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e-Meeting, May 25th – June 5th, 2020

**Agenda Item: 8.3**

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

**Source: Rapporteur (Ericsson)**

**Document for: Discussion, Decision**

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# 1 Introduction

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

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

# 5 Requirements

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

Generic requirements:

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

Use case specific requirements:

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

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

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| **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. |
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# 6 Evaluation methodology

## 6.1 Evaluation methodology for UE complexity reduction

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

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

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

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

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

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

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

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

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| **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. |
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## 6.2 Evaluation methodology for UE power saving

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

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

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

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

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

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

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| **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. |
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## 6.3 Evaluation methodology for coverage recovery

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

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

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

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

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

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

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

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

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

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

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

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

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| **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. |
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## 6.4 Evaluation methodology for other performance impacts

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

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

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| **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. |
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# 7 UE complexity reduction features

## 7.1 Introduction to UE complexity reduction features

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

## 7.2 Reduced number of UE Rx/Tx antennas

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

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

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

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

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

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

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

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| **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. |
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## 7.3 UE bandwidth reduction

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

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

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

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

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

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

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| **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. |
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## 7.4 Half-duplex FDD operation

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

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

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

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

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

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

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

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| **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. |
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## 7.5 Relaxed UE processing time

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

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

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

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

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

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

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

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| **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. |
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## 7.6 Relaxed UE processing capability

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

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

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

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

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

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

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

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

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| **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. |
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## 7.7 Combinations of UE complexity reduction features

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

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

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| **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. |
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# 8 UE power saving and battery lifetime enhancement

## 8.1 Reduced PDCCH monitoring

Several contributions [16, 22, 28, 30, 33, 39, 47, 51, 63, 69, 72, 87] propose to reduce the existing blind decode (BD) and CCE limits. In [7, 84] it is proposed to study whether it is motivated to reduce the exiting BD/CCE limits, considering its power saving benefit. Meanwhile, [26] argues that the number of BD and CCEs monitored by a UE can be controlled by network configurations and BD/CCE limits reduction should not be considered for RedCap UEs in Rel-17. Furthermore, [11] believes that CCE limit reduction does not provide a substantial power saving benefit.

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

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

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

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

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

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

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| **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. |
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# 9 Other comments

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

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| **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. |
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