**3GPP TSG RAN WG1 #109-e R1-2203889**

**e-Meeting, May 9th – 20th, 2022**

**Agenda item:** 9.1.2

**Source:** Moderator (Samsung)

**Title:** Moderator Summary on Rel-18 CSI enhancements

**Document for:** Discussion and Decision

## Introduction

The scope given in the Rel-19 NR Evolved MIMO WID [1] pertaining to CSI enhancement is as follows:

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| 1. Study, and if justified, specify CSI reporting enhancement for high/medium UE velocities by exploiting time-domain correlation/Doppler-domain information to assist DL precoding, targeting FR1, as follows:    * Rel-16/17 Type-II codebook refinement, without modification to the spatial and frequency domain basis    * UE reporting of time-domain channel properties measured via CSI-RS for tracking 2. Study, and if justified, specify enhancements of CSI acquisition for Coherent-JT targeting FR1 and up to 4 TRPs, assuming ideal backhaul and synchronization as well as the same number of antenna ports across TRPs, as follows:    1. Rel-16/17 Type-II codebook refinement for CJT mTRP targeting FDD and its associated CSI reporting, taking into account throughput-overhead trade-off |

## Summary of companies’ views

### Issue 1: Type-II codebook refinement for CJT

Table 1A Summary: issue 1

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| **#** | **Issue** | **Companies’ views** |
| 1.1 | Work scope: Type-II codebook structures to be extended for CJT support, assuming a common design framework   * Opt1. Rel-16 regular eType-II * Opt2. Rel-16 port selection (PS) eType-II * Opt3. Rel-17 port selection (PS) FeType-II   **FL Note**: All the 3 options can of course be extended for CJT. But perhaps the scope can be reduced if there is consensus not to refine 1 or 2. | **Opt1 (R16 R-T2):** Huawei/HiSi, Samsung, Ericsson, Nokia/NSB, MTK, ZTE, Lenovo, LG, Apple, DOCOMO, NEC, vivo (high priority) , CMCC, OPPO  **Opt2 (R16 PS-T2):**  **Opt3 (R17 PS-T2):** Huawei/HiSi, Ericsson, =ZTE, Lenovo, DOCOMO, vivo, CMCC |
| 1.2 | Work scope: The number of cooperating TRPs (=N) supported in Type-II codebook refinement (note: WID specifies 4 as the max)   * N=1, 2, 3, 4   **FL Note**: This is from spec perspective, not for evaluation (evaluation can prioritize a subset) | **N=2**   * **Support:** Huawei/HiSi, Samsung, OPPO, Lenovo, LG (by default), DOCOMO, NEC, vivo, Nokia/NSB * **Not support:**   **N=3**   * **Support:** Huawei/HiSi, Samsung, vivo, Nokia/NSB * **Not support:**   **N=4**   * **Support:** Huawei/HiSi, Samsung, Apple, DOCOMO (open to N=4 for intra-site), NEC, vivo, Nokia/NSB * **Not support:** |
| 1.3 | Work scope: Rel-16/17 Type-II codebook/PMI components to be refined or reused for CJT extension   1. SD and FD basis vector designs (not precluding adding new values of N1, N2, N3) 2. SD and FD basis selection schemes (not precluding per-TRP or joint-across-TRPs selection, this refers to, e.g. the combinatorial indication and two-step FD basis selection) 3. W2 coefficient quantization scheme 4. Non-zero coefficient selection and indication schemes 5. Strongest coefficient indication scheme 6. Supported parameter combinations (keeping same set of parameters, whether the legacy values are fully reused or possibly refined for, e.g. further overhead reduction) and parameter values (including, e.g. R, K0) 7. Per layer feedback   **FL Note**: Considering work scope and continuity with legacy design (some already being deployed), we should strive for maximum reuse of legacy designs. Although one may claim that evaluation is needed to ensure whether reusing as such results in desirable performance, the above parameters are primarily “format” issue. | **1 (SD/FD basis design):**   * **Fully reuse legacy:** Huawei/HiSi (for R17), Lenovo, Samsung, Apple, DOCOMO, NEC, vivo, CMCC, Nokia/NSB * **Refinement:** Huawei/HiSi (Joint SD-FD eigen-vector basis for R16)   **2 (SD/FD basis selection scheme):**   * **Fully reuse legacy:** Samsung, Nokia/NSB, Apple, NEC, vivo, CMCC * **Refinement:** vivo (per TRP SD basis selection)   **3 (W2 quantization):**   * **Fully reuse legacy:** Samsung, MTK, Apple, vivo, CMCC, Nokia/NSB (re. co-scaling, both reference amplitudes may need reporting for TRPs other than the strongest) * **Refinement:**   **4 (NZC):**   * **Fully reuse legacy:** * **Refinement:** Huawei/HiSi (joint across TRPs), Lenovo, vivo (joint across selected TRPs), CMCC   **5 (SCI):**   * **Fully reuse legacy:** * **Refinement:** Huawei/HiSi (joint across TRPs), Samsung (strongest TRP), Nokia/NSB (FD basis ref), ZTE (FD basis ref) , NEC (we also support strongest TRP indication), vivo (joint across TRPs) , CMCC   **6 (Parameter combination):**   * **Fully reuse legacy:** * **Refinement:** Samsung, ZTE, Huawei/HiSi (R values), Lenovo NEC (we also support R values) , vivo (need evaluation) , CMCC, Nokia/NSB   **7 (Per layer feedback):**   * **Fully reuse legacy:** Samsung, DOCOMO, vivo, CMCC, Nokia/NSB * **Refinement:** Huawei/HiSi (receiver side information by per-RX feedback) |
| 1.4 | Work scope: Supported NZP CSI-RS (CMR) setups in Resource Setting associated with Rel-18 Type-II codebook for CJT   * Opt1: 1 NZP CSI-RS resource, max # ports = 32 * Opt2: *K*>1 NZP CSI-RS resources with the same number of ports (representing *K* TRPs), max # ports per resource = 32   **FL Note**: Both are valid options for CJT operation.  Note that in the current Rel-15/16/17 spec and UE capability, the max # ports per resource is 32, and the highest UE capability allows a total of 256 ports across all resources. | **Opt1 (1 resource)**   * **Support:** ZTE, Samsung, Lenovo, NTT Docomo, Nokia/NSB, Qualcomm, LG, Apple, NEC * **Not support:**   **Opt2 (>1 resources)**   * **Support:** Huawei/HiSi, Ericsson, ZTE, Samsung, Spreadtrum, CATT, vivo, Xiaomi, Lenovo, CMCC, NTT Docomo, Nokia/NSB, MTK, CEWiT, Qualcomm, LG, OPPO (max total 32) * **Not support:**   **Additional restriction on the max total # ports across all resources beyond Rel-15/16/17 spec and UE capability:**   * **No:** Huawei/HiSi, Samsung, Nokia/NSB * **Yes (specify):** vivo (max=32) OPPO (32) |
| 1.5 | Candidates for Rel-16/17 Type-II codebook extension for *N*-TRP CJT   * Opt1. Per-TRP (port-group or resource) SD/FD basis selection + relative co-phasing/amplitude. Example formulation:   + = co-amplitude and   + = co-phase * Opt2. Per-TRP (port-group or resource) SD basis selection and joint (across *N* TRPs) FD basis selection. Example formulation: * Opt3. Per-TRP (port-group or resource) joint SD-FD basis selection + relative co-phasing/amplitude. Example formulation:   + = co-amplitude and   + = co-phase   **FL Note**: The above are valid options for CJT operation, with potentially different use cases.  Example formulations are for discussion purposes (spec formulation is up to the 38.214 editor).  For Opt1/2, for per-TRP SD/FD basis selection, whether to have per-TRP RRC parameter(s) for L and/or M or not is a **separate issue** | **Opt1 (per-TRP SD/FD)**   * **Support:** Xiaomi, OPPO(not both), LG, Lenovo, MTK. Samsung, ZTE, CATT, Apple, NTT Docomo (for inter-site), Fraunhofer/HHI, Intel, AT&T, Huawei/HiSi (no co-scaling), NEC, CMCC * **Not support:**   **Opt2 (per-TRP SD, joint-FD)**   * **Support:** Ericsson, Samsung, Spreadtrum, Xiaomi, CATT, OPPO(not both), Lenovo, NTT Docomo (for intra-site. The case of the same SD basis across TRPs can be also considered.), Nokia/NSB, Fraunhofer/HHI, MTK, Intel, Qualcomm, NEC(co-amplitude and co-phase should also be considered in Opt2.), vivo, CMCC * **Not support:**   **Opt3 (per-TRP joint SD-FD basis)**   * **Support:** Huawei/HiSi (no co-scaling) * **Not support:** |

Table 1B Type II CJT: summary of observation from SLS

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| **Company** | **Metric** | **Key observation** |
| Huawei/HiSi | SLS: Mean UPT, 5% UPT | * Observation 4: The CJT codebook design with joint space-frequency domain statistical eigenvectors achieves 10~15% gain for mean UPT and 12~43% gain for 5%-tile UE UPT, compared with DFT basis. * Observation 5: The full channel feedback for CJT codebook can provide about 10~20% gain for mean UPT and 30~90% gain for mean UPT and 5% UPT respectively. * Observation 6: Compared to TRP independent selection of coefficients for W2,   + Joint selection among TRPs can provide about 7~10% and 16~28% performance gains for mean UPT and edge UPT, respectively, when each TRP has 32 CSI-RS ports.   + Joint selection among TRPs can provide up to about 2~6% and 12~22% performance gains for mean UPT and edge UPT, respectively, when each TRP has 8 CSI-RS ports. * Observation 7: There is a significant performance loss at both mean UPT and 5% UPT when the frequency domain granularity changes from 2RB to 4RB, especially at 5% UPT (a loss more than 26%). |
| Ericsson | SLS: Mean UPT, 5%/50%-/95%-UPT | For mean/5%/50%/95% UPT, the gains of mTRP over sTRP are:   * RU20: 1%/5%/0%/0% * RU50: 11%/42%/13%/1% * RU70: 28%/80%/35%/2% * Full buffer: 27%/57%/-/- |
| MTK | SLS: Mean UPT | * Ideal CSI: up to 30% gain, compared to sTRP * mTRP codebook: up to 15% gain, compared to sTRP * Ideal CSI > mTRP codebook > Rel-16 eType-II for mTRP > Rel-16 eType-II for sTRP > Rel-15 Type-I MP for mTRP |
| Samsung | SLS: Mean UPT vs overhead | * Observation 1: CB2 and CB1 yield gain in throughout vs. overhead trade-off over Rel-16 T2 CB, with CB2 outperforming CB1. * Observation 2: The throughputs of CB2 and CB1 do not change significantly as overhead increases. The overhead for both codebooks is high. This implies that the set of parameter combinations can be refined for CB1/CB2 to further reduce the overhead. * Observation 3: for varying number of TRPs (),   + CB2 outperforms CB1 for any value   + The performance of CB2/CB1 remain similar as overhead is increased for the existing Rel-16 paraComb=1,2..,6. * Observation 4: Significant performance gain (e.g.35-45% in avg. UPT with CB2 and 25-35% in avg. UPT with CB1) can be achieved with mTRP C-JT CSI (N=2,3,4) over sTRP CSI (N=1). * Observation 5: the throughput-overhead trade-offs for 4 ports are similar to that for 8 ports. * Observation 6: Further significant performance gain (e.g.70-110% in avg. UPT with CB2 and 50-90% in avg. UPT with CB1) can be achieved with mTRP C-JT CSI (N=2,3,4) over sTRP CSI (N=1). * Observation 7: A similar trend is observed that CB2 (55%) > CB1 (44%) sTRP with Rel-16 eType-II CB (0%) as the case of intra-cell scenarios. |
| Nokia | SLS: Mean UPT, cell-edge (5%) UPT | * In our preliminary simulation results, we observe very significant throughput gains in intra-site (rural macro + RRH) deployment at 700 MHz, in the order of 40% for mean UE throughput and 116% for cell-edge throughput. Gains are also significant, although smaller, for inter-site (urban macro only) deployment, with increase in throughput of about 8% and 34% for mean UE and cell-edge throughput, respectively. |
| ZTE | SLS: Mean UPT, 5%/50%-/95%-UPT | * Observation 4: From evaluation results, it can be observed that, compared with sTRP and NC-JT, C-JT can bring performance gains in terms of both cell-edge and mean UPT. |
| Vivo | SLS: Mean UPT, 5%/50%-/95%- UPT | * Observation 1: Ideally, more significant gain can be obtained by JT in the Indoor Hotspot and intra-site CoMP scenarios. * Observation 2: TRP recommendation causes marginal performance loss, but it reduces feedback overhead and UE complexity significantly because more than 50% of Ues do not need to report CSI for all TRPs in the measurement set. * Observation 3:   + Compared to Scheme 2, Scheme 1 has performance gain. |
| CATT | SLS: Mean UPT, 5% UPT | * Comparing with S-TRP scheme, intra-site C-JT scheme can provide significant gain, both for the cell edge and cell average. Specifically, nearly 200% SE gains for the cell edge Ues, and 21% SE gains for the cell average are achieved. |
| CEWiT | Mutual information vs SNR | * Observation 1: Dynamic selection of TRPs shows considerable spectral efficiency improvement. * Observation 2: Spectral efficiency gain is considerable across all SNR range. |
| **Summary**:   * Performance gain of Type-II CJT over sTRP   + SLS (UPT, UPT vs overhead): Huawei/HiSi, Ericsson, MTK, Samsung, Nokia, ZTE, vivo, CATT   + Other: CEWiT (mutual information) | | |

**General observation**:

* Table 1.A:
  + [1.1]
* Table 1.B:

Based on the above inputs, the following **moderator proposals** are made:

Proposal 1.A:

Proposal 1.B:

Proposal 1.C:

Table 2 Additional inputs: issue 1

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| **Company** | **Input** |
| Mod V0 | 1. **Check and, if needed, update your view in Table 1A/1B** 2. **Share additional inputs here, if needed** 3. **Moderator proposals will be added in the next revision** |
| Lenovo | We prefer to prioritize Issues 1,1, 1,2, and 1,4 before discussing further codebook design details in Issue 1.3. Also, our preference for Issue 1.5 would depend on outcome of Issues 1.2, 1.4. |
| LG | - Issue 1.4 and 1.5 can be discussed with priority in this meeting and discussed together since they have dependency each other.  - For issue 1.2, further evaluation is needed and it is premature to make a decision/progress in this meeting.  - Issue 1.3 is codebook details so we can discuss it in future meetings and higher level discussion should be prioritized in this meeting. |
| Samsung | Re 1.3, component 4 and 7, we prefer reusing legacy design principle as much as possible. Re component 4 (NZC), we would like clarify that that exact details will depend on the CB structure. For ex, for decoupled CB, the bitmap requires bits, and for joint CB, it requires bits where . So, in our view, both bitmaps follow legacy design in principle.  Re 1.3 and 1.5 (Opt3) on joint SD-FD basis, other than the new SVD/eigen-vector basis vectors, does this also include DFT-based design? |
| NTT DOCOMO | We think it is important to discuss the target scenario first, including intra-site/inter-site deployment, and issue#1.1. And we think intra-site deployment has higher priority.  Then our preferred options for issue#1.4, #1.5 as well as #1.2 are related to the target scenario.  - For different scenarios, the preferred option could be different.  And then issue#1.3 is based on the outcome of #1.5.  - For different scenarios, the codebook formulation may be different, then the detailed design for each issue in #1.3 could be also different. |
| NEC | We provided our position in the table. In addition, we propose to consider switching between single-TRP and multi-TRP hypotheses for CJT codebook. |
| Vivo | Regarding 1.4, the max number of ports per resource set is up to 64 for resource selection rather than codebook search in current spec and UE feature, and 256 ports is the total number of ports across all CCs in a band. We have concern to increase the number of ports for one codebook search larger than 32 due to UE implementation complexity.  Re 1.5, for Opt 2, W1 arranged as the 1st polarization across all TRPs and the 2nd polarization across all TRPs can also be considered as an alternative. |
| Huawei, HiSilicon | @Samsung, the joint SD-FD basis can use eigen-vector basis or DFT basis, and the eigen-vector basis can also be used for joint SD-FD basis or separate SD-FD basis.  For the components in issue#1.3, they would depend on the decision of other issues and further evaluations, the detailed discussion can be the next step.  For issue#1.4, we don’t think there’s necessity to limit the max number of CSI-RS ports. With such limitation, the TRPs equipped with massive MIMO will not be able to use CJT. In addition, since rel-15, there’s UE capability to measure CSI-RS resources with up to 256 ports, which has been larger than that required for CJT already. |
| CMCC | We think issue #1.1, #1.2 and #1.4 should be discussed firstly, since the outcomes of these issues are much related to the detailed design of codebook, i.e. issue #1.3 and issue #1.5.  For issue # 1.3, it is more or less related to the structure of codebook in issue #1.5, so we think issue #1.3 and #1.5 should be discussed jointly. |
| OPPO | For issue#1.2, we think CSI feedback for up to 4 TRPs can be supported. However, simultaneous transmission from more than two TRPs cannot be supported without enhancement on transmission schemes (e,g. TCI state), which is out of scope. |
| Nokia/NSB | - Issue 1.3  Component 3 (W2 quantisation). Reusing legacy quantisation, in our view, does not preclude, e.g., reporting a reference amplitude for the stronger polarisation of each TRP other than the strongest TRP. In legacy single-TRP quantisation this reference amplitude is assumed 1 and not reported, but for CJT this scaling factor may be needed.  Component 4. We support reuse of legacy design as much as possible also for joint selection across TRPs, but some details may depend on the codebook structure in 1.5. |

### Issue 2: Type-II codebook refinement for high/medium UE velocities (with time/Doppler-domain compression)

Table 3A Summary: issue 2

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| **#** | **Issue** | **Companies’ views** |
| 2.1 | Work scope: Type-II codebook structures to be extended for time/Doppler-domain compression, assuming a common design framework   * Opt1. Rel-16 regular eType-II * Opt2. Rel-16 port selection (PS) eType-II * Opt3. Rel-17 port selection (PS) FeType-II   **FL Note**: All the 3 options can of course be extended for Doppler-domain compression. But perhaps the scope can be reduced if there is consensus not to refine 1 or 2.  Note that WID dictates no change in spatial- and frequency-domain designs, hence the time/Doppler-domain component is “modular” | **Opt1 (R16 R-T2):** Samsung, Huawei/HiSi, Ericsson, ZTE, Xiaomi, OPPO, CMCC, Nokia/NSB, Intel, Fraunhofer/HHI, Lenovo, LG, Apple, DOCOMO, NEC, vivo, CMCC  **Opt2 (R16 PS-T2):**  **Opt3 (R17 PS-T2):** Huawei/HiSi, Ericsson, ZTE, Xiaomi, Lenovo, DOCOMO, vivo, CMCC |
| 2.2 | Candidates for time/Doppler-domain basis design:   * Alt1A. Orthogonal (critically-sampled) DFT * Alt1B: rotation factor + orthogonal DFT * Alt2. Non-orthogonal (over-sampled) DFT * Alt3. Other waveforms (e.g. SVD-type, DPSS/Slepian, DCT, polynomial)   **FL Note**: Orthogonal DFT (Alt1) can be used as a baseline. Whether other waveforms can offer significant benefit can be assessed. | **Alt1A (orthogonal DFT):** Huawei/HiSi, Samsung, ZTE, IDC, OPPO, Apple, Nokia/NSB, Fraunhofer/HHI, MTK, Intel, Lenovo, LG, NEC, vivo(study) , CMCC  **Alt1B (rotation factor + orthogonal DFT):** Samsung (study), Fraunhofer/HHI, Apple (study)    **Alt2 (Oversampled DFT):** Samsung (study), Fraunhofer/HHI, vivo(study)  **Alt3 (Other - specify):** Samsung (study DPSS/Slepian, DCT), Nokia/NSB (study DCT)  **Alt4 (None):** Lenovo (Identity transformation) for case of a small number of time samples, vivo (no compression in time/Doppler-domain, i.e., reporting multiple W2) |
| 2.3 | Fundamental time/Doppler-domain compression parameters:   1. TD/DD basis vector length N4 (analogous to 2N1N2 and N3) 2. TD compression unit relative to slot length (analogous to the relation between FD compression unit and CQI sub-band, i.e. for FD compression) 3. The number of selected TD/DD basis vectors (analogous to L and M) 4. …   **FL Note**: While the exact details depend on the waveform (basis design) selection, some fundamental parameters are applicable for any waveform selection | **1 (TD/DD basis length):** Samsung, Nokia/NSB  **2 (TD compression unit):** Samsung, MTK  **3 (# selected basis vectors):** Samsung, Fraunhofer/HHI, Apple, Nokia/NSB |
| 2.4 | Work scope: Rel-16/17 Type-II codebook/PMI components to be refined or reused for TD/DD compression extension   1. SD/FD basis selection 2. W2 coefficient quantization scheme   Note: Rel-16/17 SD/FD basis design is **fully reused** per WID  **FL Note**: Considering work scope and continuity with legacy design (some already being deployed), we should strive for maximum reuse of legacy designs. Although one may claim that evaluation is needed to ensure whether reusing as such results in desirable performance, the above parameters are primarily “format” issue. | **1 (SD/FD basis selection):**   * **Fully reuse legacy:** Samsung, Nokia/NSB, Intel, LG, DOCOMO, vivo (study details) , CMCC * **Refinement:** Apple **(if the 3D W2 is sparse)**   **2 (W2 quantization):**   * **Fully reuse legacy:** Samsung, Nokia/NSB * **Refinement:** Apple **(if the 3D W2 is sparse)** |
| 2.5 | TD vs DD basis in codebook structure   * Alt1. TD basis, e.g. * Alt2. DD basis, e.g.   + Note that may be the identity as a special case   **FL Note**: The above example formulations are for discussion purposes (spec formulation is up to the 38.214 editor) | **Alt1 (TD basis):** CATT, Xiaomi, LG, vivo (study)  **Alt2 (DD basis)**: Samsung, Xiaomi, OPPO, Lenovo, Nokia/NSB, Fraunhofer/HHI, Intel, vivo (study), Huawei/HiSilicon |
| 2.6 | The use of legacy NZP CSI-RS to facilitate necessary measurements   1. P CSI-RS, e.g. periodicity and offset setting 2. SP CSI-RS, e.g. burst setting 3. AP CSI-RS, e.g. group triggering 4. TRS   **FL Note**: **Companies are encouraged to comment on how to use P/SP/AP CSI-RS for the purpose of CSI calculation involving Type-II with TD/DD compression.**  CSI-RS enhancement is out of scope. However, how to use/refine the legacy/current CSI-RS resource setting to facilitate necessary measurements should be discussed as it can affect evaluation and detailed designs. | **P CSI-RS**: LG  **SP CSI-RS**: Samsung, LG, Lenovo  **AP CSI-RS**: Samsung  **CSI-RS burst for AP and SP (multiple CSI-RS resources/samples):** Huawei/HiSi, Ericsson, CATT, Samsung, Nokia/NSB, DOCOMO (study) , CMCC  **TRS**: CATT, Nokia/NSB (CSI-RS+TRS), vivo (CSI-RS+TRS) |
| 2.7 | CQI definition and calculation (including prediction) associated with the PMI from Type-II with TD/DD compression, e.g. whether UE-side CQI prediction: including “future” CQI(s) with TD/DD PMI  **FL Note**: **Companies are encouraged to comment on CQI definition and calculation associated with the PMI from Type-II with TD/DD compression.**  While PMI associated with the extended Type-II CB is by nature predictive (i.e. allowing the gNB to predict future PMI), how to define/extend CQI to match the PMI needs to be discussed to ensure maximum benefit. | **Reducing CQI mismatch:** Lenovo  **CQI based on multiple reported PMIs**: Nokia/NSB  **UE-side prediction:** Huawei/HiSi, Ericsson, ZTE, vivo, Nokia/NSB, MTK, Intel, Qualcomm, Apple  **gNB-side prediction**: Ericsson, Nokia/NSB, Intel, Qualcomm  **No** **prediction**: Futurewei, Samsung (R18 enhancement doesn’t require prediction) |

Table 3B Type II Doppler: summary of observation from SLS

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| **Company** | **Metric** | **Key observation** |
| Huawei/HiSi | SLS: Mean UPT | Observation 8: The performances of R16 Type II at 30km/h and 60km/h UE speed have 25.8% and 35.3% loss compared with UE speed of 3km/h. The performances of R17 Type II at 30km/h and 60km/h UE speed have 30.7% and 40.8% loss compared with UE speed of 3km/h.  Observation 9: For UE-based CSI prediction at speed 60km/h with 10ms periodicity of CSI feedback,   * 14% average gain compared with R17 type II * 13% average gain compared with R16 type II. |
| ZTE | SLS: Mean UPT, 50%/5% UPT | Observation 2: Regarding CSI prediction scheme-2 (-based prediction), based on SLS simulation results in UMa, we can observe:   * In LOS, some performance gain and potential CSI overhead reduction can be obtained via exploring Doppler-domain information. * However, for NLOS, it is difficult to identify dominant Doppler components for CSI prediction/extrapolation, and consequently advanced algorithm (like artificial intelligence (AI) for CSI prediction) may be further studied |
| CATT | SLS: Mean UPT, 5% UPT | Observation-1:   * When the CSI feedback periodicity is 5ms, the average throughput of 60km/h has 22% loss and the 5% edge throughput of 60km/h has 45% loss compared with 3km/h. |
| Vivo | SLS: Mean UPT, 95%/50%/5% UPT | Current codebook types only cultivate spatial domain and frequency-delay domain characteristics and feedback the most important components in both domains without considering any Doppler-time domain information. However, performance degrades considerably when the UE is moving in medium/high speed where Doppler effect becomes a crucial factor, as shown by the preliminary simulation results in Figure 1. |
| OPPO | SLS: Mean UPT vs overhead | Multiple types of codebook have been introduced in Rel-15/16/17. However, most codebook design only considers low mobility. In medium/high mobility, the channel response estimated by UE and the channel of practical PDSCH transmission may be mismatched due to UE’s movement. The performance of Rel-16 eTypeII CSI reporting may be worse than that of type I codebook in medium/high mobility as show in figure 1.  Observation 1:   * The enhanced Doppler domain reporting has better performance for speed of 30km/h (Doppler frequency fd<220Hz, about 15% gain over type I) * The CSI overhead would not be increased by Doppler basis reporting. Meanwhile, time domain DFT can be considered as starting point for study. * Burst CSI-RS can further improve the performance for 60-120km/h (220Hz<fd<880Hz, 5%~10% gain) * The performance gain for velocity>=60km/h is small (fd>220Hz, about 5% gain). |
| Nokia/NSB | Autocorrelation | 1. We observe that at medium/high velocity, the coefficients of are significantly less correlated in time than the CSI-RS channel measurements, which suggests that effective compression of PMI in time/Doppler domain is hard to achieve. 2. The low time correlation of seems related to the fact that eigenvectors are calculated with a phase uncertainty, and they are calculated independently for each CSI-RS measurement occasion, hence a random phase factor tend to decorrelate the time sequence of . |
| Fraunhofer/HHI | SLS: Mean UPT vs overhead | Observation 7: Enhanced Type II CB with Doppler domain information outperforms Rel. 16 Type II CB in terms of performance and feedback overhead. |
| MediaTek | CDF of performance | Observation 3: When the channel is LOS, the rank, , and can be the same for 40 ms with acceptable performance, for both the RMa scenario with UE speed 60 km/hr and the UMa scenario with UE speed 30 km/hr.  Observation 4: For the case of RMa 60 km/hr and NLOS, the rank, , and can be the same for 40 ms with acceptable performance.  Observation 5: For the case of UMa 30 km/hr and NLOS, at least the rank and can be the same for 40 ms with acceptable performance. |
| CeWiT | Overhead, MSE | From the above table, it can be seen that with partial CSI feedback, overhead is considerably reduced, while the nMSE are quite low (order of 10-4). |
| Qualcomm | Correlation, CDF of performance | Observation 1: Two issues exist for CSI reporting under fast fading channel environment: (1) Larger overhead with frequent report; (2) CSI outdating due to report latency  Observation 2: Certain performance gain of eType-II-Doppler can be observed over delayed Rel-16 eType-II: 1.7dB @10% CDF, 0.4dB @50% CDF, under ideal environment w/o noise or interference. |
| **Summary**:   * Performance gain of Type-II Doppler (SLS) over Rel-16/17 Type-II: Huawei/HiSi, ZTE (in LoS), OPPO, Fraunhofer/HHI, CeWiT, Qualcomm * Performance loss of Rel-16/17 with medium/high speed: CATT, vivo, OPPO, Nokia/NSB, MTK | | |

**General observation**:

* Table 3.A:
  + [2.1]
* Table 3.B:

Based on the above inputs, the following **moderator proposals** are made:

Proposal 2.A:

Proposal 2.B:

Proposal 2.C:

Table 4 Additional inputs: issue 2

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V0 | 1. **Check and, if neededm update your view in Table 3A/B** 2. **Share additional inputs here, if needed** 3. **Moderator proposals will be added in the next revision** |
| Lenovo | - Prefer to prioritize discussion on Issues 2.1, 2.2 and 2.6. Suggest deferring discussion of other issues after these issues are more stable  - For Issue 2.2, we prefer adding a new alternative Alt4) corresponding to trivial/identity transformation, which could suffice if PMI corresponding to a small number of time instants, e.g., 2, are reported  - For issue 2.6, since some alternatives are correlated, suggest to shorten the options to (i) P CSI-RS, (ii) SP CSI-RS, (iii) burst AP CSI-RS, and (iv) TRS. |
| LG | - Issue 2.2, 2.3, 2.4 are codebook details so we can discuss it in future meetings and higher level discussion should be prioritized in this meeting.  - We prefer to prioritize issue 2.5 and 2.6, which are about overall codebook structure and measurement resource configuration.  - Another high level issue we need to discuss in this meeting is whether PMIs are calculated based on predicted channel for slots/symbols maybe after current CSI reference resource or measured channel for slots/symbols maybe no later than current CSI reference resource. The former case assumes UE side prediction and the latter case assumes gNB side prediction. |
| Apple | On discussion in 2.4, our understanding is while the bases vector construction is fixed by the WID already, whether at all the Doppler offsets, the same SD bases and FD components are selected really depend on the sparseness of W2. Logically it is possible at some Doppler offsets, the relevant rays’ number is small, hence forcing the same SD and FD selection as for the rest of Doppler offsets is a waste. Since overhead is always a big issue in CSI feedback, it is not desirable to take decision now without evaluation. We prefer to keep the discussion open. |
| Samsung | 2.6: re TRS for CSI reporting, we are not sure it can be used since TRS is configured primarily for other purposes and is restricted to only 1 port.  2.7: re Prediction, for codebook description and PMI reporting, we don’t prefer any dependence on UE or gNB-side prediction, i.e., the CB enhancement should work for the case of no prediction. For CB evaluations, companies can consider predictions if they want to. Whether prediction for CQI enhancement is needed can be discussed separately. |
| NTT DOCOMO | For issue 2.1, we agree that it would be good to have focused target. We think either R16 PS or R17 PS can be dropped.  For issue 2.2, we are open to any direction right now, although we agree orthogonal DFT could be a baseline. Issue 2.3 can be discussed further after issue 2.2.  For issue 2.4, our understanding is that reuse of SD/FD basis is described in WID. We are open to discuss W2 refinement.  For issue 2.5 to 2.7, we are generally open to discuss. Regarding CSI-RS resource, whether to introduce new configuration to support CSI-RS burst seems one of the important points. |
| vivo | It is feasible to reach general principles in this meeting, detailed designs such as issue 2.2, 2.3, 2.4 can be discussed after we have better picture of the framework. Options for issue 2.5, 2.6, 2.7 can be listed for further study.  We think another solution to allow UE to report the PMI based on the predicted channel should be also considered. In UE can predict the CSI in slot n based on multiple previous received CSI-RS estimates |
| Huawei, HiSilicon | We can prioritize issues 2.1, 2.5 and 2.6, the other issues may depend on the decision of these issues.  For issue#2.6, we have similar view with Samsung on the use of TRS. |
| CMCC | We think issue #2.1 and #2.5 should be discussed firstly so that the basic codebook structure can be determined.  For issue #2.3 and #2.4, they are more about codebook details and we can discuss it in future meetings.  For issue #2.7, although we think PMI or CQI prediction is more related to the implementation on UE or gNB side, we are open to discuss the spec impact of prediction. |
| OPPO | The WID only includes refinement of type II codebook. Enhancement on CQI is out of scope. we prefer to prioritize the study of codebook enhancement based on legacy CQI mechanism. |
| Nokia/NSB | - Issue 2.2. In our understanding Alt4 proposed by Lenovo is already included as a special case in Alt 2 of 2.5  - Issue 2.6. We propose to study the use of CSI-RS+TRS in case of UE reporting future PMIs. In this case it may be possible for a UE to extrapolate/predict future channels from measurements of the two RS, because the time correlation functions of all CSI-RS ports is similar to that of the TRS port.  - Issue 2.7.  We agree CSI extrapolation/prediction and time-domain compression can be discussed separately, and that compression is applicable to past PMIs, future PMIs or a combination of both. We also think that prediction/extrapolation is either a UE or gNB implementation. However, there has to be a common understanding between UE and gNB on the timeline of the reported PMIs (past, future or both) and associated CQI(s).  We propose to study reporting of a single CQI because we think MCS selection does not change as rapidly as the fast-fading coefficients of W2 and there can be significant feedback overhead saving, especially for subband CQI reporting. |

### Issue 3: TRS-based reporting of time-domain channel properties (TDCP)

Table 5 Summary: issue 3

|  |  |  |
| --- | --- | --- |
| **#** | **Issue** | **Companies’ views** |
| 3.1 | Work scope: Targeted use case(s) of TRS-based TDCP reporting  DL reception   * Opt1.1. Aid CSI prediction at gNB, in general * Opt1.2. Aid CSI prediction at gNB, targeting DL reception configured with 1- or 2-port NZP CSI-RS   Range of UE speed   * Opt2.1. Medium-speed only (e.g. 10-30kmph) * Opt2.2. High-speed only (e.g. 30-120kmph) * Opt2.3. Both medium and high-speed (e.g. 30-120kmph)   **FL Note**: The WID dictates this as a CSI reporting and to “assist DL precoding”. The targeted use case(s), as usual, won’t be a part of the specs. But they need to be considered at least for **evaluation** and design.  Note that CSI-RS for tracking comprises only 1 port. | DL reception:   * **Opt1.1.** (General): Ericsson, Nokia/NSB, Lenovo, vivo * **Opt1.2.** (1- or 2-port): Samsung   Range of UE speed   * **Opt2.1**. Medium v: * **Opt2.2**. High v: Samsung * **Opt2.3**. Medium+high v: Ericsson, ZTE, vivo (need evaluation), Xiaomi, NTT Docomo, Lenovo, CMCC, Nokia/NSB |
| 3.2 | Work scope: CSI reporting format for TDCP   * Alt1. Stand-alone CSI report (not tied or inter-dependent with other CSI parameters)   + Note: Not precluding multiplexing with other UCI parameters (e.g. CSI, ACK, SR, …) on PUCCH/PUSCH, if applicable * Alt2. Tied/inter-dependent with other CSI parameter(s)   **FL Note**: This affects how TDCP is determined and reported. | **Alt1 (stand-alone):** Ericsson, ZTE, Samsung, Apple, DOCOMO, CMCC, Nokia/NSB  **Alt2 (not stand-alone, be specific):** vivo, Nokia/NSB, Lenovo, LG |
| 3.3 | Candidates for TDCP   * Opt1. Doppler shift * Opt2. Doppler spread * Opt3. Cross-correlation in time * Opt4. Number of peaks in CIR * Opt5: CSI-RS resource and/or CSI reporting setting configuration assistance   **FL Note**: A few candidates have been proposed and will be down-selected. | **Opt1 (Doppler shift):** ZTE, Xiaomi, Samsung, CEWiT, vivo (reporting multiple Doppler shifts)  **Opt2 (Doppler spread):** Ericsson, Samsung, Nokia/NSB, CEWiT  **Opt3 (XCorr):** Ericsson, Samsung, CEWiT, Nokia/NSB (study)  **Opt4 (# CIR peaks):** Ericsson  **Opt5 (Resource/reporting config assistance):** Apple, MTK, Lenovo |
| 3.4 | The need for SLS and/or LLS for evaluating TRS-based TDCP  **FL Note**: LLS can include actual modulation/demodulation process but lacks the overall system perspective (scheduling, link adaptation, traffic model, HARQ). On the other hand, SLS relies on BLER prediction model of the actual modulation/demodulation process. | **SLS:**   * **Yes:** Samsung, Ericsson (2nd priority), vivo, Nokia/NSB * **No:**   **LLS:**   * **Yes:** Ericsson, vivo * **No:** |

**General observation from Table 5**:

* [3.1]

Based on the above inputs, the following **moderator proposals** are made:

Proposal 3.A:

Proposal 3.B:

Proposal 3.C:

Table 6 Additional inputs: issue 3

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V0 | 1. **Check and update your view in Table 5** 2. **Share additional inputs here if needed** 3. **Moderator proposals will be added in the next revision** |
| Lenovo | In our opinion, supporting codebook enhancements for both CSI-RS based reporting and TRS based reporting would impose a huge burden on the group in terms of discussion, simulation work and spec impact. Prefer to down select between both approaches: (Alt-1). CSI-RS based codebook design and (Alt-2) TRS based codebook design, where for Alt-2 reusing Rel. 16/17 legacy codebooks for CSI refinement can be achieved (without the need to design a new Type-II codebook) |
| LG | Issue 3.1 should be prioritized. In our view, the use case and purpose of Type II codebook refinement and reporting time domain information via TRS are overlapped, i.e., PMI prediction for time varying channel, but they have a quite different specification impact. So, we prefer to down select one. |
| Apple | For 3.1, actually the report from TRS may be used for gNB to configure relevant CSI reports, e.g. the one as discussed in Section 2.2, supporting gNB side CSI prediction is not the only use case. |
| Samsung | @Lenovo: In our understanding, TDCP feedback doesn’t involve TRS-based codebook design. Therefore issue 2 (Type-2 codebook) and issue 3 (a new UCI, possibly standalone) are separate and not competing with each other |
| NTT DOCOMO | For issue 3.3 and 3.4, we are open to discuss at this stage. |
| Vivo | Prefer to agree on general framework of TRS-based reporting like issue 3.1 in this meeting. However, we are not sure what is the difference between Opt1.1 and Opt1.2.  Regarding Opt2 in issue 3.3, multiple Doppler shifts measured from multiple TRS ports, each precoded with a specific SD-FD basis, may be beneficial to achieve better prediction.  Regrading Opt3 in issue 3.3, cross-correlation in time needs to be clarified. Whether AR (Autoregression) is included? |
| Huawei, HiSilicon | Issue 3.1 can be prioritized so that we can be clear to evaluate what benefits can be achieved for what metrics, and the baseline, and scenarios for evaluation can also be determined. |
| OPPO | The difference between option 1.1 and option 1.2 is unclear to us. We prefer to prioritize Issue 2 over issue 3. In our understanding, the scope of issue 2 can include that of issue 3 depended on the detail solutions for issue 2. |
| Nokia/NSB | - Issue 3.1. Agree with Apple, in our understanding Opt.1.1 includes for example, aiding gNB to configure/trigger RS resources and CSI reports with different granularity in time depending on UE speed, etc. Also agree with Samsung that TDPC reporting is a very different approach from Type-II enhancement in time domain and it does not involve codebook design  - Issue 3.3  Opt 3. In our understanding this is the auto-correlation in time of the TRS signal (sometimes the term cross-correlation is used to indicate the correlation between two different signals)  Opt 4. In our understanding, this is a about reporting parameters of the Doppler spectrum (Fourier-transformation of the time auto-correlation) |

## Evaluation Methodology (EVM)

Please refer to the companion excel spreadsheet is attached. The spreadsheet may be updated based on companies’ inputs.

Table 6 Additional inputs: EVM

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V0 | 1. **Check the companion excel spreadsheet (V01) and share more inputs here, if needed** |
| Samsung | Few comments:   * Re spatial consistency, at least for T2 Doppler CB, since the common understanding is that the targeted UE speed is not sufficiently high to cause a change in location, it’s unclear if spatial consistency is really needed. So, our preference is not to mandate it, at least for T2 Doppler CB. However, if the majority wants to, we can reluctantly accept it. * BS antenna height for CJT depends on scenarios (cf. 38.901): RMa, DU, Uma, Indoor |
| NTT DOCOMO | For CJT CSI, we’d also like to see the performance gain of CJT over NCJT, in addition to the performance gain of CJT over S-TRP, to check the benefits of CJT vs. NCJT, from operator perspective. |
| Huawei, HiSilicon | At least for dense urban/urban macro, UE distribution of 20% outdoor 80% indoor should also be a scenario for evaluation, which may be a typical case for dense urban/urban macro. |
| Nokia/NSB | - Regarding spatial consistency, we are also fine with Samsung’s proposal to make it optional  - Regarding UE distribution, we think it makes sense to simulate 100% outdoors for medium/high speed CSI, to better evaluate the impact of velocity on CSI reporting without the bias of stationary users |

# References

|  |  |  |  |
| --- | --- | --- | --- |
| 1 | R1-2203151 | CSI enhancement for coherent JT and mobility | Huawei, HiSilicon |
| 2 | R1-2203229 | On CSI enhancements for Rel-18 NR MIMO evolution | Ericsson |
| 3 | R1-2203265 | CSI enhancement for high/medium UE velocities and CJT | ZTE |
| 4 | R1-2203322 | Discussion on CSI enhancement for coherent JT | Spreadtrum Communications |
| 5 | R1-2203380 | Aspects of CSI Enhancements | InterDigital, Inc. |
| 6 | R1-2203443 | On Rel-18 CSI enhancements | CATT |
| 7 | R1-2203543 | Views on CSI enhancement for high-medium UE velocities and coherent JT | vivo |
| 8 | R1-2203683 | Discussion on CSI enhancement | NEC |
| 9 | R1-2203725 | Considerations on CSI enhancement for high/medium UE velocities and coherent JT (CJT) | Sony |
| 10 | R1-2203795 | Discussion on CSI enhancement | xiaomi |
| 11 | R1-2203890 | Views on CSI enhancements | Samsung |
| 12 | R1-2203955 | CSI enhancement for high/medium UE velocities and coherent JT | OPPO |
| 13 | R1-2204099 | CSI enhancement for high/medium UE velocities and CJT | FUTUREWEI |
| 14 | R1-2204143 | Potential CSI enhancement for high/medium UE velocities and coherent JT | LG Electronics |
| 15 | R1-2204164 | Discussion of CSI enhancement for high speed UE and coherent JT | Lenovo |
| 16 | R1-2204231 | Views on Rel-18 MIMO CSI enhancement | Apple |
| 17 | R1-2204289 | Discussion on CSI enhancement for high/medium UE velocities and CJT | CMCC |
| 18 | R1-2204369 | Discussion on CSI enhancement | NTT DOCOMO, INC. |
| 19 | R1-2204468 | Discussion on CSI enhancement for coherent JT | Spreadtrum Communications |
| 20 | R1-2204508 | CSI enhancement | Sharp |
| 21 | R1-2204540 | CSI enhancement for high/medium UE velocities and CJT | Nokia, Nokia Shanghai Bell |
| 22 | R1-2204679 | CSI enhancements for medium UE velocities and coherent JT | Fraunhofer IIS, Fraunhofer HHI |
| 23 | R1-2204691 | CSI enhancment for high/medium UE velocities and coherent JT | MediaTek Inc. |
| 24 | R1-2204748 | Discussion on CSI Enhancements for high/medium UE velocities and coherent JT | CEWiT |
| 25 | R1-2204787 | On CSI enhancements | Intel Corporation |
| 26 | R1-2204858 | CSI enhancement | AT&T |
| 27 | R1-2205016 | CSI enhancements for high-medium UE velocities and Coherent-JT | Qualcomm Incorporated |
| 28 | R1-2203270 | Evaluation assumptions for CSI, simultaneous multi-panel UL transmission and 8-Tx UL operation | ZTE |
| 29 | R1-2203548 | Discussion on CSI prediction at UE | vivo |
| 30 | R1-2203895 | Initial SLS results on Type-II CSI enhancements for CJT | Samsung |
| 31 | R1-2204913 | Discussion on field test results of CSI enhancement for coherent JT | Huawei, HiSilicon |