronics, Lenovo/Motorola Mobility, Spreadtrum, China Telecom, China Unicom, CMCC  |
|
| Further study and evaluation are needed for Rel-17 Type II PS codebook enhancement (5).  | Ericsson, Qualcomm, Apple, Fraunhofer IIS/HHI |

Based on above majority view, following proposal is suggested:

***Proposal 1:*** *Rel-17 Type II port selection codebook enhancement utilizing DL/UL reciprocity of angle and delay should be supported and specified.*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | Support. |
| CATT | Agree with the proposal. |
| ZTE | In general we are fine with this proposal. In our simulation, performance gain can only be observed based on the enhancement given in Section 2.2, especially in “The mapping between SD-FD precoding basis and CSI-RS port”, where multiple basis pairs are mapped to one port with FDM manner. Without this mapping enhancement, we do not observe gain for Rel-17 approach. Hence we think the mapping enhancement should be supported. At least the discussion on this should be prioritized.  |

## Details of Rel-17 Port Selection Codebook Enhancement

Certainly further detailed technical agreement is subject to Proposal 1. Therefor following summary is mainly for technical comments/discussion and will be adjusted according to RAN1 progress.

#### 2.2.1 Basic Codebook Structure

In general, there are two alternatives for basic codebook structure to start from:

Alt 1： Enhancement based on R16 Type II PS CB type structure, i.e. $W\_{1}W\_{2} W\_{f}^{H}$

Alt 2：Enhancement based on R15 Type II PS CB type structure, i.e. $W\_{1}W\_{2}$

So far following companies have shared their views/preference over basic codebook structure, which can be summarized as follows. Of cause more discussion/clarification are required in order to understand better among RAN1 companies, i.e. functionality/benefits of $W\_{f}^{H}$and other matriceswhich are to be discussed and addressed in section 2.2.2.

**Table 2 Summary of Companies’ Views**

|  |  |
| --- | --- |
| **Views** | **Companies** |
| Alt 1： Enhancement based on R16 Type II PS CB type structure, i.e. $W\_{1}W\_{2} W\_{f}^{H}$ | Futurewei, vivo, OPPO, Lenovo/Motorola Mobility, LG Electronics, DOCOMO, Nokia, Huawei/HiSi |
|
| Alt 2：Enhancement based on R15 Type II PS CB type structure, i.e. $W\_{1}W\_{2}$ | ZTE, CATT, Samsung, OPPO, Spreadtrum, Qualcomm |

Based on above majority view, following proposal is suggested:

***Proposal 2:*** *Support* $W\_{1}W\_{2} W\_{f}^{H}$ *as basic codebook structure for Rel-17 PS codebook enhancement whereas detailed design of matrices* $W\_{1}, W\_{2} , and W\_{f} $ *are FFS.*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | Support. |
|  |  |
| CATT | For Alt 1, different companies have different design on W*f*. For Alt 2, on the other hand, the codebook structure is well defined. Hence, more details of Alt 1 W*f* should be provided before making any decision.  |
| ZTE | We do not support this proposal. The numbers of supporting companies for Alt 1 and Alt 2 are similar. Besides the reason from CATT, * If CSI-RS is precoded with both FD and SD vectors and Wf is selection matrix, we don’t see the rationale of supporting Alt 1, since Alt 1 is actually a special case of Alt 2 in this case, based on our analysis in R1-19007769.
* If Wf is DFT matrix, the benefit of extra DFT based Wf in UE side is not clear as gNB can already precode delay information in CSI-RS, especially when delay information used by gNB to precode CSI-RS is eigenvector. The extra DFT based Wf in UE side also introduces extra UE complexity to perform DFT operation.

Therefore, we believe more study is needed to compare different detailed schemes before down-selection. |

#### 2.2.2 Potential Enhancements, up to rank 2

This section is mainly for summarizing detailed design/preference for each matrix.

* **Enhancement on** $W\_{1}$

There are three alternatives for $W\_{1}$as follows.

* **Alt1:** $W\_{1}$ **is a port selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis**
* **Alt2:** $W\_{1}$ **is a port-group selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis**

Conceptually, all CSI-RS ports in a given CSI-RS resource can be divided into several port groups, supported by Samsung, Fraunhofer IIS/ HHI and DOCOMO. For example, all ports in a port group can be associated with the same SD basis but may be with different FD basis whereas $W\_{f}^{H}$may be used for further port selection in a given port group.

* **Alt3:** $W\_{1}$ **is a SD-FD basis selection matrix whereas each CSI-RS port can be associated with one or more SD-FD beamforming bases**

$W\_{1}$ is a basis selection matrix selecting multiple SD-FD precoding basis so that each selected port may be associated more than one SD-FD precoding basis, e.g. ZTE and Huawei.

* Other enhancements can include: Futurewei, Nokia/Nokia Shanghai Bell, Huawei/HiSi, CATT and Fraunhofer IIS/ HHI have consider free port selection. Huawei/HiSi and Qualcomm have proposed that more ports can be selected compared to R16 PS codebook. LG and CATT have considered polarization independent and/or layer-specific port selection. Fraunhofer IIS/ HHI have proposed to study identical port selection for a subset of transmission layers.

**Table 3 Summary of Enhancement for** $W\_{1}$

|  |  |
| --- | --- |
| **Companies** | **Views** |
| **Futurewei** | Enhanced port selection in W1 such that the selected ports do not have to be consecutive. |
| **Nokia/Nokia Shanghai Bell** | Support free selection of the SD-FD pairs by the UE, i.e., without the constraints of Rel-15/16 port selection, regarding polarisation structure, grouping of consecutive pairs, separation of groups, etc. |
| **LG** | Consider polarization independent and/or layer (layer-group)-specific port selection. |
| **Huawei/HiSi** | $W\_{1}$ is enhanced with free selection by selecting more than 8 (up to all) beamforming ports in a CSI-RS resource |
| **CATT** | * Polarization common and polarization independent port selection shall be further evaluated.
* Free selection and successive selection for port indication should be further studied.
* Layer-specific and layer-common port selection shall be studied considering tradeoff between performance and overhead.
 |
| **Fraunhofer IIS/ HHI** | * The constraint of neighboring beamformed port selection as in the Rel. 15 and Rel. 16 Type II PS codebooks shall be relaxed;
* Study identical port selection for a subset of transmission layers.
 |
| **Qualcomm** | Consider simple enhancement allowing more ports to be selected compared to Rel-16 eType II port-selection while preserving no larger CSI overhead. |

* **Enhancement on** $W\_{2}$

$W\_{2}$ is combination coefficients matrix.CATT has proposed that differential quantization can be considered, with R16 Type II PS CB differential quantization as a starting point..

* **Enhancement on** $W\_{f}$ **(if applicable)**

There are two alternatives for $W\_{f}$as follows.

* **Alt1:** $W\_{f}$ **is a DFT matrix**

$W\_{f}$is a DFT matrix, e.g. by Futurewei, Lenovo/Motorola Mobility, Vivo and Nokia/Nokia Shanghai Bell.

**Table 4 Summary of the enhancement on parameter** $W\_{f}$

|  |  |
| --- | --- |
| **Companies** | **Views** |
| **Futurewei** | Enhancements on$W\_{f}$quantization with a smaller value of **Mv.** |
| **Nokia/Nokia Shanghai Bell** | $W\_{f}$is restricted by the gNB to the first$M^{(DL)}$DFT components and$M^{(DL)}$can be configured from a set of values including at least FD component 0. Configuration and values of$M^{(DL)}$are FFS. |
| **Lenovo/Motorola Mobility** | Introduce additional parameter values for Rel. 16 Type-II port selection codebook, e.g., include WB reporting with **M**=1 |

* **Alt2:** $W\_{f}$ **is a selection matrix**

$W\_{f}$is a selection matrix to selectFD basis from a given port group, or select a SD-FD basis from given SD-FD bases mapped to that selected CSI-RS port.

* **The value of R**

VIVO, ZTE, Nokia/Nokia Shanghai Bell and Huawei/HiSi have considered larger values of parameter R.

**Table 5 Summary of the enhancement on parameter R**

|  |  |
| --- | --- |
| **Companies** | **Views** |
| **Nokia/Nokia Shanghai Bell** | Support extending the values of parameter R controlling the number of PMI subbands. Possible values are: 1, 2, 4, 8 |
| **VIVO** | The SD-FD based CSI-RS precoder can support more elaborate PMI granularity (larger R) without increasing CSI feedback overhead and with the increasing R, the gain of average throughput is larger; by BS indicating FD basis, larger R can be supported and with the increasing R, the gain of average throughput is larger. |
| **ZTE** | As FD vectors are invisible to UEs, gNB can use a smaller frequency-domain granularity, i.e., a larger R value. |
| **Huawei/HiSi** | Larger R (numberOfPMISubbandsPerCQISubband), e.g., R equals to the size of CQI subband |

Based on tdoc review and up to our best understanding of proposals, following proposal is suggested. From FL perspective, subject to the decision over Proposals 1 and 2, it may be more beneficial for RAN1 to consolidate next level details/design and understand each other better so that further comparisons/evaluation can be within a limited but understandable technical set.

***Proposal 3-1:*** *Study following Type II PS codebook enhancements for*$ W\_{1}$

* *Down-select one from following Alternatives:*
	+ *Alt1:* $W\_{1}$ *is a port selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis*
	+ *Alt2:* $W\_{1}$ *is a port-group selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis*
	+ *Alt3:* $W\_{1}$ *is a SD-FD basis selection matrix whereas each CSI-RS port can be associated with one or SD-FD beamforming bases*
* *Free port or port-group selection up to K1 ports or port-groups*
* *Polarization independent selection*
* *Layer common selection, up to rank 2 at least*

***Proposal 3-2:*** *Study following Type II PS codebook enhancements for*$ W\_{2}:$

* *Enhancement on*$ W\_{2} $*quantization/reporting*

***Proposal 3-3:*** *Study following Type II PS codebook enhancements for* $W\_{f}$*:*

* *Down-select one from following Alternatives*
	+ *Alt1:* $W\_{f}$ *is a DFT matrix*
	+ *Alt2:* $W\_{f}$ *is a selection matrix from a given port group or SD-FD bases.*

***Proposal 3-4:*** *Study and determine the value range of* ***R*** *if need*

|  |  |
| --- | --- |
| Company | Comments |
| Nokia/NSB | In case of free selection of ports/port groups/SD-FD bases, we think it’s worth studying the overhead saving, if any, of combining the free port selection indicator with the NZC bitmap***Proposal 3-1:*** *Study following Type II PS codebook enhancements for*$ W\_{1}$* *Down-select one from following Alternatives:*
	+ *Alt1:* $W\_{1}$ *is a port selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis*
	+ *Alt2:* $W\_{1}$ *is a port-group selection matrix whereas each CSI-RS port is associated with single SD-FD beamforming basis*
	+ *Alt3:* $W\_{1}$ *is a SD-FD basis selection matrix whereas each CSI-RS port can be associated with one or SD-FD beamforming bases*
* *Free port, port-group or SD-FD basis selection up to K1 ports, port-groups or SD-FD bases*
* *Polarization independent selection*
* *Layer common selection, up to rank 2 at least, or layer specific selection (free selection indicator and NZC bitmap combined)*

***Proposal 3-2:*** *Study following Type II PS codebook enhancements for*$ W\_{2}:$* *Enhancement on*$ W\_{2} $*quantization/reporting*
	+ *FFS: whether the NZC bitmap needs separate reporting, in case of free selection, for example for RI=1 for layer common/specific selection or for RI*$\geq $*1 for layer specific selection*
 |
| vivo | Regarding proposal 3-1,Firstly, we need to make a precise presentation of $W\_{1}$.In our understanding, the UE needs to report the port selection matrix, say $ P$ , which can be used to deduce $W\_{1}=W\_{1}^{full}P$by the network, where $W\_{1}^{full}$ is the overall matrix containing all possible SD-FD or SD bases.Secondly, we think the listed alternatives have different interpretation of $W\_{1},W\_{2}$, $W\_{f}$ which needs to clarify.In addition, it can also be another alternative that $W\_{1}$ is the matrix of selected SD bases obtained by the reported port selection codebook $ P$ and the overall SD basis matrix $W\_{1}^{full}$, whereas each CSI-RS port is associated with single SD beamforming basis. While the FD-bases can be settled in the part of $W\_{f}$. This structure is more like Rel-16 eTypeII-PS codebook with little change. This is different from the alt1 or alt 3 but not contradictory. No matter CSI-RS ports are precoded by SD-FD bases or SD bases, $ P$ can be the corresponding basis selection matrix.So we propose,1. Clarify the meaning of $W\_{1}, W\_{2}$, $W\_{f}$of each Alt by using more precise representation.
2. Add Alt4 as follows:

Alt4: $P$ *is a SD basis selection matrix used to obtain the exact SD basis matrix* $W\_{1}$ *whereas each CSI-RS port can be associated with one SD beamforming basis*Regarding proposal 3-2, 3-3, 3-4, we are OK with the proposals. |
| CATT | ***Proposal 3-1:***Layer independent selection shall also be studied. ***Proposal 3-3:*** A third alternative can be added:***Alt3:*** $W\_{f}$ is omitted or $W\_{f}$ is identity matrix.***Proposal 3-4:*** Since the computation complexity of and feedback overhead can be made irrelevant to PMI subband size for the enhanced codebook, the PMI subband size can be set to any value based on gNB implementation. Therefore, it does not need to discuss the range of R. |
| ZTE | We think more discussion is needed for these details. We should discuss and align our understanding on the proposals in section 2.1 and section 2.2.1 first. Otherwise there is no point to discuss all these details.For Alt 2, the details to be discussed is much fewer than Alt 1. We should list Alt 2 details before down-selection. |

* **The mapping between SD-FD precoding basis and CSI-RS port**

For the mapping between a SD-FD precoding basis and CSI-RS port, Vivo, ZTE, oppo, Nokia/Nokia Shanghai Bell, Spreadtrum and Huawei/HiSilicon prefer to enhance CSI-RS utilization via mapping multiple SD-FD beamforming bases into one CSI-RS port. On the other hand, Qualcomm suggest that allowing a lower density of CSI-RS resource is sufficient to achieve the same functionality of reducing CSI-RS overhead.

**Table 6 Summary of the enhancement on mapping between SD-FD precoding and CSI-RS port**

|  |  |
| --- | --- |
| **Companies** | **Views** |
| **VIVO** | For SD-FD based CSI-RS precoding, BS can map multi basis to one port to save the CSI-RS resource and indicate the mapping relationship to UE. |
| **ZTE** | Support Rel-17 port selection codebook enhancement with mapping X>$P\_{CSI-RS}$ SD-FD pairs to CSI-RS ports in more than one RB, where $P\_{CSI-RS}$ is the number of configured CSI-RS ports. |
| **oppo** | A possible solution is partitioning PMI subband into O segments, so that whole band comprise comb-O frequency unit and multiple beams can be multiplexed in one CSI-RS port in FDM manner |
| **Nokia/Nokia Shanghai Bell** | Support enhancement of CSI-RS utilization conveying one or more SD-FD pairs per port. The gNB maps P SD-FD component pairs to P\_(CSI-RS)≤P CSI-RS ports. The details of the mapping function are FFS. |
| **Huawei/HiSilicon** | Applying multiple beamforming vectors over single CSI-RS port, with FDM or other multiplexing manners, can effectively improve utilization of CSI-RS. |
| **Spreadtrum** | Support the number of SD-FD pairs being larger than the number of CSI-RS ports. |
| **Qualcomm** | * Many-to-one pair-to-port mapping requires large spec impact and complicate UE capability signaling;
* allowing lower density achieves same functionality of many-to-one pair-to-port mapping;
* RAN1 should not consider many-to-one mapping between SD-FD bases and CSI-RS port.
 |
| **CATT** | More than one CSI-RS resource can be configured so that the number of CSI-RS ports of all configured CSI-RS resources is equal to or greater than that of beams, and each SD-FD pair is mapped to one CSI-RS port. |

Based on tdoc review and up to our best understanding of proposals, following proposal is suggested.

***Proposal 4***: *Study the mechanism of conveying one or more SD-FD beamforming bases per CSI-RS port:*

* *FDM: mapping Of SD-FD bases into single CSI-RS port at frequency domain*
	+ *FFS detailed mapping mechanism at frequency domain and associated indication/the maximal value*

|  |  |
| --- | --- |
| Company | Comments |
| Nokia/NSB | ***Proposal 4***: *Study the mechanism of conveying one or more SD-FD beamforming bases per CSI-RS port:* * *FDM: mapping Of SD-FD bases into single CSI-RS port at frequency domain*
* *CDM: mapping of SD-FD bases into single CSI-RS port CDM-ed across PRBs within a PMI subband*
 |
| vivo | Considering Alt4 in our comment on the former proposal 3-1, the proposal can be updated to ***Proposal 4***: *Study the mechanism of conveying one or more SD-FD/SD beamforming bases per CSI-RS port:* * *FDM: mapping Of SD-FD/SD bases into single CSI-RS port at frequency domain*

*FFS detailed mapping mechanism at frequency domain and associated indication/the maximal value* |
| CATT | There is an alternative proposal to solve the problem of insufficient CSI-RS ports. That is, more than one CSI-RS resource is configured to provide enough number of CSI-RS ports. The FDM multiplexing of one CSI-RS port within one CSI-RS resources violates the definition of antenna port and requires significant specification change. We would like to make the proposal more general like:***Proposal 4***: *Study the mechanism of conveying one SD-FD beamforming basis per CSI-RS port or more than one SD-FD beamforming bases per CSI-RS port.*  |
| ZTE | We think this is a critical issue on whether Rel-17 enhancements can achieve gain.  |

## Others

Remaining proposals for Rel-17 Port Selection Codebook Enhancements are also listed as follows for reference:

|  |  |  |
| --- | --- | --- |
| **Issues** | **Companies** | **Views** |
| ** Indication/reporting mechanism** | **Samsung** | Study indication/reporting mechanism such as reporting only a subset of PMI components from Rel.16 Type II PS codebook |
| **Apple** | For CSI enhancement utilizing partial reciprocity of DL/U channels, more dynamic wideband and Introduce two sets of parameter configurations that model both strong and weak channel reciprocity, where the UE can select one of the parameter configuration sets based on the strength of the channel reciprocity |
| **Lenovo/Motorola Mobility** | Introduce two sets of parameter configurations that model both strong and weak channel reciprocity, where the UE can select one of the parameter configuration sets based on the strength of the channel reciprocity |
| **SRSSpreadts****s****SRS Triggering/ Configuration** | **Futurewei** | FeMIMO supports enhanced SRS frequency hopping transmission with partial overlapping between frequency resources of different hops to improve delay estimation performance. |
| **CATT** | The bandwidth and density of SRS are configured as same as that of CSI-RS to obtain accurate delay information of uplink channel. |
| **Lenovo/Motorola Mobility** | Aperiodic SRS triggering is needed in conjunction with the beamformed CSI-RS for the reciprocity-based codebook, with a limited time gap between the transmission of both RSs |
| **Others** | **InterDigital, Inc** | * Per-layer PDPs and overall channel PDP follow a similar regime.
* It is observed that channel’s PDP and per-layer PDPs are highly correlated in UL and DL.
 |
| **vivo** | * Enhance procedure on timing calibration to counteract the timing mismatch between gNB and UE for FDD CSI enhancement.
* For SD based CSI-RS precoding and BS indicating FD basis, less CSI-RS ports are consumed and less spec change is needed.
 |
|  |  |
| **Sony** | * Companies should study the feasibility of signaling to the UEs the set of CSI-RS beams actually used for co-scheduled transmissions. An indication from the UE to the gNB of those beams suppressed by the UE should also be studied.
* In TDD and FDD FR1 systems exploiting DL/UL channel reciprocity, the UE can signal to the BS the DL covariance matrix of noise and interference. The ways of transferring this information from the UEs to the BS need to be further studied and specified.
 |

|  |  |
| --- | --- |
| Company | Comments |
| vivo | For Alt4, the SD based CSI-RS precoding method, the FD basis information can be indicated to UE directly and this may bring the least influence to codebook because the R16 structure can be reused.We also think timing calibration is an important issue to be solved in order to counteract the timing mismatch between gNB and UE for FDD CSI enhancement. |
|  |  |

# Summary of CSI enhancement for Multi-TRP

## Summary of Evaluations for Rel-17 Multi-TRP CSI Enhancement

Four companies, i.e., Intel, Samsung, VIVO, and ZTE, have provided simulation results on CSI enhancement for multi-TRP. Some performance results of joint CSI feedback are summarised in the following table:

* Companies’ contributions can have more simulation results for more extensive study, taking into account variations of testing scenarios, reference schemes with DPS/NCJT, traffic loading, etc. The purpose of summary is mainly for a quick overview of SLS results to identify performance variations at high level. It is encouraged to check companies’ contributions for more evaluation results.
* For the sake of overview, following table has included results (if available) with *common simulation settings as much as possible, i.e. with similar RU*.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Cell average | Cell edge (5%-ile) | Notes |
| Intel | **34%** (Joint) vs **-8%** (Independent) | **-5%** vs **-32%**  | * Relative gain between Multi-TRP over single-TRP
* Scenario: Indoor hotspot
 |
| Samsung | **21.87%** | **16.41%** | * Relative gain between Joint CSI feedback over independent CSI feedback
 |
| ViVo | **5.67%** (Joint) vs **2.92%** (Independent) | **8.31%** vs **3.34%**  | * Relative gain between Multi-TRP over single-TRP
* Scenario: Dense urban with ideal BH
* RU=25%
 |
| **9.33%** (Joint) vs **4.23%** (Independent) | **15.98%** vs **2.57** | * Relative gain between Multi-TRP over single-TRP
* Scenario: Dense urban with non-ideal BH
* RU=25%
 |
| ZTE | **4.7%**  | **6.0%**  | * Relative gain between Joint CSI feedback over independent CSI feedback
* Scenario: Dense urban
* RU=22.22%
 |

Based on companies’ proposals and evaluation results, it seems to be beneficial to enhance CSI reporting for Multi-TRP, with potentially moderate gain for UMa and good gain for indoor hotspot.

Therefore to address “Evaluate and, if needed, specify CSI reporting for DL multi-TRP and/or multi-panel transmission” in the WID, following proposal is suggested:

***Proposal 5:*** *Rel-17 CSI reporting for DL multi-TRP and/or multi-panel transmission shall be enhanced to support and enable more dynamic channel/interference hypotheses for NCJT*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | It seems that this proposal is for EMBB. In our opinion, MTRP enhancement in Rel-16 includes M-DCI for both ideal backhaul and non-ideal backhaul scenarios. Also, simulation results in our paper show that CSI enhancement for MTRP can bring significant gains for both non-ideal backhaul and ideal backhaul. Therefore, we believe that the CSI enhancement should consider the assumptions of non-ideal backhaul and ideal backhaul for M-DCI based MTRP.Thus, we think proposal 5 can be modified as:***Proposal 5:*** *Rel-17 CSI reporting for DL multi-TRP and/or multi-panel transmission shall be enhanced to support and enable more dynamic channel/interference hypotheses for NCJT in both ideal backhaul and non-ideal backhaul scenarios.* |
| CATT | Support this proposal. |
| ZTE | Support this proposal.Actually, we have more results which provide obvious performance gain with enhanced CSI reporting for larger RUs. This is aligned with the observation with LTE FeCoMP. |
| MediaTek | Support proposal 5. |

## CSI Measurement Mechanism Enhancements for Multi-TRP

Multi-TRP based URLLC schemes were specified in Rel-16. The current CQI derived by single-TRP hypothesis may not represent actual PDSCH decision with repetitions so that MCS selection etc at NW may not be sufficiently accurate for URLLC transmission. Some companies, Vivo, CATT, CMCC, Intel and Ericsson, have proposed that CSI enhancement for URLLC schemes in Rel-16 should be considered in Rel-17. Furthermore, VIVO proposes to support CSI enhancement for HST-SFN schemes in Rel-17.

On the other hand Qualcomm have commented that RAN1 should initially focus on joint CSI for SDM scheme (scheme 1a), because “NCJT” mentioned in the WID often referred to either single-DCI based SDM scheme (scheme 1a) or multi-DCI based multi-TRP transmission in the discussions/agreements during Rel-16.

***Proposal 6:*** *Discuss and determine in RAN1-103e about whether Rel-17 MIMO shall enhance CSI for Multi-TRP based URLLC schemes and Multi-TRP based HST SFN transmission*

* *CSI enhancement for Multi-TRP based URLLC schemes:*
	+ *Yes:* Vivo, CATT, CMCC, Intel, Ericsson
	+ *Lower priority: Qualcomm*
* *CSI enhancement for Multi-TRP based HST SFN transmission*
	+ *Yes: Vivo*
	+ *Lower priority:*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | Support. The CSI feedback in different schemes could be diverse. |
| CATT | CSI enhancement for Multi-TRP based URLLC schemes is supported. CSI enhancement for Multi-TRP based HST SFN can also be considered. |
| ZTE | This proposal seems unnecessary. The motivation and the spec impact is unclear even if we agree on it. Suggest discuss other proposal first. |
| MediaTek | Although seeming out of scope, we are fine to discuss it in R17 FeMIMO. However, we prefer not to make a conclusion in this meeting. It is better to collect more evaluation results showing it is indeed beneficial to have CSI enhancement for URLLC and/or HST SFN. |

Following CSI measurement schemes have been widely discussed by companies’ contribution with following preference:

* **Scheme 1-1:** CSI-RS port groups in a resource are associated to different TRPs/TCI states
	+ Yes (6): CMCC, Qualcomm, Docomo, NEC, Nokia, LGE,
	+ No: Ericsson, OPPO
* **Scheme 1-2:** CSI-RS resources are associated to different TRPs/TCI states.
	+ Yes (11): CMCC, Docomo, Intel (for eMBB/URLLC), NEC, Fraunhofer/IIS, LGE, OPPO, CATT, ZTE, FutureWei, Nokia/NSB
	+ No:
* **Scheme 1-3:** CSI-RS resource sets are associated to different TRPs/TCI states.
	+ Yes (6): CMCC, Docomo, MTK, NEC, LGE, CATT
	+ No:
* **Scheme 2:** CSI-RS reports associated to different TRPs/TCI states.
	+ Yes (4): Lenovo/MotoMobility, Intel (for URLLC), VIVO
	+ No: LGE, Docomo, Qualcomm

The majority of companies prefers to enhance CSI measurement for NC-JT in Rel-17 by Scheme 1-2. The main technical benefit is that the TCI state configuration at resource level for Scheme 1-2 can reuse existing CSI feedback framework and additional association between CSI-RS resources is required for a given Multi-TRP transmission hypothesis. On the other hand, companies preferring Scheme 1-1, i.e. different port groups in a CSI-RS resource can be associated to different TCI states/TRPs, think that Rel-17 UE can simply report the CRI corresponding to a CMR [22]. Ericsson and Oppo do not prefer Scheme 1-1 mainly due to more specification impact and relatively harder to extend and support a large coordination set with more TRPs in future releases.

Six companies prefer to Scheme 1-3. To support the CSI report under a multi-TRP hypothesis, two NZP CSI-RS resource sets associated to different TRPs can be configured and for a resource set, no restriction is enforced over TCI states. Comparing with Scheme 1-2, Scheme 1-3 may have less specification impact [7].

Lenovo and VIVO prefer to enhance CSI measurement for NCJT in Category 2, considering that it is more applicable to the NW with non-ideal backhaul and less specification efforts are required [4] and Category 2 has less restriction over network capability for optimizing available scheduling resources across different TRPs [18]. Three companies (LGE, Docomo, and Qualcomm) have concerns over Category 2, due to more specification impact by introducing new restrictions over two *CSI-ReportConfig*s and unnecessary configuration/indication overhead.

Samsung proposes to support the schemes in Category 1 for single-DCI based multi-TRP and allow UE to be configured between schemes in Category 1 and 2 for multi-DCI based multi-TRP. The reasons are that the schemes in Category 1 are suitable for the scenario where multiple TRPs are connected via an ideal or low-latency backhaul and the scheme in Category 2 is suitable for the case where multiple TRPs are connected via a non-ideal backhaul.

Based on above majority view supporting scheme 1-2, following proposal is suggested:

***Proposal 7:*** *For Rel-17 CSI enhancement for DL multi-TRP and/or multi-panel transmission, NZP CSI-RS resources in a CSI-RS resource set for channel measurement are associated to different TRPs/TCI states at resource level*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | We cannot support this proposal. Some reasons are given as follows:* Scheme 1 doesn’t support non-ideal backhaul scenario very well.
	+ In non-ideal backhaul scenario, common understanding is that different TRPs independently execute scheduling and determine transmission resources. For Scheme 1, if a UE periodically reports CSI to one TRP, the TRP receiving the CSI has to periodically transfer the CSI to the other TRP via the backhaul, leading to large latency and unnecessary burden on the backhaul.
* Regarding Scheme 1, one report containing multiple CSIs associated to different TRPs/TCI states will cause larger CSI payload size and more specification efforts, such as defining more groups of ports/sets/resources associating to TRPs, new report quantities, formats, and omission handling, etc.
* Scheme 2, on the contrary, can be supported with little CSI framework update except simple association setup. Some even think it is naturally ready for non-ideal backhaul M-DCI based MTRP. And it can also be tailored for ideal backhaul cases. In addition, we think Scheme 2 is more flexible for CSI report configuration and CSI-RS resource configuration that same or different configurations for different TRPs can be achieved.

Therefore, Scheme 2 should be supported. |
| CATT | In joint CSI reporting, each resource can be associated with one TRP. However, further discussion is needed on whether the resources corresponding to different TRPs are within the same resource set or not.  |
| ZTE | Support this proposal. |
| MediaTek | We prefer Scheme 1-3 over Scheme 1-2. Scheme 1-2 requires the introduction of CMR-to-CRI mapping whereas Scheme 1-3 only requires to add one more resource set.To vivo: gNB can still configure multiple CSI reports using the existing R16 CSI framework to support non-ideal backhaul M-DCI based MTRP. Here, the focus is to additionally support joint CSI measurement/reporting, where ideal backhaul should be a valid assumption. |

What RAN1 may needs to discuss and decide next is to determine what single transmission hypothesis of Multi-TRP/panel really means, from NZP/ZP CSI-RS resource configuration perspective and associated measurement behavior therefore at the UE side. In order words, for a given CSI reporting configuration, the UE shall be able to identify single or plural Multi-TRP transmission hypotheses within a given boundary of measurement resource configuration.

For example, Qualcomm proposes to extend the principle in Rel-15, i.e., CMRs of a *CSI-ReportConfig* with one TCI state correspond to single-TCI state hypotheses whilst CMRs with two TCI states correspond to multi-TRP hypothesis. The hypothesis of a CSI is uniquely determined by the corresponding CRI.

In [5], ZTE proposes the implicit method to identify the hypothesis of one CMR. Specifically, the joint CSI computation on two CSI-RS resource configured with the same two TCI states corresponding to the multi-TRP hypothesis. If UE selects a CRI corresponding to a CSI-RS resource with two TCI states, UE will determine CSI based on the interference between the CSI-RS resource and its associated CSI-RS resource.

***Proposal 8:*** *For CSI measurement over a Multi-TRP/panel transmission hypothesis, study following measurement resource configuration/association mechanism and down-select one Alternative in RAN1 104e:*

* *Alt 1: One CMR resource configured with two TCI states and one CSI-IM resource for interference measurement*
* *Alt 2: Two CMR resources in a resource set each of which is configured with two identical TCI states and one CSI-IM resource for interference measurement*
	+ *FFS any restrictions over CMR resources*
* *FFS whether/how to support interference measurement based on NZP CSI-RS in Rel-17*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | We cannot support the proposal before we have agreement on Proposal 7. |
| CATT | This issue is highly related to proposal 7, and it can be discussed with lower priority. |
| ZTE | Support |
| MediaTek | Agree with vivo and CATT |

## CSI Reporting Mechanism Enhancements for Multi-TRP

For a given multi-TRP hypothesis, three companies [5][14][22] propose that the CSI includes one CRI, two RIs, two PMIs, two LIs, and one CQI. Specifically, as in Rel-16 SDM-based NC-JT, transmission layers of that codeword correspond to different TCI states and reported CSI should consist of one combined CQI across TRPs [22]. Due to non-coherent JT, corresponding CSI report should consist of two separate PMIs/RIs corresponding to two TRPs. Nokia and Spreadtrum have proposed that reported RIs is restricted to following sets: {1,1},{1,2},{2,1},{2,2}.In addition, the UE should report separate layer indicators (LIs) as the strongest layer given that two PTRS ports is specified for SDM scheme in Rel. 16 [22].

Two companies CATT and Samsung proposes the UCI would contain two sets of {RI, PMI, CQI} corresponding to the cooperating TRPs.

Futurewei [1] propose the UE may report one or more CQIs within a single CSI report considering that the UE can determine or select a measurement resource for CMR, CSI-IM or muting.

***Proposal 9:*** *For a CSI associated with single Multi-TRP/panel transmission hypothesis, the UE is expected to report*

* *One CRI, two RIs, two PMI, two LIs and [one] CQI*
* *FFS: restrictions among reported CSI quantities, e.g. among ranks and PMIs*
* *FFS: restrictions of applicable codebook*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | First of all, we need to agree on the supported transmission schemes for CSI enhancments. Only after that can we decide the CSI reporting quantities of each individual transmission scheme.So we think it is too early to have this proposal. |
| CATT | For joint CSI feedback, CQI report per codeword is preferred. In addition, CQI per TRP based on single-TRP transmission hypothesis can also be reported.Furthermore, report quantities for non-PMI based port selection should also be considered.  |
| ZTE | Support |
| MediaTek | Support the proposal in principle. The number of reported CQI (1 or 2) should be configurable per CSI report in order to support multi-DCI based multi-TRP. |

Another discussion point for CSI reporting is how many CSI can be configured by a given CSI reporting configuration. In Rel-15, UE reports the single CSI for a given *CSI-ReportConfig*. When one UE is configured by more than one CMRs, the UE will select the best hypothesis and indicate associated CRI. Four companies (NEC, Docomo, Ericsson, and Qualcomm) have proposed that single CSI report should include two CSIs, i.e., one CSI corresponding to the best hypothesis among single-TRP hypotheses and the best hypothesis among multiple-TRP hypotheses. The purpose of two CSIs in the single CSI report is to improve the NW scheduling flexibility.

***Proposal 10:*** *For a CSI reporting configuration in Rel-17, the UE can be expected to report*

* *One CSI associated with the best single-TRP hypothesis following legacy reporting mechanism and*
* *One CSI associated with the best multi-TRP hypothesis following Rel-17 reporting mechanism*

|  |  |
| --- | --- |
| Company | Comments |
| vivo | In non-ideal backhaul scenario, with the independent scheduling assumption, reporting both best single-TRP CSI hypothesis and multi-TRP CSI hypothesis doesn’t make sense. As shown in the table in our paper, simulation results show that UE selecting and reporting the best CSI hypotheses can bring significant gains for non-ideal backhaul.We would like to update the proposal as:***Proposal 10:*** *For a CSI reporting configuration in Rel-17, the UE can be expected to report* * *Alt 1: One CSI associated with the best single-TRP hypothesis following legacy reporting mechanism and one CSI associated with the best multi-TRP hypothesis following Rel-17 reporting mechanism*
* *Alt 2: One CSI associated with the best one among multi-TRP and single-TRP hypothesis following Rel-17 reporting mechanism*
 |
| CATT | Support this proposal in principle. However, whether the hypothesis for CSI calculation is indicated/configured by network or recommended by UE should be clarified.  |
| ZTE | We prefer to further discuss this issue as the outcome from other proposals may impact it. In addition, single-TRP CSI feedback can be configured in another CSI reporting. |
| MediaTek | We prefer to have more flexibility, i.e., it should be configurable to report both hypotheses or either one of hypotheses. Signaling overhead can be reduced if only one hypothesis is reported. |

## Others

Companies are also proposing other enhancements for Multi-TRP CSI which can be discussed further once basic CSI measurement enhancement is more or less clarified and agreed by RAN1:

|  |  |  |
| --- | --- | --- |
| **Issues** | **Companies** | **Views** |
| **Overhead reduction for RI feedback** | **NEC** | Overhead reduction for joint RI feedback can be studied for the typical cases. |
| **MediaTek Inc** | The allowed RI pairs can be specified for a multi-TRP hypothesis to limit signaling overhead, and it should be configurable to allow one of the RIs to be reported as 0. |
| **UE implementation complexity** | **Huawei/HiSilicon** | In Rel-17, depending on final design, new UE capability design should be considered to address potential “under-reporting” issue consider new CPU occupancy rules and counting principles, for joint CSI measurement for multi-TRP transmission. |
| **Samsung** | Design new CPU occupation rule for dynamic NC-JT CSI report |
| **Qualcomm** | An SDM CSI hypothesis occupies two CPUs, two active resources, and a number of active ports corresponding to both TCI states. These numbers are separate from single-TRP hypotheses. |
| **Interference hypothesis** | **ZTE** | UE shall calculate interference from the coordinated TRP considering the selected precoder and beam used by the coordinated TRP. |
| **NEC** | For multi-TRP/panel transmission, inter-TRP/panel interference measurement can be based on CSI-RS resource(s) configured for channel measurement for other TRPs. |

Four companies [2][8][14][22] have provided the views related to UE implementation complexity from CSI enhancement for multi-TRP. Specifically, Huawei/HiSilicon, Samsung and Qualcomm have proposed that CPU occupancy rules and counting principles of active CSI-RS resources/ports should be re-visited in Rel-17 for Multi-TRP CSI measurement.

# Proposals for Online/Offline Discussion

TBD

# Work Plan

TBD

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# Appendix

* **Companies’ proposals on CSI enhancements for FDD**

**Table A-1 Companies’ proposals on CSI enhancements for FDD**

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| **Futurewei** | * FeMIMO supports enhancements on Wf quantization with a smaller value of Mv.
* FeMIMO supports enhanced port selection in W1 such that the selected ports do not have to be consecutive.
* FeMIMO supports reduced size for the PMI indicators for FD basis, bitmap, and W2 coefficients.
* FeMIMO supports enhanced SRS frequency hopping transmission with partial overlapping between frequency resources of different hops to improve delay estimation performance.
 |
| **Huawei, HiSilicon** | * Port selection CB enhancement based on angle and delay reciprocity should be supported and specified in Rel-17.
* Both Alt1 and Alt2 can be used as basic codebook structure for R17 port selection codebook enhancement. Alt1 is slightly preferred due to better design flexibility for payload/performance/overhead trade-off.
* With R16 Type II port selection codebook as a start point, following enhancements can be considered:
	+ $W\_{1}$ is enhanced with free selection by selecting more than 8 (up to all) beamforming ports in a CSI-RS resource;
	+ $W\_{f}$ can be limited with very few vector(s), e.g. 1/2/4;
	+ Larger R (numberOfPMISubbandsPerCQISubband), e.g., R equals to the size of CQI subband
 |
| **InterDigital, Inc.** | * Further study each category prior to a down-selection.
* Study delay-compensated precoding for Type II port selection enhancement
 |
| **vivo** | * With the enhancement on delay information, there is an obvious improvement on the average throughput gain with the same CSI feedback overhead.
* The utilization of delay information provided by partial reciprocity can bring considerable performance gain.
* The codebook structure enhancement should follow Rel-16 codebook structure.
* Enhance procedure on timing calibration to counteract the timing mismatch between gNB and UE for FDD CSI enhancement.
 |
| **ZTE** | * Rel-17 codebook structure based on FDD reciprocity is designed based on CSI-RS precoded in both frequency domain and spatial domain.
* For codebook enhancement in Rel-17 based on FDD reciprocity, support UE selects SD-FD pairs jointly, and the codebook structure is $W=W\_{1}W\_{2}$.
* Support Rel-17 port selection codebook enhancement with mapping X>PCSI-RS SD-FD pairs to CSI-RS ports in more than one RB, where PCSI-RS is the number of configured CSI-RS ports.
 |
| **CATT** | * R15 Type II PS CB type structure is used as baseline for R17 enhanced PS CB.
* Codebook enhancement based on FDD channel reciprocity shall be supported.
* More than one CSI-RS resource can be configured so that the number of CSI-RS ports of all configured CSI-RS resources is equal to that of beams, and each SD-FD pair is mapped to one CSI-RS port.
* Polarization common and polarization independent port selection shall be further evaluated.
* Free selection and successive selection for port indication should be further studied.
* Layer-specific and layer-common port selection shall be studied considering tradeoff between performance and overhead.
* The bandwidth and density of SRS are configured as same as that of CSI-RS to obtain accurate delay information of uplink channel.
* Differential quantization can be considered with R16 Type II PS CB differential quantization as a starting point.
* Non-zero coefficients are indicated by using port indication information.
 |
| **Samsung** | * for the study phase of Rel. 17 FDD CSI enhancement, use Rel. 16 reg. T2 CB as a reference performance, in addition to the Rel. 16 PS T2 CB “baseline”
* for performance evaluation,
	+ refine the two codebook structure alternatives:
		- Alt1:
	+ $P\_{CSIRS}=P\_{SD}×P\_{FD}$ *CSI-RS ports, where* $P\_{SD}$ *beam-forming vectors* $\{b\_{i}\}$ *in SD and* $P\_{FD}$ *beam-forming vectors* $\{f\_{k}\}$ *in FD*
	+ *Codebook components:*
		- *Selection of* $2L $*out of* $P\_{SD}$ *SD ports and* $M$ *out of* $P\_{FD}$ *FD ports*
		- $K^{NZ}<2LM$ *NZ coefficients*
		- *Amplitude/phase of the selected NZ coefficients*
		- Alt2:
	+ $P$ *CSI-RS ports, each associated with a pair of SD-FD beam-forming vectors* $\left(b\_{i},f\_{i}\right)$
	+ *Codebook components:*
		- *Selection of* $X$ *out of* $P$ *or* $P/2$ *ports*
		- *Amplitude/phase of the selected* $X$ *ports*
	+ study indication/reporting mechanism such as reporting only a subset of PMI components from Rel.16 Type II PS codebook
 |
| **OPPO** | * Support to specify Rel-17 Port selection exploiting both angle/delay reciprocity in Rel-17 MIMO.
* Spatial/frequency beam shall be transparent to UE, no need to specify spatial and frequency weighting structure. Support freely port selection.
* Partitioning PMI (CQI) subband into O segments, UE may select antenna port and frequency unit freely.
 |
| **Sony** | * Companies are encouraged to study whether enhanced modeling of intra-cluster delay spread is needed and, if so, how to model it.
* BS manufacturers should confirm whether the standard deviation values proposed for the amplitude and phase calibration errors, i.e., 0.7 dB and 5 degrees, are realistic. BS manufacturers are also encouraged to report on the frequency-dependency of the amplitude and, mainly, phase errors in realistic deployments.
* Companies should study the feasibility of signaling to the UEs the set of CSI-RS beams actually used for co-scheduled transmissions. An indication from the UE to the gNB of those beams suppressed by the UE should also be studied.
* In TDD and FDD FR1 systems exploiting DL/UL channel reciprocity, the UE can signal to the BS the DL covariance matrix of noise and interference. The ways of transferring this information from the UEs to the BS need to be further studied and specified.
* Possible enhancements of CSI to improve the UL and DL code book selection when channel reciprocity is poor can be investigated and studied.
 |
| **Apple** | * For CSI enhancement utilizing partial reciprocity of DL/U channels, more dynamic wideband and subband CSI reporting configuration can be considered
* For Type II port selection codebook enhancement, further evaluation and justification is needed
 |
| **LG Electronics** | * For Rel-17 PS CB, support Rel-16 Type II PS CB structure based enhancements.
* For Rel-17 PS CB, consider polarization independent and/or layer (layer-group)-specific port selection.
* Discuss how to configure/indicate codebook parameters and/or additional information obtained from UL/DL channel reciprocity at gNB side.
 |
| **FraunhoferIIS, Fraunhofer HHI** | * Due to the sub-optimal performance of Rel. 17 PS codebook compared to Rel. 16 PS and Rel. 16 PS free selection, further discussions are essential to justify its need.
* Study identical port selection for a subset of transmission layers.
 |
| **Nokia,Nokia Shanghai Bell** | * Support Rel-17 PS codebook structure based on Rel-16 PS codebook, *i.e.*, $W=W\_{1}\tilde{W}\_{2}W\_{f}^{H}$, where
* the basis $W\_{f}$ is restricted by the gNB to the first $M^{(DL)}$ DFT components and $M^{(DL)}$can be configured from a set of values including at least FD component 0.
* The basis $W\_{1}$ indicates the free selection of SD-FD component pairs and is reported by the UE.
* The reported nonzero coefficients in $\tilde{W}\_{2}$ correspond to the selected SD-FD component pairs.
* The gNB calculation of SD and FD components is implementation specific and not restricted to specified codebooks.
* The pairing of SD and FD components by the gNB is transparent to the UE, i.e., the UE does not know the number of distinct SD components and FD components per beam used to precode the CSI-RS ports.
* Support extending the values of parameter R controlling the number of PMI subbands. Possible values are: 1, 2, 4, 8.
* Support enhancement of CSI-RS utilization conveying one or more SD-FD pairs per port. The gNB maps P SD-FD component pairs to P\_(CSI-RS)≤P CSI-RS ports. The details of the mapping function are FFS.
* The FD basis, $W\_{f}$, applied at the UE is configured by the network. $W\_{f}$ consists of the first $M^{(DL)}$ DFT components. Configuration and values of $M^{(DL)}$ are FFS
* The SD basis, $W\_{1}$, applied at the UE selects $L$ SD-FD pairs out of $PM^{(DL)}$ possible choices.
* Support free selection of the SD-FD pairs by the UE, i.e., without the constraints of Rel-15/16 port selection, regarding polarisation structure, grouping of consecutive pairs, separation of groups, etc.
* The number of selected SD-FD pairs is reported by the UE and corresponds to the number of reported NZCs.
 |
| **Lenovo, Motorola Mobility** | * Consider Rel. 16 Type-II port selection codebook as the starting point for FDD reciprocity codebook
* Discussion on whether the CSI-RS beamforming is UE-specific or cell-specific is irrelevant and is already implied from the Port Selection matrix design of both Rel. 15 and Rel. 16 Type-II port selection codebooks
* Introduce additional parameter values for Rel. 16 Type-II port selection codebook, e.g., include WB reporting with M=1
* Aperiodic SRS triggering is needed in conjunction with the beamformed CSI-RS for the reciprocity-based codebook, with a limited time gap between the transmission of both RSs
* Introduce two sets of parameter configurations that model both strong and weak channel reciprocity, where the UE can select one of the parameter configuration sets based on the strength of the channel reciprocity
 |
| **Spreadtrum Communications** | * Support Alt2, i.e., enhancement based on R15 Type II PS CB type structure.
* Support the number of SD-FD pairs being larger than the number of CSI-RS ports.
 |
| **NTT DOCOMO, INC** | * Since the UL dominant sub-space is different than that of DL when considering phased arrays (with fixed inter-element spacing) for transmission, allow UE to pick L SD beams out of the K (≥L) beamformed CSI-RS ports.
* Allow UE to select FD bases as well in order to provide higher flexibility and performance. FD bases selection can be either SD beam common or SD beam specific.
 |
| **Ericsson** | * Only marginal gain is seen with R17 PS over R16 PS based on current results, further study is needed to justify the enhancement.
 |
| **Qualcomm Incorporated** | * RAN1 should carefully study the performance of FDD reciprocity before specifying potential enhancements.
	+ If performance gain is observed, RAN1 should justify the source of the gain and the discussion of enhancement techniques should be based on the justification.
* If RAN1 decide to specify Rel-17 FDD CSI, consider simple enhancement allowing more ports to be selected compared to Rel-16 eType II port-selection while preserving no larger CSI overhead.
* RAN1 should not consider many-to-one mapping between SD-FD bases and CSI-RS port.
 |

* **Companies’ proposals on CSI enhancements for Multi-TRP**

**Table A-2 Companies’ proposals on** **CSI enhancements for Multi-TRP**

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| **Futurewei** | * FeMIMO supports associating a group of measurement resources to one CSI report configuration of a UE and let the UE determine or select whether a measurement resource is for CM, IM, or muting. The UE may then report one or more CQIs within a single CSI report.
 |
| **vivo** | * The CSI framework designed in Rel-17 should consider both ideal backhaul and non-ideal backhaul scenarios.
* Support Cat2 for CSI enhancement for MTRP.
* Support CSI enhancement for different single-DCI-based MTRP transmission schemes, including HST-SFN schemes specified in Rel-17.
* Support CSI feedback with UE’s recommendation for a preferred transmission scheme for MTRP CSI enhancement.
* For CSI enhancement based on Cat2, support UE indication of whether the target TRP is suitable for transmission in the following period in the CSI feedback for each MTRP.
* For CSI enhancement based on Cat2, the UE will determine CSI reporting quantities based on the indication of whether the target TRP is suitable for transmission or not.
 |
| **ZTE** | * Support Category 1, i.e.
	+ For a reporting setting CSI-ReportConfig, more than one CSI-RS port groups in a resource or resources or resource sets are associated to different TRPs/TCI states,
		- the UE will determine CSI reporting quantities based on pre-defined/indicated/configured/UE-selected channel and interference hypotheses across TRPs /TCI states
		- and then report one or more CSIs within a single CSI report.
* In one CSI-RS resource set for channel estimation, two CSI-RS resources configured with the same two TCI states are associated to different TRPs,
	+ If UE selects a CRI corresponding to a CSI-RS resource with two TCI states, UE will determine CSI based on the interference between the CSI-RS resource and its associated CSI-RS resource.
		- The CSI includes two RI, PMI, LI and one combined CQI.
* UE shall calculate interference from the coordinated TRP considering the selected precoder and beam used by the coordinated TRP.
 |
| **CATT** | * For multi-TRP CSI enhancement, category 1 is supported.
* Indication/configuration/report on the transmission scheme assumed for CSI calculation can be considered.
* At least the following CSI feedback quantities need to be supported:
	+ PMI/RI for each TRP/panel
	+ CQI for each codeword or TRP
 |
| **CMCC** | * Support Category 1 that reporting one or more CSIs within a single CSI report for one reporting setting CSI-ReportConfig.
* Two CRI and corresponding CQI, RI and/or PMI could be reported in joint CSI reporting, whether one or two CQI/RI/PMI is reported is related to the transmission scheme.
* Within a single CSI report，the result of choosing DPS or NCJT scheme could be indicated implicitly to the TRPs according to the CSI reporting quantities.
 |
| **Samsung** | * On CSI enhancements for multi-TRP,
	+ Support Category 1 for single-DCI based multi-TRP
	+ Allow UE to be configured between Category 1 and 2 for multi-DCI based multi-TRP
	+ Support CMR to be re-used as IMR for both non pre-coded and pre-coded CSI-RS
* Propose UE-selected dynamic reporting between NC-JT and non-NC-JT CSI
	+ Study UCI structure optimized for dynamic NC-JT CSI report
* Design new CPU occupation rule for dynamic NC-JT CSI report
 |
| **OPPO** | * Support only Category 1 to avoid redundant specification effort and simplify signaling design.
* For Category 1, support only resource based configuration (configuration of more than one resources or resource sets associated to different TRPs/TCI states).
* Consider joint CSI report to support overlapped PDSCHs, non-overlapped PDSCH and S-TRP.
 |
| **Apple** | * In Rel-17 CSI enhancement for MTRP, consider the enhancement to both CSI measurement configuration and CSI report quantity configuration to reflect the reciprocal relationship between CMR and IMR, especially for NCJT
 |
| **LG Electronics** | * Support enhancement for CQI reporting reflecting inter-TRP interference based on NZP CSI-RS resource for IM.
	+ by reporting RI/PMI/CQI for one TRP together with updated CQI for another TRP in which the RI/PMI are reflected as interference.
	+ by reporting RI/PMI for one TRP together with joint CQI reporting for single DCI based multi-TRP transmission
* Category 1 can be considered for CSI enhancements for multi-TRP transmission.
 |
| **FraunhoferIIS, Fraunhofer HHI** | * For SDM multi-TRP NC-JT, a CSI report is associated with multiple NZP CSI-RS resources whereas each NZP CSI-RS resource is associated with a different TRP (i.e., TCI state), and a CSI report contains a single CSI (one CQI, one or more PMIs/RIs) for a selected set of CMR(s)/IMR(s).
 |
| **Nokia,Nokia Shanghai Bell** | * Support a combination of solution 1) and 2) of category 1, i.e., enhancement to a single CSI Reporting Setting with two port groups within the same CMR associated to different TCI states/TRPs and multiple CMRs within the same resource set associated to different TCI states/TRPs.

Consider, at least, the following enhancements.* Modification to the TCI state definition, to allow association of two TCI states to two groups of ports within a CMR
* Introducing support for the calculation of 2 sets of PMI/RI for NCJT, one for each group of CSI-RS ports, when 2 TCI states are associated to the same CMR:
	+ Each PMI is applicable to a single group of ports
	+ The combination of reported RIs is restricted to the following sets: {1,1},{1,2},{2,1},{2,2}
	+ A single CQI is reported
 |
| **NEC** | * Category 1 with one report setting and a single CSI report with two CSIs should be supported.
* Overhead reduction for joint RI feedback can be studied for the typical cases.
* For multi-TRP/panel transmission, inter-TRP/panel interference measurement can be based on CSI-RS resource(s) configured for channel measurement for other TRPs.
 |
| **MediaTek Inc** | * For CSI enhancement of multi-TRP, Category 1 is prioritized in R17.
* For channel measurement of multi-TRP, two periodic/semi-persistent NZP CSI-RS resource sets can be configured.
* For channel measurement of multi-TRP, two aperiodic NZP CSI-RS resource sets can be triggered by a trigger state.
* One CSI report can include $K\_{m}$ CRIs for multi-TRP hypotheses and $K\_{s}$ CRIs for single-TRP hypotheses, where $K\_{m}$ and $K\_{s}$ are configurable.
* FFS Maximum configurable numbers for each codebook type
* For a multi-TRP hypothesis, individual PMI and RI are generated for each CMR.
* The allowed RI pairs can be specified for a multi-TRP hypothesis to limit signaling overhead, and it should be configurable to allow one of the RIs to be reported as 0.
* For a multi-TRP hypothesis, the number of CQI to be reported is configurable.
 |
| **Intel Corporation** | * Support category 1 MTRP CSI for single-DCI based MTRP transmission (eMBB)
* One CSI report with multiple CSI-RS resources corresponding to different TRP is configured
* At least RI1, RI2, PMI1, PMI2, CQI is included in the CSI report, where RI1, PMI­1 corresponds to first TRP, RI2, PMI2 corresponds to the second TRP
* Consider optimization of CSI feedback for DPB and NC-JT
* Alt. 0: Separate CSI report for DPB
* Alt. 1: Selection of DPB or NCJT at the UE for one CSI report
* Alt. 2: Reporting of DPB and NCJT in one CSI report
* Support category 1 MTRP CSI report for multi-DCI based MTRP transmission (eMBB)
* One CSI report with multiple CSI-RS resources corresponding to different TRP is configured
* At least RI1, RI2, PMI1, PMI2, CQI1, CQI2 is included in the CSI report, where RI1, PMI1, CQI1 corresponds to first TRP and RI2, PMI2, CQI2 corresponds to the second TRP
* Support enhanced CSI feedback for MTRP transmission with PDSCH repetition
* Alt 1: CSI optimized for MTRP transmission with PDSCH repetition (Category 1 MTRP CSI)
* Alt. 2: Two CSI reports corresponding to two TRP with aligned RI value (Category 2 MTRP CSI)
 |
| **Lenovo, Motorola Mobility** | * Discuss CSI enhancements for multi-DCI mTRP along with single-DCI mTRP
* The UE should be configured by the network to report mTRP-based CSI feedback under multi-DCI setup
* Support Category 2 CSI feedback as a starting point
* The number of CSI reports fed back should be limited to within the number of channel hypotheses or the number of TRPs
* Joint CSI reporting content should be discussed under different mTRP configurations
* CSI feedback corresponding to each TRP is decomposed to up to two CSI reports, each including information corresponding to two different sets of layers
* Consider CQI enhancements that enable joint CQI reporting for different hypotheses
 |
| **Spreadtrum Communications** | * Both Category 1 and Category 2 could be considered for M-TRP.
* Support limited rank pair for NC-JT, e.g., {1, 1}, {1, 2}, {2, 1}, {2, 2}.
* Study how to demonstrate the validity of CSI parameters for joint reporting in NC-JT.
* A new design of CSI composition and CSI Part 2 omission priority should be considered for joint reporting in NC-JT.
 |
| **NTT DOCOMO, INC** | * Support Category 1 - For a reporting setting CSI-ReportConfig, more than one CSI-RS port groups in a resource or resources or resource sets are associated to different TRPs/TCI states,
* UE can report two CSIs as a CSI pair within a single CSI report by default. The number of CSI pairs to be reported within a single CSI report can be RRC configured and up to X.
* For a CSI-ReportConfig based on Category 1 for MTRP transmission schemes,
* Support UE to report two CRIs per CSI pair within a single CSI report,
* Support RRC to configure the number of RI, LI, PMI, and/or CQI to be reported per CSI pair within a single CSI report.
* For a CSI-ReportConfig based on Category 1 for MTRP transmission schemes,
* UE can be configured to report both single-TRP CSI and MTRP CSI in a single CSI report.
 |
| **Ericsson** | * For CSI enhancement for multi-TRP, support category 1.
* For associating channel measurement resources to TRPs/TCI states, downselect among one of the two alternatives:
* Alt 1. different NZP CSI-RS resources are associated with different TRPs
* Alt 2. different NZP CSI-RS resource sets are associated with different TRPs
* In NR Rel-17, support the possibility to report multiple CSIs in a single CSI report where the multiple CSIs may include single-TRP CSI as well as multi-TRP CSI.
* In NR Rel-17, unify the Rel-17 MTRP CSI framework enhancements to consider MTRP CSI for both NC-JT and multi-TRP URLLC schemes.
 |
| **Qualcomm Incorporated** | * For multi-TRP CSI enhancements, RAN1 should initially focus on joint CSI for SDM scheme (scheme 1a).
* Support Category 1 for multi-TRP CSI enhancements.
* Study the pros and cons of the following two approaches within Category 1 to enable CSI report for SDM scheme:
* Approach 1: Support two TCI states for one CSI-RS resource for CMR, where the CSI-RS ports consists of two port groups associated with the two TCI states.
* Approach 2: Support two CMRs corresponding to two CSI-RS resources for a NCJT CSI hypothesis.
* Support one-to-one mapping between CSI-IM and CRI codepoint for a given CSI-ReportConfig.
* An SDM CSI hypothesis occupies two CPUs, two active resources, and a number of active ports corresponding to both TCI states. These numbers are separate from single-TRP hypotheses.
* For multi-TRP CSI enhancements:
* Only Type I codebook is supported.
* The maximum number of CSI-RS ports across both TRPs should not exceed 32 ports.
* The same number of CSI-RS ports per TRP is supported.
* SDM CSI report should consist of one CRI, one CQI, two RIs, two LIs, and two PMIs.
* If a CSI-ReportConfig consist of both single-TCI state and multi-TCI state hypothesis types, UE reports two CSIs corresponding to the best hypothesis within a given type and the corresponding CRIs.
 |