

Dresden, Germany, 28th June – 2nd July 2010**Agenda item:** 6.3.2.2**Source:** NTT DOCOMO**Title:** E-mail discussion on PDSCH muting for CSI RS design**Document for:** Discussion and decision

1. Introduction

Simulation assumptions for the evaluation of PDSCH muting for inter-cell CSI RS design were agreed to clarify the performance benefit of muting in R1-101956, and currently performance evaluations are ongoing. The primary aim of this email discussion is to discuss the results of the performance evaluation in terms of impact to legacy (Rel8/9) performance as well as Step 1 results (MSE) so that we could focus on the Step 2 results (throughput) during the next meeting.

Furthermore, the rapporteur would like to propose to clarify the specification impacts of PDSCH muting (e.g., required signalling and implications on rate matching) so that RAN1 can finally decide whether to support PDSCH muting or not given the results of the performance evaluation and the identified specification impacts. In addition, simulation methodologies could also be discussed to better understand the assumptions and results of each contribution submitted in the previous meetings.

Thus, the topics for this email discussion are summarized as follows.

- Observations on the impact to legacy (Rel-8/9) performance
- Review of Step 1 results: MSE performance
- Specification impact of PDSCH muting
- Simulation methodologies

More detailed formulations of each topic are shown in Section 2. Note that the observation of Rel-10 performance is captured in the chairman's notes of RAN1 as below, and so it is not included in the list above. Nevertheless, each company could still discuss by taking Rel-10 UE impact into account.

Observation:

- *Transparent muting has an impact on Rel-10 UE*

2. e-mail discussion

1. How significant is the additional performance degradation to Rel-8/9 UEs due to PDSCH muting on top of the degradation by CSI-RS?

Case1: When PDSCH muting is applied within a subframe transmitting CSI-RS of the serving cell.

Case2: When PDSCH muting is applied in other subframes than the ones transmitting CSI-RS of the serving cell.

Proposal: Followings are captured as *observation* of the results of the legacy impact of PDSCH muting

- There is a performance impact due to muting for case 1 and case 2.
- Especially, when PDSCH muting is applied in other subframes than the ones transmitting CSI-RS of the serving cell, performance degradation of Rel-8/9 UE becomes more significant.
- Thus, it is preferable that PDSCH muting (if supported) is limited to the same subframe as the ones transmitting CSI-RS on the condition that sufficient reuse factor providing the muting gain can be obtained.

Company	Views
DOCOMO	- Case 1: Number of punctured REs increases by applying muting. Therefore, the performance degradation is further increased compared to the case without muting. However, the additional performance degradation by muted REs is not significant compared to that by CSI-RS REs. - Case 2: By applying muting in the different subframe as CSI-RS, the performance of muted subframe is also degraded similarly to CSI-RS subframe. This leads to further restriction of eNB scheduler for Rel-8/9 UE assignment. Therefore, muting between subframes should be avoided as much as possible.
Huawei	- Case 1: We share the same view as NTT DOCOMO that when PDSCH muting is applied within the same subframe as the serving cell CSI-RS, the additional performance degradation by muted REs are negligible beyond the degradation by serving cell CSI-RS puncture. According to R1-101955, additional 8 RE data muting cause less than 2% performance degradation beyond serving cell 4 CSI-RS REs puncturing. - Case 2: Muting in other subframe than the serving cell CSI-RS subframe will degrade the performance of those muted subframes, though slightly better than that in the serving cell CSI-RS subframe. From a performance and scheduling point of view, it is preferred not set too frequent period of the CSI-RS or muting subframes, larger than 5ms in total should be acceptable. If the available resources permitted, it'd be good to put muting and serving cell CSI-RS in the same subframe.
ZTE	- For both case 1 and case 2, we see the R8/9 performance degradation depending on the CoMP measurement set size. In case 1, The degradation is relatively small for CoMP measurement set size equal to 3, while it is obvious when the CoMP measurement set size reaches 6. In case 2, if the number of CSI-RS reuse per subframe for the same CoMP measurement set is smaller than that in case 1, the performance loss should be also smaller. - In order to have clean subframe for R8/9 PDSCH transmission, we prefer to put PDSCH muting in as small number of subframes as possible.
Texas Instruments	- Case 1: From our evaluations (R1-102819), PDSCH muting creates significant performance degradation relative to PDSCH RE puncturing only (no muting). For example, if PDSCH muting is enabled with MCS = 16QAM-1/2, significant SNR degradation is observed and there is a BLER floor at 4E-3 at high SNR. Such phenomenon is not observed without PDSCH muting. Proposal: Considering the significant performance degradation from muting, our view if PDSCH muting (if enabled) should first show significant performance improvement (in CoMP context) if it is to be considered as a viable candidate for standardization. - Case 2: We agree with NTT DOCOMO's views. That is, PDSCH muting, if at all applied, should be restricted to within the subframe transmitting CSI-RS of the serving cell. This simplifies eNodeB scheduler implementation during scheduling of Rel-8/9 LTE UEs during subframes where inter-cell CSI measurement does not occur. Moreover, we suggest that PDSCH muting should be considered at RE positions of non-serving cell CRS positions for 4 TX/2TX antenna transmissions.
LG Electronics	- Case 1 : Slight degradation when RE are muted along with CSI-RS, but negligible. The large portion of the performance loss comes from insertion of either CSI-RS or

	muted RE. (Similar observations as NTT DoCoMo and Huawei). - Case 2 : Performance loss similar to CSI-RS insertion is seen. Considering channel estimation for CoMP should be most update-to-date as possible, and legacy impact, muted REs should be at least supported in subframes where serving cell CSI-RS is transmitted.
Intel	The R8/9 PDSCH performance loss due to CSI-RS is higher than due to muted PDSCH, giving some preference to the case 2 over case 1. However, usage of PDSCH muting in the subframes other than CSI-RS subframe would lead to the R8/9 scheduling restrictions, which are not desirable. To minimize impact on R8/9 PDSCH performance and relax requirements on eNode-B scheduling, it is preferable to limit PDSCH muting to the same subframe where CSI-RS is transmitted.
Samsung	- Case 1: We agree with NTT DoCoMo in that for a subframe with CSI-RS transmission, the additional performance degradation from muted REs on Rel 8/9 UEs is relatively small compared to that of CSI-RS. However, we do not think the performance degradation is negligible. In a previous contribution from Samsung (R1-102192), it was observed that muting added a performance degradation of 5% on top of the performance degradation caused by CSI-RS. - Case 2: We observed similar performance degradations when muting is applied subframes without CSI-RS. Considering the fact that there is noticeable performance degradation from muting to Rel 8/9 UEs, it would be beneficial to restrict the application of muting to as small number of subframes as possible. One such example would be to restrict muting to subframes with CSI-RS transmissions. However, we do not think that such a restriction is a standardization issue and can be easily applied in the implementation stage if required.
Panasonic	- Case 1: From link level perspective, performance loss for the cases with up to 16REs for CSI-RS and/or muting is smaller than that of CSI-RS with 2RE/PRB/port for 8tx without muting according to our observation in R1-101263. So this could be tolerable with muting for up to 3 cells for 4tx or up to 1 cell for 8tx - Case 2: We support DOCOMO's view, namely we'd prefer allocating CSI-RS of multiple cells within limited subframes as indicated in R1-102873.
ALU/ASB	- Case 1: The PDSCH muting within the CSI-RS subframe would have the results of non-negligible degradation to R8/9 UEs due to more puncturing, which also depends on the deployment scenarios. Therefore, our view is that the PDSCH muting does not need to be introduced unless the feature required inter-cell measurement, such as CoMP, is specified. . - Case 2: PDSCH muting (if supported) subframes should be a "limited number". Whether the subframe is CSI-RS subframe or not is FFS. The concrete number is FFS.
Nokia, NSN	- Case 1: Obviously there is a Rel-8/9 performance impact by introducing muted PDSCH resources and this impact also scales with the number of muted resources. However, the additional performance degradation is rather small relative to the one due to the CSI-RS transmission itself. The overall impact is mitigated to a large extent if PDSCH muting happens only in the CSI-RS sub-frame as the impact gets averaged over the radio frame. - Case 2: In our previous studies we have shown that PDSCH muting spanning over multiple sub-frames should be avoided because it leads to the worst impact in terms of legacy performance. Rather than spreading the muting in time, it is preferable to concentrate a larger amount of muted PDSCH resources within the CSI-RS sub-frame itself.
Qualcomm	- For both Case 1 and Case 2, we observe non-negligible loss due to muting (results in R1-102332). To minimize impact to Rel 8/9 UEs, we prefer minimizing the number of subframes impacted due to CSI-RS puncturing/muting by allocating CSI-RS

	resources for neighboring cells in the same subframe, and scheduling the Rel 8/9 UEs in other subframes. - Whether the muted subframes are CSI-RS subframes or not depends on the reuse provided by CSI-RS. If sufficient reuse is available it is desirable to have CSI-RS of multiple cells on the same subframe. However, if the reuse provided by CSI-RS is small it should be possible to configure muting and CSI-RS on different subframes.
CATT	- For both case 1 and 2, there will be loss for Rel 8/9 UEs due to PDSCH muting but not very significant compared to the case where the CSI-RS locations are already punctured. - Muting in other sub-frames will degrade the performance of Rel-8/9 UEs in those sub-frames, so it should be avoided as much as possible.
Ericsson/ST-Ericsson	- Case 1: It is reasonable to expect that muting further degrades the performance when used together with CSI RS in the same subframe. But we also expect that the additional performance degradation will be less than the degradation already introduced by CSI RS. - Case 2: It would be good to avoid spreading out the muted REs over many subframes since legacy UE performance will be hurt. But this can also be a eNodeB implementation issue depending on the configuration possibility of the muting.

2. How is the performance gain of PDSCH muting against the cases of CSI-RS without PDSCH muting and CRS in terms of MSE performance?

Proposal: Following *s* are captured as *observation* of the results of the step-1 evaluation.

- MSE performance improvement is achieved by CSI-RS with PDSCH muting compared with CSI-RS without muting and CRS in channel estimation of neighboring cells.
- Throughput performance should be evaluated to further clarify the benefit of muting

Company	Views
DOCOMO	- In the serving cell, the MSE performance is not improved by applying muting compared to that using channel estimation by CRS. - In the neighboring cell, the MSE performance is improved by applying muting. However, to confirm the benefit of PDSCH muting, the throughput performance with various CoMP transmission schemes should be evaluated.
Huawei	Step1: MSE evaluation - In homogeneous network, applying muting and using channel estimation by CRS exhibits similar performance in serving cell; - For neighboring cell measurement, muting gives significant MSE performance gain than CSI-RS without muting and large performance gain than CRS channel estimation [R1-103102]; - In heterogeneous network, the MSE is very bad based on CSI-RS without muting even for serving cell measurement with large-biased range expansion of pico cell or when the macro UE locates close to a CSG cell.
ZTE	The MSE performance with PDSCH muting is better than the MSE performance without PDSCH muting and MSE performance with CRS, especially for channel measurement on inter-cell CSI-RS. However, the gain gap on CoMP Ues' throughput performance (step2) does not look as large as on MSE performance. Our simulation shows that muting can bring about 10% throughput gain to CoMP UE but meanwhile can have negative impact to non-CoMP UE. The overall impact therefore depends on the percentage of CoMP UE in system.
Texas Instruments	- For CSI-RS, as seen in our evaluation (R1-102820), N-MSE with PDSCH muting on inter-cell measurement RE is significantly smaller (best case N-MSE equals -32 dB at high SNR) than the N-MSE seen without PDSCH RE muting (best case N-MSE equals nearly -3 dB).

	However, we agree with NTT DOCOMO that throughput benefits with PDSCH muting should be shown for different CoMP transmission schemes, considering realistic channel estimation errors (residual errors from non-measurement cells) and associated CSI feedback methodologies. - For CRS-based inter-cell measurement, it is observed that PDSCH muting on inter-cell CRS position achieves robust channel estimation and similar MSE performance against muting for CSI-RS. Note that CRS-based inter-cell measurement is possible in <i>scenarios where CSI-RS may not be applicable</i> (note that the decision on whether or not to employ CSI-RS in case of 2 TX/4TX eNodeB transmissions is not finalized). The higher PRB density of existing CRS (16-24 Res/PRB) potentially improves channel tracking and time-/frequency domain interpolation accuracy of inter-cell channel estimates. In contrast, the accuracy of CSI-RS based inter-cell measurements is limited due to its low duty cycle. Therefore, we propose to <i>study inter-cell PDSCH RE muting for CRS to facilitate better inter-cell measurement and better channel tracking on inter-cell RS</i>
LG Electronics	MSE is improved in both serving cell and neighbor cell channel estimation via CSI-RS, when muting is applied in coordinated manner. We do not have results comparing CRS based CE MSE and CSI-RS with muting based CE MSE.
Intel	There is remarkable MSE performance improvement of CSI-RS with muting over CSI-RS without muting. The MSE performance gain is due to improved CINR on CSI-RS, which is critical in the considered scenario with small CSI-RS RE density within PRB and limited channel measurement processing gain.
Samsung	- We have observed muting to result in MSE performance enhancements especially for low geometry Ues (UE in cell edges). The MSE performance enhancements consequently generated improved link throughput results for the low geometry Ues. - However, for high geometry Ues (Ues close to eNB), although there was MSE performance improvement, it did not lead to a link throughput increase. In fact, a link throughput decrease was observed due to reduction in the number of PDSCH REs. Overall, we observed that PDSCH muting can only benefit low geometry Ues. Therefore, we feel that a careful study is needed on muting in terms of system-wide performance impact.
Panasonic	Our observation in R1-02871 is that CSI-RS with PDSCH muting provides best performance compared to other 2 cases in terms of MSE performance in case RSRP difference between serving cell and coordinated cell below 5dB for SCM-Config.1. That RSRP difference would be typical scenario for CoMP UE. However we support DOCOMO's view namely the benefit should be verified via throughput performance with various COMP transmission scheme.
ALU/ASB	- The PDSCH muting can help to improve the MSE performance of CSI estimation. While the MSE gap is relatively large compared to no inter-cell interference. The throughput should be further evaluated to decide the actual gain of muting.
Nokia, NSN	In terms of MSE performance, with CRS taken as reference, PDSCH muting benefits to both the serving cell and the neighbour cells, however the main benefits are mostly for the neighbour cells where MSEs levels are significantly improved compared to CRS. We highlight the fact that due to the very low CSI-RS density of 1 RE/port, muting in neighbour cells is highly recommended if inter-cell CSI measurements over CSI-RS are specified in a further release. MSE performance with CSI-RS and no PDSCH muting leads to worse performance compared to CRS.
Qualcomm	Although PDSCH muting helps in improving the MSE of CSI-RS, it is necessary to see improvements in overall system performance in addition to throughput performance with CoMP schemes before agreeing on support of muting.
CATT	PDSCH muting in serving cell will improve the MSE performance of the CSI-RS in neighbouring cell and vice versa. However over all system performance should be investigated.

Ericsson/ST-Ericsson	We agree with DoCoMo that for channel estimation on neighboring cells, MSE can be improved by muting. But MSE is not the appropriate performance metric in this case since what is relevant is system level gains. Those gains should be demonstrated under realistic assumptions on feedback overhead, channel estimation and interference estimation for various CoMP schemes.
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3. What is the specification impact to support PDSCH muting in Rel.10?

Proposal:

Continue discussion on whether or not to support muting in Rel-10 by taking following possible specification impacts into account:

- Rate matching around muted RE
- Following signaling support (implicit or explicit) to UE:
 - Enabling/disabling of muting
 - Muted RE location (offsets and duty cycle), where more study will be needed on
 - Signaling formats
 - Reduction of muting patterns
- Power usage of muted RE

Company	Views
DOCOMO	At least, following two aspects should be considered. - Signaling to support muting: UE must have the following knowledge regarding the muting parameters explicitly or implicitly. - Muted RE location within a subframe - Muted subframe offset - Muted subframe duty cycle (5, 10, 20 msec,...) - Similarly to CSI-RS, rate matching for muted RE should be applied to avoid the performance degradation of Rel-10 UE.
Huawei	Share the view of DOCOMO. A further clarification: - Muting configurability is to be specified, i.e. muting can be disabled in some scenarios, and can be enabled in other scenarios, depending on the network operation. Since muting can be disabled, the impact to R10 is neglectable in the scenarios without muting requirement. - Muting configurability will reduce the risk of any redesign of further release cell-specific RS, e.g. finding available REs / Impact on R10 Ues, to support future system evolution with inter-cell CSI measurement requirements or some serving-cell measurement in some hetnet scenarios. Considering the risk of no muting configurability in R10 versus the small standard impact and impact on R10 system, it'd be good to specify it in R10.
ZTE	We would like to clarify following questions before looking into the specification impact of muting: 1). Whether the UE needs to know extra information besides the configuration information for all intercell CSI-RS in the CoMP measurement sets in which its serving cell may involve, and if yes, whether muting configurability, which is cell-specific, should be dynamic or semi-static depending on the involving inter-cell CoMP measurement sets, which are kind of (inter-cell)UE-specific and could be dynamic changing. 2). Whether the muting configurability in one cell could inversely affect the CSI-RS measurements in surrounding cells and therefore UE does not only need to know the inter-cell CSI-RS configuration, but also the inter-cell muting configuration. For now, we prefer to the static muting configuration that can be derived from inter-cell CSI-RS's as much as possible, and that leaves specification impact as small as possible. We have no strong preference between rate-matching and puncturing on PDSCH transmission around muting RE's if muting is statically configured; however, we prefer to

	PDCH puncturing if muting configuration can be changed on-the-fly.
Texas Instruments	We support NTT DOCOMO's views. In addition, the standardization impact of PDSCH muting on inter-cell CRS should be considered.
LG Electronics	- PDSCH data should rate match around Muted REs - Configurability of Muting should be supported • RE muting may affect interference estimation (namely neighbor cell load interference) and possibility of RE muting with different periodicity compared with serving cell CSI-RS should supported. - RE muting supported in specification by configuration of multiple CSI-RS set. Serving cell feedback and measurement for Rel-10 only relies on 1 CSI-RS set, where the serving cell actually configures multiple CSI-RS sets. The multiple CSI-RS will naturally be orthogonal to each other and REs for other CSI-RS set is muted (the same concept between FDM/TDM CSI-RS antenna ports). • In order to forbid used of muted REs for other purposes (e.g. neighbor cell interference measurement) other than neighbor cell channel estimation, which is the only use case identified up to now for Rel-10 Ues. If serving cell informed the UE there are additional CSI-RS transmitted (but not measured) in muted RE, then UE cannot possibly use muted RE for interference measurement purposes, and at the same time have full forward-compatibility for CoMP.
Intel	Specification impact is mostly in the definition of the signalling required to support transmission of CSI-RS with muting: CSI-RS subframe location, muted PDSCH configuration within subframe (CSI-RS number of antenna ports, CSI-RS pattern) and potentially PDSCH muting periodicity.
Samsung	Agree with DoCoMo's view. Signalling support and rate matching are essential issues that need standardization support. Additionally, RAN1 might need to consider the utilization of transmission power of muted off REs. One possible usage for the muted off transmission power is to boost the transmission power on the CSI-RS if it occurs in the same time period.
Panasonic	We support DOCOMO and Huawei's view.
ALU/ASB	We do not see the necessity of signalling the muting configuration to the UE at the current phase without any features requiring inter-cell measurement in Rel-10
Nokia, NSN	If introduced, PDSCH muting is expected to impact specifications as follows: - PDSCH should be rate-matched around muted Res. - Muted PDSCH resources should be signalled to the UE. A simple way is to link those to the CSI-RS sub-frame and the CSI-RS pattern itself assuming muting occurs only in CSI-RS subframes, which makes most sense as discussed in question 1. - The number of PDSCH muting patterns – reuse factor in terms of muting – should also be limited, simplifying both testing and signalling. - A mechanism should be specified for enabling/disabling PDSCH muting.
Qualcomm	The muting information should be in the same format as the CSI-RS pattern configuration information for the serving cell, for which we proposed to use an index into an enumerated set of patterns. We assume that parameters that may impact the CSI-RS pattern, such as presence of CRS antenna port 2, 3, use of normal CP vs. extended CP, can be assumed to be the same in the neighbour cell as in the serving cell, because this would be the typical case in UE-transparent CoMP operation. Therefore relatively low signalling overhead could be achieved.
CATT	1. Considering the overall performance of Rel-8/9/10 UE, muting shall be configurable: - Required signalling, e.g. ● Muted RE location within a subframe ● Muted subframe offset ● Muted PRB within a subframe, i.e., muting in some of the PRBs only ● Muted subframe periodicity 2. rate matching around the muted PDSCH 3. others?
Ericsson/ST-	Similar concerns as for CSI RS, including which REs to use, various offsets and re-use

Ericsson	factor, configuration strategy (RRC based?), how to avoid antenna port 5 with even more REs being removed, interference estimation for the UE. As Qualcomm indicates, much of configuration aspects could probably be inherited from the CSI RS design but the issue of interference estimation and antenna port 5 avoidance becomes more difficult and should at least be addressed in the discussions. It should also be clarified how the UEs should measure interference when muting is used in conjunction with CoMP. It is not obvious and the system impact of having UEs with widely different behaviour could be quite large.
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4. Questions or comments on simulation methodologies and assumptions in particular contributions in the previous meetings?

Company	Views
Huawei	The step2 muting evaluation results of CBF in [R1-103102] show the conclusions: - Applying muting has an obvious gain over non-muting schemes (10.7% for 50th percentile UE; 37% for 5th percentile UE). - The CRS based scheme has much less gain over non-muting scheme(2.5% for 50th percentile UE, 7% for 5th percentile UE). CRS cannot provide enough accurate inter-cell CSI measurement to reach any CBF gain, and CSI-RS with muting configurability is necessary. In addition, muting is important in some hetnet scenarios.
Texas Instruments	It is proposed to study PDSCH muting on inter-cell CRS and its standardization impact. This can be done regardless CSI-RS and/or muting is supported or not. Inter-cell CRS measurement with PDSCH muting provides robust MSE performance against CSI-RS, as shown in R1-102820.
LG Electronics	Step 2 muting evaluation results in [R1-102698] show following conclusions: - For CoMP-JPT 9% and 12% gains for cell average and cell edge respectively - For CoMP-CBF up to 20% gains Even with same feedback mechanisms the CSI-RS estimation effects entire transmission performance, and is seen to be the bottleneck for certain enhanced MIMO transmission techniques.
Nokia, NSN	Simulation methodology should be clearly described by companies providing results. In our view, the latter should be mostly link-level oriented in order to capture properly the impact of inter-cell interference on realistic channel estimation over CSI-RS with/without PDSCH muting where realistic channel estimation over CRS is taken as a reference.
Ericsson/ST-Ericsson	We agree that simulation assumptions should be clearly described and full set of estimation effects should be part of the simulations, channel estimation as well as interference estimation. Interference estimation based on CRS is known to lead to substantial performance loss (much larger than the potential gain of introducing muting) via pessimistic CQI in low load situations so it is not a viable choice in these evaluations.

5. Others

Company	Views
LG Electronics	CSI-RS estimation performance should not be the bottleneck for any potential enhanced MIMO (coordinated and non-coordinated) techniques, and methods of achieving better CSI-RS estimation should be strongly considered.
Nokia, NSN	- One important aspect to be discussed in our view is the topic of interference estimation over CSI-RS in general, although it extends beyond the scope of this e-mail discussion. We identified issues in that respect due to the very low agreed density of 1 RE/PRB/port. We end concluding that CRS is the only viable candidate for interference estimation. From that angle, the issues typically raised with interference estimation in conjunction with RE muting are not relevant anymore. - Another potential aspect is the question of the reuse factor achieved through PDSCH muting. Agreed assumptions implicitly set a reuse factor of 3 (because of the 3-sector intra-cell setup), while we did see benefits at MSE level of higher

	reuse factors (i.e. PDSCH muting extending beyond the cells of the center site).
Ericsson/ST-Ericsson	Nokia indicates that interference estimation based on CSI RS is difficult. If that is indeed the case, then muting can be introduced to give improved interference estimation which can have substantial impact on the very common scenario of low system load. We know from Rel-8 that CRS based interference estimation have substantial problems in such scenarios and with the introduction of CSI RS we should take the opportunity to fix this once and for all.

Proposal:

- Muting evaluation should include how many reuse factors will be needed to obtain the gain of muting.