3GPP TSG-RAN WG1 Meeting #103-e Tdoc R1-20xxxxx

e-Meeting, October 26th – November 13th, 2020

**Agenda Item: 8.6.1**

**Title: FL summary #2 for Potential UE complexity reduction features for RedCap**

**Source: Moderator (Ericsson)**

**Document for: Discussion, Decision**

# 1 Introduction

Contributions [1] – [28] submitted to RAN1#103e AI 8.6.1 plus relevant parts from a few contributions [29] – [34] that were submitted to other agenda items under AI 8.6, as well as initial evaluation results in [35], were summarized in FL summary #1 (FLS1) in R1-2008869 ([Inbox](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/R1-2008869.zip), [Docs](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008869.zip)).

This document captures the following RAN1#103e RedCap email discussion.

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| [103-e-NR-RedCap-02] Email discussion for potential UE complexity reduction features – Johan (Ericsson)   * 1st check point: 10/29 * 2nd check point: 11/4 * 3rd check point: 11/10 * Last check point 11/12 |

Issues are tagged and color coded as follows. Search for ‘Phase 1’ to find the questions that are the focus for the first discussion round.

1. Phase 1: the focus for the first discussion round
2. Phase 2: the focus for a later discussion round
3. Phase 3: the focus for a later discussion round

The structure of this document follows the structure in TR 38.875 V0.0.2 with two exceptions. First, a Conclusions section has been inserted at the end of each subsection in Chapter 7. Second, the subsection on ‘Relaxed UE processing capability’ has been split into three subsections ‘Relaxed maximum number of MIMO layers’, ‘Relaxed maximum modulation order’, and ‘Other relaxed UE processing capability’.

Follow the naming convention in this example:

* *RedCapComplexityFLS2-v000.docx*
* *RedCapComplexityFLS2-v001-CompanyA.docx*
* *RedCapComplexityFLS2-v002-CompanyA-CompanyB.docx*
* *RedCapComplexityFLS2-v003-CompanyB-CompanyC.docx*

If needed, you may “lock” a spreadsheet file for 30 minutes by creating a checkout file, as in this example:

* Assume CompanyC wants to update *RedCapComplexityFLS2-v002-CompanyA-CompanyB.docx*.
* CompanyC uploads an empty file named *RedCapComplexityFLS2-v003-CompanyB-CompanyC.checkout*
* CompanyC then has 30 minutes to upload *RedCapComplexityFLS2-v003-CompanyB-CompanyC.docx*
* If no update is uploaded in 30 minutes, other companies can ignore the checkout file.
* Note that the file timestamps on the server are in UTC time.

# 6 Evaluation methodology

## 6.1 Evaluation methodology for UE complexity reduction

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| For cost/complexity evaluation of UE complexity reduction techniques, the methodology used in TR 36.888 was used as a starting point.  Reference NR devices were defined as follows for FR1 FDD, FR1 TDD and FR2, respectively.   * All mandatory Rel-15 features (with or without capability signaling) * Single RAT * Operation in a single band at a time * Maximum bandwidth:   + For FR1: 100 MHz for DL and UL   + For FR2: 200 MHz for DL and UL * Antennas:   + For FR1 FDD: 2Rx/1Tx   + For FR1 TDD: 4Rx/1Tx   + For FR2: 2Rx/1Tx * Power class: PC3 * Processing time: Capability 1 * Modulation:   + For FR1: support 256QAM for DL and 64QAM for UL   + For FR2: support 64QAM for DL and 64QAM for UL * Access: Direct DL/UL access between UE and gNB   Detailed cost breakdown for the reference NR devices according to Table 6.1-1 was assumed in the study. The RF-to-baseband cost ratio was assumed to be 40:60 for an FR1 UE and 50:50 for an FR2 UE. The study considered impacts on cost/complexity reduction from support of multiple RF bands with FR1 and FR2.  **Table 6.1-1: Detailed cost breakdown for the reference NR devices**   |  |  |  |  | | --- | --- | --- | --- | | **Functional block** | **FR1 FDD (2Rx)** | **FR1 TDD (4Rx)** | **FR2** | | **RF** | | | | | Antenna array for FR2 |  |  | ~33% | | Power amplifier | ~25% | ~25% | ~18% | | Filters | ~10% | ~15% | ~8% | | RF transceiver (including LNAs, mixer, and local oscillator) | ~45% | ~55% | ~41% | | Duplexer / Switch | ~20% | ~5% | ~0% | | **Baseband** | | | | | ADC / DAC | ~10% | ~9% | ~4% | | FFT/IFFT | ~4% | ~4% | ~4% | | Post-FFT data buffering | ~10% | ~10% | ~11% | | Receiver processing block | ~24% | ~29% | ~24% | | LDPC decoding | ~10% | ~9% | ~9% | | HARQ buffer | ~14% | ~12% | ~11% | | DL control processing & decoder | ~5% | ~4% | ~5% | | Synchronization / cell search block | ~9% | ~9% | ~7% | | UL processing block | ~5% | ~5% | ~7% | | MIMO specific processing blocks | ~9% | ~9% | ~18% | |

**Phase 1: Question 6.1-1: Can the above description of the cost evaluation methodology be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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One contribution [2] proposes to add a disclaimer to the TR that the cost/complexity estimates are very rough, simplified and subjective, and that they do not account for design costs or economies of scale, and do not account many components present in real devices such as multiple band support, displays, cameras, microphones, etc., and cannot be used to guarantee low-cost in the market, or at least include the following disclaimer from TR 36.888:

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| NOTE: This study assesses, from a 3GPP standpoint, the technical feasibility of low-cost LTE devices for MTC.  Given that factors outside 3GPP responsibility influence the cost of a modem/device, this study item (and the text above) cannot guarantee, or be used as a guarantee, that such modem/device will be low-cost in the market. |

**Phase 1: Question 6.1-2: Can the above disclaimer from TR 36.888, but with the words “*low-cost LTE devices for MTC*” replaced with “*reduced-capability NR devices*”, be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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# 7 UE complexity reduction features

## 7.1 Introduction to UE complexity reduction features

## 7.2 Reduced number of UE Rx/Tx antennas

### 7.2.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| The antenna configurations for RedCap UEs that were considered in the study are:   * For FR1: 1Rx/1Tx and 2Rx/1Tx * For FR2: 1Rx/1Tx and 2 Rx/1Tx   The evaluation of cost/complexity reduction has been performed with respect to a reference NR UE. The reference NR UE has the following antenna configuration:   * For FR1 FDD: 2Rx/1Tx * For FR1 TDD: 4Rx/1Tx * For FR2: 2Rx/1Tx |

**Phase 2: Question 7.2.1-1: Can the above description on the reduced number of UE Rx/Tx antennas feature be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.2.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for a device with reduced number of UE Rx antennas, relative to the reference NR device (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.2.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by reducing the number of UE Rx antennas are follows:   * FR1 FDD (2Rx 🡪 1Rx): ~26% * FR1 TDD (4Rx 🡪 2Rx): ~30% * FR1 TDD (4Rx 🡪 1Rx): ~46% * FR2 TDD (2Rx 🡪 1Rx): ~30%   Note that the estimated cost is Table 7.2.2-1 is based solely on the reduction of number of Rx antennas. That is, the cost reduction due to the reduced number of downlink MIMO layers resulting from the reduced number of Rx antennas has not been taken into consideration. The cost reduction resulting from combinations of different complexity reduction techniques will be captured in clause 7.9.  By comparing Table 7.2.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:   * RF: Antenna array (only FR2) * RF: Filters * RF: Transceiver (including LNAs, mixer, and local oscillator) * Baseband: ADC/DAC * Baseband: FFT/IFFT * Baseband: Receiver processing block * Baseband: Synchronization/cell search block   Furthermore, all sourcing companies indicated that the RF cost savings (but not the baseband cost savings) accumulate across supported bands in both FR1 and FR2.  **Table 7.2.2-1: Estimated relative device cost for reduced number of UE Rx antennas**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Reduced number of UE Rx antennas** | **FR1 FDD**  **(2Rx 🡪 1Rx)** | **FR1 TDD**  **(4Rx 🡪** **2Rx)** | **FR2 TDD**  **(4Rx 🡪 1Rx)** | **FR2 TDD**  **(2Rx 🡪 1Rx)** | | RF: Antenna array | - | - | - | 18.2% | | RF: Power amplifier | 24.0% | 25.0% | 25.0% | 18.0% | | RF: Filters | 4.5% | 7.6% | 3.9% | 4.3% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 24.9% | 30.6% | 17.8% | 23.7% | | RF: Duplexer / Switch | 18.3% | 4.9% | 4.9% | 0.0% | | **RF: Total relative cost** | **71.7%** | **68.1%** | **51.6%** | **64.2%** | | BB: ADC / DAC | 6.4% | 5.3% | 3.4% | 2.4% | | BB: FFT/IFFT | 2.3% | 2.2% | 1.2% | 2.2% | | BB: Post-FFT data buffering | 5.9% | 5.7% | 3.4% | 6.4% | | BB: Receiver processing block | 13.7% | 15.8% | 9.0% | 13.3% | | BB: LDPC decoding | 9.7% | 8.7% | 8.6% | 8.6% | | BB: HARQ buffer | 13.6% | 11.6% | 11.4% | 10.5% | | BB: DL control processing & decoder | 4.9% | 3.9% | 3.9% | 4.9% | | BB: Synchronization / cell search block | 5.6% | 4.8% | 2.7% | 4.1% | | BB: UL processing block | 5.0% | 5.0% | 5.0% | 7.0% | | BB: MIMO specific processing blocks | 8.2% | 7.8% | 6.8% | 15.8% | | **BB: Total relative cost** | **75.3%** | **70.7%** | **55.5%** | **75.3%** | | **RF+BB: Total relative cost** | **73.9%** | **69.7%** | **54.0%** | **69.7%** | |

**Phase 1: Question 7.2.2-1: Can the above observations of the relative cost estimation for reduced number of UE Rx antennas be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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**Device size:**

In addition to reduction in cost/complexity benefits, the contributions [1, 2, 4, 5, 6, 8, 10, 12, 16, 19, 21, 28] have also highlighted that the reduction in number of UE Rx antennas is also beneficial in terms of reducing the size/form factor for devices, such as wearables in FR1. The contribution [2] has expressed the view that a RedCap technique, such as reduction of the number of antennas, shall not be considered a requirement to achieve a compact form factor for any use case. The contribution [28] has also expressed a similar view. More specifically, it is proposed in [28] to clarify that size reduction of device is neither an objective for RedCap study, nor within cost/complexity reduction study scope, and cannot be used to justify the choice of reduction mechanisms for RedCap UE.

With regards to the device size reduction in FR2, the contribution [28] has indicated that form factor consideration does not justify 1 Rx for RedCap in FR2. It is mentioned in [1] that reducing only the Rx branches has limited impact on reducing the device size in FR2. In [26], it is mentioned that in FR2 depending on the power, complexity, and form factor of the RedCap UE, 1Rx or 2 Rx may be selected.

Some companies say the device size is expected to increase with an increase in the number of supported bands [1, 4]. Such increase may depend on UE implementation and frequency band separation. [1]

Note that the following agreement was reached in RAN1#101e:

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| Agreements:   * [...] * Potential benefits in terms of reduced device size can be mentioned where applicable in the TR (e.g. in the section on reduced number of antennas), but the SI will not aim to quantify such benefits. |

**Phase 2: Question 7.2.2-1: Should it be captured in TR 38.875 that reduced number of UE Rx antennas can be beneficial in terms of reducing the device size in FR1?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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**Phase 2: Question 7.2.2-2: Should it be captured in TR 38.875 that reduced number of UE Rx antennas can be beneficial in terms of reducing the device size in FR2?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.2.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Concerning the impact on performance, several contributions observe that a reduced number of antennas impacts coverage, spectral efficiency, power consumption, data rate, PDCCH blocking probability, latency, reliability, and number of users supported.

**Coverage:**

* P0: Most companies have reported a loss in DL coverage/performance, either quantitatively or qualitatively, when reducing the number of Rx antennas [1, 2, 3, 4, 5, 6, 9, 11, 12, 14, 15, 16, 19, 20, 21, 22, 23, 26, 27, 28] . It is the recommendation of the FL that the discussion on quantitative values of the coverage loss and bottleneck channels be considered under AI 8.6.3.

**Data rate/throughput:**

* P1: [1, 2, 3, 4, 5, 6, 15, 16, 18, 19, 20, 22, 23, 24, 28] have indicated that there will be negative impact on DL data rate/throughput when reducing the number of Rx antennas. The main reason is that reducing the number of Rx antennas will also reduce the number of transmission layers that can be transmitted in the DL. However, [3, 4, 14, 16, 19, 22, 24, 26] have also highlighted that in spite of the reduction in Rx antennas, the UEs will be able to fulfil the data rate requirements of most RedCap use cases (except high-end wearables in FR1), as given in the SID.

**Latency and reliability:**

* P2: In [26], it is observed that in FR2, support of 1 Rx antenna at the UE can satisfy the latency requirements for industrial wireless sensors and video surveillance cameras (with 100 MHz).
* P3: In [19], it is observed that reducing the number of receive antennas does not affect the reliability and latency in most cases. However, if the UE is in the cell-edge the latency can increase. In [1], it is highlighted that the UEs with reduced of number of UE Rx branches can sufficiently fulfil the latency and reliability requirements of all RedCap use cases.

**Power consumption:**

* P4: [4] and [16] have noted that power consumption is also saved by fewer RF chains and by less complexity of multi-antenna processing. In [6], it has been noted that the power consumption of 1 Rx UE is lower than that of a 2 Rx UE.
* P5: [1, 11, 13, 15, 19, 27, 28] have noted that although the reduction in Rx antenna can reduce power consumption in the RF and the baseband modules, due to longer reception time needed for downlink channels, the power consumption will be increased. In [1, 15], it has been highlighted that the actual impact depends on the DL traffic.
* P6: The evaluation results in [4] show that the power saving gains when reducing the number of UE Rx antennas from 2 to 1 are about 14% for instant messaging traffic, 11% for Heartbeat traffic and 15% for VoIP traffic. In [24], it has been mentioned that more evaluations are needed to understand the impact on overall power consumption due to lower consumption in RF/baseband modules and longer reception time.

**Spectral efficiency/network capacity loss:**

* P7: [1, 2, 3, 5, 12, 13, 15, 16, 18, 19, 21, 23, 24, 27, 28] has reported a loss in spectral efficiency/network capacity. In [4], it has been reported that the spectral efficiency decrease, but cell capacity (cell served throughput) increases. In [6], it has been noted that degree of spectral efficiency loss depends on the proportion of RedCap UE, traffic model and traffic load. The quantitative values of the loss can be discussed under AI 8.6.3.
* P8: [11] has reported the loss is sector/cell edge spectral efficiency when reducing the number of Rx antennas.
* P9: In [6], it is also noted that the impact can be managed by network by access control mechanism.

**PDCCH blocking probability:**

* P10: [1,13, 15, 19, 23, 24, 28] have noted that there will be increase in PDCCH blocking probability. This is due to use of higher ALs in order to compensate for the performance degradation from a reduced number of Rx antennas.

**Number of users supported:**

* P11: In [26], it is observed that for FR2, the number of users that can be supported is impacted by almost 50% if the number of UE Rx antennas is reduced from 2 to 1. It is also observed that 1 Rx antenna at the UE may be able to support a high number of users. It has been noted in [24] and [28] have also reported a reduction in the number of users supported. In [24], it has been mentioned that this aspect should be discussed under AI 8.6.3.

**Phase 2: Question 7.2.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P11) be used as a baseline for the TP drafting for TR section 7.2.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.2.4 Analysis of coexistence with legacy UEs

Several contributions have analyzed coexistence issues with legacy UEs. The finding can be listed as follows:

* C1: There will be coexistence impact depending on the coverage recovery solutions and other enhancements (e.g., early RedCap indication in RACH) adopted for RedCap during the initial access stage [1, 2, 5, 9, 11, 15, 21, 24]. Note that depending on the outcome of discussions taking place under AI 8.6.3, no coverage recovery may be needed to compensate for the performance loss due to reduced number of UE Rx antennas.
* C2: Blocking impacts if RedCap UE need to use higher aggregation levels for PDCCH reception [1, 2, 5, 24].
* C3: There will be coexistence issues if common DL broadcast channels (e.g., SIBx/RAR/paging) are used for both legacy UEs and RedCap UEs [1, 5, 15, 16, 24]. This is because the system treating the UEs the same will mean conservative handling of all UEs. It has also been noted in [16] that the common channels can be transmitted separately for redcap UE and normal NR UE, which can be realized by the gNB’s scheduling implementation.
* C4: RedCap UEs with reduced number of Rx antennas can coexist with legacy UEs in general [4, 11, 15, 16, 19].
* C5: The network deployment (cell planning) may be required to be adjusted [24]. It is also been mentioned in [24] that this aspect can be considered in RAN4.
* C6: 1 Rx RedCap UEs would cause significant performance degradation to legacy UEs due to coexistence needs or may cause network block for RedCap UEs accessing when the number of UEs in one cell is large [3].

**Phase 2: Question 7.2.4-1: Can the above list (C1-C6) be used as a baseline for the TP drafting for TR section 7.2.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.2.5 Analysis of specification impacts

Several contributions [1, 2, 3, 4, 5, 9, 11, 12, 13, 15, 16, 19, 20, 21, 22, 23, 24, 28] also point out the specification impacts from reducing the number of UE Rx antennas. Potential RAN1 impacts depend on the techniques that may be used to compensate for the coverage and spectral efficiency loss. The extent of RAN1 impacts would also depend on the outcome of link budget analysis that is taking place under AI 8.6.3.

Some techniques highlighted in different contributions that will have RAN1 specification impacts are:

* S1: PDCCH repetition: [12, 15, 22, 24]
* S2: Additional repetitions for PDSCH: [12, 22, 24]
* S3: AL greater than 16: [11, 15, 24]
* S4: Compact DCI: [15, 24]
* S5: CSI report enhancement to improve spectral efficiency: [15]
* S6: Early indication of RedCap UE in random access: [1, 22, 15]
* S7: Group scheduling to reduce PDCCH overhead and solve PDCCH blocking issue [15]
* S8: Cross-repetition channel estimation [12]

It has been noted in [3] that depending on the performance target, e.g., peak data rate and coverage recovery, there could be no/marginal specification impacts for UEs with 2Rx (20MHz) but there would be specification impact for 1Rx UEs even with larger bandwidth (for coverage/throughput improvement).

Several contributions [1, 2, 4, 5, 13, 15, 16, 19, 20, 28] have mainly also highlighted potential RAN4 specification impacts, including RRM, receiver characteristics, demodulation performance requirements, CSI reporting requirements, RF, and procedure requirements (e.g., cell change, radio link management, beam management, etc.). It is also mentioned in [5] that RAN4 needs to evaluate and specify the new minimum number of Rx antennas for different bands. In [5], it also suggested that UL transmit antenna gain should be evaluated in RAN4 for size-limited RedCap UEs, e.g. some wearables. In [1, 28], it is indicated that the impact is more significant when reducing the number of receiver branches to 1. It has been mentioned in [1] that the impacts are manageable and comparable (at least for FR1) to the corresponding changes done for Cat M1 UEs in LTE.

In addition, [19] has indicated that there would be potential RAN2 impact due to signalling of reduced antenna capability. It has also been noted in [1] that early indication (S6) will also have RAN2 specification impacts.

**Phase 2: Question 7.2.5-1: Should RAN4 specification impacts be captured in TR 38.875 for UE antenna reduction? If yes, list the most critical ones to be captured.**

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| **Company** | **Y/N** | **Comments** |
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**Phase 3: Question 7.2.5-2: Can the above list (S1-S8) be used as a baseline for the TP drafting for TR section 7.2.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.2.6 Conclusions

Based on the analysis summarized in previous sections, several companies have explicitly indicated their preference on the number of UE Rx antennas as baseline for RedCap. We summarize the preferences of companies on the *minimum* number of Rx antennas below.

Options for FR1 FDD bands:

* Option 1: 1 Rx, suggested in [1, 4, 5, 6, 8, 10, 11, 12, 15, 18, 21, 22, 23, 24, 26]
* Option 2: 2 Rx (same as the reference case), suggested in [3, 9, 28]

**Phase 1: Question 7.2.6-1: Should TR 38.875 make recommendations on the minimum number of Rx antennas for RedCap FR1 FDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.6.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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Options for FR1 TDD bands:

* Option 1: 1 Rx, suggested in [4, 5, 6, 10, 12,15, 16, 18, 22, 26]
* Option 2: 2 Rx, suggested in [1, 2, 3, 8, 9, 11, 21, 23, 24, 28]
* Option 3: 4 Rx (same as the reference case), not suggested in any contribution

**Phase 1: Question 7.2.6-2: Should TR 38.875 make recommendations on the minimum number of Rx antennas for RedCap FR1 TDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.6.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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Options for FR2 bands:

* Option 1: 1 Rx, suggested in [5, 8, 11, 15, 18, 21, 26]
* Option 2: 2 Rx (same as the reference case), suggested in [9, 28]

**Phase 1: Question 7.2.6-3: Should TR 38.875 make recommendations on the minimum number of Rx antennas for RedCap FR2 UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.6.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.3 UE bandwidth reduction

### 7.3.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| In the study, the main UE bandwidth reduction options considered are:   * For FR1: 20 MHz * For FR2: 50 MHz or 100 MHz   The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with maximum bandwidth capability shown below.   * For FR1: 100 MHz for DL and UL * For FR2: 200 MHz for DL and UL   For the baseline UE bandwidth capability of RedCap UEs, the same maximum UE bandwidth in a band applies to both RF and baseband. It is also primarily assumed that this maximum UE bandwidth applies to both data and control channels and that this maximum UE bandwidth is assumed for both DL and UL. A few contributions analyze other mixes of bandwidths. |

**Phase 2: Question 7.3.1-1: Can the above description on the UE bandwidth reduction feature be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.3.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for a device with reduced maximum UE bandwidth, relative to the reference NR device (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.3.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by reducing the UE bandwidth from 100 MHz to 20 MHz is ~31% for FR1 FDD and ~33% for FR1 TDD. For FR2, the average estimated cost reduction achieved by reducing the UE bandwidth from 200 MHz to 100 MHz and 50 MHz is ~16% and ~23%, respectively.  By comparing Table 7.3.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:   * Baseband: ADC/DAC * Baseband: FFT/IFFT * Baseband: Post-FFT data buffering * Baseband: Receiver processing block * Baseband: LDPC decoding * Baseband: HARQ buffer   Furthermore, ~75% of sourcing companies indicated that the cost savings do not accumulate across supported bands.  **Table 7.3.2-1: Estimated relative device cost for reduced maximum UE bandwidth**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Reduced UE bandwidth** | **FR1 FDD** | **FR1 TDD** | **FR2 (200 MHz 🡪 100 MHz)** | **FR2 (200 MHz 🡪 50 MHz)** | | RF: Antenna array | - | - | 33.0% | 33.0% | | RF: Power amplifier | 24.1% | 23.8% | 17.9% | 17.8% | | RF: Filters | 10.0% | 14.7% | 8.0% | 8.0% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 43.7% | 53.0% | 40.6% | 40.3% | | RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% | 0.0% | | **RF: Total relative cost** | **97.7%** | **96.4%** | **99.5%** | **99.0%** | | BB: ADC / DAC | 2.8% | 2.0% | 2.0% | 1.0% | | BB: FFT/IFFT | 1.1% | 1.0% | 1.9% | 0.9% | | BB: Post-FFT data buffering | 2.3% | 2.1% | 5.6% | 2.8% | | BB: Receiver processing block | 9.1% | 9.9% | 14.2% | 9.1% | | BB: LDPC decoding | 4.3% | 3.9% | 5.4% | 3.8% | | BB: HARQ buffer | 4.9% | 3.9% | 6.0% | 3.5% | | BB: DL control processing & decoder | 4.5% | 3.7% | 4.7% | 4.5% | | BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% | 7.0% | | BB: UL processing block | 3.5% | 3.6% | 5.5% | 4.9% | | BB: MIMO specific processing blocks | 8.2% | 8.4% | 17.0% | 16.5% | | **BB: Total relative cost** | **49.7%** | **47.6%** | **69.3%** | **54.0%** | | **RF+BB: Total relative cost** | **68.9%** | **67.2%** | **84.4%** | **76.5%** | |

**Phase 1: Question 7.3.2-1: Can the above observations of the relative cost estimation for UE bandwidth reduction be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.3.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Many contributions analyze the performance impacts if bandwidth reduction is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views. In the summary below, if an impact is specific to only FR1 or only FR2, it is denoted accordingly.

**Peak data rate:**

* P1: (FR1) There is an impact on peak data rate due to BW reduction [2, 15, 19, 20, 24].
* P2: (FR1) The most demanding DL peak rate requirements (150 Mbps) can be met by 20 MHz UE BW with 2 MIMO layers [3, 4, 6, 8, 10, 12, 14, 23, 24, 26].
* P3: (FR1) The most demanding DL peak rate requirements (150 Mbps) can be met by larger than 20 MHz UE BW, e.g. 40 MHz [4, 5, 8, 12, 26].
* P4: (FR1) The most demanding UL peak rate requirements (50 Mbps) can be met by 20 MHz UE BW [8].
* P5: (FR1) Single MIMO layer, 20 MHz UE BW, and 64QAM can meet the peak bit rate requirements of most use cases [1, 2, 4, 6, 8, 14, 26].
* P6: (FR2) All the data rate requirement can be met by 50 MHz and 100 MHz BW [1, 4, 14, 24].

**Latency:**

* P7: The latency requirements for industrial wireless sensors can be satisfied [1, 19].
* P8: For video surveillance cameras, the latency requirements can be satisfied [1].
* P9: For the use cases that are considered in this study, the latency associated with increased transmission time (due to the reduced bandwidth) is likely to be insignificant compared to the latency associated with the DRX functionality [19].
* P10: For larger message sizes, the latency can be increased if the large messages need to be segmented into multiple transport blocks and sent over multiple slots [19].
* P11: (FR2) The latency requirements for industrial wireless sensors may be satisfied with UE BW as small as 20 MHz. For video surveillance cameras, the latency requirements can be satisfied using 20 MHz BW for small file sizes. For larger file sizes, BW needs to be increased to ~100MHz to get more UE multiplexing capacity. 20 MHz active BWP may be enough for most cases [26].
* P12: (FR2) Bandwidth reduction results in a longer SSB/SIB1 acquisition time. However, it is not necessary to have stringent SSB acquisition requirements for RedCap use cases [1].
* P13: (FR2) To minimize the SSB/CORESET acquisition time (for multiplexing patterns 2 and 3), it may be beneficial to support 100 MHz as the max UE BW [5, 26].
* P14: (FR2) For both 50 MHz and 100 MHz bandwidth options in FR2, there will be longer SSB/SIB1 acquisition time for certain SSB and Type 0 PDCCH configurations [2, 5, 24, 25].
* P15: Longer SSB/CORESET acquisition time issue only occurs for SSB and CORESET multiplexing 2 with 240 kHz SCS SSB + 120 kHz SCS 48RB CORESET 0 if the maximum UE bandwidth is 100 MHz [5].

**Reliability:**

* P16: Reliability should not be impacted as it is envisaged that BLER targets can still be achieved at a reduced bandwidth [19].
* P17: All the RedCap bandwidth options can meet the reliability target of RedCap use cases [1].

**Power consumption:**

* P18: UE bandwidth reduction may reduce power consumption [4, 11, 13].
* P19: Evaluation is needed to assess the effects of less RF/BB modules vs longer Rx time [19, 24].
* P20: There is no clear power consumption advantage or disadvantage due to UE bandwidth reduction. It may depend on the specific traffic scenario [1].
* P21: BW reduction has no impact on the power consumption of data channels [13].
* P22: In connected mode, when the RedCap UE operates in initial DL/UL BWP larger than maximum UE bandwidth of RedCap UEs, more power consumption would be expected due to RF retuning [5].

**Coverage:**

* P23: The impact of reduced BW on DL and UL channels would not be large; some negligible loss may be observed due to reduced frequency diversity [1, 11, 15, 19, 27].
* P24: (FR1) UE bandwidth 20 MHz is enough to support PDCCH AL 16 in FR1 [1].
* P25: (FR2) For some use cases, increasing the max UE BW from 50 to 100 MHz may lead to an increase in mean SINR [26].
* P26: (FR2) RedCap UE may not receive AL8/16 [24].
* P27: (FR2) Due to not enough number of CCEs in the CORESET, AL 16 cannot be supported without performance loss for 50 MHz UE BW and SCS = 120 kHz [1, 26].
* P28: (FR2), Reducing the bandwidth to 50 MHz will have impact on PBCH coverage if the SSB is configured with 240 kHz SCS [1, 2, 8, 11, 27, 28].
  + The loss is assessed to be less than 1 dB [1, 11, 27].
* P29: (FR2) Reducing the bandwidth to 50 MHz will have impact on PDCCH coverage if COREST#0 is configured to have 69.12 MHz bandwidth [1, 2, 4, 8, 16, 27, 28].
  + The loss is assessed to be ~ 1.5 – 3 dB [1, 2, 8].
* P30: (FR2) Reducing the bandwidth to 50 MHz will have impact on initial access (message 2/3/4) if COREST#0 is configured to have 69.12 MHz bandwidth [3, 20, 23, 27].

**PDCCH blocking probability:**

* P31: PDCCH blocking probability may be increased due to small CORESET bandwidth [13].
* P32: (FR2) Using 50 MHz instead of 100 MHz may cause considerable reduction in the PDCCH multiplexing capacity and PDCCH blocking probability [24, 26].
* P33: (FR2) PDCCH blocking probability is only slightly increased if the maximum UE bandwidth is further reduced from 100 MHz to 50 MHz [1].

**Capacity or spectral efficiency:**

* P34: Bandwidth reduction will not have a significant impact on capacity and spectral efficiency [1, 11, 19].
* P35: There may be some degradation in DL and UL spectral efficiency due to the loss in frequency selective scheduling gain [15].
* P36: Network capacity may be impacted for initial access [15].
* P37: The spectral efficiency may be affected due to an increase in PDCCH blocking probability resulting from the use of a smaller CORESET bandwidth [13].
* P38: (FR2) The number of users that can be supported is impacted by almost 50% if the max UE BW is reduced from 100 MHz to 50 MHz [26].
* P39: (FR2) If dedicated channel for RedCap is introduced for supporting maximum UE bandwidth of 50 MHz, the network capacity would be impacted [20].

**Phase 2: Question 7.3.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P39) be used as a baseline for the TP drafting for TR section 7.3.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### Analysis of coexistence with legacy UEs

Many contributions analyze the coexistence impacts if bandwidth reduction is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views. In the summary below, if an impact is specific to only FR1 or only FR2, it is denoted accordingly.

**General:**

* C1: (FR1) For FR1, with 20MHz bandwidth capability, Redcap UEs should be able to coexist with the legacy UE [1, 11, 16, 19].
* C2: (FR2) For FR2, with 100MHz bandwidth capability, there is no coexistence impact [1, 11, 16].
* C3: There may or may not be impacts on the coexistence with legacy UEs, depending on the cell load and the solutions for RedCap and normal UEs camped on the same cell [4].

**Initial access and initial BWP:**

* C4: There may be issues with frequency-division multiplexed RACH Occasions [24].
* C5: (FR1) For initial access in FR1, the RedCap UEs can share SSB, SIB1, other SIs, RAR and Msg4 configured for normal NR UEs [5].
* C6: (FR2) The RedCap UEs with 100 MHz maximum UE bandwidth can share SSB, SIB1, other SIs, RAR and Msg4 configured for normal NR UEs [5].
* C7: (FR2) Compared with maximum UE bandwidth of 100 MHz, to support the RedCap UEs with 50 MHz maximum UE bandwidth, more serious configuration or scheduling restrictions to normal NR UEs would be expected. It may reduce the configuration or scheduling flexibility of legacy NR UEs [5].
* C8: Separate SIB1 for RedCap devices can be configured to solve coexistence problems [9].
* C9: (FR2) Limiting the supported SCS combinations for SSB/CORESET0 may be considered [9].
* C10: (FR2) There may be issues, such as backward compatibility or configuration restriction, with SSB and CORESET0 for supporting RedCap UE with 50MHz bandwidth [2, 4, 8, 15, 17, 23, 24].
  + Two initial access procedures will have to coexist: one for ‘regular’ UEs, one for RedCap UEs [2].
* C11: (FR2) With 50MHz UE BW, there may be misalignment between Redcap UE’s receiving bandwidth and the scheduling bandwidth of PDSCH for common channel during initial access procedure [16].
* C12: Supporting RedCap UEs may result in a high load in the initial BWP [24].
* C13: RedCap UEs may not support the bandwidth of the initial UL BWP configured for normal UEs in SIB1 depending on Rel-15 cell configuration [1, 5, 8, 9, 10].
  + This impacts Msg3 [1, 5] and PUCCH for Msg4 [1].
  + A separate UL BWP for RedCap devices can be configured to solve coexistence problems [9].
* C14: For both IDLE/INACTIVE and RRC-CONNECTED modes, if RedCap UEs are offloaded to a different BWP than initial BWP, it is beneficial from UE implementation perspective to have SSB transmitted in the operating BWP for RedCap UEs [4].

**Other aspects:**

* C15: Paging capacity may be an issue [24].
* C16: (FR2) In Idle mode, if the maximum UE bandwidth of RedCap UEs is 50 MHz, paging configuration for normal NR UEs may need to be restricted if the RedCap UEs and normal NR UEs share the same paging resources [5].
* C17: PDCCH blocking probability will increase with bandwidth reduction [15].
* C18: A reduced bandwidth Redcap UE is unable to measure the PRS across a wide bandwidth [19].
* C19: Legacy UE performance might be impacted if RedCap UEs accessing the cell with full backward compatibility [17].
* C20: RedCap UEs performance might not be guaranteed if accessing the cell with full backward compatibility. [17].

**Phase 2: Question 7.3.4-1: Can the above list (C1-C20) be used as a baseline for the TP drafting for TR section 7.3.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### Analysis of specification impacts

Many contributions analyze the specification impacts if bandwidth reduction is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views. In the summary below, if an impact is specific to only FR1 or only FR2, it is denoted accordingly.

**General:**

* S1: (FR1) The specification impact is expected to be small in FR1 [11, 13, 21, 27],
* S2: (FR2) RAN1 specification impact is expected to be small for UE with 100 MHz bandwidth in FR2 [11].

**Initial access and initial BWP:**

* S3: (FR1) Rel-15 SSB and/or CORESET0 should be reused [12, 20].
* S4: (FR1) No spec impacts related to cell search, system information acquisition, RAR and Msg4 reception are expected for RedCap UEs [5].
* S5: (FR2) No spec impacts related to cell search, system information acquisition, RAR and Msg4 reception are expected for RedCap UEs with 100 MHz maximum UE bandwidth [5].
* S6: Support dedicated initial BWP or dedicated initial access procedure for RedCap [5, 7, 10, 12, 15, 16, 17, 24].
* S7: There is no need to define a dedicated initial BWP for RedCap UEs [1].
* S8: There are solutions that can be used to support RedCap UEs camping on a cell with initial DL or UL BWP bandwidth larger than the maximum UE bandwidth [1].
* S9: It is feasible to allow a RedCap UE to camp on a cell even when the initial DL or UL BWP configured in the cell is larger than the maximum UE bandwidth [1].
* S10: Support RF retuning for frequency-division multiplexed RACH Occasions or SSB/CORESET0 [1, 10, 24, 25].
* S11: During initial access procedure, if size of initial UL BWP configured for normal NR UEs is larger than the bandwidth of the RedCap UEs, Msg3 transmission of the RedCap UE can be flexibly scheduled and Msg3 hopping can be enabled if dedicated initial UL BWP is configured for the RedCap UEs [5].
* S12: For frequency-hopping Msg4 PUCCH or Msg3 PUSCH transmissions, the UE needs to frequency hop within the initial UL BWP, which may have a bandwidth larger than the maximum RedCap UE bandwidth [1].
* S13: Support configuring separated CD-SSB for RedCap UEs [17].

**Specification impact if dedicated initial BWP, dedicated initial access procedure, or dedicated BWP is introduced:**

* S14: Support initial BWP enhancement including at least one of following: multiple initial BWPs, enhancement on CORESET0, or narrow band Redcap UEs operate in a wide band system [15].
* S15: Using a separate DL BWP for SIB transmissions towards RedCap UEs [10].
* S16: Using a separate UL BWP for initial access of RedCap UEs (as well as common UL BWP shared with normal UEs) [10].
* S17: Initial BWP with non-CD SSB transmission dedicated for RedCap UEs [4].
* S18: Support dedicated BWP for RedCap [5, 7, 24].
* S19: UE switching to the dedicated BWP immediately after random access procedure may be considered to offload UEs from initial BWP [7, 26].
* S20: Mechanism for RedCap BWP switching (e.g., for switching UE from initial BWP to the dedicated BWP quickly or for other performance optimization considerations) [7, 26].
* S21: Introduce longer CORESET duration (Should be discussed in AI 8.6.3) [12, 24].
* S22: Introduce simplified BWP operation for RedCap [16].
* S23: Decouple the DL and UL BWP design for RedCap UE [16].
  + Support small DL bandwidth and large UL bandwidth.
  + Support fewer DL BWP configurations than that of UL.
* S24: Support SRS transmission or CSI report for inactive BWP(s) [15].

**System information:**

* S25: A new set of system information may be needed to indicate whether the cell supports RedCap UEs and to provide RRC configuration information [1].
* S26: System information that is needed for supporting RedCap UEs may be added as new information elements to existing SI blocks or as new SI blocks [1].
* S27: Support configuring separated resources for RedCap UEs in legacy SIB1 for RACH and paging [17].

**Paging:**

* S28: In Idle mode, dedicated paging occasions are considered for the RedCap UEs [5, 24].
* S29: The legacy paging procedure will work fine for RedCap UEs with 20 MHz bandwidth in FR1 and 50 MHz or 100 MHz bandwidth in FR2 [1].

**UE identification and capability signaling:**

* S30: Earlier identification of the RedCap UEs should be considered [5, 21].
  + S1: Identification of the RedCap UE before Msg3 transmission is needed if size of initial UL BWP configured for normal NR UEs is larger than the bandwidth of the RedCap UEs [5].
  + S1: The type of RedCap UE needs to be identified before RAR/Msg4 transmission [5].
* S31: Capability signaling defining that the UE supports a reduced bandwidth [4, 19, 21].

**RAN4:**

* S32: Most RF core requirements can be reused for supporting RedCap UE bandwidth reduction. However, certain modifications may be considered to reflect that the UE may not measure on the SSB at all times, if scheduled in other parts of the carrier [1].
* S33: There may be some minor performance impacts that need to be considered in RAN4 [19].

**Other aspects:**

* S34: In RRC\_CONNECTED, the RedCap UE can be scheduled within the maximum reception bandwidth even though the initial DL BWP configured for normal NR UEs is larger than the maximum UE bandwidth of RedCap UEs [5].
* S35: UE behavior, such as not expecting resource allocations exceeding the number of PRBs corresponding to BW limitation [2].
* S36: Support for RedCap UEs to be able to perform processing of the wider bandwidth PRS over a longer time period [19].
* S37: Study the maximum number BWPs for RedCap UEs [7].

**Additional specification impacts due to supporting 50 MHz UE in FR2:**

* S38: If the maximum UE bandwidth of RedCap UEs is 50 MHz, to guarantee the performance of RedCap UEs, dedicated common CORESET may need to be configured for system information acquisition, RAR and Msg4 reception [5].
* S39: Specification impact for reading system information [3]
* S40: Define a separate CORESET0 for RedCap UEs [27].
* S41: To allow the 240 kHz SCS SSB configuration to be used UEs with 50 MHz maximum bandwidth, the minimum guardband for SSB reception needs to be specified [1].
* S42: UE performance requirements may have to be defined for both SSB and CORESET0 in case of 50 MHz UE [11].
* S43: Enhancements are needed to compensate for potential PDCCH coverage reduction if FR2 50MHz maximum UE bandwidth is supported for initial access [9].
* S44: Reducing the UE RF bandwidth to 50MHz in FR2 may have significant specification for SSB/CORESET0 configurations using 240 kHz SCS [11, 21].
  + Potential solutions needed to address this issue require specification work
    - S45: Cell barring for the RedCap UEs. For example, the above-mentioned bandwidth is larger than the supportable maximum bandwidth of the RedCap UEs [21].
    - S46: Allowing to omit reception of channel/signal outside of its supportable maximum bandwidth, and so on [21].
    - S47: Additional or separate DL BWPs for RedCap UEs at least for some, if not all, common control [8].
    - S48: Some limitations or modifications may also need to be captured for FR2 50MHz e.g for multiplexing or retuning [2].

**Phase 3: Question 7.3.5-1: Can the above list (S1-S48) be used as a baseline for the TP drafting for TR section 7.3.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### Conclusions

For FR1, most contributions are fine with considering only 20 MHz. A few contributions state that there is no issue if the UEs do not achieve 150Mbps. [1, 10, 14, 23] A few contributions also discuss 40 MHz [12, 14, 16, 26] due to the consideration of supporting 150 Mbps peak bitrate.

Options for FR1 bands:

* Option 1: Maximum bandwidth of 20 MHz during and after initial access
* Option 2: Maximum bandwidth of 20 MHz during initial access, with 40 MHz as optional UE capability after initial access

**Phase 1: Question 7.3.6-1: Should TR 38.875 make recommendations on the maximum bandwidth for RedCap FR1 FDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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For FR2, there are more contributions supporting the 100 MHz option [2, 3, 4, 5, 11, 16, 24, 26]. In general, more performance, coexistence, and specification impacts have been identified for supporting the 50 MHz option. One source points out that to justify 50 MHz as maximum bandwidth of RedCap devices in FR2, more gain over 100 MHz bandwidth would be required considering more standardization efforts expected for 50 MHz bandwidth [14]. Some contributions opine that only one maximum UE bandwidth option should be selected for RedCap UE [6, 14, 28].

Options for FR2 bands:

* Option 1: Maximum bandwidth of 50 MHz during and after initial access
* Option 2: Maximum bandwidth of 100 MHz during and after initial access

**Phase 1: Question 7.3.6-2: Should TR 38.875 make recommendations on the maximum bandwidth for RedCap FR2 UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.4 Half-duplex FDD operation

### 7.4.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| Half-duplex operation allows the UE to receive and transmit on different frequencies, but not at the same time. Half-duplex mode allows for UE complexity reduction by removing the need for a duplexer.  The RedCap study includes both HD-FDD operation Type A and Type B, as defined in LTE, where study of Type A is prioritized. |

**Phase 2: Question 7.4.1-1: Can the above description on half-duplex FDD operation be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.4.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for an HD-FDD device, relative to the reference NR device (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.4.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by Type A and Type B HD-FDD is approximately ~7% and ~10%, respectively.  Furthermore, all sourcing companies indicated that the RF cost savings (but not the baseband cost savings) accumulate across supported bands.  **Table 7.4.2-1: Estimated relative device cost for an HD-FDD device**   |  |  |  | | --- | --- | --- | | **Half-duplex FDD operation** | **HD-FDD operation (Type A)** | **HD-FDD operation (Type B)** | | RF: Antenna array | - | - | | RF: Power amplifier | 24.1% | 24.2% | | RF: Filters | 10.6% | 10.8% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 44.4% | 37.4% | | RF: Duplexer / Switch | 4.8% | 4.9% | | **RF: Total relative cost** | **83.9%** | **77.3%** | | BB: ADC / DAC | 10.0% | 10.0% | | BB: FFT/IFFT | 3.8% | 3.6% | | BB: Post-FFT data buffering | 9.9% | 9.8% | | BB: Receiver processing block | 24.0% | 24.0% | | BB: LDPC decoding | 10.0% | 10.0% | | BB: HARQ buffer | 14.0% | 14.0% | | BB: DL control processing & decoder | 4.8% | 4.8% | | BB: Synchronization / cell search block | 9.0% | 9.0% | | BB: UL processing block | 4.8% | 4.8% | | BB: MIMO specific processing blocks | 9.0% | 9.0% | | **BB: Total relative cost** | **99.4%** | **99.1%** | | **RF+BB: Total relative cost** | **93.2%** | **90.4%** | |

**Phase 1: Question 7.4.2-1: Can the above observations of the relative cost estimation for an HD-FDD device be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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**Device size:**

In addition to reduction in cost/complexity benefits, contribution [18] points out that HD-FDD is expected to reduce device size. Note that the following agreement was reached in RAN1#101e:

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| Agreements:   * [...] * Potential benefits in terms of reduced device size can be mentioned where applicable in the TR (e.g. in the section on reduced number of antennas), but the SI will not aim to quantify such benefits. |

**Phase 2: Question 7.4.2-1: Should it be captured in TR 38.875 that HD-FDD can be beneficial in terms of reducing the device size in FR1 FDD?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.4.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Many contributions analyze the performance impacts if HD-FDD operation is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views.

**Data rate or throughput:**

* P1: HD-FDD reduces data rate compared to FD-FDD [2, 3, 4, 6, 19, 24].
* P2: HD-FDD Redcap UEs can fulfil all the RedCap data rate requirements [1, 5, 22].
* P3: Type A HD-FDD has minor data rate and latency degradation [18].
* P4: Type B HD-FDD has a significant impact on the throughput and/or latency performance [6, 18].
* P5: It might be problematic for HD-FDD UEs to fulfill the data rate requirements of high-end wearables (e.g. 50/150 Mbps peak bitrate in UL/DL) without relying on high modulation order, MIMO and/or carrier aggregation capability [28].

**Coverage:**

* P6: HD-FDD will not result in coverage loss and the coverage of HD-FDD UEs is expected to be at least as good as that of FD-FDD UEs [1, 4, 10, 11, 13, 15, 19, 22, 26].
* P7: HD-FDD will result in coverage loss if the same data rate needs to be maintained [3, 6].

**Latency:**

* P8: HD-FDD introduces longer latency than FD-HDD [3, 6, 19, 24, 28].
* P9: An HD-FDD UE in RRC\_CONNECTED can meet the 5-10 ms latency requirement for safety related sensors [1, 4].
* P10: HD-FDD has less impact on latency compared to TDD [19].
* P11: The latency requirement can be met if NR dynamic TDD is reused for HD-FDD [5].
* P12 The safety sensor use case has strict latency requirements of 5-10 ms which seems difficult for an HD-FDD device to meet [28].

**Power consumption:**

* P13: The lower insertion loss of an HD-FDD UE leads to a higher power efficiency in the transmit chain and improved power consumption when transmitting [1, 11, 19, 23].
* P14: HD-FDD has lower power consumption compared to FD-FDD [4, 10, 19, 24, 26].
  + HD-FDD has a negative impact on UE power consumption because the UE will be “on” for a longer time before being able to return to a lower power light sleep / deep sleep state. This loss is expected to be less than the gain from the lower insertion loss [19].
* P15: Compared to the reference NR modem, half duplex operation means some components can work in a reduced power state until required [13].
* P16: The impact on power consumption of HD-FDD depends on implementation [5].

**Capacity and spectral efficiency:**

* P17: HD-FDD results in lower spectral efficiency [4, 24].
* P18: HD-FDD has minor or no impact on spectral efficiency and capacity [1, 11, 13, 15, 19].
* P19: The lower noise figure of an HD-FDD UE leads to a moderate improvement in cell spectral efficiency and capacity [19].

**Other types of performance impacts:**

* P20: HD-FDD reduces available PDCCH monitoring occasion [6].
* P21: BWP adaptation may have an impact on HD-FDD operation. [7].

**Phase 2: Question 7.4.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P21) be used as a baseline for the TP drafting for TR section 7.4.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.4.4 Analysis of coexistence with legacy UEs

Many contributions analyze the coexistence impacts if HD-FDD operation is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views.

* C1: Introducing HD-FDD operation will make gNB scheduling more complicated [2, 10, 24].
* C2: HD-FDD may introduce scheduling constraints to URLLC services and may introduce issues with pre-emption indicator monitoring [3, 19, 28].
* C3: Introducing HD-FDD operation has no impact on initial access procedure as it is not likely to require simultaneous uplink and downlink transmission in legacy implementations during initial access [1, 11, 19].
* C4: Potential impact on RACH procedure to support Type B HD-FDD UE can be expected, e.g., switching time from PRACH to Msg2 for Type B HD-FDD [15, 24].
* C5: Introducing the support of Type-A HD-FDD operation will not introduce any coexistence issues with legacy UEs [1, 5].
* C6: Introducing the support of Type B HD-FDD operation may require longer time gaps between subsequent messages in the random-access procedure and may therefore introduce longer delay in the random-access procedure for legacy UEs [1].
* C7: Introducing Type B HD-FDD operation has a significant impact on the gNB scheduler [1].
* C8: HD-FDD introduces limitation on the configuration of some common RS/channels for both legacy and RedCap UEs [3].
* C9: Scheduling effectiveness is not compromised by supporting Type-A HD-FDD UE’s in paired spectrum, since each UE could switch between DL and UL at independent points in time, according to their respective scheduled or configured uplink transmissions [23].
* C10: With Type A HD FDD, only the duplexer is dropped, and the same (full-duplex) UE modem can be reused in full-duplex and half-duplex FDD UE designs, thus avoiding UE modem market fragmentation [23].

**Phase 2: Question 7.4.4-1: Can the above list (C1-C10) be used as a baseline for the TP drafting for TR section 7.4.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.4.5 Analysis of specification impacts

Many contributions analyze the specification impacts if HD-FDD operation is introduced for RedCap UEs. The findings are summarized below. Note that some of the findings reflect different views in different contributions. Further discussions are needed to resolve these conflicting views.

* S1: RAN1 specification impact is expected to be minor [11, 17].
* S2: RAN1 specification impact is expected to be small for supporting Type A HD-FDD [1, 21].
* S3: Introducing Type B HD-FDD operation would have much more specification impacts than Type A [1].
* S4: Need to specify DL-to-UL and UL-to-DL switching time [1, 3, 4, 5, 6, 8, 12, 13, 19, 21, 22, 24].
* S5: RAN4 should decide on switching time requirements during the work item phase [19].
* S6: Need to specify HD-FDD capability signaling [1, 4, 5, 19, 21].
* S7: Need to specify how to handle DL/UL collision [1, 4, 8, 24].
* S8: For Type A HD-FDD, the guard period for DL-to-UL and UL-to-DL switching may be relaxed compared to the minimum Rx-to-Tx and Tx-to-Rx switching times defined in Rel-15 for a UE not supporting full-duplex communication [8].
* S9: The DL-to-UL and UL-to-DL switching time for a Type A HD-FDD device can reuse the same values of and specified in Table 4.3.2-3 of TS 38.211 [1].
* S10: The values of and specified in Table 4.3.2-3 of TS 38.211 cannot be used as DL-to-UL and UL-to-DL switching time for a Type B HD-FDD device [1].
* S11: Need to define applicable bands and performance requirements for HD-FDD operation [4].
* S12: RAN4 specification changes such as new reference sensitivity, RRM, and performance requirements can be expected, due to the lack of a duplexer, thus less insertion loss [1].
* S13: Thanks to the flexibility in the TDRA and HARQ timing in NR, there is less motivation to adopt features such as increasing the number of HARQ processes, multi-TB scheduling, and HARQ-ACK bundling, if Type A HD-FDD is introduced for RedCap [1].
* S14: If for unforeseeable reasons, features such as increasing the number of HARQ processes, multi-TB scheduling, and HARQ-ACK bundling, need to be introduced for enhancing the throughput for an HD-FDD UE, the specification impacts will be very significant [1].
* S15: Need to specify how DL pre-emption and UL cancellation work when HD-FDD UEs share resources with URLLC UEs [19].
* S16: Need to specify how to prioritize between eMBB traffic and URLLC traffic for the cases of (1) eMBB DL and URLLC UL and (2) eMBB UL and URLLC DL [19].
* S17: The gNB should be able to configure DL or UL durations for HD-FDD UE [12].
* S18: Type A HD-FDD operation will not impact BWP switch delay requirements [1].
* S19: Type B HD-FDD operation will require defining new BWP switch delay requirements [1].
* S20: RedCap UEs in HD-FDD mode should support BWP switching for power saving [7].

**Phase 3: Question 7.4.5-1: Can the above list (S1-S20) be used as a baseline for the TP drafting for TR section 7.4.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.4.6 Conclusions

There are mixed views regarding whether HD-FDD should be introduced for RedCap. A summary is given below.

* Contributions [2, 3, 24, 28] indicate not supportive or no strong motivation to introduce HD-FDD.
* Contributions [4, 6, 8, 10, 12, 13, 15, 18, 26] indicate HD-FDD may be considered or recommended for RedCap UE. Among these, contributions [10, 15] recommends the support of both Type A and B [10, 15], contributions [4, 6, 8, 18, 26] only recommend Type A. Contributions [6, 12] recommends HD-FDD as an optional feature for RedCap.
* Additionally, contributions [1, 23] express positive assessment regarding Type A, while express negative assessment or recommend not supportive of Type B.

Options for FR1 FDD bands:

* Option 1: Support HD-FDD operation type A.
* Option 2: Support HD-FDD operation type B.
* Option 3: No HD-FDD operation support (same as reference case).

**Phase 1: Question 7.4.6-1: Should TR 38.875 make recommendations on HD-FDD support for RedCap FR1 FDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.5 Relaxed UE processing time

### 7.5.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| In the RedCap study item, relaxed UE processing time is considered in terms of more relaxed N1/N2 values compared to those if UE processing time capability #1. Relaxed UE processing time in terms of N1/N2 potentially reduces UE complexity by allowing a longer time for the processing of PDCCH and PDSCH and preparing PUSCH and PUCCH. This implies that it may be possible to have slower processor with reduced clock frequency, possible distribution of computation load over time, possible reduced demands on parallel processing and chip area, and possible less complex channel decoder.  In the study, for the purpose of evaluation, the relaxed UE processing time in terms of N1/N2 are assumed to be doubled compared to those of capability #1, i.e.,   * N1 = 16, 20, 34, and 40 symbols for 15, 30, 60, and 120 kHz SCS (assuming only front-loaded DMRS) * N2 = 20, 24, 46, and 72 symbols for 15, 30, 60, and 120 kHz SCS |

**Phase 2: Question 7.5.1-1: Can the above description on the relaxed UE processing time feature be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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In addition to relaxed UE processing time in terms of N1/N2, a few contributions discuss relaxed CSI computation. However, it was agreed that the study of relaxed UE CSI computation time is not prioritized in the RedCap study item.

**Phase 2: Question 7.5.1-2: Should any text related to relaxed CSI computation time be captured in the TR?**

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| **Company** | **Y/N** | **Comments** |
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### 7.5.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for a device with relaxed UE processing time (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.5.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction is around 6% for FR1 FDD, 7% for FR1 TDD, and 6% for FR2 TDD.  By comparing Table 7.5.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the cost of the following functional blocks can be reduced:   * Baseband: Receiver processing block * Baseband: LDPC decoding * Baseband: DL control processing & decoder * Baseband: UL processing block   Furthermore, all sourcing companies indicated that these cost savings do not accumulate across supported bands.  **Table 7.5.2-1: Estimated relative device cost for relaxed UE processing time**   |  |  |  |  | | --- | --- | --- | --- | | **Relaxed processing time (doubled N1 and N2)** | **FR1 FDD** | **FR1 TDD** | **FR2 TDD** | | RF: Antenna array | - | - | 33.0% | | RF: Power amplifier | 25.0% | 25.0% | 18.0% | | RF: Filters | 10.0% | 15.0% | 8.0% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 45.0% | 55.0% | 41.0% | | RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% | | **RF: Total relative cost** | **100.0%** | **100.0%** | **100.0%** | | BB: ADC / DAC | 10.0% | 9.0% | 4.0% | | BB: FFT/IFFT | 4.0% | 4.0% | 4.0% | | BB: Post-FFT data buffering | 10.0% | 10.0% | 11.0% | | BB: Receiver processing block | 19.4% | 23.6% | 18.9% | | BB: LDPC decoding | 6.8% | 6.1% | 6.2% | | BB: HARQ buffer | 14.0% | 12.0% | 11.0% | | BB: DL control processing & decoder | 4.1% | 3.3% | 4.0% | | BB: Synchronization / cell search block | 8.7% | 8.7% | 6.8% | | BB: UL processing block | 3.7% | 3.5% | 5.0% | | BB: MIMO specific processing blocks | 8.5% | 8.6% | 17.0% | | **BB: Total relative cost** | **89.3%** | **88.8%** | **87.9%** | | **RF+BB: Total relative cost** | **93.6%** | **93.3%** | **93.9%** | |

**Phase 1: Question 7.5.2-1: Can the above observations of the relative cost estimation for UE with relaxed UE processing time be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.5.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Several contributions analyze the performance impact if relaxed UE processing time is introduced for RedCap UEs. The findings are listed below.

**Latency:**

* P1: Contributions [1, 4, 5, 6, 9, 13, 16, 23, 24, 26, 28] mentioned the impact of relaxed UE processing time capability on latency, where [1, 4, 5, 23] provide some numerical examples of the impact on UL and DL latency for the initial transmission and different number of retransmissions.
* P2: Contributions [1, 3, 4, 5, 16, 21, 23, 24] observe that many RedCap use cases have rather relaxed latency requirements of up to 100 ms or 500 ms and thus can afford to have more relaxed UE processing time if the trade-off between cost reduction benefits and impacts is justified.
* P3: It is mentioned in several contributions [1, 2, 5, 6, 13, 23, 24, 26, 28] 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.

**Scheduling flexibility/complexity:**

* P4: Contributions [1, 4, 6, 23, 24, 26] observe negative impacts of relaxed UE processing time on scheduling complexity, especially when taking into account different scheduling timing restriction related to N1/N2 and the fact that there already exist two UE processing time capabilities in NR.

**Data rate:**

* P5: Contributions [1, 2, 15, 24, 26] mention that sustained data rate may be impacted due to longer HARQ RTT because of the relaxed UE processing time.

**Coverage:**

* P6: Contributions [1, 2, 4, 11, 15, 24] note that no significant coverage impact is expected from a more relaxed UE processing time.

**Spectral efficiency/network capacity:**

* P7: Contributions [1, 3, 4, 11, 15] note that no impact on spectral efficiency or network capacity is expected since it is up to gNB to schedule other UEs on available resources.

**Power consumption:**

* P8: Contributions [3, 5, 13, 16] mention that relaxed processing timeline can allow for lower clock frequency and lower voltage which has an impact on the UE power consumption.
* P9: Contributions [4, 16] mentioned that power saving benefit from cross-slot scheduling can be obtained from relaxed UE processing time.
* P10: Contributions [5, 6, 11, 24, 26, 28] noted that the UE power saving gain may not be clear or may even be degraded as UE may need to stay active longer due to more relaxed UE processing time, and that it may also depend on specific implementation.
* P11: Contribution [1] notes that the NW can configure RedCap UEs to achieve power saving gain from cross-slot scheduling even if no relaxed UE processing time capability is defined.

**Phase 2: Question 7.5.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P11) be used as a baseline for the TP drafting for TR section 7.5.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.5.4 Analysis of coexistence with legacy UEs

Contributions [1, 2, 23, 24] express that multiple UE processing timelines may increase complexity at the scheduler to handle and ensure coexistence with legacy UEs.

Contributions [1, 5, 8, 9, 10, 11, 15, 16, 21, 24] observe that there can be potential coexistence issues with legacy UEs during initial access/random access if a new, more relaxed UE processing time capability is introduced. For example, there exist the timing requirement for scheduling of Msg3 which depends on N1 and N2 values of UE processing time capability #1. If gNB schedules according to legacy UEs, RedCap UEs with relaxed N1/N2, if supported, may not be able to access the cell. On the other hand, if gNB considers potential presence of UEs with relaxed processing time in a cell, it would schedule according to the worst-case timing which would degrade the performance of legacy UEs. Similarly, timing of HARQ-ACK for Msg4 is also identified as a potential coexistence issue with legacy UEs in contributions [8, 9, 10, 15]. In order to support relaxed UE processing time capability during initial access, contributions [3, 8, 9, 10, 15] mention that methods for identifying RedCap UEs, e.g., before Msg3 scheduling may need to be studied.

These identified issues are listed below.

* C1: May make scheduler more complex [1, 2, 23, 24]
* C2: Identification of RedCap UEs before Msg3 may be needed [3, 8, 9, 10, 15].

**Phase 2: Question 7.5.4-1: Can the above list (C1-C2) be used as a baseline for the TP drafting for TR section 7.5.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.5.5 Analysis of specification impacts

Contributions [1, 2, 3, 4, 13, 15, 23, 24] mention the specification impact of defining a new relaxed UE processing time capability and new values of N1/N2. Contributions [2, 23] note that the standardization effort can be high as it requires inputs and agreement from all UE manufacturers.

Other potential impacts on scheduling timing related to the existing default TDRA tables and HARQ-ACK timing range are mentioned by contributions [5, 9, 16, 21, 24]. On the other hand, contributions [1, 3, 4] note that no specification impacts beyond new definition of relaxed UE processing time are expected unless the relaxation of N1/N2 values is too excessive.

These identified impacts are listed below.

* S1: Definition of relaxed UE processing time capability and N1/N2 values [1, 2, 3, 4, 13, 15, 23, 24]
* S2: Scheduling time related to default TDRA tables and HARQ-ACK timing range [5, 9, 16, 21, 24]

**Phase 3: Question 7.5.5-1: Can the above list (S1-S2) be used as a baseline for the TP drafting for TR section 7.5.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.5.6 Conclusions

Based on the analysis of UE cost/complexity reduction, most contributions estimate that relaxed UE processing time in terms of N1/N2 only provides relatively small benefit in terms of UE cost/complicity reduction. On average, the estimate cost reduction is around 4-6% of the total RF+BB cost [35]. On the other hand, several impacts associated with the UE processing time relaxation are observed. Most prominently, many contributions mention that relaxing UE processing time capability can have an impact on latency and scheduling flexibility/complexity where many scheduling timings are dependent upon. There are also potential coexistence issues with legacy UEs, e.g., on the timing requirement for Msg3 scheduling and for HARQ-ACK of Msg4 which can have impacts on the performance of legacy UEs or potentially lead to large specification impacts on UE timing requirement during random access procedure as well as early UE identification.

Contributions [1, 2, 6, 11, 18, 23, 24, 26] suggest not to recommend relaxed UE processing time in terms of N1/N2 as a technique for complexity reduction for RedCap UEs since the gain is small and does not justify performance impacts, and potentially large coexistence and specification impacts.

Contributions [3, 8, 13] on the other hand observe that some meaningful gain can be obtained and recommend to further consider the relaxed UE processing time in terms of N1/N2 for complexity reduction for RedCap UEs in the WI phase.

Options:

* Option 1: Relaxed UE processing time in terms of N1/N2 only
* Option 2: Relaxed UE processing time in terms of CSI computation time
* Option 3: Relaxed UE processing time in terms of N1/N2 and CSI computation time
* Option 4: No relaxed UE processing time (same as reference case)

**Phase 1: Question 7.5.6-1: Should TR 38.875 make recommendations on the relaxed UE processing time for RedCap UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.6 Relaxed maximum number of MIMO layers

### 7.6.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| In the study, the main options for maximum number of DL MIMO layers considered are:   * For FR1 FDD: 1 MIMO layer * For FR1 TDD: 1 and 2 MIMO layers * For FR2: 1 MIMO layer   The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with the maximum number of DL MIMO layers support shown below.   * For FR1 FDD: 2 MIMO layers * For FR1 TDD: 4 MIMO layers * For FR2: 2 MIMO layers   It is primarily assumed that this maximum number of MIMO layers applies to DL data channel only. |

**Phase 2: Question 7.6.1-1: Can the above description on the number of DL MIMO layers reduction feature be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.6.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for a device with relaxed maximum number of MIMO layers (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.6.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by relaxing the maximum number of MIMO layers from 2 to 1 layer is ~13% for FR1 FDD, from 4 to 2 layer is ~11% for FR1 TDD, from 4 to 1 layer is ~17% for FR1 TDD, and from 2 to 1 layer is ~11% for FR2.  By comparing Table 7.6.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:   * Baseband: Receiver processing block * Baseband: LDPC decoding * Baseband: HARQ buffer * Baseband: MIMO specific processing block   Furthermore, all sourcing companies indicated that these cost savings do not accumulate across supported bands.  **Table 7.6.2-1: Estimated relative device cost for relaxed maximum number of MIMO layers**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Relaxed maximum number of MIMO layers** | **FR1 FDD**  **(2 🡪 1 layer)** | **FR1 TDD**  **(4 🡪 2 layers)** | **FR1 TDD**  **(4 🡪 1 layer)** | **FR2**  **(2 🡪 1 layer)** | | RF: Antenna array | - | - | - | 33.0% | | RF: Power amplifier | 25.0% | 25.0% | 25.0% | 18.0% | | RF: Filters | 10.0% | 15.0% | 15.0% | 8.0% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 45.0% | 55.0% | 55.0% | 41.0% | | RF: Duplexer / Switch | 20.0% | 5.0% | 5.0% | 0.0% | | **RF: Total relative cost** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | | BB: ADC / DAC | 10.0% | 9.0% | 9.0% | 4.0% | | BB: FFT/IFFT | 3.9% | 4.0% | 4.0% | 4.0% | | BB: Post-FFT data buffering | 9.7% | 10.0% | 10.0% | 11.0% | | BB: Receiver processing block | 19.4% | 24.1% | 21.8% | 19.9% | | BB: LDPC decoding | 5.2% | 4.6% | 2.4% | 4.7% | | BB: HARQ buffer | 7.2% | 6.1% | 3.3% | 5.7% | | BB: DL control processing & decoder | 4.9% | 4.0% | 4.0% | 5.0% | | BB: Synchronization / cell search block | 8.8% | 9.0% | 9.0% | 7.0% | | BB: UL processing block | 5.0% | 5.0% | 5.0% | 7.0% | | BB: MIMO specific processing blocks | 4.8% | 5.0% | 3.0% | 9.5% | | **BB: Total relative cost** | **79.0%** | **80.8%** | **71.5%** | **77.8%** | | **RF+BB: Total relative cost** | **87.4%** | **88.5%** | **82.9%** | **89.1%** | |

**Phase 1: Question 7.6.2-1: Can the above observations of the relative cost estimation for UE with relaxed maximum number of MIMO layers be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.6.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Several contributions analyze the performance impact if relaxed maximum number of MIMO layers is introduced for RedCap UEs. The findings are listed below.

Contribution [3] noted that there will be minimized network performance degradation.

**Data rate:**

* P1: With the agreed number of MIMO layers to study, peak data rates will be reduced but it can still adequately achieve the data rate requirements for all RedCap use cases [1].
* P2: Peak/max data rate will be impacted or reduced [2, 4, 9, 15, 22, 24]. One contribution [5] further noted that data rate will be reduced by 50% and 75% when the maximum number of MIMO layers is reduced from 4 to 2 or 2 to 1 layer, and from 4 to 1 layer respectively.
* P3: Reducing to 2 MIMO layers in FR1, it can provide the capability of achieving the upper bound data rate requirements [3].

**Latency:**

* P4: No latency impact [24].
* P5: [1] noted that reducing the maximum number of MIMO layers may increase latency. However, the end-to-end latency requirements of RedCap use cases are relaxed (e.g. less than 100 ms for industrial wireless sensors and 500 ms for video surveillance), except the 5-10 ms requirement for safety related sensors. However, data rate of ~80 Mbps can be achieved with 20 MHz with 64QAM per MIMO layer in FR1. This allows transmitting payload up to 10 Kbytes in 1ms in layer 1 which is more than enough for small packet size expected for safety related message and enough to ensure the 5-10 ms latency requirement for safety related sensors. In FR2, it allows larger bandwidth thus higher bit rates can be achieved. Restricting the maximum number of MIMO layers can still sufficiently fulfil the latency requirements of all RedCap use cases.

**Reliability:**

* P6: Reliability should not be impacted [1, 24], as it is envisaged that BLER targets can still be achieved. [1].

**Coverage:**

* P7: No impact on coverage [1, 4, 11, 15, 24].

**Spectral efficiency/network capacity:**

* P8: [1] noted that spectral efficiency is expressed as bit rates per Hz, as reducing the maximum number of MIMO layers will decrease the peak data rates. It is expected that the maximum number of MIMO layers will degrade the spectral efficiency. However, as higher MIMO layers are scheduled when SNR is relatively high. Thus, impacts on spectral efficiency may only be observed under good channel conditions.
* P9: Cell spectral efficiency will be impacted/reduced due to reduced data rate/throughput [1, 2, 4, 5, 6, 11, 15, 24].
* P10: Capacity will be impacted/reduced due to reduced data rate [5, 24].

**Power consumption:**

* P11: In [1], it is noted that Reducing the maximum DL/UL modulation order and/or DL MIMO support may reduce power consumption due to reduced complexity in processing a smaller maximum TB. However, the amount of power saved may not be significant if the RedCap UEs would mostly be in RRC\_IDLE/INACTIVE states. Furthermore, reducing the maximum number of DL MIMO layers can fulfil the date rate requirements of most RedCap uses cases. In many use cases, long transmission times for large TB sizes are not expected to occur frequently for RedCap use cases. Thus, a negative impact on UE power consumption is not expected. In use cases where large TB sizes occur more often, and long transmission times might become a consequence of modulation order and MIMO layer reduction for UEs in good coverage. In such cases, there will be more pronounced negative impact on UE power consumption. In summary, the impact on UE power consumption depends on the traffic and coverage scenarios.
* P12: Reduced power consumption as higher data rate consume higher power or less processing energy is required for smaller TB sizes [1, 4, 13].
* P13: No impacts on power consumption [24].
* P14: As the number of DL antennas is kept the same, there is no power saving. And since the data rate is reduced, longer receiving time is needed to receive a DL TB. Thus, it will have negative impact on UE power saving [15].

**Phase 2: Question 7.6.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P14) be used as a baseline for the TP drafting for TR section 7.6.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.6.4 Analysis of coexistence with legacy UEs

The following potential coexistence impacts were identified in the contributions:

* C1: There is no or no significant coexistence impact. [1, 2, 4, 5, 11, 15]. In [1], it is further noted that prior to the completion of initial access, it is not possible for the gNB to send the rank indication to the UE. Furthermore, a UE’s MIMO layer support could only be known to the gNB after it has retrieved the UE capability from the UE. Due to the limitation in the current specifications, legacy UEs can only be scheduled with single MIMO layer for initial access. Having a RedCap UE with reduced maximum MIMO layer support in the same network, will not affect the number of MIMO layers to be scheduled for the legacy UEs or the RedCap UEs for initial access transmissions.
* C2: Restricted to 2 MIMO layers in FR1 have no obvious coexistence issue is envisioned [3].
* C3: Implicit restrictions on TBS may impact on SIB/Msg4/Paging [24].

**Phase 2: Question 7.6.4-1: Can the above list (C1-C3) be used as a baseline for the TP drafting for TR section 7.6.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.6.5 Analysis of specification impacts

The following potential specification impacts were identified in the contributions:

* S1: UE capability indication to notify the NW of UE’s reduced capability [1, 4, 13].
* S2: Small RAN1 specification impacts [11]
* S3: Limited or no significant specification impacts [2, 15]
* S4: Reduced to 2 MIMO layers in FR1 can provide minimized specification impacts [3].
* S5: No RI and LI report are reduced for single MIMO layer support. Thus, can consider adding the descriptions with report to no RI and LI in the specifications [5].
* S6: Demodulation performance requirements for single layer may be specified in RAN4 [5].

**Phase 3: Question 7.6.5-1: Can the above list (S1-S6) be used as a baseline for the TP drafting for TR section 7.6.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### Conclusions

Some contributions [8, 9, 12, 14, 28, 20] noted the necessity of meeting the peak data rate requirements and contribution [20] mentioned that the requirements cannot be achieved based on the following restrictions:

* Restriction on one DL MIMO layer in FR1 (alternatively, 2 MIMO layers in FR1 are necessary [3])
* Restriction to one DL MIMO layer and maximum modulation order to 16QAM with 50 MHz UE BW for FR2.

[9] further mentioned that support of uplink MIMO with two layers as an optional capability can be considered to increase data rate for high-end RedCap devices.

In [3], it is noted that the cost benefit of further reducing from two layers to one layer is small and would cause substantial peak data rate loss and impact the network negatively. The gain is not justified and suggested two MIMO layers (and 2Rx) for DL should be supported by RedCap devices in FR1 [3].

[18] mentioned allowing MIMO as optional feature for devices with more than one Rx does not seem necessary as it would lead to additional device variants without a significant cost saving.

In [15, 18] it is further noted that the cost saving by reducing the maximum number of MIMO layers is fully covered by Rx antenna reductions or the only restriction on the number of MIMO layers would be from the number of supported Rx chains. Similarly, contributions [8, 26] noted that reducing the maximum number of DL MMIO layers without reducing the number of Rx chains shall not be supported as it does not provide any meaningful complexity reduction or may need to compensate for the reduced antenna number/efficiency. However, in [3], it is mentioned that there are benefits to further cost reduction achieved by economies of scales if RedCap devices are built based on the same baseband capability of two MIMO layers and not affected by the RF components of different number of Rx chains.

Nevertheless, some other companies are fine with the number of MIMO layers reduced to one as it can adequately achieve the peak data rate requirements of all use cases [1] or meet the requirements of most of the RedCap use cases [22]. It is unnecessary to define baseline RedCap devices in FR1 to reach 150 Mbps peak data rate [22]. Furthermore, limiting to a single mechanism (e.g. two MIMO layers) to reach the peak data rate is undesirable. Optional features (such as two MIMO layers or larger bandwidth) can be added to provide enough implementation flexibility to reach the 150 Mbps peak data rate and can be signaled as part of device capability suggested that higher MIMO layer support could be optional [22].

In [8], it is further noted that in the light of MIMO simplifications, the mandatory 8 CSI-RS antenna ports required in FR1, the requirement of simultaneously processing of 5 CSI reports, and CSI computation delay can be relaxed to further reduce UE complexity.

Options for FR1 FDD bands:

* Option 1: 1 layer
* Option 2: 2 layers (same as the reference case)

**Phase 1: Question 7.6.6-1: Should TR 38.875 make recommendations on the supported number of DL MIMO layers for RedCap FR1 FDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.2.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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Options for FR1 TDD bands:

* Option 1: 1 layer
* Option 2: 2 layers
* Option 3: 4 layers (same as the reference case)

**Phase 1: Question 7.6.6-2: Should TR 38.875 make recommendations on the supported number of DL MIMO layers for RedCap FR1 TDD UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.2.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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Options for FR2 bands:

* Option 1: 1 layer
* Option 2: 2 layers (same as the reference case)

**Phase 1: Question 7.6.6-3: Should TR 38.875 make recommendations on the supported number of DL MIMO layers for RedCap FR2 UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).** **Please note that there may be a relation to the questions in Sections 7.2.6 and 7.9.2 in this FL summary.**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.7 Relaxed maximum modulation order

### 7.7.1 Description of feature

Based on earlier RAN1 agreements [37], the following text proposal for the TR can be considered.

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| Restriction on maximum modulation orders reduces complexity through reducing the amount of RF and baseband processing required. Complexity reduction can be expected in the functional blocks listed below.  Restriction on maximum UL modulation order:   * RF:   + Power amplifier   + RF transceiver * Baseband:   + ADC/DAC   + UL processing block   Restriction on maximum DL modulation order:   * RF:   + RF transceiver * Baseband:   + ADC/DAC   + Receiver processing block   + LDPC decoding   + HARQ buffer   In the study, the main options for maximum modulation orders considered are:   * UL:   + FR1: 16QAM instead of 64QAM   + FR2: 16QAM instead of 64QAM * DL   + FR1: 16QAM instead of 64QAM   + FR2: 64QAM instead of 256QAM   The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with the maximum modulation orders shown below.   * UL:   + FR1 and FR2: 64QAM * DL   + FR1: 256QAM   + FR2: 64QAM   It is primarily assumed that these maximum modulation orders apply to data channels only. |

**Phase 2: Question 7.7.1-1: Can the above description on the maximum modulation order reduction feature be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.7.2 Analysis of UE complexity reduction

Based on the latest available evaluation results in [RedCapCost-v023-FL-HWHiSi02.xlsx](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Inbox/drafts/8.6/EvaluationResults/RedCapCost/RedCapCost-v023-FL-HWHiSi02.xlsx), the following text proposal for the TR can be considered. The text can be further updated if later evaluation results are provided that change the numbers significantly.

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| The estimated cost for a device with relaxed maximum modulation order (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.7.2-1 and Table 7.7.2-2.  As can be seen in the last row for the total cost in Table 7.7.2-1, the average estimated cost reduction achieved by relaxing the maximum UL modulation order from 64QAM to 16QAM is ~2% for FR1 FDD, FR1 TDD, and FR2.  By comparing Table 7.7.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:   * RF: Power amplifier * RF: Transceiver * Baseband: ADC/DAC * Baseband: UL processing block   Furthermore, ~50% of sourcing companies indicated that the RF cost savings (but not the baseband cost savings) accumulate across supported bands.  **Table 7.7.2-1: Estimated relative device cost for relaxed maximum UL modulation order**   |  |  |  |  | | --- | --- | --- | --- | | **Relaxed maximum UL modulation order** | **FR1 FDD**  **(64QAM 🡪 16QAM)** | **FR1 TDD**  **(64QAM 🡪 16QAM)** | **FR2**  **(64QAM 🡪 16QAM)** | | RF: Antenna array | - | - | 33.0% | | RF: Power amplifier | 22.6% | 22.6% | 16.1% | | RF: Filters | 10.0% | 15.0% | 8.0% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 44.3% | 54.2% | 40.4% | | RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% | | **RF: Total relative cost** | **96.9%** | **96.7%** | **97.5%** | | BB: ADC / DAC | 9.1% | 8.2% | 3.6% | | BB: FFT/IFFT | 4.0% | 4.0% | 4.0% | | BB: Post-FFT data buffering | 10.0% | 10.0% | 11.0% | | BB: Receiver processing block | 24.0% | 29.0% | 24.0% | | BB: LDPC decoding | 10.0% | 9.0% | 9.0% | | BB: HARQ buffer | 13.9% | 11.9% | 10.9% | | BB: DL control processing & decoder | 5.0% | 4.0% | 5.0% | | BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% | | BB: UL processing block | 4.3% | 4.3% | 5.8% | | BB: MIMO specific processing blocks | 9.0% | 9.0% | 18.0% | | **BB: Total relative cost** | **98.2%** | **98.4%** | **98.4%** | | **RF+BB: Total relative cost** | **97.7%** | **97.7%** | **97.9%** |   From Table 7.7.2-2, the average estimated cost reduction achieved by relaxing the maximum DL modulation order from 256QAM to 64QAM is ~6% for both FR1 FDD and TDD bands. For FR2, the average estimated cost reduction achieved by relaxing the maximum DL modulation order from 64QAM to 16QAM is ~6%.  By comparing Table 7.7.2-2 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:   * RF: Transceiver * Baseband: ADC/DAC * Baseband: Receiver processing block * Baseband: LDPC decoding * Baseband: HARQ buffer   Furthermore, more than 70% of sourcing companies indicated that these cost savings do not accumulate across supported bands.  **Table 7.7.2-2: Estimated relative device cost for relaxed maximum DL modulation order**   |  |  |  |  | | --- | --- | --- | --- | | **Relaxed maximum DL modulation order** | **FR1 FDD**  **(256QAM 🡪 64QAM)** | **FR1 TDD**  **(256QAM 🡪 64QAM)** | **FR2**  **(64QAM 🡪 16QAM)** | | RF: Antenna array | - | - | 33.0% | | RF: Power amplifier | 24.5% | 24.1% | 17.5% | | RF: Filters | 10.0% | 14.8% | 8.0% | | RF: Transceiver (including LNAs, mixer, and local oscillator) | 43.0% | 52.1% | 39.1% | | RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% | | **RF: Total** | **97.5%** | **96.0%** | **97.6%** | | BB: ADC / DAC | 8.9% | 7.8% | 3.6% | | BB: FFT/IFFT | 4.0% | 4.0% | 4.0% | | BB: Post-FFT data buffering | 9.4% | 9.4% | 10.1% | | BB: Receiver processing block | 23.0% | 27.8% | 22.7% | | BB: LDPC decoding | 7.6% | 6.8% | 6.3% | | BB: HARQ buffer | 11.0% | 9.3% | 8.1% | | BB: DL control processing & decoder | 5.0% | 4.0% | 5.0% | | BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% | | BB: UL processing block | 5.0% | 5.0% | 7.0% | | BB: MIMO specific processing blocks | 8.7% | 8.7% | 17.3% | | **BB: Total** | **91.7%** | **91.8%** | **91.0%** | | **RF+BB: Total** | **94.0%** | **93.5%** | **94.3%** | |

**Phase 1: Question 7.7.2-1: Can the above observations of the relative cost estimation for UE with relaxed maximum modulation order be used as a baseline text for TR 38.875?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.7.3 Analysis of performance impacts

According to the SID [36],

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| The study includes evaluations of the impact to coverage, network capacity and spectral efficiency |

In addition, RAN1#101e made the following agreement:

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| Agreements:   * The evaluation of performance impacts includes at least peak data rate, latency and reliability (as needed for the use cases). Other performance metrics such as power consumption, spectral efficiency and PDCCH blocking probability may also be considered if appropriate for a specific technique. |

Several contributions analyze the performance impact if relaxed maximum modulation order is introduced for RedCap UEs. The findings are listed below.

**Data rate:**

* P1: With the agreed maximum modulation orders to study, peak data rates will be reduced but it can still adequately achieve the data rate requirements for all RedCap use cases [1].
* P2: Peak/max data rate will be impacted or reduced [2, 3, 4, 5, 9, 11, 15, 22, 24]. Contribution [5, 23] further noted that data rate will be reduced by ~20% and ~33% when the maximum modulation order is restricted from 256QAM to 64QAM, and from 64QAM to 16QAM respectively.

**Latency:**

* P3: [1] noted that restricting the DL/UL maximum modulation orders may increase latency. However, the end-to-end latency requirements of RedCap use cases are relaxed (e.g. less than 100 ms for industrial wireless sensors and 500 ms for video surveillance), except the 5-10 ms requirement for safety related sensors. Data rate of ~80 Mbps can be achieved with 20 MHz with 64QAM per MIMO layer in FR1 DL. This allows transmitting payload up to 10 Kbytes in 1ms in layer 1 which is more than enough for small packet size expected for safety related message and enough to ensure the 5-10 ms latency requirement for safety related sensors. In FR2, it allows larger bandwidth thus higher bit rates can be achieved. Restricting the DL/UL modulation orders can also sufficiently fulfil the latency requirements of all RedCap use cases.
* P4: No latency impact [24].
* P5: Slightly increased latency but acceptable for RedCap use cases [16].

**Reliability:**

* P6: Reliability should not be impacted [1, 24], as it is envisaged that BLER targets can still be achieved. [1].

**Coverage:**

* P7: No impact on coverage [1, 4, 11, 15, 24].

**Spectral efficiency/network capacity:**

* P8: [1] noted that Spectral efficiency is expressed as bit rates per Hz, as reducing the maximum modulation orders in DL/UL will decrease the peak data rates. It is expected that reducing the maximum number of MIMO layers will degrade the spectral efficiency. However, as higher MIMO layers are scheduled when SNR is relatively high. Thus, impacts on spectral efficiency may only be observed under good channel conditions.
* P9: Cell spectral efficiency will be impacted/reduced due to reduced data rate/throughput [1, 2, 4, 5, 6, 11, 15, 24].
* P10: [2] noted the impact on spectral efficiency will be substantial. [3, 11] further observed substantial cell spectral efficiency loss about 23.6% - 43.6% due to UL modulation order restriction from 64QAM to 16QAM in FR1 and about 6.43% spectral efficiency reduction due to DL modulation order restriction from 256QAM to 64QAM in FR1.
* P11: Capacity will be impacted/reduced due to reduced data rate [5, 24].

**Power consumption:**

* P12: [1] noted that Reducing the maximum DL/UL modulation order may reduce power consumption due to reduced complexity in processing a smaller maximum TB. Furthermore, reducing the DL/UL maximum modulation order may also reduce the ADC/DAC power consumption. However, the amount of power saved may not be significant if the RedCap UEs would mostly be in RRC\_IDLE/INACTIVE states. Furthermore, reducing the maximum modulation order can adequately fulfil the date rate requirements of all RedCap uses cases. In many use cases, long transmission times for large TB sizes are not expected to occur frequently for RedCap use cases. Thus, a negative impact on UE power consumption is not expected. In use cases where large TB sizes occur more often, and long transmission times might become a consequence of modulation order and MIMO layer reduction for UEs in good coverage. In such cases, there will be more pronounced negative impact on UE power consumption. In summary, the impact on UE power consumption depends on the traffic and coverage scenarios.
* P13: Reduced power consumption as higher data rate consume higher power or less processing energy is required for RF components [3, 4, 11, 13, 16].
* P14: [11] noted that power saving would be marginal.
* P15: No impacts on power consumption [24].
* P16: There will have some saving on RF part, but the receive/transmit time may be longer for high data rate case [15].

**Phase 2: Question 7.7.3-1: Considering the SI objective and the mentioned RAN1 agreement on what performance impacts to include, can the above list (P0-P16) be used as a baseline for the TP drafting for TR section 7.7.3?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.7.4 Analysis of coexistence with legacy UEs

The following potential coexistence impacts were identified in the contributions:

* C1: There is no or no significant coexistence impact. [1, 4, 9, 11, 15, 16]. Contribution [1] further noted that During initial access, for the reception of paging indication or broadcasting information (SIBx), PDSCH is not expected to be scheduled with modulation order higher than QPSK. And the scheduling information for Msg3 would be carried in PDCCH using DCI format 0\_1 which allows modulation order <= 16QAM to be sent in the DCI. From modulation order perspective, there will be no impacts by restricting the UL and/or DL maximum modulation order based on the current agreement.
* C2: For the initial access procedure, lower MCS and single layer for broadcast downlink transmission and initial uplink scheduling will be used to ensure decoding performance or poor UE channel condition. In this case, RedCap UEs are still able to finish the access procedure [9].
* C3: Implicit restrictions on TBS may impact on SIB/Msg4/Paging [24].

**Phase 2: Question 7.7.4-1: Can the above list (C1-C3) be used as a baseline for the TP drafting for TR section 7.7.4?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.7.5 Analysis of specification impacts

The following potential specification impacts were identified in the contributions:

* S1: UE capability indication to notify the NW of UE’s reduced capability [1, 4, 13]
* S2: To minimize specification impacts, there should be no optimization (only reuse) of all existing tables [2]. [5] noted that restricting to 64QAM, one possible solution is to reuse the existing 64QAM table.
* S3: Limited specification impacts [15].
* S4: Small RAN1 specification impacts [1, 4, 5, 11, 20, 24]
  + Change of DCI size, CQI table and MCS table due to restricted maximum modulation order is possible but not essential [1, 4].
  + If the maximum modulation order is restricted to 16QAM, new MCS/DCI tables are introduced [5, 20] with lower/higher spectral efficiency for UE specific allocation case [20] to achieve more scheduling flexibility. It is further noted that the standardization effort would be small if the values from Rel-15/16 tables are reused [20].
* S5: RAN4 CQI performance requirement if new CQI tables are introduced [1].

**Phase 3: Question 7.7.5-1: Can the above list (S1-S5) be used as a baseline for the TP drafting for TR section 7.7.5?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### Conclusions

There are mixed views regarding the restricting of maximum modulation orders for RedCap devices. A summary is given below.

[11, 15, 23, 24] mentioned the cost saving by restricting the maximum DL modulation order is small while there will be some drawbacks such as the peak data rate is reduced by 25% when reducing the maximum modulation order from 266QAM to 64QAM in FR1 and reduced by 33% when the modulation order is reduced from 64QAM to 16QAM in FR2 [23], or the cell spectrum efficiency will be deteriorated [3, 6, 11]. The relative cost saving due to restrictions on the maximum DL modulation order will be even smaller [6, 11, 15, 23] compared to the cost saving with other more dominant techniques. Similar tradeoffs were also observed by [3, 6, 11, 23] on the maximum modulation order restrictions in UL.

Due to network performance degradation expected and small cost reduction, Contributions recommended that RedCap UEs do not support DL [11] and UL [3, 11] modulation restrictions. In contribution [23], it is also noted that 64QAM should be maintained as mandatory in both DL and UL in FR2. Furthermore, in [6], it is noted that it should be justified for a UE to apply high modulation order if the channel condition is good enough, especially for the use cases that require high data rate.

Moreover, contribution [8] noted that the benefits from limiting maximum modulation order for UL from 64QAM to 16QAM is rather limited. When considered in conjunction with other more dominating cost reduction techniques, the benefits may not be observable.

Some companies are fine to study relaxation of maximum modulation orders to 64QAM instead of 256QAM in FR1 DL [1, 3, 6, 8, 9, 15, 18, 22, 23, 26], 16QAM instead of 64QAM in FR2 DL [1, 8, 15, 26] and 16QAM instead of 64QAM in FR1 and FR2 UL [1, 9, 18]. [18] further noted that 256QAM DL and 64QAM UL can be a UE capability in FR1, whereas [26] mentioned 64QAM UL can be optional but 256QAM is not supported in FR1.

Nevertheless, in [5], it is proposed that for FR1 DL, the maximum modulation order can be restricted to 16QAM or 64QAM according to UE capability as 64QAM is not necessary for RedCap devices with low or medium load traffic. In [9], a similar proposal is provided (i.e. 16QAM for low-end devices and 64QAM for high-end devices) however for FR1 UL.

In other contributions [24], it is noted that there would be no strong motivation to reduce the maximum modulation order so far and the conclusion can be made after obtaining the cost evaluation result. Similarly, in [17], it is mentioned that the features such as maximum modulation order restrictions, reducing the maximum number of MIMO layers and reduced number of HARQ processes are related with device type discussion and should be discussed with lower priority until the device type for RedCap UEs are decided.

Options for FR1 bands:

* Option 1: Max 64QAM in DL and max 16QAM in UL
* Option 2: Max 64QAM in DL and max 64QAM in UL
* Option 3: Max 256QAM in DL and max 16QAM in UL
* Option 4: Max 256QAM in DL and max 64QAM in UL (same as the reference case)

**Phase 1: Question 7.7.6-1: Should TR 38.875 make recommendations on the supported modulation orders for RedCap FR1 UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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Options for FR2 bands:

* Option 1: Max 16QAM in DL and max 16QAM in UL
* Option 2: Max 16QAM in DL and max 64QAM in UL
* Option 3: Max 64QAM in DL and max 16QAM in UL
* Option 4: Max 64QAM in DL and max 64QAM in UL (same as the reference case)

**Phase 1: Question 7.7.6-2: Should TR 38.875 make recommendations on the supported modulation order for RedCap FR2 UEs? If yes, please indicate your preferred option (or FFS in the Option column if you prefer to down-select later in this meeting).**

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| **Company** | **Y/N** | **Option** | **Comments** |
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## 7.8 Other relaxed UE processing capability

### 7.8.1 Description of feature combinations

Some contributions discuss complexity reduction through other relaxed UE processing capability than the techniques agreed to be studied (i.e. other than reduced maximum number of MIMO layers and relaxed maximum modulation order).

**Relaxed maximum number of HARQ processes:**

Some contributions [1, 2, 6] noted that reducing the number of HARQ processes offers very limited benefit (less than 1%) on top of bandwidth reduction and other techniques and would increase scheduler restrictions and promotes market fragmentation. [3, 23] further mentioned that reducing the maximum number of HARQ processes is not required as NR has been designated to decouple the RV from soft buffer size or the soft buffer complexity estimation should assume the external memory is used such that it does not scale with the number of HARQ processes. The HARQ process partition can be up to UE implementation and the benefit is not clear [1, 3, 6]. Furthermore, the 16 HAR processes mandated for NR should be maintained for relaxed RTT [1, 23].

However, in some contributions [4, 13], it is mentioned that further cost saving can be achieved by reducing the number of HARQ processes. For example, reducing the number of HARQ processes from 16 to 8 can provide approximately 4% which is similar level as the cost saving by restricting the maximum modulation order. Further reducing the number of HARQ processes to 4, more cost saving (i.e. about 6 - 8% total cost saving) can be achieved compared to reducing the maximum modulation order, while the specification impacts are marginal (e.g. RAN4 demodulation performance requirements). The further reduction of soft buffer size has the justified number of cost breakdown at least for the low-end market [13].

Moreover, in [26], it is noted that the fronthaul delay does not depend on the duplexing mode or the numerology, the maximum number of processes supported by RedCap UE should be reduced at least for FDD deployment (up to 8 HARQ processes) with 15 kHz SCS without reducing the scheduling flexibility of gNB and proposed to decouple the maximum number of HARQ processes from the LBRM buffer size dimensioning for RedCap UE and support a constant HARQ RTT reference number for the LBRM buffer size dimensioning.

**Other techniques:**

A few contributions also discussed other techniques that would be beneficial to UE complexity relaxation. Those techniques include:

* Simplifying features that are mandatory for mandatory for Rel-15 NR UEs [8]
* Relaxing the maximum number of blind decodings and/or CCEs can reduce UE complexity especially baseband processing for PDCCH. However, the effect on gNB scheduling flexibility and blocking probably should be studied [28].
* CSI measurement / feedback but not as first priority.
* SUL can also be considered for RedCap devices in order to achieve better uplink coverage (e.g. 10 ~ 13 dB coverage gain with different uplink target rates and uplink channels.) [3, 9, 28] and higher UL bit rates [9]. It is further noted in [3] that support SUL does not directly increase the UE baseband cost.
* [8, 28] also noted that MIMO and/or CA capability is needed to achieve the DL peak rate and is more critical in case less than 64QAM is supported or for TDD that is not heavy DL-oriented. In [8, 28], it is mentioned that intra-band allows scalability and may not be so intrusive to UE implementation and pose lower RF challenges and should at least be studied. In [3], it is however noted that intra-band CA would provide little useful functions in practical deployments if limited to intra-band CA. [3] further noted that if inter-CA is assumed, the RedCap devices would have a cost roughly the same as the baseline 100 MHz bandwidth capability and supports of other capabilities (such as simultaneous transmission on multi-CC) would be necessary. From the perspective of satisfying use case requirement and cost efficiency, RedCap UEs can be restricted on single CC.
* Reduction of the maximum number of allocated for the further TBS restriction which would be beneficial for the low-ed market [8, 13]
* Restricting UL waveform to DFT-S-OFDM only [8]
* Simplified BWP operation [8]
* No support of simultaneous reception [8]
* No support of prioritization of dynamically scheduled PDSCH/PUSCH over SPS/CG PUSCH occasions respectively [8]
* PDSCH reception with receiver side puncturing on configured reserved resources [8]

**Phase 1: Question 7.8.1-1: Should any aspects of any complexity reduction technique(s) for relaxed UE processing capability other than the techniques agreed to be studied (i.e. other than reduced maximum number of MIMO layers and relaxed maximum modulation order) be captured in the TR? If yes, please describe what techniques and what aspects.**

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| **Company** | **Y/N** | **Comments** |
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### 7.8.2 Analysis of UE complexity reduction

### 7.8.3 Analysis of performance impacts

### 7.8.4 Analysis of coexistence with legacy UEs

### 7.8.5 Analysis of specification impacts

### 7.8.6 Conclusions

## 7.9 Combinations of UE complexity reduction features

### 7.9.1 Description of feature combinations

### 7.9.2 Analysis of UE complexity reduction

The initial collection of evaluation results [35] focused on cost estimation for individual cost reduction techniques, while the cost estimation for combinations of different cost reduction techniques was postponed till RAN1#103e.

Contribution [1] provides initial cost reduction estimates also for certain combinations of individual cost reduction techniques. Contribution [2] proposes that no combinations of techniques with 50 MHz UE bandwidth in FR2 will be investigated. Other contributions, e.g. [11, 15, 26], propose other specific combinations.

In order to avoid having to carry out cost estimation for very many combinations, it would be good to focus on the combinations that are considered most promising. For example, in the first draft template for cost reduction evaluation [38], the following combinations were included:

* For FR1 FDD:
  + 20 MHz, 1 layer
  + 20 MHz, 1 layer, 1 Rx
  + 20 MHz, 1 layer, 1 Rx, half duplex type A
  + 20 MHz, 1 layer, 1 Rx, half duplex type B
  + 20 MHz, 1 layer, 1 Rx, doubled N1 and N2
  + 20 MHz, 1 layer, 1 Rx, max 64QAM in DL
  + 20 MHz, 1 layer, 1 Rx, max 16QAM in UL
* For FR1 TDD:
  + 20 MHz, 2 layers, 2 Rx
  + 20 MHz, 1 layer, 2 Rx
  + 20 MHz, 1 layer, 1 Rx
  + 20 MHz, 2 layers, 2 Rx, doubled N1 and N2
  + 20 MHz, 2 layers, 2 Rx, max 64QAM in DL
  + 20 MHz, 2 layer, 2 Rx, max 16QAM in UL
* For FR2:
  + 100 MHz, 1 layer, 1 Rx
  + 50 MHz, 1 layer, 1 Rx
  + 100 MHz, 1 layer, 1 Rx, doubled N1 and N2
  + 50 MHz, 1 layer, 1 Rx, doubled N1 and N2
  + 100 MHz, 1 layer, 1 Rx, max 16QAM in DL
  + 50 MHz, 1 layer, 1 Rx, max 16QAM in DL
  + 100 MHz, 1 layer, 1 Rx, max 16QAM in UL
  + 50 MHz, 1 layer, 1 Rx, max 16QAM in UL

**Phase 1: Question 7.9.2-1: Can the cost evaluation for combinations of cost reduction techniques focus on the above list? If not, what changes are needed?**

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| **Company** | **Y/N** | **Comments or suggested revisions** |
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### 7.9.3 Analysis of performance impacts

### 7.9.4 Analysis of coexistence with legacy UEs

### 7.9.5 Analysis of specification impacts

### 7.9.6 Conclusions

# References

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| [13] | [R1-2008100](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_103-e/Docs/R1-2008100.zip) | Discussion on potential UE complexity reduction features | Spreadtrum Communications |
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| [16] | [R1-2008260](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_103-e/Docs/R1-2008260.zip) | Discussion on UE complexity reduction | OPPO |
| [17] | [R1-2008294](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_103-e/Docs/R1-2008294.zip) | UE complexity reduction features for RedCap | Lenovo, Motorola Mobility |
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