**3GPP TSG RAN WG1 #110 R1-220xxxx**

**Toulouse, France, August 22nd – 26th, 2022**

**Source: Moderator (Intel Corporation)**

**Title: Summary#1 of AI: 9.9.1 NR PDCCH reception in symbols with LTE CRS REs**

**Agenda item: 9.9.1**

**Document for: Discussion and Decision**

# Introduction

In RAN#94-e meeting a work item on eDSS support was agreed for Rel-18 [1]. The objectives of the WID include enhancements to NR PDCCH reception as shown below:

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| --- |
| The following objectives shall be included for improvement of NR spectrum efficiency for LTE-NR co-existence (RAN1):  • Study and if needed specify NR PDCCH reception in symbols with LTE CRS REs. [RAN1] |

This document contains summary of the companies’ and moderator’s proposals.

# Review and observations

The following are observations from the FL based on tdoc review. This section is not meant for agreement.

**PDCCH capacity:**

Multiple companies submitted results although different assumptions on Tx (puncturing/superposition), receivers, UE distributions, capacity calculation methodology etc. is expected to cause variation of results across companies. The numbers in the following table represent PDCCH capacity gain % with respect to baseline (no enhancement). The variation of gain numbers from within a company depends on factors such as receiver channel estimation algorithm used, UE speed, fraction of legacy vs Rel-18 UEs in the system, CORESET configuration etc.

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | Option 1-1 | Option 1-2 | Option 2 |
| Scenario 1A |  |  | 24, 61 (Huawei)  68 (ZTE)  69, 33 (Vivo)  49, 51, 71, 73 (Mediatek)  38, 65, 70, 76 (Qualcomm)  47,67,77 (Ericsson)  25, 60 (Spreadtrum) |
| Scenario 1A-2 |  |  | 13,32 (Huawei) |
| Scenario 2 | 44 (Huawei)  27, 54 (ZTE)  -32,7, 33, 56, 59 (Vivo)  -16, 3, 16, 28, 29 (Vivo)  38, 40, 44, 48 (Mediatek)  70, 82 (Qualcomm)  19,33 (Ericsson)  -6, 28, 36 (Spreadtrum) | 66, 33 (Vivo)  49, 51 (Mediatek)  140 (Qualcomm)  25 (Ericsson)  46 (Spreadtrum) | 2, 48 (Huawei)  29,59 (ZTE)  30,31,53,53 (Mediatek)  54,77,91,97 (Qualcomm)  19, 38 (Ericsson) |
| Scenario 3 | 14 (Huawei)  -47, 7, 17, 21, 29 (Vivo)  -23, -3, 8, 10, 14 (Vivo)  20, 20, 23, 24 (Mediatek)  32, 34 (Qualcomm)  14, 19 (Ericsson) | 28,14 (Vivo)  24,28 (Mediatek)  36 (Qualcomm)  17 (Ericsson) | -9, 12 (Huawei)  12, 14, 26, 27 (Mediatek)  12, 30, 33, 34 (Qualcomm)  11, 21 (Ericsson) |
| LTE BW<NR BW (Huawei) | 4 (Huawei) |  |  |
| modified Scenario 3 (2+1 symbol Rel-18 CORESET) (Ericsson) | 14,24 (Ericsson) | 19 (Ericsson) | 15,24,29,34,39 (Ericsson) |

One or more companies have raised the following observations or comments:

**Outage performance**

* worse outage performance than baseline observed for options 1-1, and 2 (gNB puncturing or superposition)

**LTE impact**:

* degradation of LTE throughput due to Option 2 superposition
* decrease for LTE PDCCH capacity for scenario 1A, 2

**Coexistence with legacy NR UEs**:

* capacity gain of option 1-1 in Scenario 2 would reduce significantly from the case of 100% NR Rel-18 UE distribution to 50% NR Rel-18 UE distribution
* TDM/FDM of CORESET with legacy
* 2 symbol CORESET requirement for 1-1 and 1-2 is problematic due to CORESET#0

**Complexity**:

* new rate-matching for Option 1-2
* Option 1-2 is out of WI scope
* Channel estimation complexity beyond clean symbol DMRS estimation, multiple UE implementation options
* significant impact to channel estimation for option 1-1 and option 2
* fragmentation of UE capabilities
* 1-symbol CORESET with puncturing/superposition demands advanced receiver/channel estimator

**Specification work:**

* RAN1 - remove the restriction in TS 38.213, additional PDCCH mapping rule, applicable search space set, how to indicate the LTE CRS pattern(s) for PDCCH
* RAN4 - performance requirements and test-cases potentially for different receiver options

**Not critical enhancement - already available tools**

* FG 3-2, FG 3-5, or FG 22-12
* Rel-17 SCell PDCCH scheduling PCell PDSCH/PUSCH

**Other detailed proposals**

* Assistance information to UE (indication to puncture for example in Option -2)
* Restriction (specified or configured) on applicability to search spaces, RRC connected UEs, 2-3 symbol CORESETs
* Indication of CRS patterns for PDCCH

# Proposals

## Principle

The intention here is to check if we can select one of following options in principle that we can then use to work on TPs or detailed proposals-

**Proposal:**

Select one of the following PDCCH enhancements (in principle):

**Option 1-1**: No NR-PDCCH-DMRS is transmitted for only the REs overlapping with LTE-CRS of the OFDM symbol, NR-PDCCH is punctured on REs colliding with LTE-CRS, NR-PDCCH must span at least 2 consecutive symbols with at least 1 symbol not overlapping with LTE-CRS

* PDCCH and PDCCH DMRS mapping to REs: Legacy
* PDCCH REs overlapping with LTE CRS: Receiver punctures
* PDCCH DMRS REs overlapping with LTE CRS: All DMRS REs on overlapping symbol Not used for CE, or legacy pattern is assumed
* gNB transmits: Irrelevant what the gNB transmits on REs overlapping with the LTE CRS REs as indicated in the CRS RM pattern.
* Channel estimator: operate on clean symbol DMRS only, Legacy

**Option 1-2**: No NR-PDCCH-DMRS is transmitted in any RE of the OFDM symbol, NR-PDCCH is transmitted on REs not colliding with LTE-CRS including the original DMRS, NR-PDCCH is punctured on REs colliding with LTE-CRS, NR-PDCCH must span at least 2 consecutive symbols with at least 1 symbol not overlapping with LTE-CRS

* PDCCH and PDCCH DMRS mapping to REs: New PDCCH rate-matching
  + No PDCCH DMRS on the symbol overlapping with LTE CRS
* PDCCH REs overlapping with LTE CRS: Receiver punctures
* PDCCH DMRS REs overlapping with LTE CRS: Not expected
* Channel estimator (UE assumption): Operate on clean symbol DMRS only
* gNB transmits: Irrelevant what the gNB transmits on REs overlapping with the LTE CRS REs as indicated in the CRS RM pattern

**Option 2:** NR-PDCCH or NR-PDCCH-DMRS is transmitted on REs not colliding with LTE-CRS, NR-PDCCH and NR-PDCCH-DMRS may or may not be punctured on REs colliding with LTE-CRS

* PDCCH and PDCCH DMRS mapping to REs: Legacy
* PDCCH REs overlapping with LTE CRS: Baseline: Process as legacy
* PDCCH DMRS REs overlapping with LTE CRS: Aware or unaware
* Channel estimator: Baseline: Process as legacy (Receiver does not puncture DMRS), Optional: Advanced receiver (Use the DMRS other than legacy behavior)
* gNB transmits:
  + Baseline: May puncture the PDCCH/PDCCH DMRS, or may superposition the two.
  + Optional: may puncture LTE CRS of Port#2&3.
  + Impact to LTE UEs should be considered if superposition is used.

|  |  |
| --- | --- |
| Company | Comment |
| Huawei/Hisi | As summarized by moderator, a number of concerns are received over all the 3 options. From our observations:   * Option 2 with punctured transmission has no appealing capacity gain (-9.3%/2.8%/24.1% for scenario#1A/2/3, respectively), and has deteriorated outage (as high as 26.8% under scenario#1A). Note that though for some scenarios, there are capacity gain, but as Option 2 cannot serve the cell edge UEs, its capacity gain attributes to a large extent to the scheduling gain of cell centre UEs with small AL values. So the capacity gains are somewhat overestimated. * Option 2 with superposition with LTE CRS (i.e., Option 2B) will cause degraded performance of LTE, which is unfriendly to the incumbent system. * In addition, as mentioned by some other companies and observed from simulation results over companies, the performance of Option 2 quite depends on the UE receiver which differ a lot over UEs, so that will cause nontrivial work load to RAN4. * Option 1-2 will introduce challenging UE implementation complexity on supporting new PDCCH RM/CE/demodulation patterns. Our understanding that, the scope of the Objective 1 for this SI is built on the assumption that UE has no capability of new PDCCH RM patterns; otherwise why not allow UE to perform PDCCH RM around the LTE CRS (which is out of scope) rather than being punctured? * Option 1-1 seems the simple solution with promising gains, but this gain is achieved still under quite limited case of Scenario 2 with LTE bandwidth = NR bandwidth and without co-existence with legacy NR UEs. That means, even Option 1-1 is scenario restricted and cannot provide universal gain.   Based on the analysis above, at the moment we do not observe a strong necessity to introduce any of the options in R18. |
| Samsung | We are OK to discuss the three options but we do not agree to select one of them.  Based on various analytical considerations and on results, we think that not introducing specification support for PDCCH receptions in presence of LTE CRS is a valid conclusion. |
| ZTE | We observe clear performance gain by the options and ok to down-select one of them. Our detailed views on each options are provided below.  Option 1-1 provides good performance gain with legacy UE receiver. One main drawback is coexistence with legacy NR UEs when a 2-symbol CORESET is configured for Rel-18 NR PDCCH as follows. In the example, half of the PDCCH resources in symbol 1 is unavailable.    Option 2 provides the best performance with advanced UE receiver, including both PDCCH capacity and coexistence with legacy NR UEs, while Option 2 increases UE complexity.  Considering both the performance gain and complexity, we are ok with either Option 1-1 or Option 2 with advanced receiver.  Option 1-2 should not be adopted considering the following aspects.   * New rate-matching for Option 1-2, which increases both NW and UE complexity * No clear performance gain over Option 1-1 * Large spec impacts * Option 1-2 is out of WI scope. |
| Qualcomm | If RAN1 decides to support an option, we propose to adopt Option 1-2.  The rationale is unchanged from the last meeting: Option 1-2 does not require UE to process irregular DMRS RE pattern while offering reasonable performance gain. For the other options, the achievable gain highly depends on the receiver – legacy receiver cannot enable PDCCH transmission of lower ALs and therefore, there must be demands for advanced receiver that takes into account irregular DMRS for channel estimation. Once Option 1-1 or Option 2 is supported, UEs are required to support various overlapping patterns (partial/full BW overlap, partial/full symbol(s) overlap, one/multiple CRS pattern(s), etc). The cost of advanced receiver / channel estimation is extremely high.  @ZTE: we disagree all of your considerations on Option 1-2:  We do not see an issue of new PDCCH rate-matching for Option 1-2. There is no spec impact from this. Besides, complexity increase due to handling irregular DMRS pattern is much higher than PDCCH rate-matching with 2 additional REs per REG.  We observe clear performance gain over Option 1-1.  We disagree that Option 1-2 has larger specification impacts than the others. Note that we have to take into account all RAN1/RAN2/RAN4 impacts.  It is surprising to see the argument that the Option 1-2 is out of WI scope, after agreeing all the options as candidates at RAN1#109-e meeting. If we need to discuss which ones are in/out of scope, we feel options that BS or UE does not puncture NR-PDCCH at all are rather out of scope. However, we think this is non-constructive argument and do not want to claim it. |
| MediaTek | We share similar view with Huawei. The PDCCH capacity gain from option1-1/1-2/option2 are observed from most of Tdocs but some companies still show no gain at all under certain configuration. In fact, the observed gain depends on many factors: # of LTE CRS pattern, coexistence with legacy UEs, NR/LTE overlapped bandwidth, etc. It is still no clear to us how much gain can be obtained by enabling PDCCH punctured by LTE CRS in practical configuration compared with other existing tools we introduced, e.g., monitoring PDCCH in other symbols, Scell scheduling. On the other hand, the implementation concerns for all the options are mentioned by many companies. In addition, the spec impact is not negligible for all the options. For example, how to handle partially overlapped PDCCH candidates with LTE CRS will need some discussion, which might not be an short discussion. Therefore, we still don’t see supporting such puncturing feature is a good trade-off between questionable PDCCH capacity gain and UE implementation complexity.  In our view, we should also include “not enabling LTE CRS to puncture NR PDCCH in Rel-18” as an option for discussion and Mediatek’s view is to not support any puncturing based on our analysis. |
| Spreadtrum | Firstly, there are other alternative solutions to resolve PDCCH capacity problem. Thus, no need to increase NR-PDCCH capacity by extend NR-PDCCH reception at symbol 1. Keep R17 DSS as baseline for R18 NR-PDCCH reception. Further NR-PDCCH capacity enhancement can be resolved by network configurations.  Secondly, from UE perspective, Option 1-1 and Option 2 have three possible channel estimation:  CE1: CE based on legacy DMRS pattern.  CE2: CE based on DMRS RE in symbol without LTE CRS.  CE3: CE based on irregular DMRS pattern.  None of them can be excluded from the specification and implementation. In addition, if NR PDCCH/DMRS and LTE CRS are superposition at gNB side, which will greatly increase the complexity of UE implementation and lead to a great CE performance difference between basic receivers and advanced receivers. The introduction of this new R18 DSS feature may lead to multiple channel estimators, different PDCCH decoding performance and significant RAN4 work for performance requirements. We are negative to the solutions which will finally depend on the UE implementation with potential multiple CE choices.  If we have to support a solution from the listed options for compromise, we prefer option 1-2 for its simplicity and fixed channel estimation. But we can open to other options or combined options to adapt to potentially different deployment scenarios only if UE implementation on channel estimation can be fixed from spec. based on legacy UE CE mechanism. |
| vivo | If RAN1 agree to support PDCCH reception on CRS symbol, we support option1-2. We are also fine with option1-1 with CE based on DMRS on clean symbol only. The loss experienced by using legacy receiver is not acceptable, and Option1-1 with legacy CE+punctured PDCCH cannot achieve attractive gain according to our simulation results, thus they are not preferred. We disagree that option1-2 is out of scope, the WID does not put any restriction on PDCCH rate matching pattern. Although option1-2 introduces new PDCCH rate matching pattern, it achieves similar gain as option1-1 with advance receiver, and it is much simpler than CE based on irregular DMRS pattern from the perspective of implementation complexity. |
| Xiaomi | We support Option 1-2. According to our observations, in addition to the capacity performance gain and stable DMRS patterns for channel estimation simplicity, Option1-2 also has better BLER performance than other schemes at lower ALs. Fortunately, lower ALs have a higher proportion in actual communication systems. We also disagree with ZTE’s consideration that Option 1-2 is out of scope. The WID does not restrict the PDCCH rate matching patterns to legacy. Whereas, Option 2 with UE receiving NR PDCCH & DMRS on the REs overlapping with LTE CRS will degrade the performance of LTE. |
| OPPO | First, we share the view from MediaTek that “not enabling coexistence between NR PDCCH and LTE CRS” can be an option to choose. Our first preference is not to support coexistence between NR PDCCH and LTE CRS.  Secondly, if one option has to be chosen from all three options in the proposal, we slightly prefer Option 1-1 with the following add-on:  *UE is not required to use PDCCH DMRS RE’s transmitted in the same symbol as LTE CRS for channel estimation. Inform RAN4 of this decision.*  We think the above adding could be a compromise among performance, spec complexity and UE implementation complexity. |

# References

[1] RP-213575, New WI: Enhancement of NR Dynamic spectrum sharing (DSS), Ericsson, 3GPP TSG RAN Meeting #94e, Electronic Meeting, Dec. 6 - 17, 2021.

[2] R1-2205864, Discussion on NR PDCCH reception in symbols with LTE CRS REs Huawei, HiSilicon

[3] R1-2205964 Discussion on NR PDCCH reception for DSS ZTE

[4] R1-2206003 Discussion on NR PDCCH reception in symbols with LTE CRS REs Spreadtrum Communications

[5] R1-2206057 Discussion on PDCCH reception on CRS symbol vivo

[6] R1-2206324 Discussion on NR PDCCH reception in symbols with LTE CRS REs Oppo.

[7] R1-2206432 DSS – NR PDCCH overlapping with LTE CRS Nokia, Nokia Shanghai Bell

[8] R1-2206842 On PDCCH receptions in symbols with LTE CRS Samsung

[9] R1-2207011 Discussion on NR PDCCH reception in symbols with LTE CRS REs Mediatek

[10] R1-2207039 Discussion on NR PDCCH reception in symbols with LTE CRS REs LG

[11] R1-2207130 Evaluation of NR PDCCH overlapping with LTE CRS InterDigital

[12] R1-2207249 NR PDCCH reception in symbols with LTE CRS REs Qualcomm

[13] R1-2207347 Discussion on NR PDCCH reception in symbols with LTE CRS REs Apple

[14] R1-2207422 Discussion on NR PDCCH reception in symbols with LTE CRS REs NTT DOCOMO.

[15] R1-2207439 NR PDCCH reception in symbols with LTE CRS REs Ericsson

[16] R1-2207591 Considerations on NR PDCCH for DSS KT

# Appendix (Summary of the agreements)

## RAN1#109-e:

**Agreement**

**To evaluate the following options:**

* + Option-1-1: No NR-PDCCH-DMRS is transmitted for only the REs overlapping with LTE-CRS of the OFDM symbol, NR-PDCCH is punctured on REs colliding with LTE-CRS, NR-PDCCH must span at least 2 consecutive symbols with at least 1 symbol not overlapping with LTE-CRS
  + Option-1-2: No NR-PDCCH-DMRS is transmitted in any RE of the OFDM symbol, NR-PDCCH is transmitted on REs not colliding with LTE-CRS including the original DMRS, NR-PDCCH is punctured on REs colliding with LTE-CRS, NR-PDCCH must span at least 2 consecutive symbols with at least 1 symbol not overlapping with LTE-CRS
  + Option-2: NR-PDCCH or NR-PDCCH-DMRS is transmitted on REs not colliding with LTE-CRS, NR-PDCCH and NR-PDCCH-DMRS may or may not be punctured on REs colliding with LTE-CRS
    - No puncture is baseline (UE side)

**Observation**

For evaluations consider the following options:

**Option 1-1:**

* PDCCH and PDCCH DMRS mapping to REs: Legacy
* PDCCH REs overlapping with LTE CRS: Receiver punctures
* PDCCH DMRS REs overlapping with LTE CRS: All DMRS REs on overlapping symbol Not used for CE, or legacy pattern is assumed
* gNB transmits: Irrelevant what the gNB transmits on REs overlapping with the LTE CRS REs as indicated in the CRS RM pattern.
* Channel estimator: operate on clean symbol DMRS only, Legacy

**Option 1-2:**

* PDCCH and PDCCH DMRS mapping to REs: New PDCCH rate-matching
  + No PDCCH DMRS on the symbol overlapping with LTE CRS
* PDCCH REs overlapping with LTE CRS: Receiver punctures
* PDCCH DMRS REs overlapping with LTE CRS: Not expected
* Channel estimator (UE assumption): Operate on clean symbol DMRS only
* gNB transmits: Irrelevant what the gNB transmits on REs overlapping with the LTE CRS REs as indicated in the CRS RM pattern

**Option 2:**

* PDCCH and PDCCH DMRS mapping to REs: Legacy
* PDCCH REs overlapping with LTE CRS: Baseline: Process as legacy
* PDCCH DMRS REs overlapping with LTE CRS: Aware or unaware
* Channel estimator: Baseline: Process as legacy (Receiver does not puncture DMRS), Optional: Advanced receiver (Use the DMRS other than legacy behavior)
* gNB transmits:
  + Baseline: May puncture the PDCCH/PDCCH DMRS, or may superposition the two.
  + Optional: may puncture LTE CRS of Port#2&3.
  + Impact to LTE UEs should be considered if superposition is used.

Agreement

For evaluations consider the following list of scenarios:

Scenario#1A: 1 symbol CORESET, overlapped with CRS – Option 2 only

Scenario#2: 2 symbols CORESET, including 1 overlapping symbol and 1 clean symbol – Option 1-1/1-2/2

Scenario#3: 3 symbols CORESET, including 1 overlapping symbol and 2 clean symbols – Option 1-1/1-2/2

Agreement

LLS simulations assumptions, [] are optional:

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Carrier frequency | 2 GHz |
| SCS | 15 kHz |
| Bandwidth | 20 MHz [5, 10 MHz], LTE bandwidth equal or smaller than NR |
| Channel model | TDL-C 300, [TDL-A 300] |
| Correlation | Low |
| Number of BS antennas | 4 Tx, (M,N,P,Mg,Ng;Mp,Np)= (1,2,2,1,1;1,1),  [2 Tx, (M,N,P,Mg,Ng;Mp,Np)= (1,1,2,1,1;1,1).] |
| Number of UE antennas | 2 Rx (M,N,P,Mg,Ng;Mp,Np)= (1,1,2,1,1;1,1) |
| DCI payload (excluding CRC) | 60 bits [50bits] |
| Interleaving | Non-Interleaved, [Interleaved] |
| Precoding | Precoder cycling per REG bundle |
| REG bundle size | 6 PRBs |
| CRS | single 4 port CRS pattern, [additional 4 port CRS pattern] |
| Channel estimation | practical – companies to report details |
| UE speed | 30 kmph [3kmph, 120 kmph, 350 kmph] |
| Power ratio of LTE-CRS RE/NR PDCCH RE, Power ratio of LTE-CRS RE/NR PDCCH-DMRS RE | Companies to report (if applicable) |

**Agreement**

SLS simulations assumptions, [] are optional:

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Carrier frequency | 2.1 GHz |
| SCS | 15 kHz |
| Simulation bandwidth | 20 MHz [5, 10 MHz]，same as that in LLS |
| BS antenna height | 25 m |
| UE height | 1.5m |
| TRP transmit power | 49 dBm 20 MHz |
| Scenario | Urban Macro (500m ISD), [Rma (1732m ISD)] |
| Device deployment | 80% indoor, 20% outdoor (Uma) [50% indoor,50% in-car (Rma)] |
| UE speeds | Indoor users: 3km/h |
| Outdoor users (in-car): 30 km/h |
| BS noise figure | 5 dB |
| BS antenna element gain | 8 dBi |
| UE noise figure | 9 dB |
| Thermal noise level | -174 dBm/Hz |
| Traffic geometry | Full Buffer |
| Macro sites | 19 |
| Downtilt | 102° or according to Scenario |
| Minimum BS to UE distance | 35m |
| KPI | Companies to report (e.g., total PDCCH capacity, PDCCH coverage/outage, Potential degradation of LTE, whether and how to achieve coexistence with legacy UEs) |
| Others | Companies to report (e.g., fraction of LTE UEs, fraction of Rel-18 DSS NR UEs, etc.). Companies to report considered baseline(s). Baseline(s) aim(s) to be comparable to the evaluated option(s) |