**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. |
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**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

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|  | 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. |
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## 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:

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| 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. |
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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 |
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# 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. |
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## 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?**

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| **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. |
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### 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 |
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### 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 |
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### 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. |
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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. |
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30. 3GPP TR 38.840 Study on User Equipment (UE) power saving in NR