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

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

**Source: Moderator (Apple Inc.)**

**Title: Feature lead summary #1 on reduced PDCCH monitoring**

**Agenda item:** **8.6.2**

**Document for:** **Discussion and Decision**

# 1 Introduction

This document summarizes the contributions made under the “reduced PDCCH monitoring” agenda item of the Rel-17 study item on “Study on support of reduced capability NR devices”.

The revised RedCap SID [1] contains the following objective related to this agenda item:

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| Study UE power saving and battery lifetime enhancement for reduced capability UEs in applicable use cases (e.g. delay tolerant) [RAN2, RAN1]:   * Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits [RAN1]. * Extended DRX for RRC Inactive and/or Idle [RAN2] * RRM relaxation for stationary devices [RAN2] |

In RAN1 #101 e-meeting, the following agreements on this topic was reached:

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| *Agreements:*   * Study the impact of BD and CCE limits reduction on power saving and PDCCH blocking probability (quantitatively) and impacts on latency and scheduling flexibility (at least qualitatively). * Reuse the power consumption models and scaling factors for FR1 and FR2 provided in TR 38.840 (sections 8.1.1, 8.1.2, 8.1.3) as appropriate. * For evaluation of UE power saving, for wearables, use the traffic models FTP model 3 and VoIP from TR 38.840 to characterize the wearables service types including IM, VoIP, heartbeat, etc. with proper modification of at least packet size and mean inter-arrival time. Values are FFS. * For evaluation of UE power saving, for industrial wireless sensor use cases, use a traffic model based on the service performance requirements for the process monitoring use case in TS 22.104 Table 5.2-2. At least 64 bytes UL message (plus headers, e.g. MAC, RLC, etc.) transmitted periodically with a periodicity 100 ms should be considered (other values are encouraged). |

# 2. Evaluation methodology for power saving techniques

## 2.1 Traffic model

As stated in the introduction, the VoIP and FTP3 models are agreed to be used for evaluation. However, the packet sizes and mean arrival rates need to be defined for wearables and video surveillance. Several contributions [4,8,18] discussed this open issue.

**VoIP model**

For VoIP model, [4,18] propose to follow the assumption in R1-070624, which is aligned with TR 38.840. In [8], it proposes, in addition to VoIP and FTP model, perform evaluations for the following two cases:

* VoIP-like model with packet size of 7.5kByte and 20ms inter-arrival time
* VoIP-like model with packet size of 75kByte and 20ms inter-arrival time

Based on the above summary, a possible way forward is to reuse VoIP model in TR 38.840 (essentially reuse R1-070624) and further discuss the necessity of two additional cases proposed in [8].

**Question 1: For VoIP traffic model, can the traffic models from TR 38.840 be reused as proposed in [4,18]? Do we need to additionally evaluate the two cases proposed in [8]?**

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| **Company** | **Comments** |
| vivo | We think the existing VoIP model in TR38.840 can be reused, if there is a need to evaluate VoIP performance. |
| OPPO | We are fine with that. It can help for evaluation of schemes for RedCap UEs. All those traffic model seems also applicable for other agendas of RedCap. |
| Xiaomi | Reusing the traffic model from TR 38.840 is the baseline. Results based on the new cases are encouraged. |
| Fraunhofer | Yes. We see VoIP according to R1-070674 as a good fit for IWSN applications whereas FTP-model should be able to fit wireless camera applications (non-streaming) and other use cases. We propose to have a short discussion about the VoIP inter-arrival time because it is quite short compared to real-world industrial sensors in automation systems.  We agree that a higher number of 7.5kBytes for the VoIP model – as proposed in [8] – should be used for evaluation in case of video-transmission (streaming). We do not see the requirement to go for 75kBytes. |
| MediaTek | Fine to use the traffic model from TR38.840 as starting point for VoIP traffic model. |
| Futurewei | We are fine with the methodology of TR38.840. In our view, we should also look at traffic models with higher data rate, (e.g., video). This is the motivation for the 75kB modification we proposed |
| SONY | The traffic models from TR 38.840, including VoIP can be reused for RedCap UEs. |
| Ericsson | No need to consider the first case “VoIP-like model with packet size of 7.5kByte and 20ms inter-arrival time”. The second case may be considered. |
| Panasonic | OK to follow the model of TR38.840. |
| CATT | VoIP TR38.840 can be reused if necessary. |
| CMCC | Fine to use traffic models from TR 38.840. |
| InterDigital | We are fine to use the traffic model from TR 38.840 as starting point. |
| Sequans | VoIP traffic models in TR38.840 can be reused as staring point. |
| Lenovo, Motorola Mobility | The VoIP traffic model in TR 38.840 can be reused as a baseline VoIP traffic model. |
| Samsung | We are OK to reuse VoIP model in TR38.840 (There is a typo, R1-070624 should be R1-070674). The parameters may be updated to be in line with RedCap traffic requirements. The corresponding parameters to consider include encoder frame length = [20]ms, max packets bundled = [1], and packet size: [75] kBtype.  We also think it’s OK reuse the DRX setting correspond to the traffic model, i.e. (DRX cycle, inActivityTimer, ON duration) = (40ms, 10ms, 4ms), |
| Qualcomm | It is enough to use VoIP model in TR 38.840 for power saving evaluation if the evaluation is to be performed with VoIP model. RedCap power saving agenda does not have to consider all possible traffic models for RedCap application if we can get sufficient evaluation result of power saving techniques based on certain models. |

**FTP-3 model**

In TR 38.840, the instant message traffic model was modelled with packet size of 0.1Mbytes and 2s mean inter-arrival time. [18] proposed to fully reuse them. While, [4] proposes to reuse the packet size assumption and increase the mean inter-arrival time from 2s to 640s. For heartbeat application, different parameters were proposed for evaluation as summarized in the following Tables.

* FTP-3 model
  + Instant message

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| --- | --- | --- | --- |
|  | Payload (Bytes) | Mean Arrival Rate | Note |
| Option 1 [4] | 0.1M | 640 s |  |
| Option 2 [18] | 0.1M | 2 s | Aligned with TR 38.840 |

* + Heartbeat

|  |  |  |
| --- | --- | --- |
|  | Payload (Bytes) | Mean Arrival Rate |
| Option 1 [4] | 100 | 300 s |
| Option 2 [18] | 64 | 100 ms |

**Question 2: Can the VoIP traffic model defined in TR 38.840 be reused for this SI. What, if any, modification is needed e.g. mean arrival rate? For heartbeat traffic model, which option should be adopted for evaluation?**

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| **Company** | **Comments** |
| vivo | We think the existing IM traffic model in TR38.840 can be reused.  In the two proposed heartbeat model, the mean arrival rate is very diverging, especially we are not sure why a dense arrival rate as 100ms is considered as an heartbeat traffic. |
| OPPO | We thought the 640s and 300s sort of time unit would be too long for RedCap use case(may be are typos?). At least the instant message would not so large interval  . In that sense the Option2 would be preferred. |
| Fraunhofer | Guess this question is about FTP-3 model... For IM we do not have a strong preference but 640s seems quite large. Maybe in [4] it is ms instead of s?  In case of heartbeat traffic, we propose to rename the traffic model because “heartbeat” for wearables might be a total different use case than the “keep alive signal” to a server that was described in [4]. |
| Futurewei | Okay to use TR38.840 as baseline. New traffic models need to be considered only if something new can be learned from them, and do not necessarily need to be tailored for a given traffic model |
| SONY | Shouldn’t this question be referring to the FTP-3 traffic model (as per the paragraph and heading above)?  For instant messaging the option aligned with TR38.840 to be considered. For heartbeat it is not very clear why a dense arrival rate is considered. |
| Ericsson | The FTP-3 model defined in TR 38.840 be reused. For Instant Message, 100 s mean arrival rate can be considered for the evaluation purposes (640 s is large, and 2 s seems small). For heartbeat traffic model, Option 1 can be considered. |
| Panasonic | Probably "VoIP traffic model" in the question would be typo of "FTP-3 model". Yes, we are ok with TR 38.840 model. |
| CATT | For IM traffic model, option 2 is preferred. Not sure why an interval time as large as 640s, i.e. more than 10 minutes, can be assumed for IM.  For heartbeat traffic model, we agree with vivo and don’t see the reason to support a dense interval like 100ms considering the heartbeat is defined as beats/second. Option 1 is preferred. |
| InterDigital | We are ok to use the TR 38.840 model. For the heartbeat, the two proposed mean arrival rates are quite different. We may need some discussion to better understand the two views. |
| Samsung | We are OK to reuse IM traffic model in TR38.840, and are also open to update mean arrival rate be in line with RedCap traffic requirements.  Option 2 captured for Heartbeat was actually used for process monitoring in our contribution according to the agreement from last meeting. It’s based on based on periodic deterministic communication instead of FTP-3 model.  In addition to the traffic parameters, it’s also necessary to reach consensus on the DRX setting corresponds to the traffic model. The same DRX setting. We suggest to reuse the DRX setting for IM, i.e. (DRX cycle, ON duration, inActivityTimer) = (320ms, 10ms, 80ms), and DRX setting for process monitoring to be (DRX cycle, ON duration, inActivityTimer) = (100ms, [1]ms, [1]ms). |
| Qualcomm | Reuse TR 38.840 instant message traffic model. There is no obvious need to study the standalone heartbeat traffic model for power evaluation performance. The reason is the heartbeat information is local to wearable, which means the device does not send heartbeat information to server or does not send the information in real time.  We wonder whether 640s and 300s are typos for 640ms and 300ms. If they are indeed 640s and 300s, a better to model such a long inter-arrival time traffic, we propose to reuse the “background sync” use case already agreed in Rel-16 TR:   * For background app sync application, for power consumption evaluation purpose, it can be assumed that idle mode operations (inclusive of page detection, RRM, deep sleep and transition overhead) contributes to X% of the use case power. The remaining portion is contributed by intermittent RRC connections due to background activities (FFS: value of X)   A minor issue is the “Mean Arrival Rate” should be “inter arrival time” |

## 2.2. Power consumption model

A few contributions [5,14,18,24] discussed the need to modify power consumption model in TR 38.840. In section 8.1 of TR 38.840, the UE power consumption model with different power state as listed in Table was agreed with a set of reference configuration assumptions, which includes the following:

* SCS: 30kHz
* System Bandwidth: 100 MHz
* PDCCH: 2 symbols, 56 maximum number of CCEs, 36 PDCCH blind decoding
* Antenna configuration: 4 Rx
* UE processing capability 1

On top of this basic model, different power scaling schemes were defined to adapt to different configurations of bandwidth, CA, antenna number, cross-slot scheduling and PDSCH-only.

Table below summarizes issues identified for scaling factors of the power consumption model in TR 38.840, which may motivate certain modifications to evaluate the power consumption of RedCap devices:

|  |  |  |
| --- | --- | --- |
| Issue Index | Description | Contribution |
| 1 | The power consumption for a “PDCCH-only” monitoring slot is the same for same-slot and cross-slot scheduling cases, i.e. max {100\*0.4/ 70\*0.4, 50, 45}. [5] | [5] |
| 2 | After applying scaling factor of bandwidth and antenna number, the power assumption for RedCap can be less than the micro-sleep value (i.e. 45). | [5,18,24] |
| 3 | The scaling factor for 2 Rx to 1Rx was missed | [5] |
| 4 | 3-OS CORESET and number of CCEs were not modelled in PS model of TR 38.840 | [14] |

[5,14] propose to define new scaling factor to address the identified issues. While, for simplicity purpose and taking into account the time left for this SI, [18] suggest reusing power consumption model in TR 38.840 without using scaling factor for power saving evaluation of RedCap SI. At least for issue 2, FL view is that it can be easily addressed by using max (xx, 45) operation.

**Question 3: Can we reuse the power consumption model in TR 38.840 without applying scaling factor? If not, which modifications are needed, e.g. what values of scaling factor should introduce?**

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| **Company** | **Comments** |
| vivo | We identified following issues when reusing the existing power model and scaling factor in TR38.840   1. If the existing bandwidth scaling (Scaling of X MHz = 0.4 + 0.6 \* (X - 20) / 80) is applied, the PDCCH-only monitoring power for 20MHz will be 40, which is lower than the micro sleep power (45), this is unreasonable. Even if we following the rule in TR38.840 “If the power after scaling is smaller than the BWP transition power, assume the BWP transition power as the output of scaling unless otherwise justified.”, the power for 20MHz PDCCH only is still too close to micro sleep. Some adjustment is needed, for example, lower the micro sleep power for 20MHz? 2. There is no scaling factor for 2Rx to 1Rx currently available. Suggest to consider 0.7 as the scaling factor which is the same as FR2, i.e. 1Rx power is 0.7 of 2Rx power. Furthermore, the existing micro sleep power does not scale with number of Rx, which seems to be unrealistic, suggest to also consider Rx scaling for micro sleep power. 3. If we follow the existing power scaling rule, for 20MHz, the PDCCH-only power for same-slot scheduling will be 100\*0.4 = 40 and PDCCH-only power for cross-slot scheduling will be 40\*0.7 = 28. There are two problems, firstly both of them are lower than the BWP switching or micro-sleep power, which is unreasonable. Secondly if we follow the rule in TR38.840 “If the power after scaling is smaller than the BWP transition power, assume the BWP transition power as the output of scaling unless otherwise justified.” both same-slot and cross-slot power will be the same as BWP switching power, i.e. 50, which is also unreasonable. Refinement for the power model is needed to obtain a reasonable outcome. |
| OPPO | We are fine with the missing part of model, Then the “3” is definitely fine to us. The 1 and 2 is also seems to be reasonable. We propose to reduce the options of further configurations. |
| Xiaomi | Some update is needed. At least issue 3 should be addressed. |
| Futurewei | Power model of 36.840 is the baseline. Modifications are needed. The solution proposed by Vivo for 2) is a good solution. For 1) and 3), a solution is to scale the microsleep power is needed and can be as simple as scaling the microsleep power |
| SONY | The issues raised by vivo are reasonable and need to be addressed. |
| Ericsson | Reuse the power consumption model and scaling factors in TR 38.840, and consider max(xx, 45) operation to avoid having values less micro-sleep power. |
| Panasonic | DCCH-only model should be revisited. Technically, we agree the issue#1, 2, 4 for PDCCH monitoring power model. Particularly on issue 4, the OFDM symbol number and positions can both be extended if possible. On issue 3, it is not simply scaling as RF part takes larger portion. We don't agree FL view on max (xx, 45) operation. |
| CATT | We agree with FL’s suggestion on issue 2. For issue 4, maybe it can be deprioritized as 1) not sure about the impact of power saving for 3-OS CORESET 2) number of CCEs is not considered in TR38.840 as it only impact the channel estimation, not sure how can we convert the complexity of CE into power saving. |
| CMCC | Fine with vivo’s view. |
| InterDigital | We agree that these issues should be addressed. For issue (2), we can follow ViVo’s recommendation. For issue (1), whether to reduce the microsleep power for 20 MHz or to follow FL’s recommendation ( max(xx, 45) ) needs further discusison. After issue (1) is resolved, issue (3) can be discussed. |
| Sequans | Some modifications are needed. Issues 2 and 3 seem reasonable to consider. |
| Lenovo, Motorola Mobility | Micro-sleep value can be adjusted considering 20MHz BW, and need to agree on scaling factor for 2Rx to 1 Rx. |
| Samsung | We think it’s not OK to reuse the scaling rule in TR38.840. The scaling factor regarding reduced number of BW and antennas are suitable for PDCCH based adaptation. But for RedCap cases, the reduction on power consumption relative to eMBB is determined by reduced complexity and UE capability. In our view, if scaling is needed, it should be applied to any power state, including sleep state. So, for the benefit of evaluation simplicity, we suggest to reuse the relative power models in TR38.840, and skip power scaling due to reduced UE operation BW and antennas for the baseline of RedCap.  To evaluate power saving from PDCCH monitoring reduction, the scaling rule of BDs in TR 38.840 can be a starting point. |
| Qualcomm | In addition to the above proposals, if a BW below 20MHz is adopted for RedCap devices, the corresponding power scaling for BW < 20MHz also needs to be defined. |

In addition, power model modification is needed to evaluate some power saving schemes proposed for RedCap devices. In [18], it was proposed to adopt the following power consumption model to study the power saving performance of extended span gap X (e.g. X>1 slot).

Where is the power for PDCCH monitoring without relaxation, i.e. PDCCH only. is the power for respective activity excluding PDCCH processing. Concrete examples of this equation were also provided in [18]

**Question 4: For evaluation of extended span gap X slots (X>1) proposal e.g. in [18], can we extend the power consumption model by using equation 1 above? If not, what modification is needed?**

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| **Company** | **Comments** |
| vivo | As discussed in [18], the is the micro sleep power, however, if we scale the with reduced BW, e.g. 20MHz, the outcome will be constant regardless of X value, i.e. always equals to , which again justifies to refine the micro sleep power according to reduced BW and Rx.  could be a simple way to model the extended span gap X, however, as discussed in our paper [5], we think more accurate approach would be to split the power contribution to Rx power and baseband power. Assuming cross-slot scheduling and only one MO=3Os per X slots, the Rx power is only considered in the 3OSs for RF reception but the baseband power for PDCCH processing can be scaled by 1/X. |
| OPPO | We are supportive for the extension into X. The equation 1 is ok |
| Futurewei | It is unclear if the extended gap is within the SID:  *• Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits [RAN1].”*  The extended gap does not reduce the number of blind decodes, it spreads them over time. Thus, RAN1 does not need to study |
| SONY | The extended span gap scheme seems to be a single company proposal [18] and we don’t need to prioritise a power model for this.  The “PDCCH only” energy in TR38.840 accounts for some RF power and some baseband power in a slot. If the processing is extended across a span of more than one slot, the baseband power would be spread across the slots, but the RF power wouldn’t. Hence Pt / X doesn’t seem to be the right way to account for processing across a span. |
| Ericsson | The proposed model is OK if extended gap needs to be evaluated. However, this model is not accurate, based on this model for X greater than a threshold then increasing the span gap will not help in power saving (P=Ps), which is not reasonable.  Alternatively, we propose the following model: P(X) = (Ps+(Pt-Ps)/X), where power consumption of a state by excluding PDCCH part (if it is included), and Pt is power consumption of the state. This ensures that the power consumption is always greater than Ps. Some results:   * For X=1 we get P=Pt, which is correct. * In “PDCCH-only” (includes PDCCH+micro-sleep in the slot), Pt=100, Ps = Pmicro=45, then for X=2 we have P=45+55/2=72.5. * In “PDCCH+PDCCH” for FR1, Pt=300, Ps = Ppdsch-only=280, then for X=2 we have P=280+20/2=290. * For very large value of X, P becomes Ps, which is reasonable. |
| Panasonic | Power consumption model for relaxed PDCCH decoding was discussed in power saving SI in Rel.16 but not concluded. It would not be required to have such new model. |
| Samsung | We think it’s necessary to consider scaling rule regarding extended PDCCH processing over X slots. The and are the relative power of baseline configuration. As explained in our reply to Q3, the scaling rules in TR38.840 regarding reduced antennas and BWP are not applicable to determine the values for and . There should still be significant power difference betwen and for RedCap baseline configuration. |
| Qualcomm | Power consumption of PDCCH processing may not be further reduced when the processing timeline is further relaxed. It is not clear why a cross-slot scheduling PDCCH-only power consumption cannot be directly used here. We do not think this formula is needed. |

# 3. Power saving techniques

## 3.1 Support of Rel-16 power saving techniques

Several contributions [4,8,26] propose to evaluate which Rel-16 power saving technique(s) can be supported for RedCap devices, which includes DRX adaptation based on DCI format 2\_6, cross-slot scheduling, adaptation of MIMO layers, RRM relaxation for neighbor cells, dormant SCell and UE assistance information. [4,8] proposed that RedCap devices can utilize all of them for power saving purpose, except UE-assist information (2nd priority in [8]) and dormant SCell subject to the conclusion on CA support of RedCap devices.

**Question 5: Can Rel-16 power saving techniques be optionally supported by RedCap device? If so, which techniques can be optionally supported?**

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| **Company** | **Comments** |
| vivo | Technically we think DCI format 2\_6, cross-slot scheduling, RRM relaxation, UE assistant information can be beneficial for RedCap UEs thus may be supported. However, given all these Rel-16 UE power saving features are optional for UE, a Redcap UE can decide to support none, some or all of them, which is a product choice. Unless we would like to make some of the features “mandatory” for RedCap UEs (which we believe there is no such need), we do not see much need to decide anything for Question 5. |
| OPPO | We consider this is more like UE capability issue and the basline comparison issue. |
| Xiaomi | Even though some Redcap UEs would stay in RRC\_IDLE and RRC\_INACTIVE modes most of time, it is equally important to reduce the power consumption during RRC\_CONNECTED mode.  The R16 UE power saving is mainly focused on RRC-Connected mode, including power saving signal/channel for C-DRX, enhancement on the cross-slot scheduling, DL maximum MIMO layer adaptation and UE assistance information. For idle mode, RRM measurement relaxation for the neighbour cell is specified. We think at least the following schemes can be taken for Redcap UEs.   * Power saving signal/channel for C-DRX; * Enhancement on the cross-slot scheduling; * UE assistance information: C-DRX parameters, RRC state transition; * RRM relaxation for idle/inactive mode;   In the meanwhile, some schemes might not suitable for Redcap UEs. As the Redcap UEs might not adopt CA, it seems power saving signal/channel working as SCell group dormancy indication is not necessary. Some UE assistance information as mentioned above, such as C-DRX parameters are applicable for Redcap while the maximum number of SCells, maximum aggregated BW and maximum MIMO layer might not be applicable since Redcap UEs with low cost/complexity will work with UE bandwidth reduction and reduced number of UE antennas. Besides, DL maximum MIMO layer adaptation might not be needed if a Redcap UE only support limited number of receive antennas to 2RX or 1RX. However, currently RAN1 is discussing the antenna configurations for Redcap UEs. We can wait for more inputs.  It is also worthwhile to notice that some possible enhancements can be considered to cate for Redcap devices. An example is that WUS applied to multiple DRX Ondurations was excluded for eMBB users in R16 as people showed concerns about the delay. However, it should be noted that a 1-to-N mapping is advantageous for the Redcap UE power savings if the UE will not consider the delay to be critical especially for IoT scenarios. |
| Fraunhofer | Yes, RedCap UEs should make use of Rel-16 power saving techniques. Adaption of MIMO layers, RRM relaxation for neighbour cells and DRX adaptation may provide benefits if used optionally. However, Cross-slot scheduling should be mandatory for all RedCap UEs as it shows substantial gains and the increase in complexity is negligible. |
| MediaTek | Yes, certainly RedCap UEs will make use of Rel-16 power saving features. Also, we expect the RedCap UEs to make use of other power saving feature that would be introduced in Rel-17.  It is infeasible to achieve the targeted power saving without Rel-16/Rel-17 features.  We don’t see any justification to not utilize such features. |
| Futurewei | It is unclear if the question is for evaluation or for what is supported. As it is the case for any new release, we should assume the rel-16 techniques are available and used when considering a new technique for redcap. i.e., should not avoid existing techniques to promote a new technique.  All optional techniques for NR are by default still optional and available to RedCap. We are OK to say that CA related ones are (maybe) not supported (like dormant cell), but that can be decided later. So the decision is whether these techniques are either included in the eval (yes) or recommended for redcap (yes). |
| Ericsson | Yes. DRX adaptation, cross-slot scheduling, and UE assisted information can be optionally supported. Also, if RedCap supports CA, Dormant BWP can be considered. Adaptation of MIMO layers may be supported depending on the number of the number of RedCap antennas and UE capability. |
| Panasonic | All power saving techniques in Rel-16 can be supported except CA related function. |
| CATT | We share the similar views as vivo and oppo. |
| CMCC | Yes. DCI format 2\_6, cross-slot scheduling, RRM relaxation for neighbor cells, and UE assistance information can be supported. In addition the support of adaptation of MIMO layers and dormant SCell is related to RedCap UE capability i.e., whether to support multiple BWPs, support of CA and number of antenna which can be discussed later. |
| InterDigital | These techniques can be optionally supported by a RedCap UE. |
| WILUS | At least, cross-slot scheduling and DRX adaptation would be helpful for RedCap UE, thus we are ok to support these features optionally for RedCap UE. Further enhancements of these features are obviously out of scope. So it is an UE capability issue not a technical issue. |
| Sequans | All Rel-16 (and eventually Rel-17) power saving techniques should be able to be supported by RedCap device. We think that two other questions should be clarified instead:   1. If any Rel-16 power saving technique(s) should be mandatory for RedCap UEs 2. Which, if any, Rel-16 power saving technique(s) should be considered as supported by reference UE in order to set a more proper baseline to evaluate performance of candidate power saving techniques for RedCap UEs. |
| Lenovo, Motorola Mobility | We think at least wake-up indication via DCI format 2\_6 and cross-slot scheduling should be supported by RedCap UEs. |
| Samsung | Most of R16 UE power saving schemes can be supported for RedCap, including WUS for C-DRX, adaptation on cross-slot scheduling, BWP switching based adaption on MIMO layers (if UE antennas is larger than 1).  Dormancy and non-dormancy BWP switching for SCells is an exception as CA is not applicable for RedCap. |
| DOCOMO | Yes, RedCap UE can support Rel-16 power saving techniques as optional. Dormant SCell is not necessary if CA is not applied to RedCap. |
| Qualcomm | We agree that these Rel-16 power saving techniques can be considered at least for RedCap power consumption. However, support of some features may not be preferred from complexity reduction perspective. Because of this, answer of this question should also take into account RedCap complexity reduction. Also, optional features for Rel-16 should still maintain optional. |

## 3.2 Candidates of power saving techniques

In general, the power saving techniques can be categorized as follows:

1. Reduced blind decoding (BD) and/or CCE limits
2. Dynamic adaptation of PDCCH monitoring or search space sets
3. Extending the PDCCH monitoring span gap from 1 slot to X slots (X>1)
4. Reduce number of maximum configurable CORESETS per BWP

### Technique 1: Reduced blind decoding (BD) and/or CCE limits

Many contributions discuss the reduced number BDs and/or CCE limits for RedCap devices. In contributions [5,6,14,15,18,19,20,22,23,26], it is proposed to reduce BDs and/or CCEs. [26] further proposed to split limit into CSS and USS and reduce them separately to guarantee the broadcast PDCCH transmission. Furthermore, [4] believes that CCE limit reduction does not provide a substantial power saving benefit and hence propose to reduce BD limit only. Meanwhile, [3,7,8,9,24,25] argue that the number of number of BD and CCEs monitored by a UE can be controlled by network configurations and BD/CCE limits reduction should not be considered for RedCap UEs in Rel-17.

Several contributions [3,5,6,20,22] provide the evaluation results of power saving performance and it was observed that the power saving gain by reducing the number of BD by half is approximately 15%. In addition, the maximum achievable power saving by reducing number of BDs to 1 is about 29% for FR1 [3,6,22] and 28% for FR2 [6] with assuming power consumption model in TR 38.840.

Moreover, contribution [3,5,9,10,18,14,26] evaluated the impact of BD reduction on blocking probability with different assumptions. In general, PDCCH blocking probability depends on various factors including number of UEs which need to be scheduled (this may depend on the traffic), CORESET size (i.e., number of CCEs), number of PDCCH candidates, and PDCCH link performance/coverage (which affects the AL probability). With a number of assumptions, [3] observed that the average blocking probability can increase from 2.8% to 5.4% (increase by a factor of 1.9) for FR1 and increase from 5% to 12% (increase by a factor of 2.3), when reducing the BD limit by half. [10] observed that for RedCap UEs, PDCCH blockage is increased due to reduced number of Rx antennas, which should be carefully study for power saving techniques. In [26], it was observed that the number of CCEs in COERSET becomes the gating factor and BD limit reduction to 25% of the original limit results in loss of one schedulable UE if CCE number is not dominant factor.

In addition, different solutions to mitigate the PDCCH blocking risk were proposed and evaluated, including group scheduling [14,18,26] and compact DCI format [14].

On a high-level, three alternatives were proposed in contributions:

* **Alt.1:** Reducing Rel-15 BDs to smaller values without any other modifications
* **Alt.2:** Reducing Rel-15 BDs to smaller values by DCI size budget reduction
  + This was proposed in contributions [4,5, 8,10,11,14,15,20, 24,27,28]. In [8], it is further proposed that a Redcap UE does not expect to process more than one DCI with the CRC scrambled by C-RNTI.
* **Alt.3:** Reducing Rel-15 BDs to smaller values and introducing new schemes to reduce PDCCH blocking probability, e.g. group scheduling or compact DCI format

**Question 6: Based on the available evaluation results so far (power saving gain vs. PDCCH blocking probability and latency performance), can we draw conclusion to support reduced BDs and/or CCEs for power saving?**

* **If yes, which schemes among three alternatives can be supported for reduced PDCCH monitoring?**
* **If no, what modification is needed or any new solutions under this area to further study?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Vivo | We think both alt 1 and alt 2 can be studied further. If we have accurate power model for RedCap (as outcome of the discussion in Question 3), there should be a fair comparison between alt 1 here and Technical 3 Extending the PDCCH monitoring span gap from 1 slot to X slots (X>1) considering the power saving benefit and complexity reduction, and the down-selection should be based on the evaluation results.  Regarding alt 3, compact DCI format is already in spec so RedCap UE can support it if there is a need, for example due to coverage recovery, therefore it seems no need to decide anything. On group scheduling, we are not sure whether it is in scope of the current SID or not, as it does not seem to match any of the objectives. |
| OPPO | It is in the Sope of SI. We prefer Alt2. Alt-3 can be further considered. |
| Xiaomi | For the purpose of power saving, we think the existing solution e.g., configure the BD via NW is sufficient. |
| Fraunhofer | Alt.3. We think that the PDCCH blocking probability is a severe issue that should be targeted by additional schemes. |
| MediaTek | No.  We believe it is premature to conclude on supporting reduced BDs and/or CCEs without having technical discussion of the provided evaluations.  On important point that we would like to highlight is that the evaluation results show power saving that can be achieved by reducing the **configured** #CCEs/#BDs rather than the reduction in **UE capability** for monitoring the #CCEs/#BDs.  Hence, there is no evaluation that provided evidence of power saving by reducing the UE capability of PDCCH monitoring. |
| Futurewei | Any reduction of BD monitoring needs to be done without affecting blocking. In that sense, Alt.2 can be considered if significant benefits can be shown |
| Ericsson | No need to reduce the existing BD and CCE limits for the purpose of power saving. The UE power consumption depends on the number of actually performed BD attempts not the maximum limits. Network can control the number of required BDs and PDCCH monitoring by proper configurations according to use case requirements without any need for specification changes. Such network configurations include using suitable number of different ALs and PDCCH candidates for each AL, and increasing the PDCCH monitoring periodicity.  Regarding DCI size budget reduction, although this technique can reduce the number of required BDs, it has the following issues:   1. significant impact on specifications as new DCI size alignment procedure and DCI formats may need to be introduced 2. limits scheduling flexibility.   Moreover, the power saving by DCI size budget reduction gain may not be significant. For example, by reducing the DCI size budget from “3+1” to “2+1”, the average number of BDs can be reduced by around 25% which leads to less than 7% power saving.  Meanwhile, gNB can consider RedCap UE capability, and also configure UE to monitor different DCI formats potentially with different sizes in a way that is suitable for RedCap UEs.  Finally, we note the BD limit for Rel-8 LTE is the same as Rel-15 NR for 15 kHz SCS (BD limit is 44). Hence, the existing BD limits can be reasonable for RedCap. |
| Panasonic | We can draw the conclusion that not to support reduced BDs and CCEs. |
| CATT | Alt.2 and Alt.3 are our preference.  Actually no matter the reduction on maximum number of BD and CCEs is supported or not, PDCCH blocking is still a serious issue need to be studied, e.g. more large AL is needed considering the reduction of Rx, the bandwidth is limited, the number of RedCap UE is numerous in the system. Group scheduling is a straightforward way to reduce PDCCH overhead, which reduces blocking possibility. |
| CMCC | We prefer Alt2 and Alt3.  PDCCH blocking and PDCCH overhead is an important issue in RedCap, especially the BD/CCE limits is further reduced and the limited bandwidth. We think group scheduling including one DCI scheduling multiple TBs for one UE or one DCI scheduling multiple UEs can both be considered to reduce the PDCCH blocking and PDCCH overhead. |
| InterDigital | Dynamic adaptation of BD and/or CCE limits can be considered for reduced PDCCH monitoring. |
| WILUS | Alt.2. if DCI formats are size-aligned, it gives a way for gNB to configure small # of BDs/CCEs without PDCCH blocking issues. |
| Sequans | Agree with MediaTek – we need more evidence and technical discussion to conclude on supporting one of the proposed alternatives. |
| Lenovo, Motorola Mobility | Reducing the number of BDs by reducing DCI size budget is preferred, since it is expected to have less impact on PDCCH blockage. Besides, Alt.3 can also be studied, and no need to restrict to the techniques in the example, i.e., prefer to remove the examples. |
| Samsung | We support smaller number of BDs and CCE limits for RedCap UEs. At least for the CCE limits, that is a consequence of the maximum bandwidth limit. Additional reductions can be considered for power saving gains from both reduced processing complexity and relaxed processing time. We also support to consider reductions in PDCCH blocking that can be a bottleneck for scheduling, and potentially result to a continuously increasing buffer, even without any PDCCH candidate/CCE reductions, due to the large numbers of RedCap UEs. PDCCH overhead is also a key design consideration because of the reduced number of UE receiver antennas and the small TBs associated with traffic types for RedCap UEs. |
| DOCOMO | No. We agree with MediaTek that it is too early to conclude on supporting any specific solutions at this stage. Also agree with Ericsson that the numbers of actually performed BDs and CCEs in a PDCCH monitoring occasion can be configured by CORESET/search space set configurations. |
| Qualcomm | For RedCap power saving, Alt. 1 can be assumed as a baseline and also take the potential further PDCCH reduction and control overhead reduction into consideration. For that further DCI size alignment and scheduling with less PDCCH can be studied. |

### Technique 2: Dynamic adaptation of PDCCH monitoring

Several contributions [5,7,10,12,15,18,19,23] discuss how to support dynamically PDCCH monitoring, which include DCI-based approach (e.g. enhanced DCI format 2\_6 or scheduling DCI format) or timer-based approach [5]. It was observed that similar proposals are being discussed in Rel-17 power saving study item. However, it maybe still desirable to discuss it in both items as different conclusions maybe made considering different power saving requirements of RedCap and power saving WI. Obviously, the standard efforts can be shared if it is approved under both agendas.

**Question 7: Can dynamic adaptation of PDCCH monitoring or search space set be supported for Redcap device to reduce PDCCH monitoring power? If not, why?**

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| --- | --- |
| **Company** | **Comments** |
| vivo | Following the WID, the dynamic adaptation of PDCCH minoring or search space set switching belongs to the power saving WID, and it is understood that the power saving WID provide general features which applicable to both normal and redcap UEs. With this understanding, we think technique 2 should be dropped in Redcap discussion to avoid duplicate work. |
| OPPO | Could be out of Sope. SI said: “Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits”. It is just limit of capability, not dynamic scheduling. Also, it seems can take care by Power Saving WI. Just want to avoid duplicated dissussing. |
| Xiaomi | Yes. Any solution for the power saving should not be precluded |
| Fraunhofer | Yes. Our understanding is that this procedure reduces the blind decoding overhead significantly especially, if there is no data for the RedCap UE. |
| MediaTek | This is out of the scope of RedCap SI. This should be discussed in the power saving WI if needed. |
| Futurewei | Agree with OPPO’s analysis that it is not within Redcap scope (but should be okay in power savings) |
| Ericsson | This does not seem to be in the scope according to the SID. |
| Panasonic | Yes, it should be supported as to reduce the wake-up time contribute the power reduction more than to reduce the number of BDs. |
| CATT | Dynamic adaptation of PDCCH monitoring or search space set is beneficial for power saving. It’s a generic power saving technique can be applied to any supporting UEs. As mentioned by several companies, it should be handled by PS WI. |
| CMCC | Yes, we think the dynamic PDCCH monitoring can be supported for RedCap UE. But as the discussion by many companies, this issue can be discussed in Power saving WI but the power saving technique can be used by RedCap UE as well. |
| InterDigital | We believe that dynamic adaptation of PDCCH monitoring is essential for power saving. However, since this technique will be treated in the Power Saving WI, we can drop it from the RedCap SI to prevent duplicate work. |
| WILUS | Our understanding is dynamic adaptation of PDCCH monitoring is out of scope and it would be better to discuss this issue in power savings WI. |
| Sequans | Seems to be out of the scope considering RedCap SID – it could be discussed in plenary if it is worth adding in scope and if possible/efficient to share standard efforts with power saving WI. |
| Lenovo, Motorola Mobility | Dynamic adaptation of PDCCH monitoring and/or search space set can be studied under RedCap SI in the context of RedCap devices. |
| Samsung | We think dynamic adaptation on PDCCH monitoring related to BDs and CCE limits can be discussed in RedCap as it is within the scope of the SID. General adaptation on PDCCH monitoring, such as SS set switching and/or adaptation of PDCCH monitoring periodicity, should be discussed in the R17 PS WI. |
| DOCOMO | This is out of scope of RedCap, but can be discussed in power saving WI. |
| Qualcomm | Dynamic PDCCH adaptation falls in the area of Rel-17 power saving enhancement WI. Companies may discuss whether this is in the scope of RedCap agenda. To avoid repetition of efforts, it should be studied in power saving enhancement WI. |

### Technique 3: Extending the PDCCH monitoring span gap from 1 slot to X slots (X>1)

In [5,18], it was proposed to extend the PDCCH monitoring span from 1 slot to X slots to reduce power consumption. More especially, [5] observed that the power consumption was further reduced if cross-slot scheduling is enabled together with span gap extension. In [18], power saving gain and latency performance were evaluated with power consumption model discussed in section 2.2.

**Question 8: Can PDCCH monitoring span gap extension be supported or further studied for Redcap device to reduce PDCCH monitoring power? If not, what modification is needed? why?**

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| **Company** | **Comments** |
| vivo | We support to further evaluate technical 3 and to compare with alt 1 or alt 2 in technical 1 based on the refined power model for RedCap UEs. |
| OPPO | Yes |
| Xiaomi | Can be further studied |
| Fraunhofer | Yes. Assuming that the RedCap UE can perform a certain number of BDs per slot, larger number of BDs can be still achieved if the span gap is increased. Hence, allowing for more scheduling flexibility while keeping the BD complexity low. Furthermore, we also agree that this feature can be combined with cross-slot scheduling to even further reduce power consumption. |
| MediaTek | This should be considered under Technique 1.  Technically, it is a reduction of the supported #CCEs/#BDs by changing the duration from slot to multiple slots. |
| Futurewei | When cross slot scheduling is used, we do not see how this can improve power consumption. |
| Ericsson | This does not seem to be in the scope according to the SID. |
| Panasonic | We are not so sure the meaning of "PDCCH monitoring span gap extension". We see the merit of the larger gap between monitoring occasions like wake-up in every 2 or 4 slots. |
| CATT | Can be further studied. |
| CMCC | Can be further studied. |
| InterDigital | We are fine with studying this further. |
| WILUS | Yes, can be further studied. |
| Sequans | We also see this as part of Technique 1 as it essentially considers extending the Rel-16 limits for span gap. Could be considered however after the necessary evidence and technical discussion required for Technique 1, as mentioned in Q6. |
| Lenovo, Motorola Mobility | Reducing the number of BDs per slot and network implementation (i.e. search space configuration) can equivalently realize extension of span gap to multiple slots. Thus, we don’t think separate discussion/specification effort is needed for this. |
| Samsung | Yes. To extend the PDCCH monitoring span gap is directly equivalent to reducing the maximum numbers of BDs and CCEs regarding the power per time unit. |
| DOCOMO | Yes, it can be further studied |
| Qualcomm | The PDCCH monitoring span extension achieve similar effect to sparse PDCCH periodicity. For that, it is within the scope of Rel-17 power saving enhancement and should be studied there. It is not clear how additional benefit can be gained from the monitoring span extension. |

### Technique 4: Reduced number of maximum configurable CORESETS per BWP

In Rel-16, a UE is expected to actively monitor a number of up to 3 CORESETs and 10 search space sets. In [5,14,26], it is proposed to study reduction of the maximum configurable CORESETs per BWP. [5] clarifies that the power consumption reduction comes from the lower UE complexity for channel tracking of different TCI states. For [26], it is mainly motivated by the fact of no need for RedCap devices to support such flexible configuration, which also causes unnecessary signaling overhead in case of massive Redcap device connections.

**Question 9: For RedCap, can the maximum number of configurable CORESETs per BWP be reduced? If not, why?**

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| --- | --- |
| **Company** | **Comments** |
| Vivo | We think it is worthwhile to consider reduce the maximum number of CORESET per BWP from 3 to 2. |
| OPPO | No. It seems also out of scope. |
| Xiaomi | More clear evidence is needed. At current stage, we think this can be achieved by configuration. |
| Fraunhofer | This can be studied. However, at the current point we don’t see a major benefit of reducing the number of CORESETs only. Alternatively, constraints to the CORESETs can be studied. |
| MediaTek | This is out of the scope of RedCap SI. This should be discussed in the power saving WI if needed. |
| Futurewei | It is not fully clear that it is within scope of the SI:” *Study UE power saving and battery lifetime enhancement for reduced capability UEs in applicable use cases (e.g. delay tolerant) [RAN2, RAN1]:*  *• Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits [RAN1].”*  The wording does not include reducing the number of CORESET. In our view, this should be discussed in the power saving WI |
| Ericsson | No, we do not expect power saving by reducing number of CORESETs. Also, it can impact scheduling flexibility. |
| CATT | Don’t see the necessity. The maximum number of configurable CORESETs per BWP doesn’t relevant to the number of BD or CCE. |
| CMCC | No. |
| InterDigital | We do not see clear benefits from this. |
| WILUS | No needed. The UE power consumption depends on the actually monitored PDCCH candidates, not # of configured CORESETs/Search spaces. |
| Sequans | Also out of the scope of RedCap SID. More evidence is needed if it’s worth considering adding in RedCap scope (and also why consider here instead of addressing in power saving WI). |
| Lenovo, Motorola Mobility | Along with DCI size budget, the max number of CORESETs configured for a UE can be reduced, for low complexity operation and accordingly, less power consumption. |
| Samsung | We are negative about reducing the maximum number of configurable CORESETs. It does not affect UE complexity and can result to increased PDCCH blocking or decreased robustness in FR2. The network should have the flexibility to configure CORESETs to the UE as in Rel-16. |
| DOCOMO | This is out of scope of RedCap |
| Qualcomm | The actual supported number of CORESETs can be UE capability. A single CORESET can be used to mimic LTE type of control region especially because RedCap BW is limited and network may not want to further split the BW into multiple CORESETs. |

Other PDCCH monitoring reduction techniques for FR2 have also been discussed in [26]. [5] further proposed to decouple the configuration of DL non-fallback DCI and UL non-fallback DCI monitoring. In [7], it was proposed to enhance DCI format 2\_6 to allow skipping multiple On periods. FL kindly reminds that only one meeting is left for this study item and realistic scoping of proposals is needed.

**Question 10: Should any other techniques for reduced PDCCH monitoring be studied, in addition to the 5 techniques identified and listed? If yes, explain and motivate.**

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| --- | --- |
| **Company** | **Comments** |
| Vivo | We think decoupling of DL non-fallback DCI and UL non-fallback DCI monitoring is a simple way to achieve BD or size reduction. It can be useful for the asymmetric DL/UL traffic cases, e.g. industrial sensors, or video surveillance, etc.  The spec impact is minor and should be easily be implemented. |
| Xiaomi | Yes. Any solution for the power saving should not be precluded. For example, Multi-TB scheduling or pre-configured transmission is good in the scenario with low mobility. And these solutions are adopted in the MTC/NB-IoT project. |
| MediaTek | Any other techniques that beyond the SI scope (“*Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits*”) shouldn’t be considered in this SI. Such techniques should be discussed in the power saving WI if needed. |
| Futurewei | As FL pointed out, with only one meeting left, we need to focus our work. Thus, at this stage, we are reluctant to consider any additional technique |
| Ericsson | No |
| Panasonic | Related to question 8 of reducing PDCCH monitoring by span gap extension, even under such condition, it is preferable for gNB to schedule all slots to keep the user throughput. In order to allow such operation, one PDCCH schedule multiple TBs over multiple slots should be supported. |
| CATT | Similar views as MTK and Futurewei. |
| WILUS | Interaction of PDCCH coverage recovery can be further considered. If RAN1 agrees to support a new technique for PDCCH coverage recovery (e.g., repetition), then it may affect PDCCH monitoring. |
| Lenovo, Motorola Mobility | We think decoupling DL non-fallback DCI monitoring from UL non-fallback DCI monitoring should be considered in order to reduce BD. |
| Samsung | We are open to techniques for reducing the blocking probability, the PDCCH overhead, and/or the number of BDs and CCE limits during SI phase. Given the time limit, it’s better to identify the techniques with high priority in this meeting. |
| DOCOMO | Agree with MediaTek. |
| Qualcomm | Techniques that can reduce the amount of PDCCHs required for UL and DL scheduling can also be studied. These techniques can help reduce the required number of BDs/CCEs for DL/UL data scheduling and hence reduce PDCCH blocking probability when BD/CCE limits are reduced.  Additional techniques (it is understood that certain techniques may be discussed in Rel-17 power saving enhancement based on splitting of task between the two agendas) to be studied/considered:   1. Ways to have additional DL control between sparsely configured SS occasions (reducing the “average” UE searches), e.g.:    1. By dynamically or on-demand configuring SS set occasions    2. By piggy-backing DL control signalling on existing SCH messages (DG or SPS)   Motivation: There may be some RedCap-specific characteristics and use cases that motivates the study of power savings techniques separate from the power savings SI. For e.g., UL heavy traffic models as well as large latency requirements for RedCap may motivate using reduced PDCCH monitoring occasions in time (i.e., reduced search space periodicity) to allow for more UL traffic opportunities (for TDD system) and at the same time reduce UE power consumption (by reducing PDCCH monitoring). However, there may be cases where we need some DL control in between these sparse SS due to: traffic or beam management (TCI/SRI updates).   1. Reduce the “average” UE PDCCH monitoring by utilizing preconfigured (PDCCH-less)   Motivation: reduce the “average” BD monitoring. Stationary conditions for RedCap   1. Dynamically change parameters for semi-static periodic messages (search space sets, SPS, CG) based on the current environment and the spatial needs   Motivation: beam overloading and blockage mitigation + reduced unnecessary BD   1. MUP (multiple user packets) in single PDSCH which is indicated by single PDSCH 2. Motivation: single PDCCH can indicate multiple TBs for different users. It reduces the PDCCH blocking probability very much when BD/CCE limits are reduced. |

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