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e-Meeting, May 25th – June 5th, 2020

**Agenda Item: 8.3**

**Title: Email discussion for Study on support of reduced capability NR devices**

**Source: Rapporteur (Ericsson)**

**Document for: Discussion, Decision**

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# 1 Introduction

This document captures the RAN1#101e email discussion [101-e-NR-RedCap-01] for the study item “Study on support of reduced capability NR devices” [1]. This email discussion focusses on high-level topics and evaluation assumptions necessary to facilitate next step’s more concrete analysis and evaluations.

The section numbering in this document follows the proposed TR skeleton [2]. The TR skeleton itself is discussed separately in email discussion [101-e-NR-RedCap-Skeleton].

# 5 Requirements

According to the study item description (SID) [2], as a baseline, the requirements for the targeted use cases are:

Generic requirements:

* Device complexity:
	+ Main motivation for the new device type is to lower the device cost and complexity as compared to high-end eMBB and URLLC devices of Rel-15/Rel-16. This is especially the case for industrial sensors.
	+ The work defined above should not overlap with LPWA use cases. The lowest capability considered should be no less than an LTE Category 1bis modem.
	+ In case of UE bandwidth reduction, Rel-15 SSB bandwidth should be reused and L1 changes minimized
* Device size:
	+ Requirement for most use cases is that the standard enables a device design with compact form factor.
* Deployment scenarios:
	+ System should support all FR1/FR2 bands for FDD and TDD.
	+ Coexistence with Rel-15 and Rel-16 UE should be ensured.
	+ This study item should focus on SA mode and single connectivity.

Use case specific requirements:

1. Industrial wireless sensors (as described in TR 22.832 and TS 22.104):
	* Communication service availability is 99.99% and end-to-end latency less than 100 ms.
	* The reference bit rate is less than 2 Mbps (potentially asymmetric e.g. UL heavy traffic) for all use cases and the device is stationary.
	* The battery should last at least few years.
	* For safety related sensors, latency requirement is lower, 5-10 ms (TR 22.804).
2. Video surveillance (as described in TS 22.804):
	* Reference economic video bitrate would be 2-4 Mbps, latency < 500 ms, reliability 99%-99.9%.
	* High-end video e.g. for farming would require 7.5-25 Mbps.
	* It is noted that traffic pattern is dominated by UL transmissions.
3. Wearables:
	* Reference bitrate for smart wearable application can be 10-50 Mbps in DL and minimum 5 Mbps in UL and peak bit rate of the device higher, 150 Mbps for downlink and 50 Mbps for uplink.
	* Battery of the device should last multiple days (up to 1-2 weeks).

**Question 1: Are the requirements clear enough or does something need to be clarified, and if so, how?**

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# 6 Evaluation methodology

## 6.1 Evaluation methodology for UE complexity reduction

Several contributions [3, 6, 10, 32, 38, 43, 50, 58, 62, 64, 90] refer to the UE cost/complexity evaluation methodology used in the LTE-MTC study item *”Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE”* described in TR 36.888.

TR 36.888 clause 5 defines a reference LTE modem with an assumed cost breakdown where 40% and 60% correspond to the RF and baseband parts, respectively, and where these parts are further broken down into components assumed to be cost drivers. A cost reduction analysis is carried out for each cost reduction technique described in TR 36.888 clause 6 and the total cost reduction for the combinations of techniques that are of interest are summarized in TR 36.888 clause 7.

**Question 2: Can the evaluation of the UE cost/complexity reduction follow the methodology in TR 36.888 and be expressed in terms of a percentage relative to the cost/complexity of a reference NR modem?**

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The methodology in TR 36.888 considers the cost/complexity of the modem but not that of the antennas. For FR2, some contributions [6, 38, 65] discuss whether to consider potential cost/complexity reduction not only in the modem but also in the antennas.

**Question 3: If the RedCap study reuses cost/complexity evaluation methodology from TR 36.888, are any modifications of the methodology needed for FR2?**

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A reference NR modem/device could, e.g. correspond to the simplest NR UE defined in Rel-15/16 that is able to support the targeted use cases as defined in the SID. One potential candidate for this could be a Rel-15 NR UE that supports all mandatory features (including mandatory features with capability signalling) but no optional features. Different reference NR modems/devices could be defined for FR1 FDD, FR1 TDD and FR2 TDD, each one with well-defined support for one or more bands, bandwidths and number of antennas (cf. TS 38.101-1 for FR1 and TS 38.101-2 for FR2).

**Question 4: What components should be included as part of the reference NR device (to be used for comparison of complexity and coverage)?**

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**Question 5: The UE complexity reduction techniques may provide benefits beyond device cost reduction, e.g. in terms of facilitating a smaller device size. Should this SI aim to determine and quantify such benefits and, if so, how?**

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## 6.2 Evaluation methodology for UE power saving

For power saving evaluations, key aspects include suitable power consumption models, traffic models, and evaluation assumptions. Contributions in [7, 44] suggest agreeing on the power consumption model and traffic model for RedCap, and [33, 39, 64, 87, 95] propose that the power consumption model and evaluation assumptions in TR 38.840 should be reused as much as possible and modifications can be applied where needed.

**Question 6: Can this SI reuse evaluation methodology for UE power saving from TR 38.840? If so, which parts can be reused, and which modifications are needed?**

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In TR 38.840, traffic models for FTP, VoIP, and instant messaging with specific parameters were considered for power saving evaluations. Power saving evaluations may need to be done for battery-limited RedCap use cases, particularly for wearables and industrial wireless sensors. In [11, 39, 87], it is suggested to use traffic model in TR. 38.840 with adaptations wherever necessary. For wearables, [11] proposes to use traffic models for VoIP, instant message and heart-beat message (FTP model 3) according to TR. 38.840, while specifying parameters of packet size and mean inter-arrival time.

**Question 7: For the wearable use cases, can the traffic models from TR 38.840 be used? What, if any, adaptations are needed?**

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For industrial wireless sensor use cases, there is no specific proposal on the traffic model. Also, these use cases are not specifically discussed in TR 38.840. In TS 22.104, Table 5.2-2, the traffic characteristics of industrial wireless sensor use cases are described considering periodic deterministic traffic.

**Question 8: For the industrial wireless sensor use cases, can the traffic models and parameters from TS 22.104 or any relevant model in TR 38.840 be used? What, if any, adaptations are needed?**

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## 6.3 Evaluation methodology for coverage recovery

Many contributions discuss simulation assumptions and performance metrics suitable for coverage evaluation. Some contributions indicate that alignment or coordination with the NR coverage enhancement (CE) study item is desirable or beneficial [4, 23, 31, 40, 45, 60, 85, 88, 92]. Some other contributions consider reusing suitable assumptions based on the self-evaluation study towards IMT-2020 submission [4, 8, 34, 40, 67, 88]. The LTE-MTC study item is mentioned in some contributions [4, 8, 56, 80, 92].

In the CE SI, most of the contributions to RAN1#101e express support for coverage evaluations based on the IMT-2020 self-evaluation link budget (see [101-e-NR-Cov-Enh] Email discussion on evaluation methodology and simulation assumptions for NR coverage enhancements, section 2.1.4).

Based on the above summary, a possible way forward is to base the coverage analysis on the IMT-2020 self-evaluation methodology and make necessary adjustments for the RedCap study.

**Question 9: Can the coverage analysis be based on the methodology used in the IMT-2020 self-evaluation?**

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The IMT-2020 self-evaluation methodology is focused on PDCCH, PDSCH, PUSCH and PUCCH. Several contributions do however propose to take a holistic approach, considering all channels and relevant messages, aiming to identify one or more performance limiting channels or messages, and minimizing the UL and DL imbalance so that a desired coverage target can be achieved [8, 17, 31, 34, 48, 60, 88].

**Question 10: For coverage analysis, can we use a link budget approach taking all relevant DL and UL channels into account? Which channels/messages should be included in the link budget?**

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The IMT-2020 self-evaluation methodology for PDSCH and PUSCH is based on obtaining the required SINR for which a target data rate is achieved. For control channels the methodology is based on obtaining the required SINR for which a target BLER is achieved.

**Question 11: For target data rates and BLER targets, can the RedCap study reuse/align simulation assumptions and performance metrics with the CE study? If not, what changes are needed?**

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The required SINR values should be obtained by means of link-level simulations. The CE study is expected to determine a set of simulation assumptions for supporting these link-level simulations.

**Question 12: To what extent should the RedCap study reuse/align simulation assumptions with the CE study? If alignment is not possible, which modifications are needed?**

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The IMT-2020 methodology contains two parts: The first part determines achievable coverage in terms of “Hardware link budget” in dB. The second part determines the achievable “Maximum range” in meters.

**Question 13: Can the RedCap SI focus on determining the “Hardware link budget”, and down-prioritize determination of the “Maximum range”?**

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## 6.4 Evaluation methodology for other performance impacts

For the studied features for complexity reduction and power saving, the potential coverage impacts should be evaluated so they can be considered in the work with the coverage recovery features. In addition, some other performance impacts may need to be evaluated. The study should at least assess to what extent the use case requirements in the SID on data rates and latencies can be fulfilled and coexistence with legacy UEs ensured when the features for complexity reduction and/or power saving are used.

**Question 14: Can the evaluation of the other performance impacts focus on data rate, latency and coexistence with legacy UEs?**

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# 7 UE complexity reduction features

## 7.1 Introduction to UE complexity reduction features

Sections 7.2 through 7.6 discuss the high-level topics for the main UE complexity reduction features. Combinations of these features are discussed in section 7.7.

## 7.2 Reduced number of UE Rx/Tx antennas

In [6, 21, 10, 25, 38], it is observed that an NR Rel-15 UE can be assumed to support at least 1 Tx antenna, and 2 Rx antennas except for bands n7, n38, n41, n77, n78, n79 where 4 Rx antennas are required. For automotive UEs 2 Rx is permitted also in the 4 Rx bands [6].

Several contributions [3, 6, 43, 50, 58, 73, 74, 97] point out that a reduced number of Rx antennas compared to a Rel-15 reference UE enables reduced complexity, e.g. in terms of the required number of RF components (e.g. LNA, PA, phase shifters, filters, ADC and DAC) and a relaxation of the baseband receiver complexity (e.g. FFT, channel estimation, buffering). In [21, 46, 68, 78, 86], it is pointed out that a reduced number of antennas may allow for a reduced form factor.

In [6, 21, 25, 29, 38, 42, 58, 78, 90], it is proposed to study a RedCap UE supporting 1 Tx and 1 or 2 Rx. In [14, 15, 32, 62, 65, 86], 1 Tx and 1 Rx are proposed for RedCap UE’s. In [3, 10, 13], 1 Tx and 2 Rx are proposed.

In [6] its proposed to study if a relaxation in FR2 radiated requirements, e.g. EIRP, EIS and spherical coverage, can facilitate reduced UE complexity. In [38] its proposed to avoid such a relaxation due to drawbacks in terms of coverage and capacity. In [65] its mentioned that the antenna gain is dependent on the number of antenna panels and antenna elements. In [15, 68] it is proposed to consider the coverage loss associated with antenna design constraints expected in wearables.

Concerning the impact on performance, several contributions [6, 43, 46, 54, 68, 73, 83] observe that a reduced number of antennas impacts coverage. Some contributions [10, 29, 36, 50, 73, 83] refer to the impact on supported number of MIMO layers and the related impact on the supported data rates. In [71], it is highlighted that reduced number of Rx antennas degrades downlink capacity of the network. Finally, some contributions [10, 43, 58, 73] mention the power saving aspect associated with a reduced number of antennas.

**Question 15: For FR1, is it enough to study 1Rx/1Tx and 2Rx/1Tx, or should any other antenna configurations or potential antenna gain aspects be studied?**

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**Question 16: For FR2, is it enough to study 2Rx/1Tx, or should any other antenna configurations or potential antenna gain aspects be studied?**

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## 7.3 UE bandwidth reduction

Almost all contributions recognize that the reduction of the UE bandwidth is beneficial in terms of UE complexity reduction [3, 6, 10, 13, 14, 15, 21, 25, 29, 32, 36, 38, 42, 43, 46, 50, 54, 58, 62, 65, 68, 73, 74, 78, 83, 86, 90, 94, 96, 97]. All these contributions have analysed the benefits of UE bandwidth reduction in terms of UE complexity in FR1. Contributions [3, 6, 32, 38, 65, 86] also discuss the benefits of bandwidth reduction in FR2.

In discussing proper choices of RedCap UE bandwidth, some contributions highlight the feasibility of reusing legacy initial access scheme, including aspects such as SSB bandwidth, CORESET#0 configurations, and initial BWP bandwidth [3, 6, 10, 14, 15, 25, 29, 32, 36, 54, 62, 65, 73, 74, 78, 83, 86, 90, 94, 96, 97]. Other aspects considered include data rates needed for RedCap use cases, leverage LTE ecosystem (i.e. same BW as LTE), UE cost saving consideration, UE power saving consideration, PDCCH performance (e.g. implication on the aggregation level), and scheduling flexibility.

Based on one or more of the above considerations, a majority of the contributions consider UE bandwidth reduction to 20 MHz bandwidth in FR1 [3, 6, 10, 13, 14, 15, 25, 29, 32, 36, 38, 42, 50, 58, 78, 83, 86, 94]. Other contributions consider further bandwidth reduction to lower than 20 MHz, e.g. 5/10/15 MHz [10, 15, 29, 36, 38, 50, 54, 65, 78, 83, 97].

**Question 17: For FR1, can the RedCap UE be assumed to support 20 MHz channel bandwidth at least for initial access? If not, what bandwidths for initial access should be studied, and why?**

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For FR2, one group of contributions considers maximum UE bandwidth in the range of 40-60 MHz [6, 32, 38, 54, 65], while a second group considers 80-100 MHz [3, 32, 54, 86]. Currently defined channel bandwidths in FR2 in these bandwidth ranges are 50 MHz and 100 MHz, respectively.

**Question 18: For FR2, what maximum UE bandwidths should be studied?**

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## 7.4 Half-duplex FDD operation

With half-duplex FDD (HD-FDD) operation, the device does not need to simultaneously transmit and receive at the same time. This allows the device to use a switch in place of one or more duplexers, typically one per frequency band. As of NR Rel-16, since the FDD bands are all in FR1, i.e. all FR2 bands use TDD, HD-FDD is only pertinent to FR1.

In LTE, two types of HD-FDD operation are specified:

* **Type A:** a DL-to-UL guard period is created by the UE by not receiving the last part of a DL subframe immediately preceding an UL subframe from the same UE, and no UL-to-DL guard period is defined (but can potentially be created by the eNB implementation by proper TA adjustment).
* **Type B:** a DL-to-UL guard period is created by not requiring the UE to receive a DL subframe immediately preceding an UL subframe from the same UE, and an UL-to-DL guard period is created by not requiring the UE to receive a DL subframe immediately following an UL subframe from the same UE.

HD-FDD operation type A is defined for normal LTE, whereas type B is defined for LTE-MTC and NB-IoT. The intention of type B is to facilitate UE implementations with a single oscillator for Tx and Rx frequency generation by introducing significantly longer DL-to-UL and UL-to-DL guard periods.

Most contributions [3, 6, 14, 29, 32, 36, 38, 43, 50, 54, 62, 65, 68, 73, 74, 78, 86, 90, 96, 97] point out that HD-FDD can contribute to UE cost reduction. The main cost reduction factor mentioned in most of these contributions is the UE not needing a duplexer for each FDD band. Many contributions cited the LTE-MTC study as a reference [TR36.888].

A few contributions [6, 21, 50, 74, 86] bring up the consideration of facilitating a single oscillator or HD-FDD operation type B. As mentioned above, this type of HD-FDD operation would require a longer guard period for switching between UL and DL.

**Question 19: For half-duplex FDD operation (in FR1), what values of DL-to-UL and UL-to-DL guard periods should be studied?**

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## 7.5 Relaxed UE processing time

In NR, there exist two UE processing time capabilities, capability #1 and #2, related to DL and UL data transmission, where the capability #2 is a more aggressive capability. In DL, UE processing time impacts how fast UE processes a scheduled DL transmission and sends a corresponding HARQ feedback, whereas in UL, it impacts how fast UE processes a scheduling UL grant and prepares for the scheduled UL transmission.

In most of the contributions [3, 6, 10, 13, 25, 29, 32, 50, 58, 65, 68, 73, 78, 86], it is observed that many NR RedCap use cases considered in [1] have rather relaxed latency requirements of up to 100 ms or 500 ms and thus can afford to have more relaxed UE processing time. However, it is also mentioned in several contributions [3, 6, 10, 25, 32, 36, 50] that for some use cases such as safety-related sensors, rather strict latency may be required, and a more relaxed UE processing may not be feasible.

In many contributions [15, 21, 25, 29, 36, 38, 46, 50, 54, 58, 65, 68, 73, 97], it is mentioned that relaxed UE processing time beyond what has been specified in Rel-15 (i.e. more relaxed than UE processing time capability #1) may reduce UE complexity and cost. However, it is noted in [3, 6, 10, 25, 43] that the actual complexity/cost reduction may not be clear as it is implementation specific, or even expected to be small and would not be sufficiently meaningful to justify the standardization effort, the impact on scheduling, and the potential limitation on scope of applicability.

With the above background, many contributions [13, 14, 15, 21, 29, 32, 36, 38, 46, 50, 54, 58, 65, 68, 73, 78, 83, 86, 97] proposed to study a more relaxed NR UE processing time capability in terms of N1/N2, while some contributions [3, 10, 25] propose to use the existing NR UE processing time capability #1 as a baseline for NR RedCap and not relax the UE processing times further.

**Question 20: Should a more relaxed UE processing time capability in terms of N1/N2 compared to capability #1 be studied?**

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In addition to UE processing time related to data transmission, some contributions [29, 38] proposed to also study other relaxations of UE processing time such as CSI computation time.

**Question 21: Would any other UE processing time relaxations need to be studied? If yes, explain and motivate.**

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## 7.6 Relaxed UE processing capability

Most contributions [6, 10, 13, 25, 29, 38, 43, 46, 50, 58, 65, 68, 73, 86] bring up reduced maximum peak data rates as a potential UE processing capability relaxation. The mentioned techniques for reducing the maximum peak data rate include restricting the maximum TBS size, the maximum code rate, the maximum modulation order or the maximum number of MIMO layers for both UL and DL.

Some contributions [6, 10, 15, 32] further note that CA support is not desired for NR RedCap UEs. However, one contribution [29] suggests that to achieve peak data rate of 150 Mbps for high-end wearables, intra-band CA may be attractive for device implementations in terms of allowing a certain level of modularity.

Furthermore, relating to the maximum peak data rate relaxation, a few contributions [25, 32, 46, 65] mention that restricting the maximum HARQ buffer size (the maximum number of soft channel bits) or the total layer 2 buffer size may also be beneficial for relaxing UE complexity/cost. Reducing the maximum number of HARQ processes is discussed as well by some contributions [10, 15, 50, 58, 68, 83]. However, one contribution [25] points out that the 16 HARQ processes mandated for NR should be kept also for RedCap since they may facilitate handling a relaxed RTT.

Some contributions [6, 10, 46, 86] make observations about the dependency between peak data rates requirements and the TDD patterns.

In relation to peak rate relaxations it may also be important to note the following restriction of the SID: *“The work defined above should not overlap with LPWA use cases. The lowest capability considered should be no less than an LTE Category 1bis modem.”*

**Question 22: What, if any, UE peak rate capability relaxations should be studied?**

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Several contributions [6, 29, 32, 38, 58, 68, 74, 86, 97] also mention other various techniques that may be beneficial for processing capability relaxation. These techniques include supporting DFT-S-OFDM as the only mandatory waveform, PDCCH relaxation, CSI measurements/feedback/reports relaxation, simplified beam management, simplified CSF procedures, simplified BWP operation, relaxed simultaneous reception of broadcast and unicast PDSCHs in FR1 or two broadcast PDSCHs, no support of prioritization of dynamically scheduled PDSCH/PUSCH over SPS/CG PUSCH occasions respective, and PDSCH reception with receiver side puncturing on configured reserved resources.

**Question 23: What, if any, other UE processing capability relaxations should be studied?**

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## 7.7 Combinations of UE complexity reduction features

The complexity reductions that can be achieved with the individual features discussed in the earlier sections may not necessarily combine linearly when multiple features are applied simultaneously. This section concerns evaluation of the total complexity reduction for combinations of features. For each feature there may be multiple options to study, so the total number of possible combinations may become quite large. Some of the combinations may be less relevant, and some of the features may be band dependent, since bands are associated with different duplex modes, bandwidths and numbers of antennas (cf. TS 38.101-1 for FR1 and TS 38.101-2 for FR2).

**Question 24: What combinations of features should be studied and how should they account for potential band dependencies?**

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# 8 UE power saving and battery lifetime enhancement

## 8.1 Reduced PDCCH monitoring

Several contributions [16, 22, 28, 30, 33, 39, 47, 51, 63, 69, 72, 87] propose to reduce the existing blind decode (BD) and CCE limits. In [7, 84] it is proposed to study whether it is motivated to reduce the exiting BD/CCE limits, considering its power saving benefit. Meanwhile, [26] argues that the 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. Furthermore, [11] believes that CCE limit reduction does not provide a substantial power saving benefit.

Moreover, several contributions discuss potential techniques for reducing the number of BD and monitored CCEs [7, 16, 30, 39, 51, 66, 72, 75, 95]. These techniques include DCI size budget reduction, reducing the number of ALs and PDCCH candidates per AL, and search space adaptation.

**Question 25: What techniques for achieving reduced PDCCH monitoring by means of smaller numbers of blind decodes and CCE limits should be studied?**

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Several contributions propose to study the trade-off between BD/CCE reduction and blocking probability, latency, and scheduling flexibility [7, 22, 26, 28, 30, 33].

**Question 26: What trade-offs should be considered when reducing the number of blind decodes and CCE limits?**

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Other PDCCH monitoring reduction techniques have also been discussed in several contributions [7, 16, 22, 28, 39, 47, 66, 75, 95, 87]. The proposed techniques include search space adaptation, BWP switching, dormant BWP, DCI-based reduced PDCCH monitoring, and multi-slot monitoring.

**Question 27: Should any other techniques for reduced PDCCH monitoring be studied, in addition to blind decodes and CCE limits reduction? If yes, explain and motivate.**

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# 9 Other comments

Comments that do not fit in any of the previous sections of this document can be provided in this section. Note that the TR skeleton is discussed in a separate email discussion [101-e-NR-RedCap-Skeleton].

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