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**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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| **Company** | **Comments** |
| FUTUREWEI | They seem clear enough. We should not get stuck on this: There is nothing in the SID that says we must develop a custom devices that exactly match and do not exceed the data rates listed for the three use cases. In the end we could decide that the “limited set of one or more device types” is just one RedCap device that exceeds these requirements. If we need to spend more time on these later we can, for now we have enough work progressing antenna reduction, bandwidth reduction, etc. |
| vivo | To update the wearable use case as the following (to cover the more typical wearable use cases)  Wearables:   * + Reference bitrate for high-end 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.   + Reference bitrate for low-end smart wearable application can be up to 3Mbps in DL and UL and peak bit rate of the device higher, up to 10Mbps for downlink and uplink.   + Battery of the device should last multiple days (up to 1-2 weeks). |
| Ericsson | We think the requirements are sufficiently clear with a few exceptions. The following clarifications may be useful:   1. The latency requirement of safety related sensors applies from RRC\_CONNECTED state and does not apply for UE access from RRC\_IDLE or RRC\_INACTIVE. 2. The reference bit rate corresponds to the typical (i.e. median) bit rate, not cell-edge bit rate. |
| ZTE, Sanechips | The requirement listed in this section is what is agreed in the SID, and is a very high level requirement. For evaluation of the candidate complexity reduction technique, finer requirement are anyway need to be defined, whether in this section, or in the following sections.  For example to support industrial wireless sensor and video surveillance the current requirement gives no peak bit rate value and we can only rely on some reference bitrate range. If we design bandwidth according to this requirement company may not easily reach consensus on the maximum bandwidth RedCap UE should support. (For the wearable use case both reference bitrate and peak bit rate are given so the requirement for maximum supported bandwidth is straight forward.)  Other clarification include the requirement for device size, which is very vague and company may have different views if 2 antenna can be supported based on this requirement.  The battery life requirement need to be clarified, this should not be viewed as a strictly requirement that the design must meet, but rather a general direction. |
| OPPO | Relaxed requirements for low end wearables shall be supported with the reference data rate about 3-5Mbps. |
| Panasonic | It would be helpful to clarify following points for mutual understanding purpose before conclusion is achieved.  - bit rate is defined as upper layer traffic and not physical layer bit rate. Therefore, if repetition or retransmission is used in physical layer, the higher bit rate per slot is required.  - video surveillance is rather constant bit rate. Industrial wireless sensors and wearable are rather per packet of non-contiguous bit rate.  - Upper layer header overhead and so on are not so explicitly taken into account.  - Latency/reliability of wearable could be handled similar to eMBB discussion i.e. rather best effort. |
| Sierra Wireless | They seem to be clear. There are three uses cases listed but we would like to see a single RedCap device that meets the requirements for all them. Having custom devices for each use case would split the production volume and would increase the overall cost of RedCap devices. |
| Convida Wireless | The requirements seem to be clear enough.  Multiple device types can be considered (Industrial wireless sensors, Video surveillance, Wearables) since they have different requirements.  We are fine with adding the “low-end smart wearable”. |
| Qualcomm | We think the following clarifications are needed for the requirements of RedCap device:   1. Clarification for the requirements on reference bit rate and peak bit rate, including:    * dependency on the slot format and duplexing mode    * achievability of reference bit rate vs MCL    * achievability of 150 Mbps peak rate on DL for wearables limited with 1T1R antenna configuration 2. Clarification for the use cases and corresponding deployment scenarios    * shall the three use cases and corresponding performance requrirements applicable to all FR1/FR2 bands ? 3. Clarification for the minimum set of RedCap UE capabilities and their relationship to those of LTE category 1bis modem    * confirm the BW, antenna number, max TBS and modulation order constraint of LTE Cat-1bis modem are lower bounds of the corresponding UE capabilties of NR RedCap device 4. Clarification for the mobility support of RedCap UE    * confirm whether or not RedCap UE deployed for IWSN and video surveillance scenarios are assumed as stationary    * confirm the moblity support for wearable RedCap devices 5. Clarification for the density of IIoT UE in IWSN deployment 6. Clarification for the typical packet size of IIoT UE in IWSN deployment |
| CMCC | We think most of the requirements are clear enough, but we want to clarify the reference bitrate is not the target cell-edge data rate and cannot be used in the link budget in the evaluation for coverage recovery. |
| DOCOMO | We think the requirements are clear enough but the discussion to map these requirements to the simulation assumptions for performance evaluation is necessary (e.g., target data rate for coverage evaluation and traffic model for power saving evaluation). |
| Huawei, HiSilicon | One clarification is needed on 99.99% communication service availability for industrial sensor. According to TS22.261, reliability covers the communication-related aspects between two nodes, while communication service availability addresses the communication-related aspects between two communication service interfaces. As defined for Rel-16 NR URLLC evaluation [TR38.824], reliability should be used rather than communication service availability from the view of RAN1 evaluation. In addition, for safety related sensors, reliability is missing. Therefore, we propose the following requirements for evaluation.  Proposal 1: for Industrial wireless sensors   * + Reliability is 99.99% and end-to-end latency less than 100 ms.   + For safety related sensors, reliability is 99.99%~99.999% and latency requirement is lower, 5-10 ms end-to-end latency (Note: 3-8 ms air interface latency) |

# 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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| **Company** | **Comments** |
| FUTUREWEI | 36.888 took two full releases to produce, a good part of which was getting these cost breakdowns. It may be OK to have a “888” cost estimate with a big disclaimer written into our TR now that technology has progressed and these are only a very rough estimate most relevant to FR1, and do not include design costs for differing from NR, economies of scale, etc etc. If needed we could also just survey if any major update needs to be made, rather than surveying all companies again on every component. |
| vivo | Fine to follow the methodology of TR36.888 for cost reduction analysis. But the percentage of cost reduction due to the following techniques were not considered in TR36.888 thus should be discussed in RedCap additionally.   * Reduced HARQ process number * Relaxed processing time capability * Relaxed PDCCH monitoring capability |
| Ericsson | Yes. For FR1, the fractional cost breakdown presented in TR 36.888 Table 5.3.1 can be used as starting point in the study. Adaptations to take NR-specific aspects can be considered, such as increased channel bandwidth, increased number of HARQ processes, new modulation and new error correction codes. |
| Xiaomi | At least for FR1, the methodology in 36.888 could be the baseline. On the base of that, some additional new aspect in NR can be further considered. |
| ZTE, Sanechips | We can try to reuse the methodology in TR 36.888. Some modification/addition maybe needed , for example, different subcarrier spacing’s impact on the cost reduction ( band width reduction), relaxed processing time’s impact , relaxed processing capabilities impact etc. |
| OPPO | Evaluation methodology as in 36.888 is beneficial to evaluate the cost percentage of one proposed techniques.  But for Redcap, we didn’t set a cost reduction target. Whether it is worthwhile workload to have a very precise cost breakdowns and cost estimation of each techniques needs to be considered. One rough estimates of the cost reduction would be enough. |
| Panasonic | For cost/complexity breakdown, we are ok to use TR36.888 methodology. But for the percentage numbers, we agree FUTUREWEI that a big disclaimer needs to be written like very rough estimate and not containing design cost and so on. On the ratio between RF versus baseband, it could also be different depending on the number of supported band, FR1/2 difference, used LSI technology and so on. |
| Sierra Wireless | Not in favour of using this methodology. The output of 36.888 was not at all indicative of where costs go in real UEs. The cost savings per technique are difficult to determine unless you manufacture chipset and modules and are very subjective. As FutureWei mentioned, this process also was very time consuming. Even when you do this process, its still a subjective decision on which techniques we agree to specify. It seems like there is already nearly consensus on some techniques, so our proposal is to use normal working procedures (i.e. companies submit tdocs outlining the cost saving for preferred techniques, we discuss, and then work towards consensus where possible) . |
| Convida Wireless | We can use the methodology in TR 36.888 as a baseline, at least for FR1.  Compared with LTE, NR introduced BWP operations which should be taken into consideration when analysing the cost/complexity of RedCap UEs in addition to other features mentioned by Ericsson. |
| Qualcomm | We think the framework adopted by TR 36.888 can be re-used as a starting point, and the following aspects need to be updated/determined:   * UE capabilities of a reference NR modem * cost break down for RF and baseband blocks of a reference NR modem * fractional cost break down of each RF/BB component (compliant with NR-specific design/deployment) |
| Verizon | We can roughly reuse the framework in TR36.888 and focus on the difference between NR and LTE. Though the cost breakdown in 36.888 may not be exactly reflecting the product relaity, it is useful as a reference nonetheless. |
| CMCC | The methodology in TR 36.888 can be used as the starting point, but need some updates for NR e.g., FR2 and features of RedCap UE should also be considered. |
| DOCOMO | Yes, the methodology in TR 36.888 can be used as baseline. |
| Huawei, HiSilicon | The methodology in TR 36.888 can be regarded as the baseline for the analyses in FR1 in view of the similar design and characteristics especially in low frequency band. For FR2, the RF and BB components may be different from FR1, so further consideration on the break down on the fraction of each component in RF and BB are needed. |

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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| **Company** | **Comments** |
| FUTUREWEI | Probably. We at least need to consider this more. Perhaps we can progress at least the main techniques (antenna reduction, bandwidth reduction, …) and FR2 cost evaluation methodology in parallel so that by the end of the study we have a better estimate of the savings and use “888” in the meantime. |
| vivo | It is not clear the same percentage of cost reduction as captured in TR36.888 for a given complexity reduction technique can be directly reused for FR2, so prefer to have some discussion about the potential modifications. |
| Ericsson | Yes. For LTE, and NR FR1, the antenna is not in the scope of the 3GPP specifications. In NR FR2 it is, and this needs to be taken into consideration in the analysis.  We propose to add a row on antenna cost/complexity to the rows found in TR 36.888 Table 5.3.1. It should take into consideration the RF components associated with the antenna in an NR UE, e.g. beamforming network, antenna panels and antenna panel elements.  In addition, FR2 UEs are expected to integrate multiple PAs and possibly multiple filters in the antenna module. This should be taken into consideration when performing the fractional cost break down in FR2. |
| ZTE,Sanechips | Antenna specific cost reduction parameter need to be added. Also, different subcarrier spacing’s impact on the cost reduction (bandwidth reduction), relaxed processing time’s impact, relaxed processing capabilities impact etc. need to be considered. |
| OPPO | We can consider some simpler modelling on the cost reduction for higher frequency in addition to of TR36.888, which is basically mainly for lower frequency. Few major factors of cost reduction for FR2 should be considered. |
| Panasonic | ADC/DAC cost would be more expensive in FR2 than FR1. The cost per antenna would be less in FR2. These aspects should be taken into account. On the other hand, similar to past TR36.888 discussion, different chip set use different functional split like ADC/DAC is located within baseband or RF. The antenna and RF split have also several variations of the integration. Therefore, these are not necessary to be concluded as single number but should accept some range of the variation. |
| Sierra Wireless | If this method is used, then cost of antennas and cost of integration of antenna should be included for FR1 and FR2. |
| Convida Wireless | The methodology may need to be modified for FR2 since the UE implementation may differ in several aspects. |
| Qualcomm | Consider including UE antennas into the methodology (e.g., number of panels, single or dual polarization) |
| Verizon | Yes. Agree with many comments above, some modification for FR2 is needed. |
| CMCC | We are fine to include potential cost/complexity reduction of antenna in FR2. |
| DOCOMO | As the RF components of FR2 is quite different from those of FR1, at least the potential modifications should be discussed. |
| Huawei, HiSilicon | The methodology of cost reduction for FR2 probably need to be modified since the RF chains and antenna components are somehow different with those for FR1 or LTE, such as the IF/RF elements, PAs, antenna elements, antenna panels etc. |

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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| **Company** | **Comments** |
| FUTUREWEI | The reference should be rel-15 without optional features and simplest antenna setup. 4RX, 2TX (2 PA), non-coherent. Note: this would be a reference for cost. For coverage we should assume a “normal” or “reasonable” network where rel-15 coverage enhancing features are not used. |
| vivo | Followings can be configured to define the reference NR device (for complexity and coverage analysis)   * Only consider Rel-15 mandatory features (mandatory without capability signaling) * 2Rx/1Tx * power class 3 * BW: 100MHz for FR1, 200MHz for FR2 |
| Ericsson | For FR1, we propose to reuse the components listed in TR 36.888 Table 5.3.1.  For FR2, the antenna module should be added to the list of RF functional blocks.  In addition, we suggest assuming (see TR 36.888 clause 5.2):   * Single RAT * Single band * TDD or full-duplex FDD * Direct DL and UL wide-area-network access from RedCap UE to eNB * The UE maximum channel bandwidth equals the maximum supported channel bandwidth according to TS 38.101-1/2, and the UE should in addition support all smaller bandwidths that should be supported for the band according to TS 38.101-1/2. * The UE is a Rel-15 UE supporting all mandatory features, including those being mandatory with capability signalling. |
| Xiaomi | The reference could be typical rel-15 UEs.   * UE bandwidth:100 MHz in FR1 and 400MHz in FR2 * 1 Tx/4Rx |
| ZTE,Sanechips | Rel-15 can be used as baseline, but some of the Rel-16 features, for example, UE power saving, two step RACH and positioning etc should be included in the capabilities list that the reference UE need to support, since most likely these features should be supported by RedCap UE. |
| OPPO | The lowest UE configuration is band dependent as in Rel-15 specification. This should be considered as baseline. |
| Panasonic | We agree the rapporteur to use reference as a Rel-15 NR UE that supports all mandatory features (including mandatory features with capability signalling) but no optional features. On the other hand, the difference of the implementation method would make large variation of the estimate. In this sense, it might not be required to be so strict on what is supported as the optionality. |
| Sierra Wireless | If this method is used, we must use a reference NR device that reflects the cost of real-world multi-band devices. We would like to see the cost analysis include the cost of supporting [14] FDD and [10] TDD bands in a single device. |
| Qualcomm | The following UE features should be included in defining the reference NR device:  • UE BW  o 100 MHz for FR1  o 200 MHz for FR2  • TX/RX antenna ports  o 1T2R for FR1 TDD/FDD bands except for n7, n38, n41, n78 and n79  o 1T4R for FR1 bands n7, n38, n41, n78 and n79  o 1T2R for FR2  • duplexing modes (TDD, FD-FDD)  • UE processing capabilities (Type-1)  • MCS  o NR Rel-15 64QAM MCS table for DL/UL  • PC3  • SA  • Single band  • Direct DL and UL access from UE to gNB |
| CMCC | Only mandatory features should be considered to define the reference NR device. |
| DOCOMO | The reference NR device includes all Rel.15 mandatory features. For the following features, we assume:   * 1Tx/4Rx for FR1, 1Tx/2Rx for FR2 * Maximum 100 MHz BW for FR1, maximum 200 MHz for FR2   Regarding mandatory with/without capability signalling, we think the features mandatory without capability signalling are the baseline, but we are open to include the features mandatory with capability signalling if each feature is identified as reasonable for reference NR device assumption. |
| Huawei, HiSilicon | The reference should be at least the UEs with mandatory requirements defined in R15/R16. The antenna reference is 1Tx, as well as 4Rx for band n7, n38, n41, n77, n78, n79, and 2Rx for other FR1 bands and all the FR2 bands. For FR1, the other references are 100MHz bandwidth capability, 200MHz bandwidth capability for FR2, supporting full-duplex FDD, processing time Capability 1 , 23dBm power class, 64QAM (or possibly 256QAM considering already readiness in LTE years ago) for both UL/DL, and some processing capabilities like maximum TBS, MIMO layers, number of HARQ processes etc. defined in NR R15/R16. |

**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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| **Company** | **Comments** |
| FUTUREWEI | It may be OK to state in the antenna reduction that there could be size benefits for 2RX to 1RX but any such benefit needs to be listed with the additional drawbacks. So far do not see a strong need to quantify size reduction. |
| vivo | This is mainly relevant for use cases requiring compact form factor, e.g. wearables. For wearables, the antenna implantation is very challenging thus 1Rx should be supported. In addition, the per antenna performance loss due to size limitation should also be quantified, for example, we observed a -3dB antenna loss for a smart watch. |
| Ericsson | No. Form factor is highly relevant and should be taken into consideration when discussing the suitable number of antennas. Beyond this we believe it will be difficult to quantify form factor gains, which makes it a difficult to study and probably not worth the effort. |
| Xiaomi | Since the device former size is quite critical in the wearable use case, the analysis on the former size is worthwhile. Maybe it is different to provide quantitative analysis, but at least some qualitative conclusion can be draw for the Rx reduction. |
| ZTE,Sanechips | Considering the time limit there should not be quantitative analysis requirement for this aspect. |
| OPPO | Much smaller device size shall be considered for wearables, compared with the normal UE, e.g. smart phone. To quantify this size restriction into evaluation, we suggest modelling it into > 3dB additional loss for RX and TX. We can further consider the Band dependency loss. |
| Panasonic | The contribution to discuss such aspects is welcomed but not required to have the alignment/agreement of the analysis, especially quantify aspects. These can be described in TR as some company's view. |
| Sierra Wireless | It may be difficult to accurately quantify size reduction, but the study should provide some information on the size reduction befits of the UE complexity reduction techniques. Size reduction is an important factor in some of the targeted use cases, so it should be considered. |
| Convida Wireless | Indeed, reducing the number of Rx/Tx antennas or supporting half-duplex FDD operation mode only may contribute in reducing the form factor of different devices. However, quantifying such reduction is challenging because it is implementation dependent. Therefore, no need to quantify any reduction in the form factor in the TR. |
| Qualcomm | We think the main benefits of compact form factor will be reflected in the cost reduction. Moreover, 1T1R antenna configuration should be considered as the baseline for RedCap UE. We don’t see a strong motivation to introduce additional performance metrics and perform non-essential evaluations. |
| CMCC | We are fine to also consider the benefits of facilitating a smaller device size, but whether and how to quantize such kind of benefit and apply it in the analyses need further discussion, |
| DOCOMO | No. We do not see any strong motivation to discuss explicitly on RedCap device size. If there is any UE requirements on device size, we can discuss possible techniques and quantify the benefits to meet the device size requirement. However, in SID, there is no specific requirements for device size. Moreover, through the discussion on processing/complexity reduction such as Tx/Rx antenna reduction, RecCap UE would have relatively smaller device size than regular NR devices and we think it is enough to consider. |
| Huawei, HiSilicon | Quantifying benefits for device size may be fine if there could be proper metric to evaluate it. However, as far as we know, such proper metric for quantitative analysis seems out of reach to RAN design. Compared with other aspects (e.g., cost reduction or power saving), in our view, size reduction is of lower priority. |

## 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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| **Company** | **Comments** |
| FUTUREWEI | We need to be careful to stay within the scope of the SID objective for RAN1. If those techniques require a model and company estimates to be able to make an agreement, we can reuse. However, the range seen in the estimates from the rel-16 power savings were too large, if we go this way we need to try to have tighter estimates. |
| vivo | Consider to reuse the power saving evaluation methodology including the power models from TR38.840 can be reused whenever possible. However, there were no appropriate power model to quantify the power saving gain for the following cases, which should be developed in this SI   * Power comsumption scaling model for reduced BW in FR2 and further refinement (esp, the sleep model) for FR1 with BW=10/20MHz * Power consumption scaling model for UE processing capability relaxation * Further refinement of power consumpion scaling model for PDCCH monitroing capability relaxaition, i.e. #BD, #CCE * Power consumption scaling model for peak data rate restrction   In addition, in power saving SI we only consider the relative power saving gain but did not quantified the UE battery life, but in RedCap SI we have the clear battery life target therefore a way to quantify it should be developed. |
| Ericsson | The power consumption methodology presented in TR 38.840 can be reused for RedCap power saving evaluations for FR1 and FR2. For power saving evaluations, proper ranges of parameters (e.g. bandwidth and number of antennas) should be used based on RedCap requirements. As a starting point the procedure in clause 8 should be used, especially clause 8.1.3 where scaling of bandwidth and number of antennas for power consumption evaluations are provided. |
| ZTE,Sanechips | While we can try to reuse the methodology in TR38.840, we need to acknowledge that the intention and scope of two studies are different. The PS study is focusing on the all aspects that will potentially contribute to the saving of power consumption, while this study for RedCap UE only focus on saving power from reduced BD and CCE. Therefore the methodology will be different in both cases. Also we need to understand that maybe we cannot compare this effect of saving from this study against the result from that study.  Characteristics that are specific to Redcap UE, for example, bandwidth, antenna number will require different model parameters as compare to the one in TR38.840, also the PDCCH monitoring time maybe relaxed to more than one slot, so the corresponding model may need to be adjusted. |
| OPPO | Power consumption model and evaluation assumptions in TR 38.840 can be reused as the baseline. For the aspects not covered, e.g., less RXs, further relaxed processing timeline etc., updated power model would be needed |
| Panasonic | 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. |
| Sierra Wireless | Given the limited time, the methodology in 38.840 may be a large burden. Extended DRX and RRM relaxation do not need a detail power study and are led by RAN2. If we limit the study to only looking at the PDCCH reduction technique (i.e. reducing blind decodes) a much simpler model can be used and a full power study may not even be needed. |
| Qualcomm | If power saving evaluation is needed for RedCap UE, we should reuse Rel-16 power saving evaluation methodology (Appendix in TR 38.840), including UE power consumption model (Section 8.1), UE power consumption scaling (Section 8.1.3) and simulation assumptions (Section 8.2). The modification should reflect reduced capabilities for RedCap UE which include PDCCH monitoring reduction and other capability reductions. |
| Verizon | We can reuse the methodology with modified parameters and focus on the relative changes introduced by new features. |
| CMCC | The evaluation methodology for UE power saving from TR 38.840 can be reused, but the power model needs to be revised, because the reference configuration of power model in TR 38.840 is based on eMBB UE, e.g., 100MHz bandwidth, 4Rx, 256QAM, 4x4 MIMO. In addition, the power consumption scaling in section 8.1.3 in TR 38.840 can be used to adapt the power model according to the features of RedCap UE. |
| DOCOMO | The UE power consumption model in TR 38.840 can be used as baseline. Detail parameters, such as UE BW, number of Tx/Rx, and number of BD/CCEs, should be modified to appropriate values for RedCap UE. |
| Huawei, HiSilicon | Yes, the evaluation methodologies in TR 38.840 can be the baseline, when evaluations are to be performed. First, the power models for FR1 & FR2 reference configuration can be reused, as well as the scaling model for different BW/antenna number. Since the scaling for BW is defined for relatively large BW, when it comes to the case that BW is smaller than 20MHz, the value may not be so precise. We can further discuss the scaling for small BW. Second, the traffic model should fit for REDCAP, while it should not be too complicated. In TR 38.840, both FTP traffic and instant message use FTP model 3 but with different parameter. We think it is a good way to follow. |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | As above, need to stay within the RAN1 SID objective. After RAN2 is done with these objectives, perhaps we can estimate the battery life of the delay tolerant use cases (nice to have, not must have). |
| vivo | The traffic model for connected mode can be reused.  Paging modelling for Idle mode should be defined for different use cases, to study the power benefit of eDRX and RRM relaxation, the paging modelling includes the paging cycle, paging rate, etc. |
| Ericsson | The traffic models in TR 38.840 can be used for wearable use cases. The instant messaging and VoIP traffic types can be considered for wearable use cases. However, suitable traffic parameters at least for inter-arrival time, packet size and codec parameters should be adjusted according to wearable use cases and data rate requirements. |
| ZTE,Sanechips | Models in 38.840 can be used as a starting point. Some parameters, for example Extended DRX parameter, may need to be adjusted. |
| OPPO | Traffic models from TR 38.840 can be used as baseline. |
| Panasonic | We agree the rapporteur view that the traffic models from TR 38.840 can be reused. Potential new values for parameters can be adapted as per needed, e.g. packet size and inter-arrival time. |
| Sierra Wireless | If we only study reduced PDCCH monitoring, then we don’t need a complex traffic model only a paging model (e.g. required (e)DRX cycle and paging rate). |
| Qualcomm | Yes, these traffic models can be reused.  Wearable use cases may also include low-end medical devices and eHealth, which may have different traffic models compared to smart watches. Such traffic models need to be investigated in addition to the smart watch traffic models. |
| Verizon | The models are OK. |
| CMCC | The traffic models from TR 38.840 can be reused, but some parameters may need to be revised, e.g., packet size, mean inter-arrival time, considering different RedCap UE scenarios. |
| DOCOMO | The traffic models in TR 38.840 can be used as baseline for wearable use case. Detail parameters can be modified to appropriate values for the use case. |
| Huawei, HiSilicon | According to our observation from smart watch product, the dominated traffic types are VoIP, Instant message and Heart beat. The services including voice call and video call can be categorised into VoIP. The services including WeChat, Map, navigation, and AI assistant can be regarded as Instant message. And the application layer message from client to server to inform that the service is still alive can be called Heart beat.  The traffic model for VoIP is well defined in R1-070674, so we can reuse it as what we did in Rel-16 power saving WI. For Instant message and Heart beat, the traffic characteristics can be represented by FTP model 3. But the parameters, i.e. the packet size and mean inter-arrival time should be determined based on wearable traffic. |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | As above, need to stay within the RAN1 SID objective. After RAN2 is done with these objectives, perhaps we can estimate the battery life of the delay tolerant use cases (nice to have, not must have). The sensor traffic model could be developed in parallel. |
| Ericsson | The traffic model and parameters provided in Table 5.2-2 in TS 22.104 would be enough for RedCap industrial wireless sensor use cases. Among the listed communication service performance requirements for industrial wireless sensors considering periodic deterministic communications, the processing monitoring case seems relevant to RedCap. |
| ZTE,Sanechips | TS 22.104 can be used as a starting point, but some parameters need to be adjusted based on the requirement of RedCap UE. |
| OPPO | We are open to consider TS 22.104 traffic model. A model will facilitate the evaluation. |
| Panasonic | We agree the rapporteur view. |
| Sierra Wireless | If we only study reduced PDCCH monitoring, then we don’t need a complex traffic model only a paging model (e.g. required (e)DRX cycle and paging rate). |
| Qualcomm | Yes. These traffic models can be used for IWSN. At the same time, we also need to consider the model for downlink traffic. |
| CMCC | The traffic models and parameters from TS 22.104 can be reused. |
| DOCOMO | The traffic models and parameters from TS 22.104 can be used. |
| Huawei, HiSilicon | The communication service performance requirements for industrial wireless sensors were specified in Table 5.2-2 in TS 22.104. For simplification, the traffic models and parameters listed in this table can be used. Furthermore, considering the battery life requirement for RedCap industrial wireless sensor use cases specified in SID (i.e. at least few years), the message size would be small and the transfer interval would be large as much as possible. Therefore, among the three cases defined in Table 5.2-2, the traffic models and parameters related to processing monitoring case can be studied with high priority. That is, 20 bytes message size with 100 ms ~ 60 s transfer interval. |

## 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | YES |
| vivo | We should follow the conclusion from coverage enhancement SI and reuse the methodology to Redcap study as much as possible. Necessary modifications to the evaluation parameters should be made for RedCap specifically, e.g. reduced BW, reduced number of antenna, reduced antenna gain |
| Ericsson | Yes, it’s a good baseline but requires some adaptations:   1. **Hardware link budget:** We prefer to only determine the “Hardware link budget” and leave “Calculation of available pathloss” as an optional alternative. The “Hardware link budget” can furthermore be simplified and follow to the below template:   Maximum Loss Calculation Template:   |  |  | | --- | --- | | Physical channel name | Value | | Transmitter |  | | (1) Tx power (dBm) |  | | Receiver |  | | (2) Thermal noise density (dBm/Hz) |  | | (3) Receiver noise figure (dB) |  | | (4) Interference margin (dB) |  | | (5) Occupied channel bandwidth (Hz) |  | | (6) Effective noise power           = (2) + (3) + (4) + 10 log(5)  (dBm) |  | | (7) Required SINR (dB) |  | | (8) Receiver sensitivity           = (6) + (7) (dBm) |  | | (9) Max CL           = (1) - (8) (dB) |  | | (10) Receiver Antenna Gain |  | | (11) Transmitter Antenna Gain |  | | (12) Maximum isotropic loss (a.k.a. ‘Hardware link budget’) = (9) + (10) + (11) |  |  1. **Channel-specific interference margins:** The IMT-2020 methodology does not provide a methodology for determining the “Receiver interference density”, i.e. the interference margin. We propose that the interference margin is determined based on system-level simulations (SLS). To estimate the interference margins and antenna gains from SLS, we identify a subset of users with SINRs corresponding to the quality requirement of the channel. For this subset we average interference margins. See example below for Msg2 PDSCH transmission with IoT=(I+N)/N. For the time being, the channel-specific interference margins can be set to [0] dB.     **Channel-specific antenna gains:** If the SLS approach is agreeable, we also propose to derive the applicable RX and TX antenna gains for each channel based on actual RX and TX gain statistics collected from the SLS similar as the interference margin as illustrated above where the ‘Antenna gain’ corresponds to the sum of the RX and TX antenna gain. Otherwise, the channel-specific antenna gain would be calculated according to the IMT-2020 methodology. |
| Xiaomi | YES. Coordination with the CE study item may save much repetitive work on determining the baseline, then more focus on the solution estimation. |
| ZTE,Sanechips | Yes we should try to reuse the methodology from TR37.910, however the link budget in that TR is based on FR1, so for FR2 we need new link budget.  Generally we don’t want to introduce new model, considering the time limit of this SI. |
| OPPO | Methodology used in the IMT-2020 self-evaluation can serve as the baseline, but we need to consider other aspects, such as the impact of small form factors of wearables as we comment in previous question. |
| Panasonic | The basic framework itself should be aligned with CE SI. Our understanding of CE SI is it is not yet concluded whether to use the methodology used in the IMT-2020 self-evaluation or not. The possible difference between CE SI and this SI would be, in CE SI, the more focus would be noise limited operation to cell edge to extend the coverage but in this SI, the more focus could be interference limited operation to compensate coverage loss. System level evaluation would be required to obtain the required SINR condition. |
| Sierra Wireless | Yes but we should re-use as much of the Coverage Enhance SI as possible. Before this can start, we need to agree on the complexity reduction techniques first so that we only study channels (e.g. PDCCH, PDSCH) which are affected by the agreed complexity reduce techniques (e.g. HD-FDD, 1 RX antenna, reduced BW). |
| Qualcomm | The IMT-2020 self-evaluation methodology (link budget analysis) considers three scenarios (Indoor hotspot/Rural/Dense Urban) and two channel model variants (channel model A and channel model B) for eMBB evaluation. For RedCap coverage evaluation, it needs to discuss whether all these scenarios and channel models should be included. Also, some parameters (e.g. #antenna ports for both UE and gNB, bandwidth) may need to be adjusted based on the study of UE complexity reduction. Another thing to clarify is whether to use the same UE receiver noise figure for the RedCap device and the legacy eMBB UE.  For FR2, it is preferred to also include an MCL-focused link budget table as in 36.824. |
| Verizon | Should at least provide a reference for the more deployment independent MCL. |
| CMCC | The methodology in the IMT-2020 self-evaluation can be reused, and the some assumption in CovEnh SI can be also reused. |
| DOCOMO | We prefer to align with the methodology used for CE SI. In our understanding, they are discussing which tables (IMT 2020 or TR36.824) they will use for the CE SI, so we may wait their conclusion. |
| Huawei, HiSilicon | According to the SID, coverage recovery is to compensate for potential coverage reduction due to the device complexity reduction. In our simulations, there is no UL performance loss considering the same antenna configuration, while DL coverage loss is obvious due to less antennas and narrower BW, which means it will consume more DL time-frequency resource than eMBB UE to reach the same DL data rate. Thus the impact on DL performance loss should be evaluated firstly, even if DL channel may not be the bottleneck from the view of coverage. So we propose the following simulations with higher priority:   * For PDCCH, AL-4/8/16 should be considered. * For PDSCH, typical modulation order and coding rate, such as QPSK/16QAM, 1/3/1/2 coding rate should be considered.   Evaluation methodology based on link-level simulation we proposed are summarized below:   * Step 1: Obtain the required SINR for the given target data rate for NR legacy UEs. * Step 2: Obtain the required SINR for the given target data rate for NR RedCap UEs. * Step 3: Obtain the performance loss on the basis of required SINR.   Meanwhile if there is enough time, the coverage based on the IMT-2020 self-evaluation link budget can be considered secondly. If link budget is indeed needed, we propose to reuse the evaluation assumptions in coverage enhancement SI as much as possible and consider some necessary modifications, such as reduced UE bandwidth, reduced UE TX/RX antennas. System-level simulation seems unnecessary. |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | Start with ITU |
| Vivo | We should follow the conclusion from coverage enhancement SI and reuse the methodology to Redcap study as much as possible. Necessary modifications to the evaluation parameters should be made for RedCap specifically, e.g. reduced BW, reduced number of antenna, reduced antenna gain as they have direct impact to the link budget performance.  All DL and UL channels should be looked at. |
| Ericsson | Since it is not obvious which channel(s) that are limiting the coverage, we propose to align with the outcome of the CE SI and base the analysis on the same channels as they do. |
| Xiaomi | Considering the cost reduction technique especially the Rx reduction result more coverage loss in the DL, in this case, the PDSCH and PDCCH could be prioritized. But we are OK with to look at both DL and UL channels. |
| ZTE,Sanechips | All channels need to be evaluated. Also we need to first identify the bottleneck channels which are limiting the coverage, and we need to decide if the coverage recovery is for any impacted channel, or only meant to recover the MCL. |
| OPPO | At least take into PDCCH/PDSCH/PUSCH/PUCCH/PRACH into consideration. Take into Msgs during random access procedure into consideration.  FFS for broadcast channel. |
| Panasonic | Yes, link budget approach should be used, although the required SINR reference point may be determined by system level simulation. |
| Convida Wireless | All the DL and UL channels for RedCap UEs in RRC-connected state should be considered. Also, the channels in RRC-idle should be considered, i.e. for system information, paging and random access. |
| Qualcomm | We think both DL and UL channels including broadcast and unicast channels should be evaluated. The broadcast channel, especially RMSI PDCCH, message 2 PDCCH, message 2 PDSCH and message 3 PUSCH may probably be the bottleneck of coverage due to limited beamforming capability and no support of HARQ retransmission and repetition.  In addition, for beam switching reliability in FR2, L1 measurement reports need to be included in the evaluation [refer to R1-2004499 for details]. |
| Verizon | In principle, should align with the CE SI on methodology and (common) assumptions. Focus on the differences between RedCap and regular NR. |
| CMCC | Following the channels/messages evaluated in CovEnh SI. |
| DOCOMO | PDCCH, PDSCH, PUCCH, and PUCCH can be the baseline as CE SI. However, it is unclear which channel/signal is the bottleneck due to reduced capability and hence, all relevant DL and UL channels/signals, such as SSB and PRACH, can also be included in the link budget evaluation. |
| Huawei, HiSilicon | We think the channel evaluated inIMT-2020 self-evaluation may be enough for Redcap coverage evaluation. Not mandatory to consider more channels and messages unless deemed necessary according to the outcome from coverage enhancement SI for certain specific channels. |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | FFS |
| vivo | For a particular physical channel, the required SINR may be different compared to normal UE due to reduced BW, reduced number of antennas. |
| Ericsson | As a rule, we should seek alignment with the CE SI. Preferably we should first be able to review the outcome of the ongoing CE simulations assumptions discussions before we take a final decision. |
| ZTE,Sanechips | We can try to reuse the methodology, but the actual metric may be different. For example, compare with the required SINR in NR CE study, the value for RedCap UE will be different since different use case will lead to different data rate. For control channel, BLER, DCI format, number of TX/RX antenna will all have impact on the required SINR. |
| OPPO | For use cases with relaxed delay requirement, relaxed BLER target can be considered. |
| Panasonic | In CE SI, the more focus would be noise limited operation to cell edge to extend the coverage but in this SI, the more focus could be interference limited operation to compensate coverage loss. This could make some difference on the required SINR point. |
| Convida Wireless | Agree with ZTE that the actual metric may be different. For instance, miss detection probability metric may be needed for coverage evaluation of Msg1 or sequence-based PUCCH. |
| Qualcomm | Yes in principle. Nevertheless, we need to look at the detailed evaluation methodology being discussed in Coverage Enhancement SI and decide whether it matches reduced UE capabilities. |
| CMCC | We think it may not be reasonable to directly reuse the target date rates for coverage enhancement SI since it is expected that RedCap UE’s cell edge data rate is likely to be lower than eMBB UE. How to determine the target data rates for RedCap UE still needs discussion. We think it is also necessary to clarify the relationship between the target data rate and the reference bit rate requirement. |
| DOCOMO | The BLER targets can be reused. If the target data rate for RedCap aligns with that for CE SI (e.g. eMBB for DL (FR1): 10 Mbps for Outdoor to indoor, 1 Mbps for rural), the target data rate can be also reused. |
| Huawei, HiSilicon | Same reply as to question 10 |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | FFS |
| vivo | We should follow the conclusion from coverage enhancement SI and reuse the methodology to Redcap study as much as possible. Necessary modifications to the evaluation parameters should be made for RedCap specifically, e.g. reduced BW, reduced number of antenna, reduced antenna gain |
| Ericsson | Same reply as to question 11: As a rule, we should seek alignment with the CE SI. Preferably we should first be able to review the outcome of the ongoing CE simulations assumptions discussions before we take a final decision. |
| Xiaomi | FFS, especially the antenna efficiency loss need to be well considered. |
| ZTE,Sanechips | We can use the link level simulation assumption from CE study as reference, but the configuration may be different, for the same reason as we explain in the previous question. |
| OPPO | Consider the impact of less RXs into the modification. |
| Panasonic | FFS |
| Qualcomm | Yes in principle, but some parameters may need to be adjusted for RedCap UE, such as the number of RBs and the DMRS configurations. |
| CMCC | To study this issue after some outcomes from CE SI. |
| DOCOMO | If the target data rate is aligned with that for CE SI, the simulation assumption can be aligned. And if not we have to consider to modify the simulation assumption, e.g. different number of RBs, MCS, for the target data rate for RedCap. |
| Huawei, HiSilicon | Same reply as to question 10 |

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”?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | YES |
| vivo | Following the conclusion from coverage enhancement SI |
| Ericsson | Yes. We prefer to further simplify the analysis based on the link budget template proposed in our reply to Question 9. |
| Xiaomi | YES. The main target of the estimation in this SI is to figure out the coverage gap, comparing the link budget between normal device and RDDCAP is enough. |
| ZTE,Sanechips | Yes. Prefer to use MCL. |
| OPPO | We would prefer only on matrix Maximum range. |
| Panasonic | Yes. |
| Sierra Wireless | Yes. Prefer to use MCL. |
| Qualcomm | We prefer to use the “hardware link budget” or “MCL”. |
| Verizon | Yes. Perfer MCL. It is more useful for wider audience too, in our view. |
| CMCC | We are open to either one. |
| DOCOMO | In our understanding, “Maximum range (m)” is calculated using “Hardware link budget (dB)”, so we may just select a metric and Hardware link budget is fine for us. |
| Huawei, HiSilicon | Again, whether RedCap SI should focus on determining the “Hardware link budget” or “Maximum range” can refer to the conclusions from CE SI, which is on-going. |

## 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | We may need to dig into each technique to see what other impacts we want to list for that technique. For example, if we find that a technique would require us to use the highest aggregation level for PDCCH all the time, we may need to include some statement or evaluation on PDCCH blocking. We would not want to agree to the list now and be told we could not include something relevant later. |
| vivo | FFS |
| Ericsson | Yes. |
| Xiaomi | It depends on the detailed techniques. For example, for the reduced PDCCH monitoring, the impact on the PDCCH blocking should be investigated as well |
| ZTE,Sanechips | Can be used as starting point. It’s better to clarify that data rate refers to peak data rate only. |
| OPPO | We are not sure the study of impact can lead to. Genearally, if there is strong impact, then we will no choose the technology. |
| Panasonic | We would agree FUTUREWEI view. |
| Sierra Wireless | Yes. |
| Qualcomm | The evaluation methodology and metrics for co-existence needs to be clarified.  Performance evaluation for latency and FR2 should be use case specific. For example,   * end-to-end latency evaluation is desirable for IWSN/IIoT, but not for other use cases. * For FR2, spatial beam direction separation between RedCap and non-RedCap devices need to be evaluated. |
| CMCC | Yes |
| DOCOMO | Yes, the performance impacts on these aspects should be evaluated. |
| Huawei, HiSilicon | Yes but don’t preclude other key aspects for some particular cases if any. When studying the features for complexity reduction, power saving and coverage recovery, the corresponding impacts on data rate and latency should also be considered. For example, the impact incurred by reduced BW/antenna number on the data rate needs to be studied, so as to ensure the reduced BW/antenna number can meet the data rate requirements for the target use cases discussed in SID. Additionally, from the aspect of strict latency requirement for safety related sensors (5~10ms), the impact of the features (e.g. to provide reduced complexity and power consumption) on latency should also be evaluated. As for the coexistence with legacy UEs, it would be preferable to list the potential impacts on the coexistence with legacy UEs firstly and then evaluated. |

# 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | 2RX/1Tx should have antenna switching |
| vivo | Both 1Rx/1Tx and 2Rx/1Tx should be studied.  The antenna gain loss for wearables due to size limitation should be quantified. |
| Ericsson | Yes, it is enough. In FR1, the scope of the 3GPP specifications ends at the antenna connector. We prefer to align with earlier 3GPP UE complexity reduction studies that have excluded antenna aspects. Concerning wearables, at least for low bands, we believe that a 1TX/1RX solution with reasonable antenna aperture should facilitate many applications. |
| Xiaomi | 1Rx/1Tx should be the baseline for studying due to the limited physical space in wearable and sensor devices.  On the base of 1Rx/1Tx, 2 Rx/1Tx can be considered as well for the use case requiring high data rate |
| ZTE,Sanechips | 1Rx/1Tx and 2Rx/1Tx |
| OPPO | Loss of Antenna gain due to small form factor for wearable shall be studied |
| Panasonic | Yes, to study 1Rx/1Tx and 2Rx/1Tx is enough. |
| Sierra Wireless | Yes, study of 2Rx/1Tx and 1Rx/1Tx is enough. |
| Convida Wireless | Yes, 1Rx/1Tx and 2Rx/1Tx are enough. |
| Qualcomm | Yes, we think it is sufficient to study 1T1R and 1T2R in FR1.  Moreover, 1T1R should be assumed as a baseline for RedCap UE. If a RedCap UE supports 2 RX antennas, it can be reported via capability signalling after RRC connection. |
| CMCC | Yes, study of 2Rx/1Tx and 1Rx/1Tx is enough. |
| DOCOMO | Both 1 and 2 Rx should be studied. 1Rx may be baseline at least for IWSN however further discussion may be needed on the feasibility to meet smart wearable requirements only by 1Rx. |
| Huawei, HiSilicon | Yes for FR1 and 1Rx/1Tx is in our view studied for some specific cases or band, thus is of low priority. |

**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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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | OK with 2Rx/1Tx |
| vivo | Similar as FR1, both 1Rx/1Tx and 2Rx/1Tx should be studied |
| Ericsson | In addition, since in FR2 the scope of the 3GPP specifications includes the antenna, we think it’s reasonable to study relaxed spherical coverage requirements that may enable reduced antenna configurations in terms of reduced number of panels and reduced number of antenna elements per panel. |
| ZTE,Sanechips | 1Rx/1Tx and 2Rx/1Tx |
| OPPO | OK with that |
| Panasonic | Yes to study 2Rx/1Tx is enough. |
| Sierra Wireless | Yes, 2Rx/1Tx is Ok. |
| Convida Wireless | Consider both 2RX/1Tx and 1Rx/1Tx, but 2RX/1Tx with higher priority |
| Qualcomm | In FR2, both 2Rx/1Tx and 1Rx/1Tx should be studied. (1Rx e.g., for industrial wireless sensors applications). |
| Verizon | Our current view is that 2Rx/1Tx is more relavent |
| CMCC | Yes |
| DOCOMO | At least, 2Rx/1Tx should be studied. 1Rx/1Tx needs to be further studied taking into account which use case can be assumed for FR2. |
| Huawei, HiSilicon | Yes for FR2 |

## 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | Nothing below 20MHz should be studied as the lowest capability is no less than cat 1b LTE (20 MHz). In addition to the reasons above, 20MHz will also be useful for future RedCap unlicensed devices. Given the inputs, we could probably take a working assumption on 20MHz and try to flesh out the section under that assumption. |
| vivo | The 10MHz BW should be considered in the study as well, as it does not require spec change for initial access.  Our understanding of the statement in the SID “The lowest capability considered should be no less than an LTE Category 1bis modem.” is mainly related to the data rate but not directly restrict our design of the operating BW. |
| Ericsson | Yes. Ericsson prefers that a RedCap UE should support at least a maximum 20 MHz bandwidth in FR1.  In FR1 it is very important to preserve all the existing configuration options for SSB and CORESET#0 while minimizing the specification impact when RedCap is introduced in Rel-17. We foresee that the market acceptance of RedCap will be significantly weakened if enabling RedCap support in the network needs to come at the cost of losing certain configuration options for SSB or CORESET#0. In FR1, CORESET#0 bandwidth can be up to 17.28 MHz. Therefore, a RedCap UE can be expected to support 20 MHz channel bandwidth during initial access.  20 MHz can also be considered a sweet spot that balances the device cost and the required data rate for various services outlined in the SID. For the low-to-mid end data rate services, no MIMO is needed if 20 MHz is assumed, which is beneficial for devices with small form factors. If smaller bandwidth is used, e.g. 10 MHz, MIMO or CA might be needed for low-to-mid end data rate services, which can be challenging for certain devices. |
| Xiaomi | Studying on 20MHz bandwidth should be the baseline for one of the Redcap UEs, if more than one type is defined, where we are open to study bandwidth that is smaller than 20MHz. |
| ZTE,Sanechips | According to Note1 in SID, “The lowest capability considered should be no less than an LTE Category 1bis modem.” Since the maximum bandwidth of LTE Cat 1bis UE is 20 MHz, the maximum bandwidth of RedCap UE should be no less than 20 MHz. For low-end use cases, 20 MHz UE bandwidth is enough to achieve the data rate requirement. For high-end use cases such as small size wearables, 20 MHz bandwidth is not enough to achieve the 150 Mbps DL peak data rate for single antenna case. Considering initial access should support different capability RedCap UEs, 20 MHz bandwidth can be considered as the baseline for initial access in FR1. |
| OPPO | 20 MHz channel bandwidth shall be supported, and smaller bandwidth such as 10MHz shall also be considered at least for use case not requiring high peak data rate such as low end wearables.  If allowed for more options, 40/50MHz can also be considered.  Decoupling UL/DL bandwidth shall also be studied for non- symmetrical traffic for use case such as video surveillance. |
| Panasonic | No need to study 5 or 10 MHz when the system bandwidth is 20MHz or more. This is inline with cat 1b LTE modem assumption described in WID. The co-existence operation impact when the system bandwidth is less than 20 MHz should not be excluded. |
| Sierra Wireless | We should only study 20MHz. Using narrower BW will have more spec impact and limit the peak data rates and higher BW for FR1 are not needed. |
| Convida Wireless | In our understanding, UE bandwidth reduction is a key feature to significantly reduce UE complexity and cost.  Therefore, we support to also study bandwidths lower than 20 MHz.  For a low-end RedCap UE that only requires e.g. 10 MHz for meeting the data rate requirement, e.g. IWS, it seems wasteful to implement a 20 MHz receiver only for initial access. |
| Qualcomm | Yes, 20 MHz UE BW should be assumed for initial access.  In FR1, we think a RedCap device should support at least a max UE BW of 20 MHz. Further reduction of max UE BW leads to diminishing gain in cost reduction and power saving, but significant loss in coverage, data rates, latency, scheduling flexibility and co-existence with legacy NR UEs. |
| CMCC | Yes |
| DOCOMO | For reusing existing SSB, CORESET#0, and corresponding SIB1 PDSCH, supporting 20MHz UE BW would be enough. However, for reusing existing random access procedure, when 8 ROs are FDMed with 30kHz SCS, the total BW is larger than 20MHz. If RedCap UE supports maximum 20MHz BW (i.e., maximum initial UL BWP size), the ROs outside of initial UL BWP cannot be used and hence, UE may not able to transmit PRACH corresponding to the best SSB. In addition, as stated in SID, the lowest capability considered should be no less than an LTE Category 1bis modem, supporting larger than 20MHz BW can be included in the study at least for initial access. |
| Huawei, HiSilicon | We propose that nothing below 20MHz UE bandwidth should be considered for Rel-17 REDCAP UEs in FR1, from the aspects of satisfying the key date rate requirement with maximized reduction of device cost and power consumption, meanwhile being compatible with Rel-15 design of SSB and CORESET#0 to minimize specification impact and retain attractive commercial values of this type of UEs. |

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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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | Less than 80-100MHz have impacts due to PBCH and coreset selection, which is part of initial access. So we should assume 80-100 MHz, and focus on whether there is enough cost benefit to recommend 80MHz over 100MHz to RAN4. |
| vivo | FFS |
| Ericsson | We are open to study 50 and 100 MHz, and since these bandwidths are already specified for FR2, we have a strong preference for these bandwidths over the other proposals in order to minimize the impacts on specifications, implementations and deployments.  In FR2, even though the maximum SSB bandwidth can be up to 57.6 MHz and CORESET#0 bandwidth can be up to 69.12 MHz, in our view these SSB and CORESET#0 configuration options can still be used in cells supporting 50 MHz RedCap UEs. As discussed in our contribution R1-2003289, a UE may need to skip certain SSB or PDCCH subcarriers outside of the UE receive bandwidth. This will result in some coverage loss that should be studied and that can be mitigated through suitable coverage recovery solution should SSB and PDCCH become the coverage limiting channels. |
| ZTE,Sanechips | The maximum bandwidth for RedCap in FR2 should be selected from the bandwidth set. We can study 50 MHz and 100 MHz maximum UE bandwidths. The concern for 50Mhz is if 240 kHz SSB is supported in FR2, the SSB bandwidth would be 57.6 MHz. In this case, if the RedCap UE maximum bandwidth is 50 MHz, further study is need to see if the RedCap UE can receive SSB with acceptable performance. |
| OPPO | 50MHz shall be considered for FR2 |
| Panasonic | To evaluate/compare both groups of view, i.e. to compare the case maximum UE bandwidth in the range of 40-60 MHz and the case maximum UE bandwidth in the range of 80-100 MHz |
| Sierra Wireless | Due to time constraints we should ONLY study 100MHz or at least prioritize 100MHz. 80MHz does not provide significant UE cost savings and going below 80MHz will have large specification impacts and legacy network impacts. |
| Convida Wireless | In FR2, even more than in FR1, UE bandwidth reduction is a key feature to significantly reduce UE complexity and cost.  Therefore, we support to also study maximum bandwidths of 50 MHz or even lower. |
| Qualcomm | In FR2, study 50 MHz or 100 MHz for at least initial access. |
| Verizon | For 50MHz, or anything lower, their benefit in cost/power saving vs. 100MHz should be justified, can’t just assume. |
| CMCC | In FR2, 50 MHz or 100 MHz should be considered. |
| DOCOMO | The UE BW which supports SSB/CORESET0 multiplexing pattern 2/3 and corresponding SIB1 PDSCH should be studied at least for initial access. For SSB/CORESET0 multiplexing pattern 2 with SSB/CORESET0 SCS are 240/120 kHz, the required UE BW is larger than 100 MHz. |
| Huawei, HiSilicon | We feel that 100MHz should be studied in FR2. In FR2, we propose both 120kHz and 240 kHz SCS should be supported. So the maximum bandwidth of SSB bandwidth and CORESET#0 can be up to 57.6MHz and 69.12MHz. In order to reuse Rel-15 SSB bandwidth and minimize specification impact, reduced UE bandwidth should be no less than that.  (Note: At least 69MHz to support Pattern1 with <240kHz 20RB SSB, 60kHz 96 RB CORESET0, with 0RB offset>. If want to fully support Pattern 2 and Pattern 3, it requires ~128MHz with <240kHz 20RB SSB, 120kHz 48 RB CORESET0, with 49RB offset>) |

## 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | FFS |
| vivo | If considered, suggest to prioritize type A. |
| Ericsson | We propose to study DL-to-UL and UL-to-DL guard periods of 0.5 ms to facilitate a single local-oscillator implementation, which corresponds to 7 OFDM symbols with 15 kHz SCS, 1 slot with 30 kHz SCS, 2 slots with 60 kHz SCS, and 4 slots with 120 kHz SCS. |
| Xiaomi | For HD-FDD operation Type A, the transition time defined in 3GPP TS 38.211 Table 4.3.2.3 for Tx-Rx and Rx-Tx switching can be reused (i.e. 25600Tc for FR1).  For HD-FDD operation Type B, the transition time should be FFS.  In addition, we are not sure whether we should directly reuse the concept of DL-to-UL and UL-to-DL guard period as in LTE. For example, we are not sure whether UE should always drop the last part of DL reception if an uplink transmission follows. We suggest to further discuss UE behaviour if there is no enough Tx-to-Rx or Rx-to-Tx transition time. |
| ZTE,Sanechips | Send LS to ran4 for this issue |
| OPPO | FFS |
| Panasonic | Similar to past LTE discussion, this should be concluded in RAN4. |
| Sierra Wireless | Only Type A should be studied due to time constraints. Type B would slow the speed down, and the cost impact of a single vs dual oscillator is not significant. |
| Convida Wireless | Support studying both HD-FDD type A and type B. |
| Qualcomm | We think HD-FDD operation similar to Type-A HD-FDD of LTE should be studied in FR1, which is supported by LTE Cat-1bis modem. As a result, the size of guard period should be on the order of OFDM symbol instead of slot/subframe.  Specifically, we don’t see a strong motivation to study HD-FDD device with single PLL/LO. This is because reducing the number of PLL/LO from two to one brings marginal gain in cost saving, but leads to significant loss in performance including latency, throughput and scheduling flexibility. |
| CMCC | If considered, suggest to prioritize type A. |
| DOCOMO | LTE HD-FDD type A/B as baseline |
| Huawei, HiSilicon | HD-FDD will cause low data rate, coverage reduction and high latency since the UEs with HD-FDD cannot simultaneously transmit and receive signals and require big guard overheads, e.g. two full subframes of guard period before and after the start and end of an uplink transmission in LTE, respectively. However, the rough cost reduction estimation may be less than 10% compared with FD-FDD according to TR36.888. So we propose to support FD-FDD as the baseline for REDCAP UEs. Additionally, if it were studied, the guard period would have been based on RAN4 inputs. |

## 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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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | No |
| vivo | The SID clearly tasked RAN1 to study the relaxation of UE processing time, such study should be carried out by quantifying the cost/complexity reduction and power saving benefit by the relaxation and after which the recommendation can be made. It is not proper to exclude it even before any study. |
| Ericsson | We are ok to study it. We observe that there can be a dependency with the PDCCH monitoring relaxation feature, since if a more relaxed limit for PDCCH monitoring is introduced, there may not be much additional complexity reduction from relaxed processing time in terms of N1/N2. |
| Xiaomi | It’s better to carry out the study before the exclusion |
| ZTE,Sanechips | FFS. We need to first decide methodology for evaluation of delay requirement, TR37.910 can be used as a starting point. |
| OPPO | Yes |
| Panasonic | Not required. |
| Sierra Wireless | No. Some of the use cases in the SID may not be able to afford more relaxed processing time. It is also not clear how much cost reduction can be attained with such optimization. |
| Convida Wireless | Yes, it should be studied. |
| Qualcomm | It can be studied, to verify whether and how much the relaxed UE processing time helps with cost reduction and power saving. |
| CMCC | We are open to study it. If a more relaxed UE processing time capability is studied, the default PUSCH TDRA table may be needed further examination because it is designed according to N2 of capability #1, and the more relaxed N2 may cause some entries in current default PUSCH TDRA table cannot be used by RedCap UE. |
| DOCOMO | Yes, it should be studied as included in the objective of the SID |
| Huawei, HiSilicon | We propose not to relax UE processing time compared with capability #1 for REDCAP UEs. Because relaxing processing time imposes limitation on the application of low latency use cases. Moreover, the cost saving arising from relaxed processing time seems trivial compared to other potential techniques. |

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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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | No. Note: we may be ok with the proposal to have the cross-slot scheduling rel-16 power savings feature where the UE could assume the cross-slot scheduling is being used. |
| vivo | There are a lot of other timelines related to N1/N2, which should also be considered together with N1/N2 relaxation. |
| Ericsson | We have not identified any further relaxation that we think need to be studied, but we are open to hear views from UE vendors regarding potential bottlenecks that they may have identified. |
| ZTE,Sanechips | We are Ok to study CSI computation time |
| OPPO | More relaxed UE processing time capability shall be studied for delay tolerant use case. Cross-slot-only should be be supported for RedCap. This is complementary to relaxed PDCCH processing. |
| Panasonic | Cross-slot scheduling related relaxation for PDSCH buffering reduction and PDCCH processing time reduction should be taken into account. |
| Sierra Wireless | No |
| Convida Wireless | We are Ok to study the relaxation of CSI computation time. |
| Qualcomm | We think cross-slot scheduling, relaxation for CSI computation latency and relaxed RTT of HARQ procedures can be studied. |
| CMCC | FFS |
| DOCOMO | We are open to study but have not identified any other features. |
| Huawei, HiSilicon | No, from UE capability perspective. However some HARQ timeline can refer to that in cross-slot scheduling from power saving perspective. |

## 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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| **Company** | **Comments** |
| FUTUREWEI | The techniques to be studied under section 7.6 have not yet been agreed. We are only OK with listing in the TR techniques that we all agree to include in the study. We are not OK with treating this as a ”blank check” for whatever proposal anybody wants to include that somehow requires less processing as we only have limited time and we should focus on the WID objectives that we were able to clearly define.  Specifically, we are not ok to include generic ”TBS reduction” or ”peak data rate reduction” or ”modulation restriction” or ”HARQ simplifications”. The only technique that we are ok to include now is ”restriction to a single MIMO layer”. We are also OK to state ”Section 7.2 reduced number of UE Rx/Tx antennas and Section 7.3 UE bandwidth reduction will reduce the UE processing.” Our recommendation is to progress those two objectives, and then decide later whether we will study anything beyond those techniques. This will also avoid us getting stuck now in arguments about what exact data rates and how many types of devices redcap supports. The SID has some requirements for different services, but can be satisfied with just one redcap device that meets all the requirements. There is nothing in the SID that says we must develop a custom devices that exactly match and do not exceed the data rates listed for the three use cases. |
| vivo | Reduced number of HARQ processes |
| Ericsson | We are open study peak rate capability relaxations related to reduced channel bandwidth, reduced number of DL MIMO layers, reduced modulation order, and reduced maximum TBS. We would also like to understand the benefits of the modular approach based on intra-band CA proposed in [29]. |
| Xiaomi | Agree with Futurewei’s opinion. Some processing capability is related the UE bandwidth such as maximum TBS and the number of Tx/Rx such as the MIMO layer. In this case, we could prioritize the study on UE bandwidth reduction and Tx/Rx reduction. After that, we could study if any other capability can be further reduced with little impact on the performance requirement. |
| ZTE,Sanechips | Modulation restriction, max TBS size , supported code rate , maximum number of MIMO layers and maximum HARQ processes |
| OPPO | Support lower MCSs, at most 2 MIMO layer, not support 256QAM for DL and 64QAM for UL.  Decoupling UL/DL UE capability shall also be studied for non- symmetrical traffic for use case such as video surveillance. |
| Panasonic | The maximum peak data rate depends on the maximum TBS size, the maximum code rate, the maximum modulation order and the maximum number of MIMO layers for both UL and DL, which should be studied. Which peak data rate is used can be also different among use cases. |
| Sierra Wireless | UE processing capability reduction may not provide as much UE cost savings as others. Cost of processing is not as significant as reduction in hardware components. We do not see a need to reduce the UE peak data rate for each of the specific use cases, rather have a single RedCap device for all.  We can study reduction of modulation order as it would provide relaxation on device performance requirements. However, we do not see a need to reduce the TBS size or to restrict to a single MIMO layer (for 2Rx). |
| Convida Wireless | Study reducing the number of HARQ processes and restricting the modulation order. |
| Qualcomm | We think at least the following aspects can be studied for UE peak rate capability relaxation:   * half duplexing operation only (HD-FDD and TDD) * reduced number of MIMO layer * MCS restriction * TBS restriction * max UE BW reduction * DMRS configuration * Single band ans single RAT (No support for intra-band CA and inter-band CA) |
| Verizon | Peak rate reduction should be justified for cost and power saving benefit, qualitifively, especially for FR2. |
| CMCC | We are open to study the UE peak rate capability relaxation techniques |
| DOCOMO | FFS. If only one set of UE features (or something like UE category) is defined for the support of RedCap, to meet the requirements for all the three use cases by one set of UE features, any other relaxation features except for MIMO layer reduction may be difficult to support. However, if few sets of UE features are defined, it would be beneficial to assume additional peak rate relaxation for lower set(s) of UE features (e.g. peak rate relaxation only for industrial sensor use case). Possible candidates of relaxation techniques are reduced number of HARQ process, reduced modulation order, and TBS reduction. |
| Huawei, HiSilicon | We think techniques such as reducing the maximum TBS, supporting only one layer MIMO, limiting the maximum modulation scheme to 64QAM, will be beneficial for complexity reduction and cost saving. And restricting number of HARQ process can also be considered for REDCAP UEs for cost saving if no obvious impact the peak data rate and the scheduling flexibility. |

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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| **Company** | **Comments** |
| FUTUREWEI | See above. Redcap devices should be as close to “normal” NR as possible with some big-ticket techniques providing major cost reductions. Spending time on very many small optimizations has not been agreed nor will be worthwhile. |
| vivo | FFS |
| Ericsson | In general, we don’t think any of the relaxation techniques mentioned should be studied.  However, if other techniques should be studied, we prefer to focus on beam managements, CSF procedures or CSI measurements. Nevertheless, the scope should be clearly defined and not contain techniques that would be better addressed as power saving features. |
| ZTE,Sanechips | CSI measurement/feedback/report relaxation |
| OPPO | More relaxed BWP switching delay shall be studied. |
| Panasonic | FFS. It should avoid too many small optimizations. |
| Sierra Wireless | None or as low priority |
| Qualcomm | We think the following aspects can be studied for UE processing capability relaxation:  • reduced number of HARQ processes  • HARQ-ACK bundling  • restriction on the DCI size/formats to be monitored, reduced PDCCH monitoring and CCE limits  • CSF simplification  • UCI multiplexing simplification  • BWP hopping/switching simplification and potential optimization  • Beam management simplification (for FR2) |
| Verizon | Beam management simplication for FR2 |
| CMCC | FFS |
| DOCOMO | We are open to study but have not identified any other features. |
| Huawei, HiSilicon | FFS. Need to first get through the list set in the SID before extending it without any consideration of the time units it might take. |

## 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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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | We should be able to consider this later, where we investigate a particular combination. If possible, we should avoid working on a technique that will obviously not have any large additional benefit over antenna and bandwidth reduction. |
| vivo | FFS |
| Ericsson | To support an aggregated estimate of the complexity reduction we propose three reference band configurations:  **FR1 FDD:** Single-band UE supporting 70 MHz channel bandwidth (corresponding to the largest bandwidth currently specified for an FR1 FDD band) and requiring 4 RX.  **FR1 TDD:** Single-band UE supporting 100 MHz channel bandwidth and requiring 4 RX.  **FR2 TDD:** Single-band UE supporting 200 MHz channel bandwidth and requiring 2 RX. |
| Xiaomi | OK to study it. And different combinations aim to provide different performance. For example one combination target to low data rate requirement case with more cost reduction and another combination target to high data rate requirement case with less cost reduction. |
| ZTE,Sanechips | Focus on the techniques such as antenna number, peak data rate etc. The combination should be evaluated for both FR1 and FR2. |
| OPPO | whether to support a feature needs to consider whether there is additional gain when introducing it. |
| Panasonic | We agree the complexity reductions may not necessarily combine linearly when multiple features are applied simultaneously. In order to avoid too many combinations, it should be discussed later. |
| Sierra Wireless | As we mentioned, the baseline device should consider a large number of bands (14 FDD bands and 10 TDD bands) that way if there is band dependencies, it gets consider in the total aggregated cost reduction for that technique. |
| Convida Wireless | We may first study each feature separately. |
| Qualcomm | Most of the features of UE complexity reduction described in Sections 7.2 to 7.6 can be combined. HD-FDD operation work for FDD bands only. Specifically, the following UE features for complexity reduction are band-specific:   * For FR1:   + Max UE BW of 20 MHz excluding intra-band and inter-band CA   + TX/RX antenna number reduction     - 1T1R for all TDD/FDD bands of FR1     - 1T2R configuration for bands n7, n38, n41, n78 and n79 (FFS)   + HD-FDD operation on FDD bands only * For FR2:   + Max UE BW of 50 and 100 MHz excluding intra-band and inter-band CA   + TX/RX antenna number reduction: 1T2R and 1T1R |
| DOCOMO | FFS. It may be better to discuss first how many sets of UE complexity reduction features need to be discussed, i.e. only one sets of UE complexity reduction features covering all of three use cases, or a few sets of UE complexity reduction features need to be defined |
| Huawei, HiSilicon | From our view, the individual features discussed in the earlier sections should be studied with high priority. The potential combinations could be considered later after identifying the individual features for UE complexity reduction if necessary. |

# 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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | FFS. Should see what is possible within the current configuration ranges. |
| vivo | Study the relaxation the number of BD and CCE that is required per slot for the UE. |
| Ericsson | In order to reduce the number of blind decodes and CCE limits, the possibility of reducing the maximum numbers of DCI sizes, ALs and PDCCH candidates per AL that the UE needs to monitor simultaneously should be studied. |
| Xiaomi | For the purpose of UE power saving, current NR already supports limiting the BD and CCE per slot by NW’s configuration. So, we don’t see the motivation of limiting the BD and CCE per slot by means of restricting the PDCCH processing capability.  In this case, we suggest to first clarify why limiting the BD and CCE via NW configuration is not enough. After that, we could consider some other technique to reduce PDCCH monitoring. |
| ZTE,Sanechips | PDCCH related configuration settings, including maximum number of DCI sizes, search space configuration, total number of search spaces , total CORESET numbers etc |
| OPPO | FFS |
| Panasonic | The current reference configuration of Rel.16 power model for scaling the BD/CCE assumes two symbol CORESET at the beginning of a slot. If the proposed techniques are beyond the reference configuration, modification/extension is needed for evaluation/justification. |
| Qualcomm | The techniques include static reduction of BD and CCE limits compared to Rel-15 and dynamic PDCCH BD and CCE limits. |
| CMCC | We are open to study the reduction of BD/CCE limits, but the PDCCH performance impact e.g., the blocking probability should be carefully considered. |
| DOCOMO | RRC configurations for supporting smaller number of BDs and CCE limits should be the baseline, and it is necessary to study whether further enhancement is necessary for reducing the number of BDs and CCE limits |
| Huawei, HiSilicon | The techniques for achieving reduced PDCCH monitoring by means of smaller numbers of BDs and CCE limits would be identified at least taking into account the power saving gain, scheduling flexibility at gNB side, as well as less scheduling impact on NR RedCap UE. Since the fewer number of CCEs would bring scheduling constrains and little benefit on power saving, we suggest to focus on the techniques of reducing the max. # of DCI sizes. |

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?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | FFS. Should at least include the impact on blocking probability. |
| vivo | To quantify the complexity and power saving benefit.  To evaluate the system performance impact, e.g. scheduling restriction. |
| Ericsson | To consider the possible impacts on scheduling flexibility and capacity, the impact of blind decodes and CCE limits reduction on the PDCCH blocking probability should be studied. |
| Xiaomi | The trade off between power saving and PDCCH blocking probability should be considered. |
| ZTE,Sanechips | Need to consider the impact on blocking probability and scheduling delay. |
| Panasonic | If smaller numbers of blind decodes and CCE limits are studied, blocking probability should be studied. |
| Sierra Wireless | Scheduling flexibility or blocking probability. |
| Convida Wireless | We may quantify the impact of PDCCH blocking on scheduling latency and whether it will meet the provided SID requirements or not. |
| Qualcomm | PDCCH blockage probability and its impact on latency and resource utilization efficiency for some use cases. |
| CMCC | We support to consider the impact on blocking probability and latency, scheduling flexibility |
| DOCOMO | The impacts on blocking probability and scheduling flexibility should be considered. The impacts on latency should be considered at least for safety related sensors. |
| Huawei, HiSilicon | As the reply to Question 25, at least the following aspects should be considered for reducing the number of BDs and CCE limits: the power saving gain, scheduling flexibility at gNB side, as well as less scheduling impact on NR RedCap UE. |

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.**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | No, stay within the SID. |
| vivo | To study the benefit and trade-offs of relaxing other PDCCH monitoring related parameters, including   * The maximum number of configurable CORESET per BWP. * The maximum number of configurable search space per BWP. * The DCI size budget. |
| Ericsson | No. |
| Xiaomi | 1. When coverage recovery technique such as repetition is supported, techiniques to reduce PDCCH monitoring in this case should be considered. For example, support configuring different AL for different number of repetitions to reduce the total BD 2. Multi-TB scheduling can be considered for the use case of low mobility such as video survilliance and industrial sensors |
| ZTE,Sanechips | The other techniques for reduced PDCCH monitoring which are not related to the BD and CCE limits reducing are out of the scope. |
| Panasonic | Search space adaptation, BWP switching, dormant BWP, DCI-based reduced PDCCH monitoring, and multi-slot monitoring should be studied. |
| Sierra Wireless | No |
| Qualcomm | Dynamic configuration of DL control resources and reduced dependency on PDCCH messages/grants for some cases (e.g., pre-configuration of dynamic re-tx). Sparse PDCCH monitoring periodicity achieves a similar effect to reducing the BD or CCE limit per slot in the average sense. Reduction of PDCCH overhead reduces the actual numbers of BDs/CCEs for UE to process.  Consider the possible massive number of IIoT terminals with small packets for industrial wireless sensors network, the following technologies can be studied:  Enhancement for CG-UL and SPS-DL  The main advantage for CG-UL and SPS-DL enhancement of providing multiple opportunities for each occasion is that UE does not need to monitor DL and UL grants anymore except handling the retransmission grants with low probability.  DCI piggyback over PDSCH  DCI piggyback over PDSCH can help a lot for power saving. The UE does not need to keep monitoring control frequently. Instead, the UE can monitor a sparse control over time, and if there is data for the UE, the DCI can be piggyback in the PDSCH portion to keep the UE scheduled.  MUP (Multiple User Packets) over single PDSCH  The PDCCH loading can be reduced greatly by using MUP. The basic concept of the MUP is that we can use single DCI to indicate single PDSCH in normal way. The single DCI should be common for a group UEs and transmitted in a CSS. The TBs of the group UEs are aggregated into single TB and transmitted over single PDSCH.  More details about enhancements for CG-UL and SPS-DL, DCI piggyback over PDSCH, and MUP over single PDSCH can be found in [87] |
| CMCC | We think the study of power saving can contain the following aspects:  1) Study whether the R15/R16 power saving features can be used in RedCap UE according to capability of RedCap UE, e.g., BWP switching, if more than one BWPs is supported, dormant BWP if CA is supported, DCI format 2\_6, cross-slot scheduling.  2) Study the PDCCH capability reduction of RedCap UE, e.g., the CORESET/search space/DCI size number, compact DCI.  3) Study the PDCCH monitoring reduction techniques, e.g., DCI-based reduced PDCCH monitoring  4) Study the scheduling signalling overhead reduction of network, due to the larger access number of RedCap UE, e.g., multi-UE SPS triggering. |
| DOCOMO | We are generally fine to study any other PDCCH monitoring reduction techniques, but the relation with Power saving WI should be carefully considered. |
| Huawei, HiSilicon | Techniques for reduced PDCCH monitoring specified in Rel-16 UE power saving WID such as WUS can be considered to reuse for NR RedCap UEs, whenever applicable.  Furthermore, other methods such as cross-slot scheduling and BWP based maximum MIMO layer adaptation could also be considered. |

# 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].

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | The rapporteur should be commended for the large amount of material covered in this discussion. However we need to take great care to be able to progress the most important aspects as time is limited, especially during the COVID-19 pandemic where meetings are less efficient. Care should be taken not to exceed the scope of what we have in the SID, and “nice to have” aspects should be deferred as we progress the big ticket aspects. We do not want to see something akin to an MTC study in rel-11 (rel-17 here) and then the work finally completing in Rel-13 (rel-19 here). The amount of coverage compensation will be less as we are not LPWA, but we have FR2, size considerations, power considerations, three use cases, etc etc.  If needed, we can ask RAN to clarify the scope or objectives. |
| Xiaomi | How many UE types should to be defined should be discussed first, because we saw large gap in the requirements, such as peak data rate, for the use cases captured in the SID |
| ZTE,Sanechips | We would like the following two issues:  1.Which Rel-16 or Rel-17 WI feature the RedCap UE should also support  2.How many base UE type should we target for FR1 and for FR2. |
| Sierra Wireless | The key objective of this SID is to reduce the average selling price of devices which is linked to development costs and production volume. The SID should strive to limit to a single RedCap variant as multiple variants adds to development costs and reduces production volume for each variant. |
| Qualcomm | In section 6.2, we can add a table and study the traffic model for video surveillance cameras use case. Example: TR 38.888, A.1 MTC Traffic model/characteristics regular reporting  Study other power savings techniques, e.g.: event-based reporting, message bundling, and SPS/UL-CG optimizations [87]  Study beam management issues for FR2 including reducing beam overloading and beam blockage (due to preconfigured RedCap UE configurations) [89] |
|  |  |
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