**3GPP TSG RAN WG1 #102-e R1-200xxxx**

**e-Meeting, August 17th – August 28th, 2020**

**Agenda Item: 8.3.1.2**

**Source: Moderator (InterDigital, Inc.)**

**Title: Feature lead summary #2 on CSI feedback enhancements for enhanced URLLC/IIoT**

**Document for: Discussion and Decision**

# Introduction

This contribution is a summary of contributions [2]-[24] submitted under AI 8.3.1.2 (CSI feedback enhancements) and few contributions [26]-[27] submitted under AI 8.3.1.1 (HARQ feedback enhancement) which include some proposals related to UE feedback enhancement for more accurate link adaptation. The AI is related to the following objective of the revised work item on Enhanced IIoT and URLLC support for NR [1]:

|  |
| --- |
| 1. Study, identify and specify if needed, required Physical Layer feedback enhancements for meeting URLLC requirements covering    * + UE feedback enhancements for HARQ-ACK [RAN1]      + CSI feedback enhancements to allow for more accurate MCS selection [RAN1]   Note: DMRS-based CSI feedback is not in scope of this WI |

# Priority of the issues

**List of the issues identified:**

**Issue #1-1: Support aperiodic CSI report on PUCCH**

**Issue #1-2: Triggering method of aperiodic CSI report on PUCCH**

**Issue #1-3: Additional conditions for A-CSI reporting on PUCCH triggered by DL DCI**

**Issue #1-4: PUCCH resource determination for A-CSI on PUCCH**

**Issue #1-5: Reduction of CSI computation time**

**Issue #1-6: Priority applicable to P/SP-CSI on PUCCH and (if supported) A-CSI on PUCCH**

**Issue #2-1: introduce new CSI report type(s)**

**Issue #2-2: Need for enhancing accuracy of sub-band differential CQI feedback**

**Issue #3-1: Need for additional information bundled to HARQ-ACK**

**Issue #3-2: Enhanced CSI reporting for multi-TRP scenarios**

**Please provide the company’s view on the priority of the issues listed above:**

|  |  |  |
| --- | --- | --- |
| **Company** | **Priority of the issues** | **Comments** |
| example | High: 1-1, 1-2, 2-1, 3-1  Medium: 1-3, 1-4, 1-5  Low: 1-6, 2-2, 3-2 |  |
| Sony | High: 1-1, 2-1,  Medium: 2-2, 3-1  Low: 1-2, 1-3, 1-4, 1-5, 1-6, 3-2 | Consider feedback for PDCCH. |
| FUTUREWEI | High: 2-1  Medium: 1-1, 3-2, 2-2  Low: 1-2, 1-3, 1-4, 1-5, 1-6, 3-1 | Support new CSI report type(s) such as report of channel/interference statistics to allow for more accurate MCS selection. |
| InterDigital | High: 1-1, 1-2, 2-1, 3-1  Medium: 1-3, 1-5, 2-2  Low: 1-4, 1-6, 3-2 | Feedback for PDCCH (Medium) |
| Qualcomm | High: 3-1, feedback for PDCCH  Medium: 1-6,  Low: 1-1, 1-2,1-3,1-4,1-5, 2-1, 2-2, 3-2 | We support to study channel state information feedback for PDCCH. |
| DOCOMO | High: 1-1, 1-2  Medium: 1-3, 1-4, 1-5, 2-1  Low: 1-6, 3-1 | Low: Feedback for PDCCH |
| HW/HiSi | High: 1-1, 1-2, 2-2  Medium: 1-3, 1-4, 2-1,1-5  Low: 1-6, 3-1, 3-2 | For 1-3 and 1-4, we think they are very important, but during this phase not as important as 1-1 and 1-2. We would appreciate an exchange of views on 1-3 and 1-4 and maybe a list of candidate methods, however. |
| Panasonic | High: 1-1, 1-2, 1-4, 1-6  Medium: 1-3, 1-5, 2-1, 2-2, 3-1  Low: 3-2 |  |
| Intel | High: 2-1  Medium: 1-6  Low: 1-5 | It seems details of A-CSI on PUCCH got many lines in the issue list. We first need to decide general support of A-CSI on PUCCH in order to go to the details.  In our view w/o analyzing and introducing new CSI measurements/reporting, other discussed mechanisms could not combat bursty interference dominated in URLLC scenarios, |
| vivo | High: 1-5, evaluation methodology/assumptions  Medium: 1-1, 1-2, 1-4, 1-6, 2-1  Low: 1-3, 2-2, 3-1, 3-2 | Currently, the timeline required for CSI computation is longer than the PDSCH processing. Whether and how to reduce the CSI computation time needs to be discussed with high priority.  The potential gains by CSI enhancements need to be further clarified. So we suggest to discuss how to evaluate the performance and identify the benefits for the enhancements. |

# Enhancements for faster CSI reporting

In this section, we provide summary of contributions related to the enhancements for faster CSI reporting.

## A-CSI on PUCCH

**Issue #1-1: Support aperiodic CSI report on PUCCH**

* Yes: Huawei [2], Futurewei [3], NTT DCM [23], vivo [4], ZTE [5], CATT [10], NEC [11], CMCC [17], Spreadtrum [18], Panasonic [20], InterDigital [15], Intel [12]
  + Trigger reporting based on traffic needs,
  + Less overhead than A-CSI on PUSCH in DL-dominant traffic
  + Report useful for retransmissions and subsequent TBs
* No: Samsung [16], Sony [8]
  + Small throughput gains as it does not benefit initial transmission
  + Latency too high for URLLC
  + Not useful in case of bursty interference
  + Retransmissions are rare
  + Specification impact, e.g. may require new field(s) in DCI
* Further study: Apple [21], Sharp [22], Lenovo [13]

The A-CSI on PUCCH has been discussed in the previous releases and it is observed that majority companies support the A-CSI on PUCCH. However, a few companies still have concerns on the benefits of the A-CSI on PUCCH for the URLLC scenario.

**Question #1:** considering that the A-CSI on PUCCH issue has been discussed and evaluated in the previous releases, can we make the decision to support the A-CSI on PUCCH based on the majority support?

* If no, what would be the suggested next step for this issue?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | We do not see the benefit but OK to consider given majority wants it. |
| Samsung | No | Decisions should be based on technical merits, not on a popularity contest.  Next step can be to identify technical merits under realistic assumptions and discuss/conclude on those assumptions. |
| Nokia/NSB | No | To our understanding, the Rel-17 discussion should be for CSI feedback enhancements to allow for more accurate MCS selection. This A-CSI on PUCCH was discussed during Rel-16 SI phase, but there was no sufficient gain to be included in the Rel-16 URLLC WI. Need better justification unless performance gains are showed compared to other proposals in this agenda item.  Also, we see that there are many other related problems arise with this solution vs compared to other solutions, and we have a limited time in the WI to finalize may be only one main direction due to that.  May be a good approach for now is that keep this just as one possible solution for further studies. |
| FUTUREWEI | Yes | A-CSI on PUCCH can be considered. |
| InterDigital | Yes | There were technical evaluations in R16 study that already showed gains at least for some URLLC scenarios. There are many possible use cases and scenarios for URLLC and certainly we cannot expect that the gain would be significant for all UEs in all scenarios. However, if the gain exists in relevant scenarios, supporting the enhancement can be justified.  If it is not acceptable to make a decision now then as a next step we can agree on the relevant scenarios and evaluate based on those. |
| Qualcomm | No | First, we would like to clarify that the discussions on all issues in Section 3 are only for A-CSI report on PUCCH measured using CSI-RS. Our response below is based on this understanding.  This topic was discussed in Rel-16 URLLC SI phase, and was not included in the Rel-16 WI because there’re not sufficient gains compared to other technologies. Better justifications and performance gains need to be identified before we can make a decision to support the proposal. Below we list our concerns on the issues with A-CSI report on PUCCH, which need to be addressed.   * Performance gain: as commented by Samsung, performance gains need to be identified compared to the baseline schemes (e.g., A-CSI on PUSCH or P-CSI on PUCCH) under realistic assumptions on the CSI-RS overhead, CSI estimation accuracy, interference condition, etc. * Downlink CSI-RS overhead vs CSI accuracy vs A-CSI report latency: One key question for the design is how frequently should CSI-RS reports and CSI-RS transmission be triggered? If the A-CSI report is to be triggered for every PDSCH transmission, then this incurs a very large CSI-RS/PUCCH overhead. On the other hand, if the A-CSI report is not triggered very frequently, then how should the base station determine whether or not to trigger a A-CSI report from the UE? * Significant spec impact: as commented by Nokia, there are many related problems that arise with this solution. Just to name a few: how to trigger the A-CSI report; how to indicate the CSI-RS resource, PUCCH resource; how to determine the timing of CSI-RS/PUCCH; how to solve collisions between A-CSI on PUCCH and other uplink channels (SRS, SR, P-CSI, SP-CSI on PUCCH, SP-CSI on PUSCH, A-CSI on PUSCH); CSI report content. Everything need to be sorted out in order to make the solution work.   UE implementation impact: related to the spec impact, the UE has to implement all aspects that are listed above. This will incur significant UE implementation complexity. |
| DOCOMO | Yes | Technical evaluations are presented in TR38.824 showing that A-CSI on PUCCH brings some gains for some URLLC scenarios. As InterDIgital mentions, there are various use cases for URLLC and thus, A-CSI on PUCCH will be beneficial for some of them. |
| Spreadtrum | Yes | We support this A-CSI on PUCCH enhancements.  In some heavy DL traffic scenarios, there is little chance for PUSCH transmission. However, CSI reports are essential for DL scheduling, especially URLLC traffic requires more instant A-CSI reports. Also evaluations in Rel-16 URLLC SI showed the gain of A-CSI on PUCCH in some scenarios. |
| HW/HiSi | Yes | As also described in the following sections A-CSI on PUCCH has advantages compared to traditional A-CSI, because it reduces the control overhead. Furthermore, it is very applicable for traffic scenarios that are typical for URLLC. |
| Panasonic | Yes | In Rel.16, aperiodic CSI is reported only PUSCH and triggered by UL DCI format. However, if there is no UL data, using UL DCI format to trigger aperiodic CSI report in PUSCH without UL-SCH consumes PDCCH resource and too much resource for small amount of CSI report case. In addition, even if URLLC PUSCH is 1-symbol or 2-symbol, UCI and DMRS cannot be FDMed within a symbol for UCI multiplexing. Then, aperiodic CSI in PUSCH is not suitable for URLLC. |
| Intel | No | It has been shown by several sources, that link adaptation in URLLC/IIOT scenarios is limited by unpredictable interference. A-CSI on PUCCH does not solve this problem.  Furthermore, A-CSI on PUCCH triggered by DL assignment mainly target optimization of MCS for retransmissions, that could not bring much system gain overall in URLLC scenarios.  As a medium priority we can consider GC-DCI for CSI trigger as a new approach to trigger CSI reports with low overhead. |
| vivo | FFS | We are open to discuss.  Before making the decision, whether and how to reduce the CSI computation time should be discussed first, since it is important to harvest the benefits for A-CSI report on PUCCH.  On the merits of A-CSI on PUCCH, we think performance evaluation is needed to identify how much gain can be achieved. In order for that, evaluation methodology and assumptions need to be discussed first. |

**Issue #1-2: Triggering method of aperiodic CSI report on PUCCH**

* Option-1: A-CSI is triggered by DL scheduling DCI
  + Yes: Huawei [2], NTT DCM [23], vivo [4], ZTE [5], CATT [10], NEC [11], CMCC [17], Spreadtrum [18], Panasonic [20], InterDigital [15]
    - Less overhead than UL-DCI in DL-dominant traffic
  + No: Samsung [16], Intel [12], Sony [8]
    - Specification impact, e.g. may require new field(s) in DCI
  + Further study: Apple [21], Sharp [22], Lenovo [13]
* Option-2: A-CSI is triggered by group-common DCI
  + Yes: Intel [12]
    - Less DL signaling overhead
  + No: Huawei [2], ZTE [5], NTT DCM [23], CATT [10]
    - Packet arrival time varies between UEs
    - Increase of blind decoding
  + Further study: Sony [8]
    - Consider overhead cost
* Option-3: A-CSI is triggered by NACK (without DCI)
  + Yes: ZTE [5]
    - May be useful for SPS PDSCH and sporadic traffic
  + No: Sony [8]
    - Not much benefit over soft combining (different RV’s)

The most of companies supporting A-CSI on PUCCH seems to also support DL DCI based triggering as it can avoid unnecessary PDCCH overhead in DL-dominant traffic cases.

**Question #2:** based on the majority support, can we at least agree on that DL DCI based triggering is used for A-CSI on PUCCH if the A-CSI on PUCCH is supported?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | No | It isn’t useful for 1st PDSCH transmission. If we really want it for the retransmission (which is supposed to be rare in URLLC), then can consider Option 3. |
| Samsung | No | Majority support should not be the reason for an agreement. |
| Nokia/NSB | No | The question 2 heavily dependent on answer to question 1. Agree also with Samsung. |
| FUTUREWEI | Yes | Agree that DL DCI based triggering is used for A-CSI on PUCCH. We are also open to Option 3 where A-CSI is triggered by NACK. |
| InterDigital | Yes | There seems to be very little support for other options and the technical concerns for those are justified. |
| Qualcomm | No | We think the discussion can be deferred after evaluation results on Question #1 are provided/concluded. |
| Apple |  | Qualcomm raised a good point on evaluation. It would be good to have evaluation based design – not only for this particular issue. |
| DOCOMO | Yes | Agree that DL DCI based triggering. Also, we are open to discuss NACK based triggering. |
| Spreadtrum | Yes | It is easy to reuse these DL grant DCI to trigger A-CSI reports and select a PUCCH resource for them.  UE-specific DCI is more preferred compared with UE-group-specific DCI. UE-group DCI is designed for a group of UEs. Regarding A-CSI reports, they are per-UE requirements more than a group of UEs. Additionally, it needs a new DCI format defined for A-CSI reports on PUCCH. And a new RNTI should be introduced for this new DCI format. Obviously, this new DCI format will complicate UE implementation of PDCCH monitoring and also create some new problems of DCI size budgets. |
| HW/HiSi | Yes | In our view A-CSI in DL DCI is an elegant method, since no extra DCI overhead is needed.  For A-CSI in group common it is questionable how applicable it is, since the traffic patterns from various UEs might not be aligned.  Regarding Option 3, that is also a choice that could be considered in addition to option 1. For spectrum efficiency, it is also benfifical to have access to freash CSI reports in case of ACK, which then can be applied on the following TBs (for e.g. in ITS use cases, where larger packets on high layer result into multiple consecutive TBs in PHY) |
| Panasonic | Yes | Same reason in Question #1. |
| Intel | No | See our previous reply |
| vivo |  | It depends on the conclusion of Question #1. |

**Issue #1-3: Additional conditions for A-CSI reporting on PUCCH triggered by DL DCI**

* Option-1: New field in DCI
  + NTT DCM [23]
* Option-2: PDSCH is NACK
  + Huawei [2]
* Option-3: DL DCI with high priority index
  + InterDigital [15]
* Option-4 : Activation by MAC CE
  + InterDigital [15]

Note: one or more of abovementioned options can be used together

Several contributions discussed details on how to trigger A-CSI on PUCCH actually, which include explicit indication in DL DCI and implicit trigger based on PDSCH decoding status or priority indicator in the assodicated DL DCI in order to reduce the DL and/or UL signaling overhead.

**Issue #1-4: PUCCH resource determination for A-CSI on PUCCH**

* Option-1 : RRC
  + Panasonic [20]
* Option-2 : MAC CE
  + InterDigital [15]
* Option-3: Same as HARQ-ACK
  + OPPO [14], Spreadtrum [18] (under conditions), Panasonic [20], NTT DCM [23]
* Option-4: DCI field (e.g. PRI)
  + NTT DCM [23], Panasonic [20]
* Option-5: CSI request field
  + Panasonic [20]

Note: gray highlight here means that a company mentioned the proposal in the tdoc but not clearly indicate whether the company supports it or not

Several contributions discussed the options related to the PUCCH resource determination when A-CSI on PUCCH is supported. Similar to the Issue #1-3, this issue is also the next level of details which can be discussed after the support of A-CSI on PUCCH is agreed.

**Question #3:** regarding Issue #1-3 and Issue #1-4, these issues are a next level of details to be discussed if A-CSI on PUCCH is agreed. Do we need to put this issue on hold until the A-CSI on PUCCH is agreed?

* In the meantime, please provide any additional options if you have

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony |  | Consider the details after agreeing whether to support or not support this feature. |
| Samsung | Yes | For the reasons mentioned in “Question #3” |
| Nokia/NSB |  | These issues can be revisited once the basic direction of the solution is identified. |
| FUTUREWEI | Yes | Agreed that the next level of details can be discussed after Questions #1 and #2 have been resolved. |
| InterDigital | Yes |  |
| Qualcomm | Yes | As commented under “Question #2”, these issues can be discussed/revisited once a decision on Question #1 is made. |
| Apple | Yes | Yes, while we are open to all studies/proposals, we can wait for better clarity to treat such issues |
| DOCOMO | Yes |  |
| Spreadtrum | Yes | We are open to this issue. |
| HW/HiSi | No | We think it would be good to progress also on issues 1-3 and 1-4 in parallel. At least companies can exchange and align their views, so that progress can be quicker once the A-CSI on PUCCH is supported.  For issue 1-3: In addition to NACK triggered A-CSI (Option 2), we also think it would be good to include Option 1 and Option 3.  For issue 1-4: we think a maybe more important question that will set to direction for further work is whether HARQ-A/N and CSI report are on the same resource or on different resources (or if both should be allowed) Both approaches have their pro’s and cons’s. Then, after that we could maybe list candidate methods for separate and for joint reporting and shortly characterize them? |
| Panasonic | Yes | These issues should be discussed after agreeing whether to support A-CSI on PUCCH and/or A-CSI reporting on PUCCH triggered by DL DCI. |
| Intel | Yes | Need to first decide on the direction itself |
| vivo |  | It depends on the conclusion of Question #1. |

## Reduction of CSI computation time

**Background**

The minimum CSI computation time is larger than PDSCH processing time (e.g., PDSCH processing capability 2) in current specification. Therefore, even if A-CSI reporting is triggered in the symbol where a PDSCH is scheduled, a UE may report A-CSI later than the associated HARQ feedback (or HARQ feedback is delayed to be reported together with A-CSI) which may result in delayed retransmission scheduling.

**Issue #1-5: Reduction of CSI computation time**

* Yes: Futurewei [3], Ericsson [6], vivo [4], CATT [10], Lenovo [13], OPPO [14], CMCC [17], propose to study how to support reduction of CSI computation time
  + To improve accuracy/timeliness of CSI report for URLLC
  + To allow reporting of CSI at the same time as earliest possible transmission of HARQ-ACK or PUSCH based on PDSCH processing capability 2 (N1/N2)
  + Proposals to ease CSI computation:
    - Simplified CSI report: CATT [10], Lenovo [13]
    - Partial report (e.g. based on previous RI/PMI): Ericsson [6], Vivo [4], OPPO [14]
    - Simplified measurement from data reception status: OPPO [14]
    - Only report sub-band CQI: CMCC [17]
    - More capable UE: Ericsson [6], Futurewei [3]
    - Reporting CQI’s for more than one table in a report: Intel [12]

**Observations**

The minimum required CSI computation time has been specified in section 5.4 of 38.214. Several companies observed that for a UE with PDSCH (PUSCH) processing capability 2, timeline requirement allows for reporting of HARQ-ACK (or transmission of PUSCH) earlier than for reporting A-CSI triggered from same DCI.

**Question #4:** should CSI computation time reduction be supported for faster CSI reporting in Rel-17?

* If yes, any additional restriction is required to reduce the computation time?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | No | This issue is created due to DL Grant triggered A-CSI, which we do not think is beneficial for URLLC purpose. |
| Samsung | No | This is difficult for UE implementation – no meaningful reductions are possible. |
| Nokia/NSB | No | First, we should investigate the performance impact or gains compared to the increase in complexity at the UE side. In our investigations, considering the case of increasing the CQI reporting frequency or reducing the ‘CQI processing delay’ does not make a huge difference to URLLC performance, since the channel (especially intereference) coherence time is extremely small. |
| FUTUREWEI | Yes | CSI computation time reduction could enable faster CSI feedback. It can be defined as optional UE capability and optional network feature in Rel-17 to better support URLLC. |
| InterDigital | Yes | This is useful when the signal part of the CSI has coherence time of the order of slot. It is true that the gain is less if the interference varies a lot, but it should be noted that not all UEs experience such conditions, e.g. UEs close to cell center may not experience big interference variations. |
| Qualcomm | No | First, we would like to clarify that the discussions on all issues related to the CSI computation time in Section 3.2 are only for A-CSI report measured using CSI-RS. Our response below is based on this understanding.  UE CSI computation time has been extensively discussed and optimized during NR Rel-15. In particular the CSI computation delay requirement 1 in NR Rel-15 is defined for a very restricted/simplistic scenario in which only wideband CQI corresponding to up to 4 CSI-RS port in a single CSI resource without CRI report is requested and only single-panel codebook is configured. Further reducing the computation timeline is very difficult for UE implementation, and we don’t see a meaningful way to achieve this. |
| Apple | No | If the main reason for CSI fluctuation is interference (both intra-cell and inter-cell interference), then the root cause for that is the NR design itself and small time units enabled for scheduling. Faster CSI feedback is supposed to lead to faster scheduling decision which leads to even-faster changes in interference a UE experiences, feeding such a vicious cycle really does not help. We don’t see the point of tightening CSI processing time. |
| DOCOMO | Yes | We are open to discuss this. In our understanding, this issue is not only related to A-CSI triggered by DL grant but also for the existing A-CSI on PUSCH. The proposed scheme like partial reporting could help to reduce the computation time. |
| Spreadtrum | No | The definition of CSI computation time had taken the factors in to account thus two types of processing time are given. From our understanding, this faster CSI computation of enhancement to URLLC is unclear, and it will significantly increase the complexity of UE implementation. |
| HW/HiSi |  | We cannot really answer this question with yes/no at this stage. And we think that RAN1 should look further into this. If faster CSI processing can be achieved with reasonable UE complexity, then this is of course desirable.  In such case, restrictions would be needed and the contents of the CSI report should be discussed. As mentioned by multiple companies, the dominant component that is contributing to quick channel state changes is the interference. So this one direction to look into.  But we think firstly, we should agree on the tool to carry the CSI report, i.e. A-CSI on PUCCH, and then discuss the details what to be included in the report |
| Panasonic | Yes | To reduce the CSI computation time would be beneficial if A-CSI reporting on PUCCH is supported. |
| Intel | No/not yet | We also observe that reduced CSI computation time on its own does not combat the main limiting factor of link adaptation – unpredictable interference.  However, we are open to revise the numbers once new procedures are introduced in this WI |
| vivo | Yes | Reducing the CSI computation time is necessary for timely CSI acquisition for URLLC. And it is important to harvest the benefits for A-CSI report on PUCCH. Whether and how to reduce the CSI computation time should be discussed in high priority. |

**Question #5:** Is CSI computation time reduction issue tied with A-CSI on PUCCH?

* If yes, should we put this issue on hold until the decision is made for A-CSI on PUCCH?
* If no, in which case the CSI computation time reduction can provide gain?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | Agree to consider this after decision is made for A-CSI on PUCCH. |
| Samsung | No | There is only a lower level relevance. |
| Nokia | No | We assume that the FL refer to the A-CSI computation time. We would be happy if the UE can reduce the computation times, but it looks to us that this kind of seperate investigations are not within WI objective. |
| FUTUREWEI | Yes | Agree that this issue can be discussed after decision is made for A-CSI on PUCCH. |
| InterDigital | Yes | If A-CSI on PUCCH is not supported, the relevance of reducing CSI computation time is unclear. |
| Qualcomm | No | As commented above, CSI computation time has been heavily optimized in NR Rel-15 and 16, and it is very difficult for UE implementation to further reduce it, regardless of whether CSI report is conveyed over a PUCCH or a PUSCH. |
| Apple | No | See our reply above |
| DOCOMO | No | Same as our input for Question #4. CSI computation time reduction can be considered for A-CSI on PUSCH as well. |
| Spreadtrum | No | We prefer not to treat it in Rel-17. |
| HW/HiSi | No | Reduced CSI computation time should not be pre-requisite for A-CSI on PUCCH.  A-CSI on PUCCH can have significant gain compared to tradition A-CSI due to reduced control overhead. We have evaluated the performance difference between A-CSI on PUCCH and traditional A-CSI in R1-1903190) for the Rel-15 enabled use case and observed gain of 37%.  In addition, some URLLC use case have bursty data traffic and less strict latency requirements (example power grid). Also for such use cases, A-CSI is beneficial and the UE processing time capability #1 is sufficient to even apply the CSI report on the retransmission.  Another use case that benefits from A-CSI in general is ITS (remote driving). Here, one large packet on higher layer is broken down into several TBs that are transmitted consecutively in bursts. Even with the current CSI processing time, the CSI report can be used for the following transport blocks. |
| Panasonic | Yes | This issue could be discussed after agreeing whether to support A-CSI reporting on PUCCH triggered by DL DCI. |
| Intel |  | We observe that many proponents of reduced CSI computation time assume that this CSI is triggered by DL assignment DCI, thus we see correlation.  However, we are not ready to prioritize A-CSI on PUCCH and associated discussions on computation time. |
| vivo | No | If CSI computation time can be reduced, it would be beneficial for URLLC to obtain A-CSI report on PUSCH or PUCCH (if supported). |

## Priority of P/SP-CSI/[A-CSI] on PUCCH

**Background**

The P/SP-CSI on PUCCH has been considered as a lowest priority as compared with other CSI reporting types and no priority index associated with the CSI reporting configuration. Therefore, even if it is targeted for URLLC traffic link adaptation, it may be dropped if it collides with a higher priority CSI reporting (e.g., A-CSI reporting, SP-CSI on PUSCH) irrespective of whether the higher priority CSI reporting is targeted for eMBB or URLLC.

**Issue #1-6: Priority applicable to P/SP-CSI on PUCCH and (if supported) A-CSI on PUCCH**

* Mediatek [9], Samsung [16], Intel [12], propose that P/SP-CSI on PUCCH can have priority index 1 in some cases
  + Proposals for assignment of priority:
    - BLER target of the configured CQI table: Mediatek [9]
    - Semi-static configuration or activation: Intel [12]
* NTT DCM [23] and Panasonic [20] propose that A-CSI on PUCCH (if supported) can have priority index configurable, e.g. indicated from DCI
* NTT DCM [23] also proposes that priority used in clause 5.2.5 in 38.214 for A-CSI PUCCH is higher than for A-CSI on PUSCH
* FutureWei [3] proposes CSI reporting procedures with less CSI report dropping due to collision

**Observations**

Several companies propose to introduce an additional means to support priority configuration or determination of P/SP-CSI on PUCCH as well as A-CSI on PUCCH (if supported) so that dropping of those CSI reporting due to collision with a high priority CSI reporting targeting eMBB.

**Question #6:** Should possibility of configuring priority index 1 at least for P/SP-CSI be supported in R17?

* If A-CSI on PUCCH is supported, should it be possible to configure it with priority index 1

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | No | CSI is not so critical for latency purpose as the gNB can still schedule the UE without the latest CSI report. However, if we attach a high priority to CSI and it collides with a LP PUSCH, the LP PUSCH is dropped, which is an overkill. Whereas in Rel-16, the CSI can be muxltiplexed into the LP PUSCH thereby transmitting both to the gNB, which is a better outcome. |
| Samsung | Yes | Because separate report is needed for URLLC (e.g. low MCS table) and can be often dropped either due to collisions or due to resource availability when multiplexed with HARQ-ACK. Spec impact is practically zero. |
| Nokia/NSB | No | We do not see the necessity of having high priority index 1 for P/SP-CSI even for URLLC traffic as already agreed in Rel-16. |
| FUTUREWEI | No | Consider defining additional CSI transmission opportunity in PUCCH or PUSCH to reduce CSI report dropping due to collision. |
| InterDigital | Yes | This could be useful for example if the URLLC traffic is periodic and the network wants to get a fresh CSI just before a traffic burst. |
| Qualcomm |  | Medium priority. We think that there are technical metrics on supporting high priority P/SP-CSI to give gNB more accurate information about the channel condition for URLLC. |
| Apple |  | It can be discussed along with other proposals. |
| DOCOMO | Yes | Share the same view as InterDigital. This would be useful for periodic URLLC traffic. |
| Spreadtrum | Yes | Since P/SP CSI reports are always low priority in Rel-16, it may drop P/SP CSI when collision with HP HARQ-ACK or SR. However, P/SP CSI with high priority would be essential due to DL/UL URLLC scheduling. |
| HW/HiSI |  | For A-CSI on PUCCH it is definitely desirable to support priority 1. The details mechanism could be decided, it could follow the priority of the scheduling DCI.  For P/SP-CSI, it can also be helpful to configure priority index 1 for deterministic URLLC traffic that is multiplexed with eMBB but it also could be solved by other means.  Low priority. |
| Intel | Yes | We think R16 decisions on always low priority for P/SP-CSI on PUCCH were motivated by no objective to enhance CSI accuracy.  This time, this assumption can be reconsidered. It may be as important as to improve the CSI measurements overall, since there may be no value in a sophisticated report suddenly dropped due to low priority. |
| vivo | No | We are not sure the necessity for P/SP-CSI of high priority, given that gNB can trigger A-CSI of high priority for URLLC. |

# Enhancements for more accurate CSI reporting

## Enhancements for bursty interference conditions

**Background**

Several companies identified the following issues on the existing CSI report types for URLLC scheduling especially under bursty interference environment

* Channel/interference measurement resource configuration is not flexible enough
* Channel and interference should be measured at the same time always although only interference part is changed dynamically
* Wideband CQI is not accurate when a small number of RBs are scheduled
* Channel prediction is not accurate at the scheduler with existing CSI

**Issue #2-1: introduce new CSI report type(s)**

* Yes: Futurewei [3], Ericsson [6], Nokia [7], Intel [12] propose enhancements to provide additional or more relevant information to help scheduler select MCS for reliable transmission when interference is bursty
  + Proposals
    - Separate CSI reporting of signal information and interference information: Futurewei [3]
    - Report interference statistics (e.g. minimum, maximum, stddev): Futurewei [3]
    - Report CQI or SINR statistics (e.g. variance): Ericsson [6], Nokia [7]
    - Explicit interference averaging: Intel [12]
    - Filtered CSI reporting (e.g. report only when CQI changes): Intel [12]
    - Report the CQI associated with the worst-M sub-bands: Nokia [7]

**Observation**

The necessity of a new CSI report type for better capturing interference characteristics is seen by several companies but the proposals are diverging at this point and more details are needed.

**Question #7:** Should new CSI report type(s) be supported to better capture interference characteristics in URLLC scenarios?

* If yes, do we need to agree on common scenario, assumptions and metrics for comparing the different schemes?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | More information especially on the characteristic of the intereference is useful for accurate MCS selection at the gNB. |
| Samsung | No | Robustness is key in URLLC. Short-term/instantaneous statistics cannot be relied upon for future scheduling. There is also always the issue with accuracy of measurements, quantizations, and reliable, practically error-free, feedback, dependence on transmission scheme, diversity scheme, .... |
| Nokia/NSB | Yes | As we see from our evalutions, we see certain gains with such approaches. It is convenient to have an agreed/unified way forward for comparing the performance of the different proposals. |
| FUTUREWEI | Yes | Report of interference statistic such as standard deviation, max, and min, etc., allows for more accurate MCS selection at the gNB. The interference statistics need not be short term. Detailed format of reporting can be FFS. |
| InterDigital | Yes | For UEs subject to fast interference variations such enhancements are helpful for the network. We need to agree on common assumptions to compare different candidates. |
| Qualcomm | No | URLLC system should be designed to be robust against very rare event. It is unclear to us whether/how statistical CSI information could help increasing the reliability, and if so to what percentile the statistics need to be reported/measured.  For example, it is unclear how an 80% percentile CSI report or the variance of the CSI report could be helpful to achieve a 1e-5 BLER target. Need more evaluation results to justify the proposal. |
| DOCOMO | Yes | Reporting of statistics information could help gNB to select accurate MCS. |
| Spreadtrum |  | We are open for this issue. |
| HW/HiSi | Yes | Firstly, we should agree on the tool to carry the CSI report, then we should discuss this issue here. As many companies have pointed out, this is an area that has potential to improve the performance. |
| Panasonic | FFS | Need to have evaluation first and identify potential benefits. |
| Intel | Yes | We consider this as the main objective of this WI, since all other optimization do not directly solve the issue of MCS setting accuracy. |
| vivo | No | The necessity to introduce new CSI report types needs to be further clarified.  In order to identify the potential gain from introduction of new CSI report types, performance evaluation is needed. The evaluation methodology and assumptions should be discussed first. |

## More accurate sub-band CQI feedback

**Background**

A few companies raised concern on the accuracy of the current subband CQI as 2-bit delta CQI used with quantization and the quantization error is relatively large, resulting in inaccurate subband CQI.

**Issue #2-2: Need for enhancing accuracy of sub-band differential CQI feedback**

* Yes: Huawei [2], Mediatek [9], CMCC [17] propose enhancements to improve accuracy of sub-band differential CQI feedback
  + Proposals
    - Sub-band CQI with no differential CQI (Huawei [2])
    - New differential CQI tables (Mediatek [9])

**Question #8:** Should performance of sub-band CQI reporting be enhanced for R17?

* If yes, do we need to agree on common scenario, assumptions and metrics for comparing the different schemes?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | Can be further studied but not high priority. |
| Samsung | Maybe | Rel-15 provides the necessary tools for sub-band CSI reporting. New simpler reporting modes can be considered. But overlap with similar work in Rel-17 MIMO should be avoided. |
| Nokia/NSB | No | We prefer to have alternative CSI/CQI report types (e.g. as in Section 4.1) which can provide similar benefits with (much) lower uplink reporting overhead.  As a potential way forward, the decision between new CSI/CQI report types and/or enhanced sub-band reporting can be based on performance evaluation. |
| FUTUREWEI | Yes | Enhanced sub-band CQI reporting can be considered. |
| InterDigital | No | The relevance of this type of enhancement to URLLC is unclear. |
| Qualcomm | No | We don’t see the benefit for enhancing sub-band CQI reporting beyond Rel-15. |
| DOCOMO | No | Can be deprioritized since similar benefits might be obtained by new CSI type in section 4.1. |
| Spreadtrum |  | We prefer it is with the low priority. |
| HW/HiSi | Yes | The sub-band CQI is very suitable for the packets sizes in URLLC applications. But the granularity of the current mechanism is too coarse to allow for accurate CSI feedback. |
| Intel |  | We are open to this |
| vivo |  | The necessity to introduce more accurate sub-band CQI feedback needs to be further clarified. In addition, how much gain from the introduction of more accurate sub-band CQI feedback should be investigated first. |

# Other enhancements

## Enhancements to support OLLA with low BLER target

**Background**

An ACK/NACK based outer loop link adaptation has been used and it worked fine with eMBB use case since it has higher target BLER (). However, for URLLC, the ACK/NACK based OLLA performs poorly since NACK occurs very rarely as it targets much lower BLER () and it cannot track the channel/interference variation dynamically.

**Issue #3-1: Need for additional information bundled to HARQ-ACK**

* Yes: Ericsson [6], Oppo [14], ZTE [5], Nokia [7], Apple [26], Qualcomm [27] propose to bundle additional information to the HARQ-ACK report
  + Proposals
    - Decoding margin: Ericsson [6]
    - Compressed CSI report: Oppo [14], ZTE [5]
    - Estimated error probability, e.g. LLR: Nokia [7], Oppo [14]
    - Recommended RV sequence: Apple [26]
    - PDSCH decoding failure reason: Qualcomm [24][27]
    - Per-TRP decoding result: Qualcomm [27]
    - Preferred beam, subband, and/or component carrier info: Qualcomm [27]
    - New Tx-Rx beam pair request: Qualcomm [24][27]
    - Instantaneous MCS/CQI feedback: Qualcomm [27]

Note: Apple [26], Qualcomm [27] contributions submitted under AI 8.3.1.1

**Observation**

OLLA performance issue is seen by several companies and those companies see the benefit of additional information bundled with HARQ feedback for better OLLA performance.

**Question #9:** Should R17 support reporting of additional information bundled to HARQ-ACK?

* If yes, what should the additional information be obtained from (e.g., PDSCH, CSI-RS, etc.)?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | We can consider the details after decision is made on this feature. |
| Samsung | Maybe | Need to have evaluation first and identify potential benefits – cannot say ‘yes’ or ‘no’ to concepts. Several proposals fall under MIMO (and some are part of Rel-17 MIMO). The remaining do not seem necessary. |
| Nokia, NSB | Yes | For outer loop link adaptation, we see it convenient to derive the additional information from the PDSCH. |
| FUTUREWEI | Yes | These features can be considered but with low priority. |
| InterDigital | Yes | For outer loop link adaptation and based on PDSCH. |
| Qualcomm | Yes | Link adaptation scheme based on traditional Ack/Nack feedback perform quite poorly in the 1e-5 BLER regime, because it is not fast enough to track the instantaneous channel fading and interference with high accuracy. Additional information besides the traditional ack/nack can be very helpful for the gNB to make accurate scheduling decisions. The potential contents for the additional information are as listed by the FL above.  For example, in case of mTRP, UE can report PDSCH decoding result per TRP in addition to the final decoding result by combining the PDSCH repetitions from both TRPs. Based on the decoding result per TRP, gNB may quickly identify and replace a TRP of poor link quality with another TRP, e.g. when a TRP has X consecutive decoding failures.  As another example, fast and instantaneous MCS/CQI feedback based on the PDSCH decoding can help maintain the link adaptation to achieve URLLC BLER requirement with efficient RB use. Furthermore, deriving the additional information from the PDSCH is more convenient than from the CSI-RS: it does not require additional CSI-RS overhead, and can afford faster feedback compared to CSI feedback based on the CSI-RS. |
| Apple | Yes | URLLC brings unique challenges, we are open to proposals to address them. |
| DOCOMO | Yes | Would be beneficial. Details should be considered after decision on whether to study this feature. |
| Spreadtrum | Yes | We are open to the suggestions. |
| HW/HiSi | Maybe | This could be studied with low priority at the stage. As mentioned by multiple companies, OLLA could need to be improved for URLLC target BLER. |
| Panasonic | FFS | Need to have evaluation first and identify potential benefits. |
| Intel | Maybe | Evaluation is required to see the benefits vs complexity/OH  Again, optimization of the resource allocation for retransmissions may not bring noticeable performance benefits since the initial transmission itself should be quite robust in URLLC scenarios |
| vivo |  | How much gain from the introduction of additional information bundled to HARQ-ACK should be investigated first. |

## Enhancements for URLLC in multi-TRP scenarios

**Background**

From Rel-16, the multi-TPR transmission (NCJT) has been supported but there is no CSI feedback design optimized for the multi-TRP transmission

**Issue #3-2: Enhanced CSI reporting for multi-TRP scenarios**

* Yes: Futurewei [3], Ericsson [6], propose CSI enhancements optimized for multi-TRP transmission schemes with high reliability
  + Proposals
    - Joint CSI report for multi-TRP URLLC scenario: Ericsson [6]
    - UE selecting whether a RS resource is for CM, IM, or muting: Futurewei [3]

The support of tailored CSI feedback design for multi-TRP transmission is proposed by two companies. Considering that multi-TRP enhancement is currently under Rel-17 FeMIMO WI, it is unclear whether this issue should be studied in the URLLC/IIoT WI.

**Question #10:** Should enhancements to CSI reporting for URLLC in multi-TRP scenarios be discussed as part of this WI?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | No | Leave it to MIMO group to handle. |
| Samsung | No | Rel-17 MIMO is handling this. |
| Nokia, NSB | No | Let MIMO guys to handle this. |
| FUTUREWEI | Yes | We are also ok if this is handled in Rel-17 FeMIMO WI. |
| InterDigital | No | Should be discussed in R17 MIMO |
| Qualcomm | No | This feature is better suited for the Rel-17 FeMIMO WI. |
| DOCOMO | No | Leave it to Rel-17 MIMO |
| Spreadtrum | No | Leave it to Rel-17 MIMO |
| HW/HiSi |  | Could be studied further, but as other companies pointed out, could be handled in MIMO |
| Panasonic | No | This issue should be handled in MIMO. |
| Intel | No | We understand MIMO is going to discuss this |
| vivo | No | Should be handled by MIMO session. |

## Miscellaneous Enhancements

[Proposals that do not fall into one of above categories]

Lenovo [13] proposal

*Proposal 3: Consider enhancements for CSI report(s) transmission to increase its transmission possibility on one or more of the scheduled repetitions with PUSCH repetition Type B.*

CMCC [17] proposal

*Proposal 2: PUCCH enhancements should also be considered to ensure the more accurate CSI feedback.*

Qualcomm [24] proposals

*Proposal 2: Study dedicated CSI feedback for PDCCH to improve the reliability/scheduling efficiency of PDCCH.*

**Question #11:** any of above proposals should be considered as a high priority topic?

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| Sony | Yes | Can consider feedbacks for PDCCH. |
| Samsung | Yes | PDCCH link adaptation is more important than PDSCH one, especially for the small TBs and low latency of URLLC – cannot even receive the PDSCH without the PDCCH and the latter cannot even benefit from HARQ |
| Nokia | No |  |
| FUTUREWEI | Yes | Improved PDCCH reliability is important for URLLC. |
| InterDigital | Yes | PDCCH link adaptation |
| Qualcomm | Yes | We support the proposal:  *Proposal 2: Study dedicated CSI feedback for PDCCH to improve the reliability/scheduling efficiency of PDCCH.*  The reliability of PDCCH is essential to achieve an end-to-end reliability for both uplink and downlink. During NR Rel-16 URLLC WI/SI, the reliability of PDCCH was studied, and a new DCI format with reduced size was introduced for enhanced reliability. However, no matter how reliable the PDCCH is designed at the physical layer, without a good link adaptation scheme for PDCCH, there is no guarantee that gNB will make correct scheduling decisions on selecting the aggregation level for PDCCH (unless it always uses AL=16 for PDCCH, which obviously does not work in practice), hence leading to (consecutive) PDCCH errors.  In the current NR system in Rel-15 and Rel-16, there is no mechanism to feedback direct channel quality information about the PDCCH channel. In theory, the gNB could infer some information about the PDCCH performance based on CQI feedback for PDSCH. However, there’re severe limitations with this approach.   * The DMRS configuration/channel estimation and coding for PDCCH is very different from that of PDSCH, making it hard for a gNB to map the CQI for PDSCH to a meaningful performance indication for the PDCCH. * The interference profile is typically different between a downlink control channel and a downlink data channel.   As such, it may not be easy for the base station to accurately infer the channel quality of PDCCH from that of the PDSCH.  To guarantee the reliability of the PDCCH channel, we think having dedicated feedback information on the PDCCH channel is critical. |
| DOCOMO | No | Feedback for PDCCH can be studied further but with low priority. |
| Spreadtrum |  | Low priority for the three proposals above. |
| HW/HiSi |  | The current scope and set of questions is already rather broad, we should not expend it further at this stage.  We acknowledge that PDCCH reliability is important for URLLC, but we are surprised that it is brought up now in the context of enhanced CSI feedback. If PDCCH is improved, it should be done in a broader perspective. PDCCH reliability was on the table during Rel-15 and Rel-16 and one candidate solution was PDCCH repetition. If PDCCH reliability and transmission efficiency shall be improved, then we also should look into PDCCH re-transmissions schemes, PDCCH combining, PDCCH-ACK, etc which is out of scope of this topic. It would be better to address this issue in a more comprehensive effort in a later release. |
| Intel | No / LP | Evaluations are required to justify the need |
| vivo | No | These topics are low priority. |

**Question #12:** any proposal which is not captured in this summary document?

|  |  |
| --- | --- |
| **Company** | **Comments** |
|  |  |
|  |  |
|  |  |

# References

1. RP-201310, Revised WID: Enhanced IIoT and URLLC support for NR, Nokia, Nokia Shanghai Bell.
2. R1-2005244 CSI feedback enhancements Huawei, HiSilicon
3. R1-2005281 CSI feedback enhancements for URLLC FUTUREWEI
4. R1-2005375 CSI feedback enhancements for Rel-17 URLLC vivo
5. R1-2005432 Discussion on CSI feedback enhancements for eURLLC ZTE
6. R1-2005514 CSI Feedback Enhancements for IIoT/URLLC Ericsson
7. R1-2005552 CSI feedback enhancements for URLLC/IIoT use cases Nokia, Nokia Shanghai Bell
8. R1-2005570 Considerations on CSI feedback enhancements Sony
9. R1-2005634 CSI feedback enhancements for URLLC MediaTek Inc.
10. R1-2005702 CSI feedback enhancements CATT
11. R1-2005776 CSI feedback enhancement NEC
12. R1-2005870 CSI feedback enhancements in Release 17 URLLC/IIoT Intel Corporation
13. R1-2005930 CSI feedback enhancements Lenovo, Motorola Mobility
14. R1-2006059 Enhancement for CSI feedback OPPO
15. R1-2006071 CSI feedback enhancements for enhanced URLLC/IIoT InterDigital, Inc.
16. R1-2006140 CSI feedback enhancements for URLLC Samsung
17. R1-2006208 Discussion on CSI feedback enhancements CMCC
18. R1-2006276 Discussion on CSI feedback enhancements Spreadtrum Communications
19. R1-2006315 Discussion on CSI feedback enhancements for URLLC LG Electronics
20. R1-2006343 Discussion on CSI feedback enhancements Panasonic Corporation
21. R1-2006515 CSI feedback enhancements for URLLC Apple
22. R1-2006573 CSI feedback enhancements for eURLLC Sharp, NICT
23. R1-2006729 Discussion on CSI feedback enhancements for Rel.17 URLLC NTT DOCOMO, INC.
24. R1-2006800 CSI enhancement for IOT and URLLC Qualcomm Incorporated
25. 3GPP TR38.824, “Study on physical layer enhancements for NR URLLC”, v16.0.0.
26. R1-2006514 UE feedback enhancements for HARQ-ACK Apple
27. R1-2006799 HARQ-ACK enhancement for IOT and URLLC Qualcomm.