**3GPP TSG RAN WG1 e-Meeting #104 R1-210XXXX**

**e-Meeting, January 25th – February 5th, 2021**

Agenda Item: 8.7.1.1

Source: Moderator (MediaTek)

Title: Summary for Paging Enhancements

Document for: Discussion and Decision

# Introduction

In RAN1 #103-e [1][2], RAN1 agrees to support paging early indication (PEI), and it remains to specify the physical design based on DCI, SSS or TRS/CSI-RS:

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| Agreements**:** For NR idle/inactive-mode paging enhancement, paging early indication before paging occasion is supported from RAN1 perspective   * FFS: Physical layer design based on DCI, SSS or TRS/CSI-RS * Send LS to inform RAN2 and kindly ask RAN2 to inform RAN1 if there is anything that RAN1 should take into consideration in the physical layer design for this feature, including any other progress RAN2 has made in this WI which may has RAN1 impact |

There is also an LS on paging enhancement from RAN2 [3]:

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| **1. Overall Description:**  In RAN2#112-e, RAN2 discussed UE grouping for paging enhancement in Rel-17 UE power saving WI. RAN2 confirmed that UE grouping is considered as a candidate of paging enhancements for UE power saving. Regarding paging for UE subgroups, RAN2 has discussed and considered the following methods:   * Paging indication for UE subgroups using paging DCI, with either same-slot or cross-slot scheduling; * Paging early indication (PEI) / wake-up signal (WUS) for UE subgroups; * UE subgroup indication by using multiple P-RNTIs; * Paging for UE subgroups using different time/frequency resources.   From RAN2 perspective, the last two methods are de-prioritized. Notice that these methods are not mutually exclusive.  **2. Actions:**  **To RAN1:**  RAN2 respectfully asks RAN1 to take the above information into consideration and provide information on the feasibility and limitations of carrying subgroup information with their recommended solution. |

Based on the agreement, RAN2 LS and companies’ contributions [4]-[31], this summary is devoted to characterize all possible PEI candidate designs over the agreed design considerations: Impact to paging detection performance, resource occupation, and power saving gain. In Section 2, fundamental assumptions for the characterization will be discussed and decided. And the subsequent sections will further specify and compare the PEI candidate designs toward the selection for PEI physical layer design.

# Initial Characterization for PEI Candidate Designs

In this Section, fundamental assumptions for the characterization will be discussed and decided.

## UE sub-grouping information in PEI

Whether to carry UE sub-grouping information in PEI is fundamental assumption/requirement to PEI physical layer design. From the observation in RAN1 #103-e, combining the two features are beneficial, particularly for the case where the original group paging rate is higher. On the other hand, from companies’ contributions, the power saving gain starts to saturate if there partition more than 8 sub-groups. Consequently, the following proposal and observation are suggested:

Proposal 1: Carrying UE sub-grouping information in paging early indication is supported.

Observation 1: The power saving gain starts to saturate if there partition more than [8] sub-groups for a UE group or a PO.

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| Agreements:  Observation: For NR idle/inactive-mode UEs, UE sub-grouping indication carried in paging early indication can provide the following power saving gains w.r.t Rel-16:   * If the original group paging rate is 10%:   + [10.6%] –[19.1%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [16.0%] –[36.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [14.3%] –[46.0%] where the baseline assumes 3 SS bursts for synchronization before PO reception * Some sources also evaluated performance if the original group paging rate is in the range between 20% and 60% and showed following results:   + [8.0%] –[19.1%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [18.1%] –[34.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [20.6%] –[42.0%] where the baseline assumes 3 SS bursts for synchronization before PO reception   The additional power saving gains w.r.t. paging early indication without UE sub-grouping are given as follows:   * If the original group paging rate is 10%:   + [0.6%] –[2.7%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [0.6%] –[4.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [0.6%] –[4.7%] where the baseline assumes 3 SS bursts for synchronization before PO reception * Some sources also evaluated performance if the original group paging rate is in the range between 20% and 60% and showed following results:   + [1.3%] –[8.0%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [2.1%] –[13.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [3.3%] –[16.1%] where the baseline assumes 3 SS bursts for synchronization before PO reception   The number of UE sub-groups evaluated ranges from 2 to 16.  The power saving gains are dependent on the assumptions about placement of PEI and PO relative to SSB.  Note: It is FFS in RAN1 another group paging rate > 10% for the evaluation of Rel-17 paging enhancement.  Note: Not all sources providing results for paging early indication without UE sub-grouping also provide results for paging early indication with UE sub-grouping. |

Companies please provide comments/suggested revisions to Proposal 1 and Observation 1 in Table 1:

Table 1: Companies’ comments/suggested revisions to Proposal 1 and Observation 1

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| **Company** | **Comment(s)/Suggested Revision(s)** |
| Qualcomm | Agreed with the proposal and observation. Added the FFS to include the subgrouping in paging PDCCH  Proposal 1: Carrying UE sub-grouping information in paging early indication is supported.  **FFS: carrying UE sub-grouping information in paging PDCCH is supported or not** |
| CATT | We can see from the power saving gain is very small (0.6% - 4.6 % for 10% paging rate) for PEI with paging subgrouping comparing to that without paging subgrouping. Since supporting paging subgrouping in the PEI would have additional overhead in PEI, we need to have strong justification before we can support it.  We should define the general procedure of PEI and associated paging procedure before discussing whether paging subgrouping is supported. |
| Intel | While we agree with the intention, we think the amount of information to be conveyed is critical here. And we have not decided on the physical layer signal/channel design. PDCCH signal can carry more information whereas a sequence based transmission may not. Sequence based transmission has other benefits which is perhaps not relevant here. Hence, depending on which signal/channel is chosen, amount of information that can be carried by PEI will be more clear. It is not clear how number of groups 8 is obtained, whether it is based on use case or just from simulation results. To this end, we suggest to go with what can be feasible for both options. Our revisions are as follows:  Proposal 1: Carrying UE sub-grouping information in paging early indication is supported, when number of sub-groups is up to [4].   * **FFS: indication for number of sub-groups > 4**   **Note: The exact number of sub-groups that can be indicated in paging early indication is to be confirmed after agreement on the signal/channel design.** |
| Xiaomi | For Proposal 1, we can support it in principle, but want to add some more clarifications to it. In our view, when DCI-based PEI is adopted, it is possible to carry PEI of UE group A in an earlier paging DCI (for example, using the reserved bits to carry PEI) of UE group B. and since there are multiple reserved bits in paging DCI, it is possible that the sub-grouping information and PEI can be both carried within the paging DCI of UE group B. In this case, we think it is more clear to say that, sub-grouping information can be carried along with PEI.  Based on above, we propose to modify the Proposal 1 a little bit as follows,  **Proposal 1: Carrying UE sub-grouping information in paging early indication is supported.**  **Note: if PEI is carried in a paging DCI, UE sub-grouping information can be also be carried in the paging DCI** |
| Lenovo, Motorola Mobility | For typical group paging rate of 10~20%, additional power saving gains of sub-grouping in PEI w.r.t. PEI without sub-grouping is very limited (the max gain for 3 SS burst based synchronization is < 5%). With TRS provisions, power saving gain is expected to be even smaller (max power saving gain of 2~3%).  We suggest RAN1 first to discuss PEI physical channel/signal design, considering with and without sub-grouping, and subgrouping in PEI and/or sub-grouping in paging DCI. |
| Samsung | We are OK to support UE sub-grouping up to [4] sub-groups based on paging PDCCH. Because the reserved bits in paging DCI can be reused directly. But the L1 signal/channel of PEI has not been discussed yet. The impact on PEI reception is not clear. We suggest to prioritize the L1 signal/channel design of PEI without UE sub-grouping, especially considering the limited gain.  Therefore, we support paging PDCCH based UE subgrouping, but not PEI. We can add FFS for PEI. |
| vivo | In principle, we are fine with proposal 1 and observation 1. However, to avoid ambiguity understanding and further save the cost for cross-layer communication, we also need to reply the LS [6] from RAN2 to declare that from RAN1 perspective the sub-grouping indication by paging PDCCH should not be considered.  In addition, in the RAN1#103-E meeting, sub-grouping on Paging DCI is also studied, it is shown that  Agreements:  Observation: For NR idle/inactive-mode UEs, UE sub-grouping indication within a PO can provide the following power saving gains w.r.t. Rel-16:   * If the original group paging rate is 10%:   + [0.3%] - [1.1%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [0.4%] - [0.8%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [0.3%] - [1.0%] where the baseline assumes 3 SS bursts for synchronization before PO reception * Some sources also evaluated performance if the original group paging rate is in the range between 20% and 80% and showed following results:   + [0.7%] - [7.6%] where the baseline assumes 1 SS burst for synchronization before PO reception   + [0.8%] - [3.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception   + [0.5%] - [4.7%] where the baseline assumes 3 SS bursts for synchronization before PO reception   The number of UE sub-groups evaluated ranges from 2 to 16.  Some companies show concern on assuming group paging rate larger than 60%.  Note: It is FFS in RAN1 another group paging rate > 10% for the evaluation of Rel-17 paging enhancement.  It is clearly subgrouping on Paging DCI can provide marginal power saving gain about 0.3 - 1.1%. It is not necessary to further study the subgrouping on Paging DCI. So, we suggest to supplement proposal 1 as follows with modifying in red:  Proposal 1: Carrying UE sub-grouping information in paging early indication is supported. And reply the LS sending from RAN2 [R2-2010884] as follow:  **From RAN1 perspective, the sub-grouping indication by using paging PDCCH is not supported.** |
| CMCC | We support this proposal, as vivo’s comment, the power saving of UE sub-grouping carried by paging DCI is limited, the UE sub-grouping indication by using paging DCI is not supported. |
| Ericsson | Support the proposal 1. We also support subgrouping indication via Paging DCI.  Regarding vivo’s comment, the observation cited from RAN1#103 applies to the case when the subgrouping is within a PO, and it does not apply when subgrouping is indicated in a paging DCI from another PO. |
| Huawei, HiSilicon | We support the proposal in general, but the proposed compromise by Chairman yesterday is preferred.  Proposal 1: Carrying UE sub-grouping information ~~in paging early indication~~ is supported at least in paging early indication.   * FFS: whether some of the sub-grouping information can be carried also in paging DCI.   The only concern in yesterday discussion is whether the power saving gain is attractive. We would like to remind that it has been already agreed the observations in RAN1#103 regarding the additional power saving gain due to sub-grouping. The original group paging rate in deployment depends on the network configuration and the paging load is dynamically changing. Therefore, using a range of group paging rate from 10% to 60% for paging enhancement evaluation is reasonable.  *The additional power saving gains w.r.t. paging early indication without UE sub-grouping are given as follows:*   * *If the original group paging rate is 10%:*    + *[0.6%] –[2.7%] where the baseline assumes 1 SS burst for synchronization before PO reception*   + *[0.6%] –[4.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception*   + *[0.6%] –[4.7%] where the baseline assumes 3 SS bursts for synchronization before PO reception* * *Some sources also evaluated performance if the original group paging rate is in the range between 20% and 60% and showed following results:*    + *[1.3%] –[8.0%] where the baseline assumes 1 SS burst for synchronization before PO reception*   + *[2.1%] –[13.0%] where the baseline assumes 2 SS bursts for synchronization before PO reception*   *[3.3%] –[16.1%] where the baseline assumes 3 SS bursts for synchronization before PO reception* |
| OPPO | Agreed with the proposal and observation. The physical layer signal/channel carrying PEI has not decided yet. It is observed that power saving gain will converge after the number of sub-grouping is above 8. More information bits can be carried through DCI than sequences. The number of sub-grouping can be related to the decision on physical layer signal/channel carrying PEI. For example, for sequence based PEI, up to 4 sub-grouping indication is supported. For DCI based PEI, up to 8 sub-grouping indication can be supported. |
| ZTE, Sanechips | We support the FL proposal.  We agree that according to the agreements in the last meeting, the additional power saving gain from sub-grouping carried by PEI can be up to 16.1%. Hence, we support to carry sub-grouping by PEI.  Regarding the number of UE sub-groups, I think “8” is based on several companies’ observations. |
| Spreadtrum | In our view, the reliability or robustness of PEI is important to achieve the power saving gain, which actually comes from the reduction of wakeup energy overhead. If the effective code rate of PEI (DCI-based or sequence-based) is too large, there could be no power saving gain. But, leaving the room for gNB configuration may be a reasonable way, i.e. gNB can configure the more subgroups when the effective code rate of PEI is still low. We suggest leaving the number of UE subgroups as FFS:   * FFS: The max number of UE subgroups |
| DOCOMO | We agree with vivo. Sub-grouping indication in PEI can provide sufficient power saving gain at least when group paging rate is higher. On the other hand, sub-grouping indication in paging DCI can provide marginal power saving gain. Also, although it may be necessary to discuss the number of sub-grouping considering PEI details, we are fine to have [8] sub-grouping. |
| LG | We support the moderator’s proposal and also fine with the observation.  According to the observation in the last meeting, PEI with sub-group indication shows best performance among the potential candidates for UE sub-grouping. Also we already observed that PEI with UE sub-grouping can provide a stable power saving gain regardless of the UE paging rate, while power saving gain of PEI w/o UE sub-grouping degrades significantly as the paging rate increases.  Thus at least UE sub-grouping using a PEI should be supported. Although we prefer to support UE sub-group indication using PEI only, but we can discuss further whether additional method can be considered (e.g. at PO) |
| Panasonic | In general, Proposal 1 is okay with us. As the PEI physical layer design has not be agreed, we also think the details and the potential support of paging DCI to indicate subgrouping should also be studied. The tentative text proposal from Chairman in the online meeting is good with us. |
| InterDigital | We agree in principle with the proposal. Given the limited gain, we do not support using the paging DCI for subgroup indication. Subgroup indication can be carried in the paging indication channel/signal.  Regarding the number of subgroups, we agree with Intel that the exact number can be decided after the paging indication structure (channel or signal) is decided. So, we think [4] may be a good start. |
| Nokia | We support the FL proposal.  As discussed in our paper we saw that DCI based PEI provides largest power saving gains, and on top of it sub-grouping can provide further benefit at least in low SINR scenario. The benefit saturates at 8 sub-groups at paging rates 10% to 40%  In addition, we do not see benefit of supporting sub-grouping indication in paging DCI within a PO. |
| Sony | The design of the PEI needs to be finalized before any decision on UE sub-grouping. |
| Apple | We feel the same way as Sony that we need to have a better idea on the PEI design before making decision on UE sub-grouping. It seems clear from the evaluations that sub-grouping only shows noticeable gain when the group paging rate is high, and there were comments from the network vendors that 10% group paging rate is likely more typical.  We are not suggesting that sub-grouping should not be considered, but we feel the design of PEI should not be dictated by whether we support sub-grouping or not. This should be a secondary consideration. However, once we agree to the proposal/observation, it will impact the design choice. |
| Nordic | We support FL proposal. If Sub-grouping is supported than it shall be in PEI. Other option is not to support sub-grouping at all. |
| MediaTek | We support carrying UE sub-grouping information via paging early indication. As stated by Huawei and Nokia, group paging rate is network dependent, and combining UE sub-grouping and paging early indication shows power saving gain up to 8.0% to 16.1%, based on equal paging probability for each UE subgroup. For the case UE sub-grouping is utilized to separate UEs of different paging probabilities, there can achieve 14% - 19% UE power saving gain, as shown in our RAN2 contribution R2-2101539.  For maximum number of subgroups to be carried in PEI, we also agree it highly depends on the specific PEI design and should be FFS at this stage. On the other hand, Observation 1 is useful to show partitioning too many subgroups for a UE group or a PO cannot achieve proportionally increased power saving gain. |
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## UE Behavior if UE Misses PEI

For characterizing PEI candidate designs, the required UE behavior when UE misses PEI will cause fundamental difference to the performance metrics. From companies’ contributions, there are two behaviors:

* Behv-A: UE is not required to monitor PO if UE misses PEI for the targeted PO
* Behv-B: UE is required to monitor PO if UE misses PEI for the targeted PO

The proposal is therefore suggested for characterizing PEI candidate designs, and companies please input your comments/suggested revisions in Table 2.

Proposal 2: The following UE behaviors are considered in charactering PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS:

* **Behv-A: UE is not required to monitor PO if UE misses PEI for the targeted PO**
* **Behv-B: UE is required to monitor PO if UE misses PEI for the targeted PO**
* **FFS: Whether selection of the required UE behavior is based on network configuration**

Table 2: Companies’ comments/suggested revisions to Proposal 2

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| **Company** | **Comment(s)/Suggested Revision(s)** |
| Qualcomm | Behv-A is assumed by the UE. This has more power saving gain than Behv-B. |
| CATT | First, we would like to clarify whether PEI would have one or multiple monitoring occasions to associate with paging monitoring occasions. Since UE might not be in a cell, the paging strategy is to page UE in the last camped cell and neighboring cells. If UE does respond to the paging, the network would extend the paging area. Thus, there could be more than one paging occasion for UE in a DRX cycle. If we want to define either Behv-A or Behv-B, we need to specify the configuration of PEI first. |
| Intel | Behv- A.  Also, “misses PEI” does not seem to be correct terminology. We suggest to revise as follows:  **Behv-A: UE is not required to monitor PO if UE does not detect PEI for the targeted PO**  On the other hand, we think the intention of the proposal is not quite clear. Purpose is to study or to agree to something? In particular, what does it mean by “considered in character(iz)ing PEI candidate designs”? Depending on choice of PEI, different behaviors may apply/make sense to different choices, and there is no reason to agree to such options here if we are just saying that we will study the available candidate PEI designs considering these possible behaviors. In such a case, there is also no need for the FFS bullet if the intention is to study. |
| Xiaomi | Our preference is Behv-B.  As to power consumption, Behv-A/B has almost the same power consumption from the UE side, since no matter how, UE has to check PEI every time. And only false detection, which is with little probability, would cause the UE to receiving PO unnecessarily by Behv-B.  But for Behv-A, when miss detection happens, UE would miss the paging DCI in PO, and gNB has to do re-paging in the next DRX cycle, thus cause extra delay and also extra power consumption from gNB side.  But for now, we can agree with this proposal and do some further study. |
| Lenovo, Motorola Mobility | We think that the network should be able to configure, per UE group, a desired UE behavior when the UE does not detect PEI. Behv-A allows for the network to skip transmission of PEI, if there is no paging in a corresponding PO. Behv-B is beneficial to avoid missed paging reception due to missed PEI detection. |
| Samsung | Behv-A is necessary. And NW can transmit PEI on-demand. |
| vivo | We agree with Samsung Behv-A is essential.  As discussed in our TDoc [R1-2100452], with considering resource overhead and the flexibility of network, it will be reasonable to allow PEI discontinuous transmission (DTX) for the case when there is no UE will be paged in a PO. So, we suggest to revise proposal 2 as below with modifying in red:  Proposal 2: The following alternatives for UE behavior are considered in charactering PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS:   * **Behv-A: UE is not required to monitor PO if UE misses PEI for the targeted PO** * **Behv-B: UE is required to monitor PO if UE misses PEI for the targeted PO for invalid PEI MO(s), FFS invalid PEI MO(s)** |
| CMCC | The UE behaviour in Proposal 2 is also related to whether PEI is assumed to be always transmitted or can use DTX transmission, e.g., if PEI can be transmitted as DTX, Behv-A is more suitable.  Considering to reduce NW’s resource overhead, we prefer DXT for PEI and Behv-A. |
| Ericsson | In our understanding this proposal is to compare the performance of the different PEI candidate designs. The actual UE behavior wrt monitoring based on the indication in the PEI should be discussed separately when more progress is made on the contents of PEI. For example, if PEI does not carry short message, UE in either Behv-A or Behv-B may still have to monitor the PO.  From the perspective of evaluating the candidate PEI designs, both Behv-A and Behv-B should be considered, and perhaps this aspect can be made clearer in the proposal.  As other companies have also commented, “*if UE misses PEI for the targeted PO*” should be replaced with “*if does not detect a PEI for the targeted PO*”. |
| Huawei, HiSilicon | We prefer Behavior B, which can guarantees the paging DCI reception performance. The power saving gain may be slightly impacted when the MDR of PEI DCI increases to 10% e.g. in the cell edge.  However, according to the discussion in Monday GTW session, people may be understood that in Behavior B the gNB may not always transmit the PEI. To avoid the confusion, we suggest to put the proposal 2-Behv-B and proposal 4 together for the discussion. From proposal 4, the gNB shall guarantee the power saving gain to make the MDR fulfill 1% or 10% target. Similarly, the proposal 2-Behv-A and proposal 3 should be put together for the discussion.  Proposal 2: The following UE behaviors are considered in charactering PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS:   * **Behv-A:**    + **UE is not required to monitor PO if UE misses PEI for the targeted PO**   + **The joint miss-detection rate (MDR) of PEI and paging PDCCH should be no worse than paging PDSCH performance for minimum impact to paging detection performance**   + **The false-alarm rate (FAR) of PEI should be no larger than [1%] for minimum impact to power saving gain with PEI** * **Behv-B:**    + **UE is required to monitor PO if UE misses PEI for the targeted PO**   + **The miss-detection rate (MDR) and the false-alarm rate (FAR) of PEI should both be no larger than [1%] for minimum impact to power saving gain with PEI**   + **Note: Conditioned on this UE behavior, there is no impact to paging detection performance**   **FFS: Whether selection of the required UE behavior is based on network configuration** |
| OPPO | We prefer Behv-B. For NR idle/inactive-mode UE, if PEI is configured, UE should always monitor PEI before target PO with both Behv-A and Behv-B. The power consuming of monitoring PEI is the same for Behv-A and Behv-B.  If UE is paged in target PO,   * For Behv-A, if UE misses PEI, UE will also miss paging. * For Behv-B, if UE misses PEI, UE will not miss PO.   If UE is not paged in target PO,   * For Behv-A, if UE misses PEI, UE will not monitor PO, which brings power saving for PO monitoring. * For Behv-B, if UE misses PEI, UE will monitor PO with power consumption.   In our view, the paging reliability should not be degraded with the introduction of PEI in R17. Behv-B can avoid missing paging by UE in target PO, if it is paged. It is preferred. |
| ZTE, Sanechips | Our preference is behavior B. The transmission of PEI is mainly for UE power saving purpose, which is at the cost of network resource overhead and energy efficiency. We don’t think the miss detection of PEI should further impact the paging performance. We agree with Xiaomi that as UE has already waked up to detect PEI, the additional energy caused by the detection of the PO is small.  Besides, the behavior A is unfavourable for both UE and network. For example, if UE misses the PEI with wake-up indication, this UE will skip the detection of PO, network will have to re-transmit the PEI, paging DCI, and paging PDSCH in the next cycle. **For other UEs who detect the same PEI or in the same UE group will be waked up again, which consumes more energy of these UEs associated with the same PEI or UE group. For network, the re-transmission of PEI, paging DCI, and paging PDSCH also costs more resource and energy.** |
| Spreadtrum | For the case that UE misses PEI, there could be some reasons, e.g. gNB DTX, UE miss detection. For gNB DTX, we think it is not friendly for UE power saving, since UE cannot early terminate PEI detection (DCI based). For UE miss detection, both Behv-A and Behv-B are reasonable. Like that discussed in DCI format 2-6, the miss detection impact should be discussed after WUS DCI is decided to introduce. Therefore, we share the similar view as CATT that this issue can be postponed. Moreover, a higher layer parameter can be introduced like for DCI format 2-6, regarding miss detection of DCI format 2-6. |
| DOCOMO | In order to keep paging performance compared with legacy, at least Behv-B should be considered. If UE does not monitor PO when UE does not detect PEI, it causes delay to receive paging message. Also, similarly as some companies, appropriate behavior seems different depending on design of PEI. |
| LG | At least Behv-A should be supported in terms of UE power saving.  Also, as pointed out some companies, it would be better to replace “misses” with “does not detect”  Regarding Behv-B, we need to clarify the exact UE behavior. In case of sequence based PEI, should the UE try to perform blind detection on all candidate sequences, including sequences for other UE sub-groups? If so, larger UE power consumption and higher complexity are expected as higher number of sequences are used. If not, (i.e. when the UE detects only sequences corresponding to its UE sub-group index) power saving gain from PEI would be marginal. |
| Panasonic | We support to discuss the UE behavior if UE misses PEI in different situations regarding network configuration, e.g. SI modification. As PEI is configured via SIB, the channel of the SI may impact the UE assumption regarding the PEI. |
| InterDigital | We think the behavior depends on whether the network is expected to always transmit the paging indication. Therefore, we think option C can provide the network full flexibility. |
| Nokia | Firstly, we think that one option supported should be that network (if PEI is configured) can transmit the PEI only when needed. In this context, Behv-A, so that when UE does not detect PEI, UE is not required to monitor PO would be beneficial from power saving perspective (to avoid unnecessary PO monitoring).  If there is an option to configure PEI is ‘always-on’ and the need to monitor PO is indicated via sub-grouping indication, Behv-B where UE is required to monitor PO if PEI is not detected, could be considered.  Note that in our understanding PEI can be used to trigger need to monitor paging PDCCH/PO, whether that is due to paging (for a given group) or due to need to receive shortMessage. In addition, at least based on current agreements, UE could always monitor PO, and doing so does not mandate monitoring/detection of PEI. |
| Sony | The two behaviours come down to the fundamental functionality of PEI. The behaviours seem to be associated to these scenarios:  Beh-A: PEI is WUS and is on/DTX. In this case, DTX would mean UE can go to sleep since it is not possible for the UE to know whether it has missed a PEI or no PEI exist in that occasion.  Beh-B: (1) PEI is WUS or GTS and is on/off. In this case, missing PEI would be an error case and the UE should assume the worst case (PEI on)  Beh-B: (2) PEI is GTS and is on/DTX. In this case, DTX would mean UE has to wake up  We propose to clarify the functionality of PEI and its connection to the two behaviours early on. This association of the two behaviours to PEI functionality has been described rather late in proposal 5-7. |
| Apple | It is not clear to use whether the proposal means that we support both behaviors, or we will study the two behaviors and make decision later. This needs to be clarified.  We agree this issue should be addressed, but we think it is better to discuss this later. This issue directly depends on whether the PEI transmission is expected to be always on, or it is transmitted only when the UE is paged. Therefore, we suggest discussing the more fundamental design principle first, and this issue can be decided much easier later on.  Our preference is that PEI is transmitted only when the UE is paged, and UE follows Behv-A. Of course the performance aspect needs to be addressed to ensure satisfactory paging performance. |
| Nokia | We think that Beh-A is essential for UE to save power. However, not OK with wording “misses”, it should be “if UE does not receive PEI” which would include also the case that UE detects PDCCH but PEI bit is set to 0. |
| MediaTek | We share the same understanding as Ericsson. The proposal is for characterization and evaluation of PEI candidate designs, instead of deciding either UE behavior. Also Sony’s suggestion is helpful to jointly describe network behaviors.  We also supportive to replace “misses” to “does not detect”. Regarding “valid” or “invalid” in vivo suggested proposal, we think this can be discussed after down-selection of PEI candidate designs. |
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We can further confirm the following properties based on Behv-A and Behv-B, respectively:

Proposal 3: When Behv-A is assumed for UE,

* **The joint miss-detection rate (MDR) of PEI and paging PDCCH should be no worse than paging PDSCH performance for minimum impact to paging detection performance**
* **The false-alarm rate (FAR) of PEI should be no larger than [1%] for minimum impact to power saving gain with PEI**

Proposal 4: When Behv-B is assumed for UE,

* **The miss-detection rate (MDR) and the false-alarm rate (FAR) of PEI should both be no larger than [1%] for minimum impact to power saving gain with PEI**
* **Note: Conditioned on this UE behavior, there is no impact to paging detection performance**

Companies please input your comments/suggested revisions to Proposal 3 and Proposal 4 in Table 3:

Table 3: Companies’ comments/suggested revisions to Proposal 3 and Proposal 4

|  |  |
| --- | --- |
| **Company** | **Comment(s)/Suggested Revision(s)** |
| Qualcomm | This is related to Proposal 2 for which we prefer Behv-A. Then we think proposal 3 is agreeable. |
| CATT | We need to define the PEI configuration and associated Behv in Proposal 2 before discussing proposal 3. We are Ok to define the miss-detection probability and false alarm rate for PEI in proposal 4. |
| Intel | Since this is related to Proposal 2, our comment is for the Proposal 3.  We think miss-detection target of 0.1% for the PEI at false alarm rate of 1% should ensure paging detection performance is not impacted. We do not see need for joint PEI and PDCCH detection and comparing this to PDSCH performance.   Hence, to simplify the analysis, we suggest the following for Proposal 3  Proposal 3: When Behv-A is assumed for UE,   * **The miss-detection rate (MDR) of PEI should be 0.1% with false alarm rate of 1% for minimum impact to paging detection performance and UE power saving gain.** |
| Lenovo, Motorola Mobility | Fine with proposal 3.  In proposal 4, suggest removing the “Note”. If a UE makes a wrong assumption, based on false detection of PEI, that there is no paging intended to the UE, the UE misses paging. Although this case may be rare, there could be small impact on the paging detection performance. |
| Samsung | In either case, the MDR of PEI can be discussed separately from paging PDCCH. For Behv-A higher target reliability of PEI should be considered than that for paging PDCCH. PEI only indicate paging PDCCH reception, no impact to paging PDSCH.  We support the modification from Intel. |
| vivo | In general, we are fine with proposal 3 and 4. |
| CMCC | Fine with proposal 3 and 4. |
| Ericsson | OK with proposals 3 and 4 as assumption for evaluations. |
| OPPO | Since Behv-B is preferred in our view, proposal 4 is fine for us. |
| ZTE, Sanechips | OK with proposals 4 |
| DOCOMO | Fine with proposal 3 and 4 as assumption for evaluations. |
| LG | We think proposal 3 is acceptable.  Regarding proposal 4, we need to clarify exact UE behavior first as we commented in table-2. The definition of missed detection and false alarm can depends on the UE behavior discussed above. |
| Panasonic | In general case that UE mis-detects the PEI, we support Behv-A which gives balance between system overhead and UE power saving. The proposal 3 is okay with us. |
| InterDigital | Agree with the proposals. |
| Nokia | With the assumption that PEI is not required to be always-on, we support proposal 3. |
| Sony | Considering the functionalities of the PEI for the two behaviours and to allow for a fair comparison the FAR in Beh-B (which is always transmitted) must be lower than Beh-A (which is only transmitted when there is a PEI), and the MDR of Beh-A lower than Beh-B.  If [1%] FAR is selected for Beh-A, then the FAR of Beh-B should be [0.1%].  If [1%] MDR is selected for Beh-B, then the MDR of Beh-A should be [0.1%]. |
| Apple | Even though the performance aspects should be considered, we think the choice between Behv-A and Behv-B mainly depends on the design philosophy whether we assume whether the PEI transmission is expected to be always on, or it is transmitted only when the UE is paged. Therefore, we suggest that the discussion start with this fundamental design point.  Also we do not think from the design point of view we should set different performance requirements for the two cases. Even if we assume PEI is always transmitted, the design should still target for good MDR performance from UE power saving point of view. |
| MediaTek | We are supportive to the requirements for limiting the impact to paging detection performance and UE power saving gain. When Behv-A is assumed, consideration of joint MDR of PEI and paging PDCCH actually follows RAN4 principle in defining requirements for Rel-16 power saving signal/DCP. Also 1% target for joint MDR is considered in RAN4. On the other hand, RAN4 also discussed whether to require 0.1% MDR on Rel-16 power saving signal/DCP but didn’t agreed it. In this regard, joint MDR and 1% target should be the right requirements. |
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## Assumptions for Resource Occupation

To characterize the resource occupation for PEI candidate designs, the following should be confirmed:

Proposal 5: For PEI design based on PDCCH and Behv-A/B, abbreviated by PEI-PDCCH-Behv-A/B,

* Resource allocation is in CSS
* For PEI-PDCCH-Behv-A: No PEI transmission only if there is no associated UE to be paged
* **For PEI-PDCCH-Behv-B: No PEI transmission only if resource conflict with legacy PDCCH**

Proposal 6: For PEI design based on TRS/CSI-RS and Behv-A/B, abbreviated by PEI-TRS-Behv-A/B,

* Resource allocation is in PDSCH region for connected-mode UEs
  + Rel-15 zero-power CSI-RS rate-matching pattern(s) or RB-symbol rate-matching pattern(s) should be configured to connected-mode UEs to avoid resource conflict
  + For UE supporting rate-matching per dynamic DCI indication, the resource can be utilized for PDSCH transmission to the UE if no PEI is transmitted.
  + For UE not supporting rate-matching per RRC configuration, the resource cannot be utilized for PDSCH transmission to the UE once the rate-matching pattern is configured to the UE.
* For PEI-TRS-Behv-A: No PEI transmission only if there is no associated UE to be paged
* **For PEI-TRS-Behv-B: PEI is always transmitted (i.e., higher priority than PDSCH of connected-mode UE)**
  + **Note: This allows the PEI to be utilized for synchronization**

Proposal 7: For PEI design based on SSS and Behv-A/B, abbreviated by PEI-SSS-Behv-A/B,

* Resource allocation is in PDSCH region for connected-mode UEs
  + Rel-15 RB-symbol rate-matching pattern(s) should be configured to connected-mode UEs to avoid resource conflict
  + For UE supporting rate-matching per dynamic DCI indication, the resource can be utilized for PDSCH transmission to the UE if no PEI is transmitted.
  + For UE not supporting rate-matching per dynamic DCI indication, the resource cannot be utilized for PDSCH transmission to the UE once the rate-matching pattern is configured to the UE.
* For PEI-SSS-Behv-A: No PEI transmission only if there is no associated UE to be paged
* **For PEI-SSS-Behv-B: PEI is always transmitted (i.e., higher priority than PDSCH of connected-mode UE)**
  + **Note: This allows the PEI to be utilized for synchronization**

Companies please input your comments/suggested revisions to Proposal 5, Proposal 6 and Proposal 7 in Table 4:

Table 4: Companies’ comments/suggested revisions to Proposal 5, Proposal 6 and Proposal 7

|  |  |
| --- | --- |
| **Company** | **Comment(s)/Suggested Revision(s)** |
| Qualcomm | For proposal 5, 6 and 7, agreed with Bhev-A PEI no transmission condition.  For proposal 6 and 7, the connected UE operation should be same as existing rate matching for Rel-16 UEs. There is no need to discuss it here. |
| CATT | The PEI resource allocation would depend on the number of PEI monitoring occasions. It is too early to discussion Proposals 5, 6, 7 before the conclusion of PEI monitoring occasions. |
| Intel | The overall intention of the proposals is not clear.  What does it even mean by “PDSCH region for connected-mode UEs”? PDSCH can be anywhere, and so can most other channels and signals in NR. There is no need to emphasize PDSCH as something special here.  Therefore, all the rate-matching related assumptions and bullets should be removed. We should count REs for OH calculations, and not based on a single gNB implementation option. In summary, PDSCH is NOT the only channel to be multiplexed in the DL, and even for PDSCH, rate-matching is NOT the only mechanism to realize coexistence.  Hence, we do not think coexistence with a specific channel should be assumed as reference for resource occupancy calculation. **The number of REs occupied by the signal/channel should be taken as reference for comparison.**  Also, it is not clear whether Note in Proposals 6 and 7 are applicable only for Behv-B or in general for PEI-TRS and PEI-SSS. In our view, PEI-TRS or PEI-SSS can be used for tracking when it is transmitted. |
| Xiaomi | Support Proposal 5. And further discuss may be needed for proposal 6/7  For PEI-TRS-Behv-B/ PEI-SSS-Behv-B, our view is that even PEI is not always transmitted, that is lower priority than PDSCH of connected-mode UE, the paging mechanism can still work(with Behv-B). And currently, we are not sure about the resource allocated to TRS/SSS-PEI. So we suggest to modify Proposal 6/7 as follows,  Proposal 6: For PEI design based on TRS/CSI-RS and Behv-A/B, abbreviated by PEI-TRS-Behv-A/B,   * If resource allocation is in PDSCH region for connected-mode UEs   + Rel-15 zero-power CSI-RS rate-matching pattern(s) or RB-symbol rate-matching pattern(s) should be configured to connected-mode UEs to avoid resource conflict   + For UE supporting rate-matching per dynamic DCI indication, the resource can be utilized for PDSCH transmission to the UE if no PEI is transmitted. * For PEI-TRS-Behv-A: No PEI transmission only if there is no associated UE to be paged * **For PEI-TRS-Behv-B: PEI is always transmitted (i.e., higher priority than PDSCH of connected-mode UE) or PEI is transmitted when there is no collision with PDSCH of connected-mode UE (i.e., lower priority than PDSCH of connected-mode UE)**   + **Note: This allows the PEI to be utilized for synchronization**   Proposal 7: For PEI design based on SSS and Behv-A/B, abbreviated by PEI-SSS-Behv-A/B,   * If resource allocation is in PDSCH region for connected-mode UEs   + Rel-15 RB-symbol rate-matching pattern(s) should be configured to connected-mode UEs to avoid resource conflict   + For UE supporting rate-matching per dynamic DCI indication, the resource can be utilized for PDSCH transmission to the UE if no PEI is transmitted. * For PEI-SSS-Behv-A: No PEI transmission only if there is no associated UE to be paged * **For PEI-SSS-Behv-B: PEI is always transmitted (i.e., higher priority than PDSCH of connected-mode UE) or PEI is transmitted when there is no collision with PDSCH of connected-mode UE (i.e., lower priority than PDSCH of connected-mode UE)**   + **Note: This allows the PEI to be utilized for synchronization** |
| Lenovo, Motorola Mobility | In proposals 5, 6 and 7, we don’t think 2nd and 3rd main bullets are necessary. Depending on whether PEI is intended to one or multiple groups of UEs, PEI transmission may or may not be skipped. Thus, we think RAN1 discussion should focus on UE behaviors, not the network behaviors. |
| Samsung | OK with Bhev-A PEI no transmission condition.  For PEI-TRS-Behv-B, and PEI-SSS-Behv-B in proposal 6 and 7, the UE behaviors are same no matter PEI is transmitted or not, i.e. UE wakes up for paging reception. Then the entire function doesn’t make any sense.  For rate-matching pattern, we share the same view as Qualcomm and Intel. No need to discuss. |
| vivo | Firstly, the topic is assumptions for resource occupation, but actually these proposals are related to the rate matching design and the corresponding network configuration with various UE behaviors for PEI detection, which should be discussed at a relatively later stage. Besides, the starting point of R17 power saving WID for paging enhancement is to reduce unnecessary UE paging receptions for the power saving purpose. Following this principle, the power saving gain is undoubtedly one of the crucial perspectives for PEI design, which should be discussed for different PEI design firstly.  For proposal 5,  PEI-PDCCH-Behv-B: PEI is always transmitted with some exception cases, e.g., conflict with legacy PDCCH, collied with SSB and RAR,  For proposal 6 and 7, it is more important to know whether the unused resources can be used from system perspective than UE perspective. From our understanding, there is no significant system-level overhead since the SSS/TRS/CSI-RS resources can be used for UEs supporting rate-matching. |
| CMCC | Support proposal 5.  Regarding proposal 6 & 7, agree with Qualcomm, three is no need to discuss rate matching behaviour. |
| Ericsson | In our understanding, these proposals are intended to evaluate the resource occupation for the different PEI candidate designs. This should be made clear in the proposals. For proposal 5, for Behv-B, always transmitting PEI cannot be assumed. In any case, our understanding is that the details wrt UE behavior would be discussed separately. |
| Huawei, HiSilicon | For this part, we prefer to firstly focus on the co-existence issue of PEI with legacy channels, e.g. some observations on rate matching of PDSCH to coexist with the PEI transmission. This is important aspect we need take into consideration because the PEI should not impact the legacy UE behavior and legacy channel performance. |
| OPPO | The issue is related to the physical channel/signal design for PEI. It is early to discussion this issue before down-selection among different physical channel/signal, i.e. DCI/TRS/CSI-RS/SSS is decided. After the physical channel/signal for PEI is conformed, we can further study issues of resource allocation, conflicting resolution, and so on. For the resource of PEI, it is proposed to use legacy defined resource. For example, DCI based PEI can share the legacy CSS. The resource allocation and conflicting resolution can follow the legacy mechanism. |
| ZTE, Sanechips | We agree with the motivation of the proposal 5~7. We think make sure that PEI can coexist well with other legacy signal or channel is an important factor to be considered in PEI design.  Regarding the last sub-bullet of proposal 6 and proposal 7, some update is suggested as below.  **For PEI-TRS-Behv-B: PEI is ~~always~~ transmitted when there is no associated UE to be paged ~~(i.e., higher priority than PDSCH of connected-mode UE)~~** |
| DOCOMO | We are fine with proposal 5 in principle. However, first of all, the intention of the proposals including proposal 5, 6 and 7 should be clarified. Are these the assumption for evaluation of the impact on other signal/channel? |
| LG | Regarding resource allocation parts(i.e. first sub-bullets) in proposal 5, 6 and 7 we have similar view with Qualcomm, Intel and Samsung. Reusing existing rate matching method should be considered since we do not see special reason so far.  Regarding 2nd and 3rd sub-bullets (i.e. PEI-XXX-Behv-A/B), intention is not clear for us.  As pointed out by Ericsson, intention of it should be captured clearly in the proposals. |
| Panasonic | Better to focus on the detailed PEI physical layer design before going into these proposals. |
| InterDigital | Agree with Panasonic. |
| Nokia | Assuming that the proposals are made in relation to consider/estimate the resource use/overhead, it would seem relevant to account the actual realized resource reservation/use. Hence, the possible multiplexing methods should be accounted when estimating the resource overhead. Like noted in our paper, the assumed RE use of the signal itself may not give a proper picture of the overhead.  In addition, if sub-grouping is supported, it should be further detailed how this is achieved with the proposed signal design and how it affects to the needed resource options. |
| Sony | We are OK with the proposal. As stated earlier, we propose to provide the association of PEI functionality to the two behaviours earlier for instance already in proposal 2.  Is RAN1 expected to downselect between these proposals? |
| Apple | The intention of these proposals is also a bit unclear to us. The proposals seem to describe mostly on how network operates in terms of rating matching indication. It helps with the understanding, but does not seem to fit in proposals.  An alternative way could be to simply describe different options, and the corresponding open issues for each of the options from standards impact point of view. |
| MediaTek | Coexistence with legacy UEs should be supported for PEI. In this regard, we can first clarify the assumptions for the PEI candidate designs. |
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The following proposals are awaiting chair’s email approval:

Proposal 1:

* Carrying UE subgroups information is considered in physical layer design for paging enhancement

Proposal 1a:

* Reply RAN2 LS (R2-2010884) with the above agreement and the following:
  + UE subgroups number RAN1 has evaluated ranges from 2 to 16
  + RAN1 prioritizes evaluation and specification on physical layer design for paging early indication

Proposal 2:

For the evaluation and comparison of PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS, the following are assumed:

* Behv-A:
  + PEI indicates UE should monitor a PO if UE’s group/subgroup is paged
  + UE is not required to monitor a PO if UE does not detect PEI at all PEI occasion(s) for the PO
* Behv-B:
  + PEI indicates whether or not UE should monitor a PO
  + UE is required to monitor a PO if UE does not detect PEI at all PEI occasion(s) for the PO

Proposal 5:

For the evaluation and comparison of PEI candidate designs, companies to report

* Description of how PEI design can co-exist with existing channels/signals, and impact to legacy UEs.
  + Rel-15 designs for multiplexing PEI with legacy channels/signals are assumed as baseline
  + Other multiplexing method with legacy channels/signals can be additionally reported with justification

# Secondary Round of Offline Discussion and Proposals

In RAN1#102-e, the following is agreed:

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| Agreements:  For the study on paging enhancements to reduce unnecessary paging reception, the following metrics are considered:   * UE power saving gain (relative to a given feature or overall) * Impact to UE paging detection probability   + FFS: Link level simulation assumptions * System impact, including   + Additional resource overhead and its implications   + Impact to Rel-15/Rel-16 idle/inactive-mode UEs and connected-mode UEs   + Impact to other legacy functionalities, including SI change and ETWS indication   + [Note: NW energy consumption evaluation is not precluded] |

Companies are invited to provide views on the following proposals for the evaluations and comparisons according to the above agreements in this Section.

Proposal 7:

To minimize the detection performance impact with PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS,

1. The following performance requirements are assumed
   1. When Behv-A is assumed:
      1. Alt-1 MDR requirement: The joint miss-detection rate (MDR) of PEI and paging PDCCH defined as follows should be no worse than the performance of paging PDSCH at MDR target of 1%:

MDRJoint = MDRPEI + (1 - MDRPEI) MDRPagingPDCCH

* + 1. Alt-2 MDR requirement: The MDR of PEI should be no larger than 0.1% at the SNR where MDR of paging PDCCH is 1%
    2. The False-Alarm Rate (FAR) of PEI should be no larger than [10%] at the SNR where MDR of the targeted paging channel is 1%
  1. When Behv-B is assumed:
     1. Alt-1 FAR requirement: PEI FRA is subject to that the joint MDR of PEI and paging PDCCH defined as follows should be no worse than the performance of paging PDSCH at MDR target of 1%:

MDRJoint = FARPEI + (1 - FARPEI) MDRPagingPDCCH

* + 1. Alt-2 FAR requirement: The FAR of PEI should be no larger than 0.1% at the SNR where MDR of paging PDCCH is 1%
    2. The MDR of PEI should be no larger than [10%] at the SNR where MDR of the targeted paging channel is 1%

1. Companies to provide:
   1. The utilized detection method for each PEI candidate design (e.g., non-coherent detection or coherent detection)
   2. The required #REs to comply with the above requirements
   3. The maximum number of subgroups that can be carried in PEI, subject to the performance requirements

Table 5: Companies’ comments/suggested revisions to Proposal 7

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| **Company** | **Comment(s)/Suggested revision(s)** |
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Proposal 8:

To check the resource overhead with PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS,

1. Assume the following network PO setting:

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| --- | --- |
| Paging cycle length (ms) | 1280 |
| #PF per paging cycle, N | 128 |
| #PO per PF, Ns | 4 |
| Paging rate per PO | 10 % |

1. Companies to report additional evaluation assumptions for each PEI candidate design:
   1. The utilized coexistence method
   2. PEI sharing by one or multiple POs
2. Based on the above assumptions, companies to provide the average number of occupied resources per PO per paging cycle for each PEI candidate design:
   1. Defined as (#REs subject to the coexistence and performance requirements) \* (resource occupation probability) / (#PO sharing a PEI)
   2. Note: The resource occupation probability depends on Behv-A/B and the utilized coexistence method.

Table 6: Companies’ comments/suggested revisions to Proposal 8

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| **Company** | **Comment(s)/Suggested revision(s)** |
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Proposal 9:

To check UE power saving gain with PEI candidate designs based on PDCCH, TRS/CSI-RS and SSS,

1. Assume the evaluation assumptions in RAN1#102-e meeting
2. Companies to report the following assumptions for each PEI candidate design:
   1. PEI detection power value, which lies between 45 (micro sleep) to 50 (PDCCH-only)
   2. UE processing timelines with assume #SS bursts before PO = 1, 2 and 3
   3. #SS burst(s) before PEI detection to comply with the performance requirements on PEI; justification required
3. Based on the above assumptions, companies to provide the average power saving gains w.r.t. 1, 2, and #SS burst before PO for each PEI candidate design

Table 7: Companies’ comments/suggested revisions to Proposal 9

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| **Company** | **Comment(s)/Suggested revision(s)** |
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Proposal 10:

To Impact to other legacy functionalities, including SI change and ETWS indication, with PEI candidate designs, companies to report whether and how the legacy paging functionalities can be kept.

Table 8: Companies’ comments/suggested revisions to Proposal 10

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| **Company** | **Comment(s)/Suggested revision(s)** |
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Proposal 11:

To check the feasibility of carrying availability indication of connected-mode TRS for idle-mode UEs with PEI candidate designs, companies to report whether and how TRS availability indication can be accommodated.

Table 9: Companies’ comments/suggested revisions to Proposal 11

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| **Company** | **Comment(s)/Suggested revision(s)** |
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# Summary

(To be updated)

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