3GPP TSG RAN WG1 #110bis-e R1-2210322

e-Meeting, October 10th – 19th, 2022

**Agenda item: 9.14.2**

**Source: Moderator (Nokia, Nokia Shanghai Bell)**

**Title: FL summary of power domain enhancements (AI 9.14.2)**

**Document for: Discussion and Decision**

# Introduction

Power domain enhancements was included as one of the enhancements to be studied and specified in the NR coverage enhancement work item approved (revised) in RAN1#96 [1]:

* *Study and if necessary specify following power domain enhancements*
	+ *Enhancements to realize increasing UE power high limit for CA and DC based on Rel-17 RAN4 work on “Increasing UE power high limit for CA and DC”, in compliance with relevant regulations (RAN4, RAN1)*
	+ *Enhancements to reduce MPR/PAR, including frequency domain spectrum shaping with and without spectrum extension for DFT-S-OFDM and tone reservation (RAN4, RAN1)*

Section 2 summarizes the key aspects of enhancements for increasing UE power high limit for CA and DC, while Section 3 summarizes the key aspects of enhancements for reducing MPR/PAR. The summaries in these two sections are based on companies’ contributions submitted under AI 9.14.2 to RAN1 #110b-e [2]-[20].

All related proposals from different contributions, organized per aspect, are listed in Appendix A, for reference.

# Summary of contributions on enhancements for increasing UE power high limit for CA and DC

Contributions submitted under AI 9.14.2 discussed several aspects of enhancements for increasing UE power high limit for CA and DC. A systematic categorization will be used in this document to summarize the content of all contributions. This is done according to both the number of submitted proposals on the different aspects and on the relevance the latter have for designing the feature, from FL’s perspective. Concerning the second criterion, its rationale is given by the natural relationship of consequentiality which exists between different aspects. In the remainder of the document, aspects are thus categorized as follows:

* **High priority aspects**
	+ De-prioritization of HPUE related power domain enhancement
	+ Coordination with RAN4
* **Mid priority aspects**
	+ RAN1 scope clarification
	+ New signaling aspects
* **Other aspects**
	+ NA

The categorization above will determine the initial priority order for the discussions to be held for AI 9.14.2. In this context, sections 2.1 and 2.2 will focus on discussions which will (2.1) and may (2.2) be discussed during RAN1 #110b-e. Section 2.3 will collect all other aspects.

Tags [OPEN], [CLOSED] and [PAUSED] will be used to identify the status of the discussion at any moment of the meeting. New sections for specific aspects will be open during the meeting, should discussions for the higher priority aspects progress fast.

## High priority aspects

Two high priority aspects are identified at the beginning of the meeting:

1. De-prioritization of high-power UE related power domain enhancement
2. Coordination with RAN4

Few companies have discussed about such aspects in the submitted contributions. Summary, discussion, and proposals on these aspects are provided in the following different sub-sections. Sub-section numbers follow the list above, for simplicity.

### [OPEN] De-prioritization of high-power UE related power domain enhancement

This aspect was discussed explicitly in one contribution. Specifically,

* One company (vivo [5]) proposes that high-power UE (HPUE) related power domain enhancement should be deprioritized in Rel-18 coverage enhancement topic.

This topic is highly relevant in the context of a discussion on this item at the beginning of the release. Therefore, the following question is formulated for collecting companies’ views.

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| --- |
| **2.1.1-Q1 Do you agree that high-power UE related power domain enhancements should be deprioritized in Rel-18 coverage enhancement discussions?** |

#### First round of discussions

FL’s recommendation is to have a first round of discussion about **2.1.1-Q1**. Companies are invited to input their views in the corresponding table below.

**2.1.1-Q1**

|  |  |
| --- | --- |
| Company | Answer/Views |
| QC | HPUE typically refers to a UE that can transmit at 26 dBm or higher in a band. Its not clear what exactly Vivo is proposing here, or what their understanding is. This effort is not about introducing HPUEs in new bands. The WID expects us to take R17 enhancements in RAN4 related to high power transmissions across multiple bands in uplink and study any RAN1 enhancement that can facilitate such operation.Note that UEs are already designed with multiple RF chains across different bands. The goal here is to see if we can use this hardware to better use. It would be a shame if UE vendors and OEMs put in the effort to build UEs capable of supporting multiple bands, only for RAN1 to not support these UEs adequately. To date DL-CA has received widespread adoption while ULCA has not seen the same level of traction. A lot of UE capability is going unused throughout a UE’s entire lifecycle.UEs have grown in sophistication on how they handle transmissions across different bands and how they handle RF exposure. It is worth using this opportunity to see if we can make sure the gNB has better awareness of a UE’s ability to support high power transmissions across different bands. How to better support scheduling in UL-CA, how to support band selection for uplink tx switching could be other aspects worth considering.@FL: not sure if this is the most constructive approach to open discussions on a new topic in a new WID. It might be more helpful for us to figure out what would be worth investigating closely. At least a handful of companies including an operator have identified potential issues that RAN1 can try to address. For future rounds, please seek input on these aspects as well. |
| DOCOMO | It is a bit unclear to us what the exact intention of “high-power UE related”. So not sure what is to be exactly deprioritized? Due to above, not sure whether here is a place to recode below; however, as an operator, we really sympathize with QC’s comment above, especially:*Note that UEs are already designed with multiple RF chains across different bands. The goal here is to see if we can use this hardware to better use. It would be a shame if UE vendors and OEMs put in the effort to build UEs capable of supporting multiple bands, only for RAN1 to not support these UEs adequately. To date DL-CA has received widespread adoption while ULCA has not seen the same level of traction. A lot of UE capability is going unused throughout a UE’s entire lifecycle.*There are some contributions which try to point out the issue which may be resolved per RAN1 effort. We do not quite understand why we start with de-prioritization without seeing them.  |
| Ericsson | It should be studied in RAN4 and RAN1 according to the WID:* Study and if necessary specify following power domain enhancements
	+ Enhancements to realize increasing UE power high limit for CA and DC based on Rel-17 RAN4 work on “Increasing UE power high limit for CA and DC”, in compliance with relevant regulations (RAN4, RAN1)

Therefore, we should start the study, and priority can be addressed as we learn more. |
| Intel | We tend to agree FL’s assessment. However, we would like to mention that this can be deprioritized in RAN1, but not in RAN4. |
| vivo | Agree. Since HPUE related discussions are happening in parallel in RAN4 in both Rel-18 coverage enhancement topic and HP basket WI, any necessary enhancement related to RAN1 can be triggered by RAN4 LS. RAN4 should decide whether to remove this bullet from Rel-18 coverage enhancement scope and handle it in RAN4 high power basket WI. |
| Panasonic  | We do not agree. We prefer to coordinate with RAN4 to discuss this aspect. |
|  |  |

### [OPEN] Coordination with RAN4

Two contributions discussed this aspect. High-level summary of companies’ opinions based on the contributions follows.

* One company (ZTE [3]), argues that RAN4 should lead the discussion on whether/how to introduce additional cases for increasing UE power high limit for CA and DC.
* One company (Samsung [16]), propose to send an LS to RAN4 asking which potential enhancements RAN4 is planning to consider for this objective.

From FL’s perspective, the two proposals share similar spirit and highlight a possible lack of clarity of the WID for what concerns the enhancements for increasing UE power high limit for CA and DC. The following question is thus asked.

|  |
| --- |
| **2.1.2-Q1** **Do you agree that RAN1 should send an LS to RAN4 to (at least):*** **ask which potential enhancements RAN4 is planning to consider for this objective**
* **inform RAN4 that RAN1 will not discuss whether/how to introduce additional cases for increasing UE power high limit for CA and DC**

**Note: If you think that an LS should be written and sent, but also think that different elements should be included, please add them to your reply.** |

#### First round of discussions

FL’s recommendation is to have a first round of discussion among companies about **2.1.2-Q1**. The goal is to identify the preferred direction RAN1 should pursue for handling this complex issue. Feel free to elaborate on your answer in the suitable box.

**2.1.2-Q1**

|  |  |
| --- | --- |
| Company | Views |
| QC | We don’t think an LS is necessary. RAN4 has already concluded its R17 work. We need to take RAN4’s work into account and figure out if we can further facilitate high power transmissions across different bands. |
| DOCOMO | The first bullet could be ok. But why the second bullet can be put here without RAN1 discussion is not very clear. We believe RAN1 should discuss whether the issue exists or not.  |
| Ericsson | The LS could bring some clarity to what RAN1 might study. RAN1 is not the right place to define power classes or high power limit behaviors, and RAN4 should provide information needed on these to RAN1 if we are to evaluate them and design mechanisms around them. |
| Intel | RAN4 is currently discussing the power domain enhancement starting from this meeting. Our view is that we can wait for some progress in RAN4 first and if they identify some issues that need to be considered/addressed in RAN1 by sending an LS, RAN1 can continue the study on this aspect.  |
| vivo | In our understanding, the LS should be triggered from RAN4 when their HPUE related discussions are stable. Therefore, LS from RAN1 seems not necessary at this stage. |
| Panasonic | We support to send an LS to RAN4. In addition, in LS, we would like to ask * Whether to apply the increasing UE power high limit by RAN4 to single carrier operation (instead of only multi-carrier operation in CA/DC)?

This is because we think that the single carrier operation with the increasing UE power high limit can provide better coverage performance than that of the operation in CA/DC. |

## Mid priority aspects

Two mid priority aspects are identified at the beginning of the meeting:

1. RAN1 scope clarification
2. New signaling aspects

Summary, discussion, and FL’s comments/proposals on these aspects are provided in the following different sub-sections, whose numbers are given in the list above. Note that “RAN1 scope clarification” is only temporarily labelled as Mid priority aspect, given the two current high priority aspects for enhancements for increasing UE power high limit for CA and DC. This labelling will change as discussion on the two high priority item progresses.

### [PAUSED] RAN1 scope clarification

Several contributions discussed this aspect. A high-level summary of companies’ opinions based on the contributions is as follows.

* One company (ZTE [3]) argues that RAN1 needs to clarify whether any RAN1 enhancement is needed, and any enhancement requiring large RAN1 specification impact without clear performance gain is not pursued.
* One company (NTT DOCOMO [18]) proposes to clarify the objective to have a well-focused target for RAN1 work.
* One company (CATT [5]) argues that the impact for RAN1 spec needs more discussion.

### [PAUSED] New signaling aspects

Four companies (Fujitsu [8], InterDigital [14], NTT DOCOMO [18], Qualcomm [19]) discussed and proposes directions for studying new signaling mechanisms between UE and gNB. Specifically,

* One company (Fujitsu [8]) proposes introducing a new signaling/report from UE to gNB to let gNB know the timing about UE autonomous Tx suspension due to SAR limit. FFS: Details of signaling/report.
* One company (InterDigital [14]) proposes supporting indication of aggregated power class in power headroom report.
* One company (NTT DOCOMO [18]) proposes studying a method for UE to report the exact availability of higher transmit power for inter-band CA/EN-DC UL transmission.
* One company (Qualcomm [19]) proposes introducing signaling mechanisms between UE and gNB focused on:
	+ increasing awareness of power or energy budget available at the UE for each carrier/band,
	+ aiding the selection of the best band combination for UL CA, and
	+ aiding scheduling policy when UE is configured with multiple bands in UL CA, for e.g., selecting preferred carrier for servicing uplink, or adaptive load sharing across carriers.

In addition, the following are also proposed in [19]:

* Introduce signaling to allow UE to report aspects related to power management and RF exposure.
* Enhance the current power headroom reporting framework to allow a user to also report P-MPR (via MPE field) for FR1 carriers.
* Enhance the current power headroom reporting framework to allow a user to report power headroom for a carrier that is configured for downlink but not for uplink (i.e., no active uplink BWP).
* Introduce MAC-CE signaling to allow UE to report energy headroom for each of the bands in a CA/DC configuration given to the UE.
	+ FFS: signaling details, including, periodicity, reporting triggers, relation to PHR, how to handle multiple bands, reference power, etc.

## Others

No additional aspects have been identified by FL.

# Summary of contributions on enhancements for reducing MPR/PAR

Contributions submitted under AI 9.14.2 discussed several aspects of enhancements for reducing MPR/PAR. A systematic categorization will be used in this document to summarize the content of all contributions. This is done according to both the number of submitted proposals on the different aspects and on the relevance the latter have for designing the feature, from FL’s perspective. Concerning the second criterion, its rationale is given by the natural relationship of consequentiality which exists between different aspects. In the remainder of the document, aspects are thus categorized as follows:

* **High priority aspects**
	+ Way of working (RAN1 and RAN4 work split)
	+ Candidate MPR/PAR reduction techniques
	+ Design aspects of FDSS-SE
	+ Design aspects of TR
* **Mid priority aspects**
	+ Parameterization for evaluations
	+ MPR/PAR reduction techniques
* **Other aspects**
	+ Complementary enhancements

The categorization above will determine the initial priority order for the discussions to be held for AI 9.14.2. In this context, sections 3.1 and 3.2 will focus on discussions which will (3.1) and may (3.2) be discussed during RAN1 #110b-e. Section 3.3 will collect all other aspects.

Tags [OPEN], [CLOSED] and [PAUSED] will be used to identify the status of the discussion at any moment of the meeting. New sections for specific aspects will be open during the meeting, should discussions for the higher priority aspects progress fast.

## High priority aspects

Four high priority aspects are identified at the beginning of the meeting:

1. Way of working (RAN1 and RAN4 work split)
2. Candidate MPR/PAR reduction techniques
3. Design aspects of FDSS-SE
4. Design aspects of TR

Most companies have discussed at large about such aspects in the submitted contributions. Summary, discussion, and proposals on these aspects are provided in the following different sub-sections. Sub-section numbers follow the list above, for simplicity.

### [OPEN] Way of working (RAN1 and RAN4 work split)

Several contributions acknowledged the fundamental nature of this aspect and discussed it in detail. High-level summary of companies’ preferences and opinions based on the contributions follows.

Six companies (ZTE [3], CATT [7], CMCC [11], MediaTek [12], Apple [13], Nokia/NSB [20]) propose to introduce a specific work split and/or actual order of work between RAN1 and RAN4:

* Two companies propose to wait until RAN4 progress is achieved and inputs are provided to RAN1 before starting corresponding RAN1 discussion.
* Three companies propose that the performance evaluation of candidate solutions to yield MPR/PAR reduction should be carried out in RAN4.
* One company (CMCC [11]) explicitly mentions the need for assessing specification impact of FDSS and TR based solutions.

From FL’s perspective, there seems to be a common understanding among companies who discussed RAN1 and RAN4 work split that RAN4 should have a paramount role for the power domain enhancements, at least for the part related to performance evaluation.

At the same time, assessing RAN1 specification impact of candidate solutions does not seem to depend on the performance evaluation carried out in RAN4. Carrying out this part of the RAN1 work seems feasible, irrespective of whether performance evaluation results are available or not.

Further selection of the solution if any, could be then carried out by RAN1 based on performance evaluation results (provided by RAN4) and specification impact analysis (made by RAN1).

In this context, freezing the number of candidate solutions (and their description) in RAN1 before #110b-e is over, and informing RAN4 accordingly (via LS, for instance) would seem a reasonable approach from my perspective. This would allow RAN4 to study the solutions and possibly take the first decisions during RAN4 #105, i.e., the latency in RAN1 would be acceptable.

Two questions are asked to collect companies’ opinions on FL’s understanding and assessments.

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| --- |
| **3.1.1-Q1 Provide your view on the following proposed RAN1/RAN4 work split:*** *RAN4 is responsible for performance evaluation of candidate solutions to reduce MPR/PAR in Rel-18. No selection of the MPR/PAR reduction solution, if any, is performed by RAN1 before performance evaluation results are shared by RAN4.*
* *RAN1 is responsible for assessing RAN1 specification impact of candidate MPR/PAR reduction solutions*
	+ *Final list of candidate solutions should be ready before the end of RAN1 #110b-e, to be included in an LS to RAN4.*
* *RAN1 is responsible for selecting the Rel-18 MPR/PAR solution, if any, based on performance evaluation (provided by RAN4) and specification impact analysis (made by RAN1)*

*Note*: *discussion on specification impact of candidate MPR/PAR reduction solutions will start after the candidate solutions have been shortlisted.* |

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| --- |
| **3.1.1-Q2 *Is there any performance evaluation/analysis that can and should be carried out by RAN1, irrespective of the study carried out by RAN4?**** ***Note: this question is asked for the sake of completeness, to ensure that RAN1 does not overlook important study directions.***
 |

#### First round of discussions

FL’s recommendation is to have a first round of discussion among companies about **3.1.1-Q1** and **3.1.1-Q2**.The goal is to identify the preferred direction RAN1 should pursue for handling the next steps. Feel free to elaborate on your answer in the suitable box, if applicable. **If you do not agree with what is being proposed, please provide a precise alternative approach/proposal to allow the discussion to progress.**

Constructive attitude is greatly appreciated, for the sake of an efficient use of the limited time RAN1 has.

**3.1.1-Q1**

|  |  |
| --- | --- |
| Company | Answer/Views |
| QC | The decision making will need to be based on net coverage gain and not just performance evaluation carried out by RAN4. RAN4 will not have the expertise to run link-level simulations to assess impact of different gNB receivers. Also, we can’t tell RAN4 that they don’t have the power to make decisions. They can make agreements if they feel sufficiently comfortable. Also, if RAN4 prefers to agree to certain transparent techniques that do not involve RAN1, that should be allowed.  |
| DOCOMO | Generally fine. If companies are willing to perform LLS, it would also be ok.  |
| Ericsson | We agree completely that RAN4 should be the final arbiter of implementation feasibility and achievable output power. However, we think it is difficult to separate design decisions from performance evaluation, so RAN1 needs to be able to perform accurate simulations of power domain enhancements. MPR evaluation methods are well established in RAN4, and we can use those in RAN1 to compare design alternatives. (Please see R1-2209673 for what we have in mind) RAN1 can then provide the spec impacts and our understanding of the performance/complexity tradeoffs to RAN4 based on these evaluations. RAN4 can then use this to select the schemes to specify, if any.RAN1 should naturally assess the RAN1 spec impact of schemes, and this work can be in parallel to RAN4 evaluations. Regarding the timeline, we think that targeting February (two meetings from now) for a go/no go decision on specifying power domain enhancements drives some urgency to identify schemes. However, identifying the final schemes already in this meeting is too early. Identifying schemes for investigation could be by next meeting, and an LS could be sent to RAN4 then on potential spec impacts, which RAN4 would have time to take into account. We actually don’t think it is super critical to have an early list of schemes to RAN4, since schemes are already being proposed in both RAN1 and RAN4, and determining simulations setups and doing the evaluations can proceed already. What could happen is that some RAN1 spec related issue is not taken properly into account in RAN4, but if RAN1 is doing a reasonable job of evaluations, we at least can reflect the issue in our conclusions.Another issue is that ‘transparent’ techniques that do not have RAN1 specification impact need to be considered along with those that do have RAN1 spec impact. In RAN1, transparent techniques should be considered as a baseline on which non-transparent techniques can build. While RAN1 would not specify them, RAN4 can develop performance requirements based on them, and indeed RAN4 are discussing transparent techniques in this meeting. Because RAN4 does not need RAN1 input, the timeline for transparent techniques can be later then non-transparent. However, the RAN4 efforts for scheme evaluation and potential MPR reduction will take considerable time. Therefore, it can be beneficial to have a separate timeline for transparent and non-transparent schemes.Given the tight timelines, we think rather than concluding on MPR/PAR reduction schemes in February, RAN4 should have a checkpoint on whether to specify, to continue study of, or to not pursue enhancements requiring RAN1 spec impact to reduce MPR/PAR. That way, if it is clear that non-transparent enhancements are beneficial, there can be time to specify them in Rel-18, or if they are clearly not beneficial, the WI time can be used for other work, and if more time is needed for study, the study can continue. If continued study is chosen, then the outcome of the work could be a TR, rather than simply a choice not to specify.After the February checkpoint, RAN4 work continues on transparent schemes, and based on the checkpoint, may continue on non-transparent schemes. We think a deadline for pursuing power domain enhancements schemes or not from a RAN4 perspective can then be in May or perhaps later, and this of course should be concluded by RAN4.**In summary, we propose*** RAN1 does performance evaluations of power domain enhancements using RAN4 methodologies, i.e. RAN1 should (see R1-2209673):
	+ Quantify relative link performance of a given transmission configuration as $SNR\_{0}+OBO$, where $SNR\_{0}$ is the SNR (in dB) needed to reach a target BLER, and $OBO$ is the output power backoff for the configuration (in dB).
	+ Determine PA output backoff using RF simulations and according to RAN4 requirements for error vector magnitude, in band emissions, spectrum flatness, spectrum emission mask, and adjacent channel leakage, spurious and accounting for counter-IM3.
* RAN4 makes the final decision on power domain enhancement schemes, as they have the expertise on implementation feasibility and achievable output power.
	+ RAN1 can inform RAN4 of their findings on specification impact and our view of performance/complexity tradeoffs.
* RAN1 can provide a list of schemes to RAN4 by RAN1#111, but this meeting (RAN1#110bis) is too early.
	+ RAN4 is already discussing a list of schemes, so it is better to give more thought than to rush an input to RAN4.
* In February (RAN1#112/RAN4#106), there is a checkpoint where RAN4 decides on whether to specify, to continue study of, or to not pursue enhancements requiring RAN1 spec impact to reduce MPR/PAR.
	+ After the checkpoint, RAN4 work continues on transparent schemes, and based on the checkpoint, may continue on non-transparent schemes.
* In May (RAN4#107), RAN4 decides if/what to specify on requirements for power domain enhancements (including transparent and, according to the checkpoint outcome, possibly non-transparent)
 |
| Intel | We tend to agree with FL that RAN1 can first identify potential candidate MPR/PAR reduction solutions and RAN4 can start with performance evaluation. However, given that RAN4 is leading WG for this topic, our understanding is that final decision on whether solutions to reduce MPR and PAR will be considered for Rel-18, should be made by RAN4, not RAN1. Note that RAN4 may also identify a set of solutions that can be considered for MPR/PAR reductions, e.g., transparent solutions. RAN1 can also consider this for further study. In addition, regarding “*Final list of candidate solutions should be ready before the end of RAN1 #110b-e, to be included in an LS to RAN4*”, given this is the first meeting for this topic, it is not clear to us whether RAN1 has sufficient time to assess all the specification impact within this meeting. We think some additional time is necessary to conclude the study in RAN1 in term of specification impact.  |
| vivo | Given this is RAN4 led item and RAN1 can provide some candidate solutions from RAN1 point of view so that RAN4 can determine final candidate solutions for evaluation in order to determine the necessity of MPR/PAR reduction enhancement. RAN4 also needs to consider their work load and feasibility of evaluating RAN1 proposed solutions from RAN4 point of view to determine final candidate solutions to be evaluated.Therefore, we propose to have following work split:* *RAN4 is responsible for performance evaluation of candidate solutions to reduce MPR/PAR in Rel-18 and determine whether the enhancement is needed. Selection of the MPR/PAR reduction solution, if any, is performed by both RAN1 and RAN4 before performance evaluation results are shared by RAN4. RAN1 sends the candidate solutions from RAN1 point of view to RAN4 to help RAN4 to decide final candidate solutions to be evaluated.*
 |
| Panasonic  | We think that RAN1 would discuss the list of candidate solutions and include them in the LS to RAN4. The list can be formulated based on below section 3.1.2. |

**3.1.1-Q2**

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| --- | --- |
| Company | Answer/Views |
| QC | Link-level evaluations will need to be carried out by RAN1. Baseline comparisons, spectral efficiencies to target, are all in RAN1 domain. |
| DOCOMO | LLS, if the need is identified, could be performed. What QC has listed above would be ok for us.  |
| Ericsson | Please see 3.3.1-Q1 for what we think RAN1 should study. |
| vivo | RAN1 can perform some link level simulations, spec. impact and complexity analysis to down-select some candidate solutions for RAN4 to consider. |
| Panasonic  | We support the question 3.1.1-Q2. |

### [OPEN] MPR/PAR reduction techniques

Several contributions acknowledged the fundamental nature of this aspect and discussed it in detail. Some companies proposed to focus the study on a specific candidate, or set of candidate solutions, whereas other companies provided suggestions on which specific waveform instances and configurations should be configured for the candidate studies. Some of these last proposals may have implications on the evaluation methodology (if any, in RAN1).

* 7 companies (Huawei/HiSi [2], ZTE [3], Lenovo [10], Apple [13], Sharp [17], Qualcomm [19], Nokia/NSB [20]) propose to consider FDSS w/ spectrum extension as a candidate solution to study.
	+ Observations made by other companies imply that a larger support for inclusion of this solution in the list exists.
* 4 companies (Intel [9], Spreadtrum [4], Lenovo [10], Apple [13]) propose to consider FDSS w/o spectrum extension as a candidate solution to study.
	+ Observations made by other companies imply that a larger support for inclusion of this solution in the list exists.
* 4 companies (OPPO [6], Lenovo [10], InterDigital [14], Qualcomm [19]) propose to consider TR as a candidate solution to study.
* 1 company (Lenovo [10]) proposes sub-PRB transmission as a candidate solution to study.
* 1 company (Ericsson [15]) proposes transparent MPR reduction schemes such as clipping and filtering, companding, and digital predistortion as candidate solutions to study.
* 1 company (Samsung 16]) proposes to further study advanced receivers to support reduced MPR.
* 1 company (Qualcomm [19]) argues that priority should be given to non-transparent techniques that allow a 0-dB MPR waveform to be transmitted at a transmit power exceeding the maximum power associated with the UE power class as candidate solution to study.

Additionally,

* One company (OPPO [5]) proposes to study performance of TR for both DFT-s-OFDM and CP-OFDM
* One company (ZTE [3]) proposes to study performance of FDSS w/ SE for pi/2-BPSK.
* Three companies (ZTE [3], Qualcomm [19], Nokia/NSB [20]) propose to study performance of FDSS w/ SE for QPSK.
* One company (ZTE [3]) proposes to study performance of FDSS w/o SE for QPSK.
* One company (Qualcomm ([19]) proposes to study the performance of TR for QPSK.
* One company (Qualcomm ([19]) proposes to study the performance of both TR and FDSS w/ SE for both inner and outer small RB allocation (1-16 RBs), where excess bandwidth is given in unit of RBs for both schemes.
* Two companies (Qualcomm [19], Nokia/NSB [20]) propose to focus only on DFT-s-OFDM and that DMRS undergo spectrum shaping as much as data symbols.

It is also worth noting that all companies who commented on the waveform to consider, but one (OPPO [6]), exclusively focus on DFT-s-OFDM. From FL’s this is consistent with the WID and:

* Considers the typical waveform configured by NW in case of coverage shortage, i.e., DFT-s-OFDM
* Considers the waveform which already naturally offers lower MPR and PAR, to further provide LB gain over the current best candidate in NR.
* Provides a more consistent way to compare different MPR/PAR reduction solutions

A proposal is thus formulated.

**FL’s proposal 1**

**DFT-s-OFDM is the target waveform for the study and design of MPR/PAR reduction solutions in Rel-18.**

In this context, the proposal to consider both inner and outer RB allocations formulated by one company (Qualcomm [19]) seems a reasonable starting point which, given the content of other companies’ contributions, seem aggregable from my perspective. This is the case also for the proposal of focusing on QPSK waveform configurations. Conversely, a discussion on the allocation sizes to consider and on possible other modulation orders may be in order (differences seem to exist across companies).

The following proposal is formulated

**FL’s proposal 2**

**For power-domain enhancements targeting MPR/PAR optimization focus on the following configurations for DFT-S-OFDM:**

* **QPSK modulation**
* **RB allocation can be anywhere in the BWP (i.e., both inner and outer RBs are considered)**
* **FFS:**
	+ **Whether only small RB allocations, e.g., 1🡪16 PRB, are considered.**
	+ **Whether other modulations are considered.**

Now, discussions on which scenarios to focus on heavily depend on the discussion on RAN1/RAN4 work split. At the same time, and following the spirit of the discussion in Section 3.1.1, there are obvious majority views in the group which could be used to down-select a number of agreeable candidate solutions to study, both in terms of performance (RAN4?) and specification impact (RAN1). These seem to be:

* FDSS w/ SE
* FDSS w/o SE
* TR (which can only be w/ SE)

Given the limited time we have for this WI, and the challenge of working in parallel with another WG, I would suggest not including single company’s proposal in the list of supported candidates, since this would hardly be justifiable. Furthermore, I think that Rx only solutions may not be fully aligned with the scope of the WI given that they would not provide a constructive means to reduce both MPR and PAR, but rather target the compensation of the effect of non-linearities arising from operating the PA at the UE according to relaxed MPR requirements (whereas the PAR target of the WID would not be met). Albeit interesting, this would require a study on advanced Rx which does not target PAR reduction and is not included in the WID.

At the same time, it does not seem to prevent interested companies from studying alternative if they so wish. RAN1 may also suggest RAN4 to consider them as benchmarks, if RAN4 so wish.

With this spirit in mind, I would propose the following.

**FL’s proposal 3**

**At least the following candidate solutions for MPR/PAR reduction will be studied in Rel-18.**

* **FDSS w/ spectrum extension**
* **FDSS w/o spectrum extension**
* **TR (which can only be w/ spectrum extension)**

**Whether other solutions will be studied as well will be decided before the end of RAN1 #110b-e.**

To avoid any misunderstanding, the goal of FL’s proposal 3 is to make sure RAN1 can provide a complete list of candidate solutions to RAN4 by the end of this meeting, as discussed in Section 3.1.1.

A question is also asked.

|  |
| --- |
| **3.1.2-Q1 Please provide your comment/preference on the following “other solutions” to study in Rel-18**1. sub-PRB transmission.
2. transparent MPR reduction schemes such as clipping and filtering, companding, and digital predistortion.
3. advanced receivers to support reduced MPR.
 |

#### First round of discussions

FL’s recommendation is to have a first round of discussion among companies about **FL’s proposal 1**, **FL’s proposal 2**, **FL’s proposal 3** and **3.1.2-Q1**.The goal is to identify the preferred direction RAN1 should pursue for handling the next steps. Feel free to elaborate on your answer in the suitable box, if applicable. Constructive attitude is greatly appreciated, for the sake of an efficient use of the limited time RAN1 has.

**FL’s proposal 1**

|  |  |
| --- | --- |
| Company | Views |
| QC | Agree |
| Ericsson | DFT-S-OFDM is a logical starting point to target the studies toward. However, if a scheme can improve CP-OFDM without modification, we think it should not be precluded. So we prefer to either leave this proposal open for now, or have the following refinement:**FL’s proposal 1****DFT-s-OFDM is the target waveform for the study and design of MPR/PAR reduction solutions in Rel-18.** * **Solutions that can be directly used for CP-OFDM can also be used in studies and designs.**
 |
| Intel | We support FL’s proposal 1. |
| vivo | Agree. DFT-S-OFDM has lower power back-off value than CP-OFDM and should be the target waveform. |
| Panasonic | We support the FL’s proposal 1. |

**FL’s proposal 2**

|  |  |
| --- | --- |
| Company | Views |
| QC | Will be good to keep pi/2 BPSK. Pi/2 BPSK applied to higher MCS values could be a viable alternative.Okay to consider inner and outer allocations. Leave out edge RB allocations as the issues impacting them are quite different.  |
| Ericsson | It is too early in the study to restrict configurations without assessing their benefit. We would be OK with the middle bullet: * **RB allocation can be anywhere in the BWP (i.e., both inner and outer RBs are considered)**

We are open to considering restrictions after some short study, when there would be some quantitative measure of potential benefit. |
| Intel | We are generally fine with the proposal. It is not very clear the meaning of inner and outer RB allocation. Our understanding is that this means the RB allocation can be inside or on the edge of BWP. If this is correct understanding, we suggest the following update:* **~~RB allocation can be anywhere in the BWP~~ RB allocation inside and on the edge of BWP is considered. ~~(i.e., both inner and outer RBs are considered)~~**
 |
| vivo | Both pi/2 BPSK and QPSK should be studied in our view. So we propose to not exclude pi/2 BPSK which is mainly for low PAPR operation. |
| Panasonic  | We support the FL’s proposal 2 in general. Particularly, we think the sub-bullet “FDSS w/o spectrum extension" is not necessary because it is supported by Rel. 16 FDSS framework without spectrum extension (SE). Then the candidate solutions in this proposal could be * Option 1: FDSS with SE
* Option 2: Tone reservation

If Option 1 is supported, it can be considered as an extension of Rel. 16 FDSS without SE framework. If Option 2 is supported, there could be two available methods that can be configured to a UE, i.e., a Rel. 16 FDSS without SE and Rel. 18 tone reservation. If both methods are independently configured to work at the same time, where each component works separately on its own. It may give rise to potential issues in the following. Therefore, we would like to ask RAN1/RAN4 to take them into account when the study is carried out. * Potential issue 1: Radio resource in frequency-domain are not utilized which results in low spectral efficiency.
* For example, in Fig. 1, only a few tones from legacy resource allocations in frequency-domain in Rel. 16 FDSS are used for data

Fig. 1. An example of radio resource allocations in frequency-domain creates issue 1* Potential issue 2: If the resource allocations in frequency-domain are not properly configured, the achievable reduction of MPR/PAR may be decreased.
* For example, in Fig. 2, Rel. 16 FDSS and tone reservation do not work well because a part of the reserved tones for UE#1 is overlapped with a part of data tones for UE#2 in a not proper configuration of the resource allocations.

Fig. 2. An example of radio resource allocations in frequency-domain creates issue 2 |

**FL’s proposal 3**

|  |  |
| --- | --- |
| Company | Views |
| QC | Agree |
| Ericsson | The list only covers schemes with RAN1 spec impact. Transparent schemes such as clipping, companding, and digital predistortion are perhaps even more important, since they can bring benefit without upgrading entire service areas of network. As such they should be the baseline on which the non-transparent schemes improve. Also, RAN4 is discussing transparent schemes, and we should not be misaligned with their part of the work. As commented above, we do not think this first meeting for Rel-18 Cov Enh power domain enhancements should be a deadline for scheme identification. Suggest:**At least the following candidate solutions for MPR/PAR reduction will be studied in Rel-18.** **Non-transparent schemes, e.g.:*** **FDSS w/ spectrum extension**
* **FDSS w/o spectrum extension**
* **TR (which can only be w/ spectrum extension)**

**Non-transparent schemes, e.g.:*** **Clipping and Filtering**
* **Companding**
* **Digital predistortion**

**~~Whether other solutions will be studied as well will be decided before the end of RAN1 #110b-e.~~** |
| Intel | We are fine with the proposal. It would be good to list the full name of the solutions, e.g., frequency domain spectrum shaping, or tone reservation in the proposal. Suggest to change the main bullet as **At least the following candidate solutions for MPR/PAR reduction ~~will~~ can be studied in Rel-18.**  |
| vivo | To narrow down the scope of the solutions, we prefer to focus on the first 2 solutions and TR can be optionally studied. |
| Panasonic  | We support the FL’s proposal 3. |

**3.1.2-Q1**

**Please use a), b) and c) as per question formulation to express your views, if any.**

|  |  |
| --- | --- |
| Company | Views |
| QC | On b: Transparent techniques will need to be used as a baseline (assuming they don’t require any spec change). We should not preclude any transparent technique. |
| Ericsson | Regarding a), this seems out of scope of the item, as it targets low data rate services which are not considered for Rel-18 Cov Enh. Regarding b) As commented for FL Proposal 3, it is essential to study transparent schemes together with non-transparent schemes.Regarding c) We are open to discuss this, but wonder if it should first be proposed in RAN4, and how much extra effort would be needed. |
| Intel | 1. Our understanding is that sub-PRB based transmission is mainly targeted for further coverage enhancement, but not specifically targeted for power domain enhancement. This can be deprioritised in the study.
2. For transparent MPR reduction schemes, we are open to discuss this.
3. it is not clear to us how to reduce MPR/PAR based on advanced receiver. It would be good to clarify.
 |
| vivo | These items should be deprioritized given the high work load. |
| Panasonic | We would like to deprioritize the other solutions due to limited timing unit. |

### [OPEN] Design aspects of FDSS

The goal of this session is to identify the design aspects of FDSS (w/ and w/o spectrum extension) which would be used to identify specification impact and describe waveform assumptions (either used by RAN1 or RAN4 depending on the outcome of the discussion in Section 3.1.1) for performance evaluations.

**FDSS**

No company proposed specific design aspects of FDSS w/o spectrum extension. From FL’s understanding the only possible design aspect in this case could be the design of the filter. However, the design would likely be the same as the one used for FDSS-SE. A corresponding proposal is made below.

**FDSS-SE**

Three companies (Huawei/HiSi [2], Qualcomm [19] and Nokia/NSB [20]) discussed the design aspects of frequency domain spectrum shaping with spectrum extension (FDSS-SE) that should be considered in RAN1. Specifically,

* One company (Huawei/HiSi [2]) proposes studying the handling of DMRS symbol of a PUSCH with FDSS-SE including the following:
	+ DMRS symbol should be filtered by FDSS.
	+ Whether the DMRS sequence is extended to the resource elements that are used for spectrum extension.
* One company (Huawei/HiSi [2]) proposes that different filters, such as, RRC, Kaiser, 3- tap filter, should be studied to find the optimal or several suitable filters for maximizing the coverage enhancement gain.
* One company (Qualcomm [19]) proposes studying FDSS-SE as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power, including the following:
	+ Excess bandwidth is given in units of RBs
	+ DMRS and data symbols undergo spectrum shaping
* One company (Nokia/NSB [20]) proposes the following design aspects for FDSS-SE:
	+ Define Extension factor (α) as Excess band size / Total allocation size.
		- Support α = 0.25.
	+ Support FDSS-SE without limitations to supported PRB allocations.

In addition, the following are proposes for further study:

* Solutions to yield only integer numbers of PRB allocations for the excess band, i.e., spectrum extension.
* How to use the existing FDRA indicator in the context of FDSS-SE.
* Solutions for FDSS-SE to guarantee low CM of DMRS.

From FL’s perspective, although candidate solutions for MPR/PAR reduction should be further discussed in Section 3.1.2, RAN1 can discuss design aspects of each candidate solution in parallel for the sake of efficiency. Therefore, the following proposal is formulated.

**FL’s proposal 4**

**The following design aspects of frequency domain spectrum shaping with spectrum extension (FDSS-SE), are considered for Rel-18:**

* **Spectrum extension size is expressed in integer units of RBs.**
* **Both DMRS and data symbols undergo spectrum shaping**
* **FFS:**
	+ **Which extensions factor(s) to consider, where extension factor (α) is given by spectrum extension size / Total allocation size.**
	+ **How to extend DMRS sequence to spectrum extensions**
	+ **How extension size is indicated**

It is also noted that at least three approaches to extension have been described in companies’ contributions. Let *M* be the output of the M-point DFT and *K* the total number of tones after extensions have been added:

1. Symmetric extension [3, 4, 5, 15, 20]: the first $\frac{K-M}{2}$ samples of the sequence of *M* samples are appended at the end of the sequence itself, whereas the last $\frac{K-M}{2}$ samples of the sequence of *M* samples are prepended to the sequence itself.
2. Cyclic extension [19]: the sequence of *M* samples is cyclically extended to obtain *K* samples.
3. Cyclic shift plus symmetric extension [2]: the sequence of *M* samples is cyclically shifted by a factor L, and then extended by symmetric spectrum extension to obtain *K* samples.

A first question is thus asked.

|  |
| --- |
| **3.1.3-Q1 Please provide your view on which approach to extension should be considered in Rel-18, and why?**1. **Symmetric extension**
2. **Cyclic extension**
3. **Cyclic shift plus symmetric extension**
4. **Other (please describe)**
 |

Finally, and concerning the filter to consider for the study of FDSS, only one company provided an explicit proposal. Namely, it has been proposed to study different filters, such as, RRC, Kaiser, 3-tap filter. From FL’s perspective, it would be first important to decide whether a specific filter should be assumed in the RAN1 study, or whether such decision should be taken only by the WG (RAN4 and/or RAN1) who will perform the performance evaluation of FDSS w/ and w/o extensions.

A second question is asked.

|  |
| --- |
| **3.1.3-Q2 Should a specific filter be assumed in the RAN1 study, or should such decision be taken only by the WG (RAN4 and/or RAN1) who will perform the performance evaluation of FDSS w/ and w/o extensions?****Please provide possible options, should you think that a specific filter should be assumed in the RAN1 study.** |

#### First round of discussions

FL’s recommendation is to have a first round of discussion about **FL’s proposal 4**, **3.1.3-Q1** and **3.1.3-Q2.** Companies are invited to input their views in the corresponding table below. Constructive attitude in this regard is greatly appreciated. In this sense, if you cannot support the proposal, please propose an alternative formulation which considers the current spirit.

**FL’s proposal 4**

|  |  |
| --- | --- |
| Company | Views |
|  QC | Agree |
| Ericsson | We’d like to clarify that these aspects are studied and can be considered against alternatives. Also, we prefer not to define extension factor just yet, and think we can focus on how much extension is needed. Lastly, for performance evaluations, how extension size is determined is more important than what signaling is used to indicate it.**The following design aspects of frequency domain spectrum shaping with spectrum extension (FDSS-SE), are considered for Rel-18:*** **If spectrum extension size is expressed in integer units of RBs.**
* **If both DMRS and data symbols undergo spectrum shaping**
* **FFS:**
	+ **Amount of extension ~~Which extensions factor(s)~~ to consider~~, where extension factor (α) is given by spectrum extension size / Total allocation size.~~**
	+ **If/how to extend DMRS sequence to spectrum extensions**

**How extension size is ~~indicated~~ determined** |
| Intel | As this is for study and not intended to make decision, we suggest to change the main bullet as “study”We think spectrum shaping filter should be an important aspect to study for FDSS-SE, e.g., impact on the performance when shaping filter is not matched between Tx and Rx, how this is related to extension factor, etc., In addition, it is not very clear to us whether power domain enhancement needs to be considered for DMRS. In Rel-16, low PAPR DMRS sequence was specified, and our understanding is that FDSS-SE may not be applied for DMRS sequence. However, we understand that if DMRS and data do not undergo the same channel, the channel estimation performance may be degraded. We suggest to at least put this FFS. Based on the above, we suggest the following update:**Study the following design aspects of frequency domain spectrum shaping with spectrum extension (FDSS-SE)~~, are considered for Rel-18:~~*** **Spectrum extension size is expressed in integer units of RBs.**
* **~~Both DMRS and data symbols undergo spectrum shaping~~**
* **FFS:**
	+ **Both DMRS and data symbols undergo spectrum shaping**
	+ **Which extensions factor(s) to consider, where extension factor (α) is given by spectrum extension size / Total allocation size.**
	+ **Impact of shaping filter**
	+ **How to extend DMRS sequence to spectrum extensions**

**How extension size is indicated** |
| vivo | Agree with FL proposal in principle.Just one minor comment, given this is a study phase of this MPR reduction enhancement, we propose to have following updates:**FL’s proposal 4****The following design aspects of frequency domain spectrum shaping with spectrum extension (FDSS-SE), are considered for studying MPR/PAR reduction enhancements in Rel-18:*** **Spectrum extension size is expressed in integer units of RBs.**
* **Both DMRS and data symbols undergo spectrum shaping**
* **FFS:**
	+ **Which extensions factor(s) to consider, where extension factor (α) is given by spectrum extension size / Total allocation size.**
	+ **How to extend DMRS sequence to spectrum extensions**
	+ **How extension size is indicated**
 |
| Panasonic  | We are open to discuss the FL’s proposal 4 as this is the extension of Rel. 16 FDSS framework. |

**3.1.3-Q1**

|  |  |
| --- | --- |
| Company | Views |
| QC | Aren’t all three equivalent in a theoretical sense?That aside, what is the assumption on gNB receiver? Will a gNB receiver discard any tones? If so, should the scheme be designed for such a receiver? |
| Ericsson | We are open to studying any of these, and downselecting as a result of the study. |
| Intel | We are generally fine with the proposals.  |
| vivo | We think symmetric extension should be prioritized. |
| Panasonic  | We prefer the symmetric extension because it can potentially provide achievable MPR/PAR reduction.  |

**3.1.3-Q2**

|  |  |
| --- | --- |
| Company | Views |
| QC | We are okay to assume a specific filter to drive RAN1 evaluations. It might help align the results.When it comes to specification, if we decide to specify this, we prefer to leave the choice of the actual filter to the UE. We can agree to boundary conditions on spectrum flatness as it is currently done for pi/2 BPSK. |
| Ericsson | It may be helpful to agree on filter(s) to help with alignment on simulation results. The most important aspect is that filters meet RAN4 requirements, e.g. spectrum flatness, and provide good performance taking into account a range of allocation bandwidths. We don’t expect that filter type is a crucial aspect, but are open to comparing alterative designs. |
| Intel | The choice of shaping filter and filter parameters can impact the PAPR reduction performance and link level performance significantly. Our understanding is that typically shaping filter is not specified in the specification. It is up to company to report the filter used in the simulations. Further, we also need to study the impact on the link level performance when the shaping filter is not matched between Tx and Rx.  |
| vivo | Either way is fine. If a common filter is needed, we propose to use 3-tap filter which was also used in earlier FDSS study. |
| Panasonic | In Rel. 15/16, the FDSS without SE does not specify an exact shaping function, however, certain requirements are defined which yield boundary conditions for shaping filter implementations, i.e., gNB does not have knowledge of the exact FDSS filter or shaping function used in a UE. This approach allows UE vendors to pursue their own implementation and performance optimizations, while the system performance is guaranteed through the minimum RF requirements specified in the specifications, such as transmit signal spectral flatness, in-band / output back-off (OOB) emissions, and EVM. We think this approach can be reused for Rel. 18 CovEnh. |

### [OPEN] Design aspects of TR

Two companies (OPPO [6] and Qualcomm [19]) discussed the design aspects of tone reservation (TR) would be used to identify specification impact and describe waveform assumptions (either used by RAN1 or RAN4 depending on the outcome of the discussion in Section 3.1.1) for performance evaluations. Specifically,

* One company (OPPO [6]) proposes studying allocation mechanism of peak reduction tone (PRTs) to a UE, including location of PRTs, the number of subcarriers of PRTs, etc.
* One company (Qualcomm [19]) proposes studying sideband tone reservation as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power.
	+ Sideband tone reservation is given in units of RBs

From FL’s perspective, although solution to be adopted for MPR/PAR reduction should be further discussed in Section 3.1.2, RAN1 can discuss design aspects of each candidate solution in parallel for the best use of meeting time. Therefore, the following proposal is formulated.

**FL’s proposal 5**

**The following design aspects of tone reservation (TR), are considered for Rel-18:**

* **Sideband tone reservation size is expressed in integer units of RBs.**
* **FFS:**
	+ **Sideband size**
	+ **Sideband size indication**
	+ **Whether PRTs are added only to data or also DMRS symbols**

Concerning the reserved tones generation, some options have been mentioned in different companies Tdocs, however no proposal was explicitly made. It would seem appropriate from FL perspective to have for this aspect a similar discussion as the one I am proposing to have for the shaping filter of FDSS (w/ or w/o SE).

The following question is asked.

|  |
| --- |
| **3.1.4-Q1 Should a reserved tones generation algorithm/approach be assumed in the RAN1 study, or should such decision be taken only by the WG (RAN4 and/or RAN1) who will perform the performance evaluation of FDSS w/ and w/o extensions?****Please provide possible options, should you think that a specific filter should be assumed in the RAN1 study.** |

#### First round of discussions

FL’s recommendation is to have a first round of discussion about **FL’s proposal 5** and **3.1.4-Q1**.Companies are invited to input their views in the corresponding tables below. Please remember that the goal is to advance as much as we can, without hindering possible further refinements. Therefore, constructive attitude in this regard is greatly appreciated. In this sense, if you cannot support the proposal, please propose an alternative formulation which considers the current spirit.

**FL’s proposal 5**

|  |  |
| --- | --- |
| Company | Views |
| QC | Looks okay. |
| Ericsson | Similar to proposal 4, we’d like to clarify that these aspects are studied and can be considered against alternatives. Aslo, for performance evaluations, how sideband size is determined is more important than what signaling is used to indicate it.**FL’s proposal 5****The following design aspects of tone reservation (TR), are considered for Rel-18:*** **If sideband tone reservation size is expressed in integer units of RBs.**
* **FFS:**
	+ **Sideband size**
	+ **Sideband size ~~indication~~ determination**
	+ **Whether PRTs are added only to data or also DMRS symbols**
 |
| Intel | Similar comment as for FDSS-FD. As this is for study and not intended to make decision, we may need to change the main bullet as “study”. It may be good to also align the terminology in the FFS. we suggest the following update: **Study the following design aspects of tone reservation (TR)~~, are considered for Rel-18:~~*** **Sideband tone reservation size is expressed in integer units of RBs.**
* **FFS:**
	+ **Sideband tone reservation size**
	+ **Sideband tone reservation size indication**
	+ **Whether PRTs are added only to data or also DMRS symbols**
 |
| vivo | We propose to deprioritize this TR evaluation as we commented earlier. |
| Panasonic  | We are open to discuss the FL’s proposal 5.  |

**3.1.4-Q1**

|  |  |
| --- | --- |
| Company | Views |
| QC | The exact algorithm used can be left to each company’s choice. SCR-TR is a well-known algorithm used in this context. It can serve as a useful baseline if required. Can be left to RAN4.Note that reserved tones can be used for other purposes too and not just for PAPR reduction. |
| Ericsson | We do not see a need to restrict the tone generation algorithm/approach at this stage. We think both RAN1 and RAN4 can study tone reservation, although some coordination of the work may be beneficial. |
| Intel | Our understanding is that the specific algorithm for the tone reservation is not defined in the specification. If supported, RAN4 would only define a set of requirements on the targeted performance metric, e.g., EVM, OOB, ACLR, etc.In this regard, we tend to think that RAN4 would be leading WG to study tone reservation solution as MPR typically is being used in RAN4. |

## Mid priority aspects

Two mid priority aspects are identified at the beginning of the meeting:

1. Evaluation methodology
2. Parameterization for evaluations

Significant attention has been given by several companies to such aspects in the submitted contributions. These are very important aspect which could be labeled as high priority is the work RAN1/RAN4 split was such that RAN1 is responsible of the performance evaluation. This is not the case at the beginning of RAN1 #110b-e. For this reason, the discussion on these two aspects is paused for the time being, and will start if and when need arises, regardless of how many high priority aspects are still being discussed. FL’s comments/proposals on these aspects are not included yet, given the above.

### [PAUSED] Evaluation methodology

Several contributions acknowledged the fundamental nature of this aspect and discussed it in detail. A high-level summary of companies’ preferences based on the contributions is as follows:

* One company (Huawei/HiSi [2]) proposes adopting the metrics of coverage enhancement gain, PAPR, CM, and reduced SNR for evaluations on coverage performance improvement of Rel-18 NR power domain enhancements as follows:
	+ The coverage enhancement gain is given by $G=∆CM+∆SNR$;
	+ $∆SNR$ is the SNR degradation under the requirement BLER=10-1;
	+ $∆CM$ is the improvement of CM at the 99-percentile of the CDF.
* One company (Ericsson [15]) proposes:
	+ Quantifying relative link performance of a given transmission configuration as SNR0+OBO, where SNR0 is the SNR (in dB) needed to reach a target BLER, and OBO is the output power backoff for the configuration (in dB).
	+ Comparing schemes at the link level using a same amount of time-frequency resource and at a same spectral efficiency and assuming Rel-17 resource allocation mechanisms.
	+ Transparent MPR reduction schemes are baselines to which non-transparent schemes are compared.
* One company (Qualcomm [19]) proposes that:
	+ For evaluating the benefits of tone reservation, use legacy R17 PUSCH waveforms as a baseline, with the excess bandwidth included in the total allocated bandwidth.
	+ For FDSS with bandwidth expansion, link-level performance evaluations are required to assess the overall coverage gains. In particular, evaluate the impact of (a) the amount power spent in the excess bandwidth region and (b) gNB receiver handling of the excess bandwidth when receiving the PUSCH transmission for further processing.
	+ For FDSS with bandwidth expansion, evaluate the impact of gNB not knowing the pulse shaping filter used by the UE (but aware of bandwidth expansion).
* One company (CATT [7]) proposes that FDSS should be carefully studied taking performance, overhead, implementation complexity and standardization efforts into account.
* One company (vivo [5]) proposes that FDSS enhancement in Rel-18 should be carefully studied and should not be specified unless justified by obvious power boost gain.
* One company (Samsung [16]) proposes further studying techniques to reduce MPR/PAR taking into consideration the implementation impact at both the UE and the gNB.
* One company (Nokia/NSB [20]) proposes that actual conclusion of the MPR/PAR reduction methods should be based on net coverage gain results combining transmitter and receiver performance.

### [PAUSED] Parameterization for evaluations

One company (Ericsson [15]) explicitly proposes a specific set of parameter configurations for performance evaluation. More precisely, it is proposed to determine PA output backoff using RF simulations and according to RAN4 requirements for error vector magnitude, in band emissions, spectrum flatness, spectrum emission mask, and adjacent channel leakage, spurious and accounting for counter-IM3. In addition**.** as a starting point, using the parameters in below table for RF simulations, and select remaining parameters that are needed for link simulations from TR 38.830, appendices A.1 and A.2.

|  |  |
| --- | --- |
| **Parameter**  | **Value** |
| Filter coefficient  | TBD (may vary according to MPR reduction scheme) |
| Modulation scheme | QPSK, 16QAM, [64QAM and 256QAM] |
| Waveform | DFT-s-OFDM |
| Carrier frequency and duplex mode | 700MHz (FDD), 4GHz (TDD), 28GHz (TDD) |
| Subcarrier spacing | 700MHz: 15 kHz, 4GHz: 30 kHz, 28GHz: 120 kHz |
| System Bandwidth | 700 MHz: 20 MHz, 4 GHz: 100 MHz, 28 GHz: [100 MHz, 400 MHz]  |
| Number of RBs and starting RB | Sweep different combination |
| Counter-IM3 | 60 dB |

## Others

As discussed at the beginning of Section 3, discussions on different aspects of enhancements for reduction MPR/PAR have been prioritized to ensure that constructive discussions and effective progress can be achieved during RAN1 #110b-e. Priority has been given to the aspects and topics discussed in sections 3.1 and 3.2, which mostly focus on way of working, evaluation methodology, and design aspects of considered MPR/PAR reduction techniques. All other aspects are listed in this section, i.e., 3.3, where proposals made by companies in their contributions are reported and described in detail.

These aspects may not be handled during RAN1 #110b-e unless technical need arises during the discussion on other aspects. For this reason, no specific FL’s proposal or recommendation is formulated at this stage. Should discussions for 3.1 and 3.2 progress fast and converge to agreements, sections for specific aspects, currently in 3.3, may be open for discussions and corresponding FL’s proposals and recommendations may be made.

### [CLOSED] Complementary enhancements

One company (Huawei/HiSi [2]) proposes studying whether/how to enhance the power control to consider the difference of power spectral density of the REs due to the FDSS.

# 4 [CLOSED] Proposals for GTW

# 5 [CLOSED] Agreements during RAN1 #110b-e

# References

1. RP-221858 Revised WID on Further NR coverage enhancements, China Telecom, Jun. 2022.
2. R1-2208412 Discussion on coverage enhancement in power domain Huawei, HiSilicon
3. R1-2208489 Discussion on power domain enhancements ZTE
4. R1-2208576 Discussion on power domain enhancements Spreadtrum
5. R1-2208672 Discussions on power domain enhancements vivo
6. R1-2208847 The study of power domain enhancements OPPO
7. R1-2208964 Discussion on power domain enhancements CATT
8. R1-2209026 Discussion on power domain enhancements for CA/DC Fujitsu
9. R1-2209079 Discussions on power domain enhancement Intel Corporation
10. R1-2209224 Power domain enhancements Lenovo
11. R1-2209364 Discussion on power domain enhancements CMCC
12. R1-2209522 Discussion on power-domain enhancements MediaTek Inc.
13. R1-2209609 Discussion on power domain coverage enhancement Apple
14. R1-2209662 Uplink power enhancements InterDigital, Inc.
15. R1-2209673 Power Domain Enhancement Evaluation Methodology and Schemes Ericsson
16. R1-2209760 Power domain enhancements Samsung
17. R1-2209789 Power domain enhancements for Rel-18 CovEnh Sharp
18. R1-2209926 Discussion on power domain enhancements NTT DOCOMO, INC.
19. R1-2210014 Power-domain enhancements Qualcomm Incorporated
20. R1-2210166 RAN1 impacts for power domain enhancements Nokia, Nokia Shanghai Bell

# Appendix A: Proposals from contributions aggregated by topic

## A.1 Enhancements for increasing UE power high limit for CA and DC

### A.1.1 Increasing UE power high limit for CA and DC

**Coordination with RAN4**

|  |
| --- |
| **R1-2208489 ZTE*****Proposal 6:*** *RAN4 should lead the discussion on whether/how to introduce additional cases for increasing UE power high limit for CA and DC.***R1-2209760 Samsung*****Proposal 1:*** *Send an LS to RAN4 asking which potential enhancements RAN4 is planning to consider for this objective.* |

**RAN1 scope clarification**

|  |
| --- |
| **R1-2208489 ZTE*****Proposal 7:*** *RAN1 needs to clarify whether any RAN1 enhancement is needed, and any enhancement requiring large RAN1 specification impact without clear performance gain is not pursued.* **R1-2209364 CMCC*****Proposal 1:*** *The impact for RAN1 spec needs more discussion.***R1-2209926 NTT DOCOMO*****Proposal 1:*** *Clarify the objective more to have a well-focused target for RAN1 work* |

**De-prioritization of HPUE related power domain enhancement**

|  |
| --- |
| **R1-2208672 vivo*****Proposal 1:*** *HPUE related power domain enhancement should be deprioritized in Rel-18 coverage enhancement topic.* |

**New signaling aspects**

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| **R1-2209026 Fujitsu*****Proposal 1:*** *A new signaling/report from UE to gNB should be introduced to let gNB know the timing about UE autonomous Tx suspension due to SAR limit** *FFS: Details of signaling/report*

**R1-2209662 InterDigital*****Proposal 3****: Support indication of aggregated power class in power headroom report.***R1-2209926 NTT DOCOMO*****Proposal 2:*** *RAN1 to study a method for UE to report the exact availability of higher transmit power for inter-band CA/EN-DC UL transmission***R1-2210014 Qualcomm*****Proposal 8:*** *To facilitate higher power transmission in CA and DC scenarios, introduce signalling mechanisms between UE and gNB focused on* 1. *increasing awareness of power or energy budget available at the UE for each carrier/band,*
2. *aiding the selection of the best band combination for UL CA, and*
3. *aiding scheduling policy when UE is configured with multiple bands in UL CA, for e.g., selecting preferred carrier for servicing uplink, or adaptive load sharing across carriers.*

***Proposal 9:*** *Introduce signaling to allow UE to report aspects related to power management and RF exposure.****Proposal 10:*** *Enhance the current power headroom reporting framework to allow a user to also report P-MPR (via MPE field) for FR1 carriers.****Proposal 11:*** *Enhance the current power headroom reporting framework to allow a user to report power headroom for a carrier that is configured for downlink but not for uplink (i.e., no active uplink BWP).****Proposal 12****: Introduce MAC-CE signaling to allow UE to report energy headroom for each of the bands in a CA/DC configuration given to the UE.* *FFS: signaling details, including, periodicity, reporting triggers, relation to PHR, how to handle multiple bands, reference power, etc.* |

## A.2 Enhancements for reducing MPR/PAR

### A.2.1 Way of working (RAN1 and RAN4 work split)

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| **R1-2208489 ZTE*****Proposal 1:*** *RAN1 should target to clarify and determine the work split between RAN1 and RAN4 for power domain enhancements in RAN1#110.* **R1-2208964 CATT*****Proposal 1:*** *The MPR/PAR reduction by FDSS with and without spectrum extension and tone reservation should be first studied in RAN 4 focusing on relevant waveform and modulation order for coverage limited UEs.***R1-2209522 MediaTek*****Proposal 1:*** *Reach a conclusion stating that RAN1 keeps power-domain enhancements related discussions on hold and waits for RAN4 progress on these objectives.***R1-2209609 Apple*****Proposal 1:*** *More RAN4 inputs are required to progress in RAN1 on enhancement on increasing maximum power limit.***R1-2210166 Nokia, NSB*****Proposal 1:*** *RAN WG4 should be the (key) responsible WG for the performance evaluations related to MPR/PAR objective***R1-2209364 CMCC*****Proposal 2:*** *Potential RAN1 impact should be discussed for spectrum shaping and tone reservation.* |

### A.2.2 Performance evaluation

**Evaluation methodology**

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| **R1-2208412 Huawei/HiSi*****Proposal 1:*** *Adopt the metrics of coverage enhancement gain, PAPR, CM, and reduced SNR for evaluations on coverage performance improvement of Rel-18 NR power domain enhancements:** *The coverage enhancement gain is given by*$G=∆CM+∆SNR$*;*
* $∆SNR$ *is the SNR degradation under the requirement BLER=10-1;*
* $∆CM$ *is the* *improvement of CM at the 99-percentile of the CDF.*

**R1-2209673 Ericsson*****Proposal 1.*** *Quantify relative link performance of a given transmission configuration as SNR0+OBO, where SNR0 is the SNR (in dB) needed to reach a target BLER, and OBO is the output power backoff for the configuration (in dB).****Proposal 3.*** *Compare schemes at the link level using a same amount of time-frequency resource and at a same spectral efficiency, and assuming Rel-17 resource allocation mechanisms.****Proposal 5*** *Transparent MPR reduction schemes are baselines to which non-transparent schemes are compared.***R1-2210014 Qualcomm*****Proposal 4:*** *For evaluating the benefits of tone reservation, use legacy R17 PUSCH waveforms as a baseline, with the excess bandwidth included in the total allocated bandwidth.****Proposal 6:*** *For FDSS with bandwidth expansion, link-level performance evaluations are required to assess the overall coverage gains. In particular, evaluate the impact of (a) the amount power spent in the excess bandwidth region and (b) gNB receiver handling of the excess bandwidth when receiving the PUSCH transmission for further processing.****Proposal 7:*** *For FDSS with bandwidth expansion, evaluate the impact of gNB not knowing the pulse shaping filter used by the UE (but aware of bandwidth expansion).***R1-2208964 CATT*****Proposal 2:*** *FDSS should be carefully studied taking performance, overhead, implementation complexity and standardization efforts into account.***R1-2208672 vivo*****Proposal 2:*** *FDSS enhancement in Rel-18 should be carefully studied and should not be specified unless justified by obvious power boost gain.***R1-2209760 Samsung*****Proposal 2:*** *Further study techniques to reduce MPR/PAR to assess the gains for coverage enhancement.****Proposal 4:*** *Further study techniques to reduce MPR/PAR taking into consideration the implementation impact at both the UE and the gNB***R1-2210166 Nokia, NSB*****Proposal 2:*** *Actual conclusion of the MPR/PAR reduction methods should be based on net coverage gain results combining transmitter and receiver performance.* |

**Evaluation parameters**

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| **R1-2209673 Ericsson*****Proposal 2.*** *Determine PA output backoff using RF simulations and according to RAN4 requirements for error vector magnitude, in band emissions, spectrum flatness, spectrum emission mask, and adjacent channel leakage, spurious and accounting for counter-IM3.****Proposal 4.*** *As a starting point, use the parameters in Table 1 for RF simulations, and select remaining parameters not given by Table 1 that are needed for link simulations from TR 38.830, appendices A.1 and A.2.*Table 1: RF simulation (‘Step 1’) parameters

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| **Parameter**  | **Value** |
| Filter coefficient  | TBD (may vary according to MPR reduction scheme) |
| Modulation scheme | QPSK, 16QAM, [64QAM and 256QAM] |
| Waveform | DFT-s-OFDM |
| Carrier frequency and duplex mode | 700MHz (FDD), 4GHz (TDD), 28GHz (TDD) |
| Subcarrier spacing | 700MHz: 15 kHz, 4GHz: 30 kHz, 28GHz: 120 kHz |
| System Bandwidth | 700 MHz: 20 MHz, 4 GHz: 100 MHz, 28 GHz: [100 MHz, 400 MHz]  |
| Number of RBs and starting RB | Sweep different combination |
| Counter-IM3 | 60 dB |

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**Others**

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| **R1-2208489 ZTE*****Proposal 2:*** *RAN1 needs to first agree on the evaluation methodology and simulation assumptions for the proposed RAN1 enhancements in the power domain.*  |

### A.2.3 MPR/PAR reduction techniques

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| **R1-2208412 Huawei/HiSi*****Proposal 5:*** *Continue to evaluate FDSS with SE. The tone reservation technique should not be further considered.* **R1-2208489 ZTE*****Proposal 3:*** *For both pi/2-BPSK and QPSK, tone reservation is not supported in Rel-18 CE WI.****Proposal 4:*** *For pi/2-BPSK, FDSS with spectrum extension can be further studied in Rel-18 CE WI.****Proposal 5:*** *For QPSK, FDSS with or without spectrum extension can be further studied in Rel-18 CE WI.***R1-2208576 Spreadtrum**1. *Enhanced FDSS without spectrum extension applied for other modulations can be further studied.*

**R1-2208847 OPPO*****Proposal 1:*** *Consider tone reservation for DFT-s-OFDM and CP-OFDM waveforms to further reduce PAPR.***R1-2209079 Intel*****Proposal 1:*** *Study frequency domain spectrum filtering for DFT-s-OFDM waveform for PAPR reduction.* **R1-2209224 Lenovo*****Proposal 1:*** *Sub-PRB based transmission could be considered as one method to realize lower MPR/PAR in Rel-18.****Proposal 2:*** *The spectral shaping framework defined in Rel-15 (for pi/2 BPSK) could also be extended to QPSK scenario to realize lower MPR/PAR in Rel-18.****Proposal 3:*** *Tone reservation principle could be used to realize lower MPR/PAR in Rel-18.***R1-2209609 Apple*****Proposal 2:*** *RAN1 to evaluate the QPSK FDSS performance with and without bandwidth extension.***R1-2209662 InterDigital*****Proposal 1****: Support methods to minimize MPR of the waveform.****Proposal 2****: Study the support of tone reservation technique to enable transmission with higher power.***R1-2209673 Ericsson*****Proposal 6*** *Candidate* *transparent MPR reduction schemes to consider include clipping and filtering, companding, and digital predistortion.***R1-2209760 Samsung*****Proposal 3:*** *Further study advanced receivers to support reduced MPR. FFS spec impacts.***R1-2209789 Sharp*****Proposal 1:*** *Study the spectral extension for MPR reduction.* **R1-2209926 NTT DOCOMO*****Proposal 3:*** *Unless a large gain is evaluated, no need for RAN1 to discuss on spectrum extension or tone reservation in Rel-18***R1-2210014 Qualcomm*****Proposal 1:*** *For power-domain enhancements targeting MPR/PAPR optimization focus on the following class of waveforms:* * *DFT-S-OFDM*
* *QPSK modulation*
* *Inner and outer RB allocations*
* *Small RB allocation (1-16 RBs)*

***Proposal 2:*** *Study non-transparent techniques that allow a 0-dB MPR waveform to be transmitted at a transmit power exceeding the maximum power associated with the UE power class.****Proposal 3:*** *Study sideband tone reservation as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power.* * *Sideband tone reservation is given in units of RBs*

***Proposal 5:*** *Study FDSS with bandwidth expansion as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power.* * *Excess bandwidth is given in units of RBs*
* *DMRS and data symbols undergo spectrum shaping*

**R1-2210166 Nokia, NSB*****Proposal 3:*** *Prioritize scenarios involving spectrum extension (and deprioritize scenarios without spectrum extension).****Proposal 4:*** *Prioritize DFT-s-OFDM for power domain enhancements in Rel-18 (& deprioritize CP-OFDM)****Proposal 5:*** *Prioritize PUSCH and the associated DMRS for power domain enhancements in Rel-18(& deprioritize other channels and signals)****Proposal 6:*** *Prioritize QPSK modulation for power domain enhancements in Rel-18(& deprioritize other modulation schemes).* ***Proposal 7:*** *Support FDSS with spectrum extension in Rel-18**• FFS: whether and how other solutions are supported.* |

### A.2.4 Design aspects of FDSS-SE

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| **R1-2208412 Huawei/HiSi*****Proposal 3:*** *Study the handling of DMRS symbol of a PUSCH with FDSS-SE** *DMRS symbol should be filtered by FDSS.*
* *Whether the DMRS sequence is extended to the resource elements that are used for spectrum extension.*

**R1-2210014 Qualcomm*****Proposal 5:*** *Study FDSS with bandwidth expansion as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power.* * *Excess bandwidth is given in units of RBs*
* *DMRS and data symbols undergo spectrum shaping*

**R1-2210166 Nokia, NSB*****Proposal 8****: Define Extension factor () as Excess band size / Total allocation size.* ***Proposal 9:*** *Support FDSS w/ spectrum extension without limitations to supported PRB allocations.* ***Proposal 10:*** *Support  = 0.25.* ***Proposal 11:*** *Study solutions to yield only integer numbers of PRB allocations for the excess band, i.e., spectrum extension.****Proposal 12:*** *RAN1 should study how to use the existing FDRA indicator in the context of FDSS-SE.****Proposal 13****: Study solutions for FDSS-SE to guarantee low CM of DMRS.* |

### A.2.5 Design aspects of tone reservation

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| **R1-2208847 OPPO*****Proposal 2:*** *Allocation mechanism of PRTs to a UE should be studied, including location of PRTs, the number of subcarriers of PRTs, etc.***R1-2210014 Qualcomm*****Proposal 3:*** *Study sideband tone reservation as a non-transparent waveform shaping technique to transmit DFT-S-OFM waveforms at a higher transmit power.* * *Sideband tone reservation is given in units of RBs*
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### A.2.6 Other enhancements on top of MPR/PAR reduction techniques

**Power control**

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| **R1-2208412 Huawei/HiSi*****Proposal* 4*:*** *Study whether/how to enhance the power control to take into account the difference of power spectral density of the REs due to the FDSS.*  |