3GPP TSG-RAN WG1 Meeting #102-e Tdoc R1-20xxxxx

e-Meeting, August 17th – 28th, 2020

**Agenda Item: 8.6.1**

**Title: FL summary #1 for Potential UE complexity reduction features for RedCap**

**Source: Moderator (Ericsson)**

**Document for: Discussion, Decision**

# 1 Introduction

This document summarizes contributions [1] – [30] which were submitted to AI 8.6.1 plus a few relevant contributions [31] – [35] that were submitted to other agenda items under AI 8.6.

This document also captures this RAN1#102-e email discussion:

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| --- |
| [102-e-NR-RedCap-01] Email discussion/approval – Johan (Ericsson)   * By 8/20 – high priority * By 8/26 – medium * By 8/28 – last check |

The questions/proposals are color coded like this:

1. High priority
2. Medium priority
3. Low priority

In the first round of discussion, please prioritize the High priority questions/proposals.

# 6 Evaluation methodology

## 6.1 Evaluation methodology for UE complexity reduction

One contribution [3] 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.

Another contribution [8] makes an observation that the methodology does not take into account economies of scale (vs. market fragmentation) amongst the cost drivers, and that this fact should be stated explicitly in Section 7.7 of TR 38.875, where combinations of reduction features are selected and assessed.

**Q 6.1-1: Can the above disclaimer from [3] and the above observation from [8] be captured in the TR?**

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| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y | The disclaimer needs to be captured before the cost/complexity estimates are included in the TR. The observation from [8] is one aspect from the disclaimer from [3]. |
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Contribution [13] proposes that the number of RedCap UE hardware variants should be limited as much as possible (i.e. ideally one) to provide economies of scale, whereas contribution [15] proposes that more than one UE type should be defined to support different peak rates for different use cases. One contribution discusses whether there is any need to define explicit RedCap UE types [19]. Other contributions propose to study this further [16, 33].

One contribution [33] proposes to updated the reference NR device definition to capture CA capability to evaluate reduction from actual NR devices deployed today. However, the feature lead’s understanding that the reference NR device ought to correspond to the simplest NR device that can be built today to address the targeted use cases, not necessarily the simplest actually deployed NR device.

Two contributions [12, 17] propose updated values for the assumed RF-to-baseband cost ratio, compared to the 40:60 split assumed in the LTE MTC study report TR 36.888.

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| --- | --- | --- | --- |
| **Contribution** | **FR1 FDD (2Rx)** | **FR1 TDD (4Rx)** | **FR2 TDD** |
| **Reference [12]** | 40:60 | 40:60 | RF cost is higher than 40%, closer to 50% or above |
| **Reference [17]** | 40:60 | 50:50 | 60:40 |

**Q 6.1-2: What RF-to-baseband cost ratio should be assumed?**

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| --- | --- | --- | --- | --- |
| **Company** | **FR1 FDD** | **FR1 TDD** | **FR2 TDD** | **Comments** |
| Example | 40:60 | 40:60 | 40:60 |  |
| FUTUREWEI |  |  |  | Not such a strong feeling as the estimates will be very rough, however very important that we agree to something. Suggest FR1 is kept the same, FR2 either the same or 50:50. |
| SONY | 40:60 | 40:60 | 50:50 | FR1 FDD: similar to 36.888  FR1 TDD: 4RX increases both RF and baseband in proportion, hence also 40:60 ratio  FR2 TDD: increased RF cost from antenna panels |
| Ericsson | 40:60 | 50:50 | 60:40 |  |
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Several contributions discuss the detailed cost breakdown for the reference NR devices either qualitatively [1, 12] or quantitatively [6, 17, 30]. For more detailed information, see the respective contributions.

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| **Functional block** | **FR1 FDD (2Rx)** | **FR1 TDD (4Rx)** | **FR2** |
| **RF** | | | |
| Antenna array for FR2 |  |  | 30%~35% [17] |
| Power amplifier | 25%-30% [17]  25% [6]  25% [20]  NA [30] | 28%-35% [17]  16% [6]  25% [20]  NA [30] | 15%~20% [17] |
| Filters | 5-10% [17]  10% [6]  10% [20]  NA [30] | 5%-10% [17]  13% [6]  10% [20]  NA [30] | 5%-10% [17] |
| RF transceiver (including LNAs, mixer, and local oscillator) | 40%-50% [17]  45% [6]  40% [20]  NA [30] | 45%-55% [17]  58% [6]  40% [20]  NA [30] | 40% [17] |
| Duplexer / Switch | 10-20% [17]  20% [6]  25% [20]  NA [30] | 2-3% [17]  13% [6]  25% [20]  NA [30] | 0% [17] |
| **Baseband** | | | |
| ADC / DAC | 5% [17]  10% [6]  9% [20]  NA [30] | 5% [17]  10% [6]  9% [20]  NA [30] | 5% [17] |
| FFT/IFFT | 5% [17]  5% [6]  2% [20]  ~5% [30] | 5% [17]  6% [6]  2% [20]  ~5% [30] | 5% [17] |
| Post-FFT data buffering | 10%-15% [17]  10% [6]  9% [20]  ~10% [30] | 10%-15% [17]  12% [6]  9% [20]  ~10% [30] | 10%-15% [17] |
| Receiver processing block | 20%-35% [17]  25% [6]  27% [20]  ~35% [30] | 20%-35% [17]  30% [6]  27% [20]  ~35% [30] | 20%-35% [17] |
| LDPC decoding | 5%-15% [17]  10% [6]  9% [20]  ~15% [30] | 5%-15% [17]  6% [6]  9% [20]  ~15% [30] | 5%-15% [17] |
| HARQ buffer | 10%-15% [17]  10% [6]  27% [20]  ~15% [30] | 10%-15% [17]  6% [6]  27% [20]  ~15% [30] | 10%-15% [17] |
| DL control processing & decoder | 5% [17]  5% [6]  4% [20]  NA (included in Receiver processing block) [30] | 5% [17]  3% [6]  4% [20]  NA (included in Receiver processing block) [30] | 5% [17] |
| Synchronization / cell search block | 5%-10% [17]  10% [6]  9% [20]  ~10% [30] | 5%-10% [17]  12% [6]  9% [20]  ~10% [30] | 5%-10% [17] |
| UL processing block | 5%-10% [17]  5% [6]  4% [20]  ~10% [30] | 5%-10% [17]  3% [6]  4% [20]  ~10% [30] | 5%-10% [17] |
| MIMO specific processing blocks | 10%-20% [17]  10% [6]  0% [20]  NA (included in Receiver processing block) [30] | 10%-20% [17]  12% [6]  0% [20]  NA (included in Receiver processing block) [30] | 15%-25% [17] |

**Q 6.1-3: Is there a need to define a detailed cost breakdown for the reference NR devices, or is it enough to define the RF-to-baseband cost ratios for the reference NR devices? Is the answer the same or different for FR1 and FR2?**

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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | We agreed to 888 as a starting point, so the question should probably be reversed to see if we have consensus NOT to have detailed breakdowns. The breakdowns are useful to see how companies arrived at their estimates and avoid just stating a big number for a preferred technique and e.g. 1% for a technique that a company doesn’t like for some reason.  That said, the exact breakdowns used are not that important. 888 is the starting point, is there a very strong need to change any of the values? In fact, 888 had a range for each, it could simplify things to take a midpoint of the ranges, or slightly higher or lower such that we add to 100%. The estimates we produce can all have a “~” in front of them, and there will need to be an overall disclaimer (see 6.1-1) before we include the % number in the TR anyway. |
| SONY | Detailed cost breakdown would be useful. This can be based on the values in TR36.888 (the numbers in the table above are consistent with (or the same as) the cost breakdown in TR36.888. We think that some of the numbers in the TDD columns of the above tables need re-visiting (TDD has 4RX and so we would expect a greater proportion of cost attributed to functions such as LNAs and receiver processing / channel estimation). We also think that some of the FR2 numbers need more consideration: we expect different breakdowns between FR1 and FR2. |
| Ericsson | If agreements can be reached during RAN1#102e, having detailed cost breakdown would be beneficial to better understand cost saving impacts from certain techniques where double counting may occur. Furthermore, it would be easier to identify which components have larger complexity and thus may assist in decision-making.  However, if agreements cannot be reached during RAN1#102e, given the limited time remaining in the SI, in order to avoid spending too much time, it might be enough to define the RF-to-baseband cost ratios for the reference NR devices and other than that just rely on the existing detailed cost breakdown in 36.888 in order to ensure the study item can be finalized in Q4 2020. |
|  |  |

RAN1#101-e agreed that “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”.

* [1] has stated that the cost, complexity and the size of a RedCap device would scale up, although not linearly, with the number of supported RF bands within FR1 or FR2. In [1], it has also been stated that the overall relative cost/complexity reduction due to reducing number of Rx branches in a multi-band case can be expected be of the similar order as in the single-band case.
* [2] has proposed that SUL defined in Rel-15 and Rel-16 can be utilized for Rel-17 RedCap to achieve better uplink coverage, while UL CA is not proper for RedCap. The contribution has also noted that support of SUL does not directly increase the UE baseband cost, as the UE only work on one band at a given time.
* [3] has stated that the complexity reduction due to reduced number of UE Rx/Tx antennas will accumulate over multiple bands.
* [4] has stated that a wearable device supports a wide range of frequency bands, and separate antenna and Rx chain is required for bands that has large frequency separations. This will further complicate the product design with form factor limitation.
* [7] has noted that the RF complexity saving may multiply across bands when the bands are spaced sufficiently far apart that different LNAs and PAs are required. The contribution also notes that the baseband complexity saving does not replicate across multiple bands.
* [22] and [30] have estimated that a UE that has ‘support of only low-band, mid-band and high-band’ with 1 Rx antenna and 1 RF chain would provide a saving of 34% relative to a reference NR device with 8 Rx antenna and 4 RF chain.
* [33] has proposed that the reference NR device for evaluation of cost/complexity reduction should be updated to capture at least CA capability to evaluate reduction from actual NR devices deployed today.

**Q 6.1-4: Should the cost/complexity reduction from support of multiple RF bands within FR1 or FR2 be evaluated based on properly scaling up single-band evaluation results?**

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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | The lead in “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” is not relevant to the proposal. For that statement, as a low priority some time before the end of the study, a statement can be added in the antenna reduction section that reducing antennas may reduce size, such as in low bands (e.g 700MHz).  For the proposal, we already agreed to:  Note: The study will consider impacts on the cost/complexity reduction from support of multiple RF bands within FR1 or FR2.  We do not agree to reverse that agreement. A statement as to whether the gains are mostly RF or baseband and whether gains accumulate is sufficient. No need to include examples of a scaled up value, though if helpful and others want to do that no objection. |
| SONY | The evaluation results should account for multiple RF bands. The scaling needs to be applied to individual items in the complexity breakdown table (i.e. the table in “Q 6.1-3”). E.g. if a UE support 2 bands, it might require 2 PAs, but it doesn’t require 2 LDPC blocks, hence the scaling for 2 bands would scale the PA complexity, but not the LDPC complexity. |
| Ericsson | UEs supporting multiple RF bands are expected to have approximately the same baseband cost/complexity as a single-band UE, as long as operation in a single band is taking place at a given time. Regarding RF, cost/complexity scaling depends on frequency separation, complexity-performance trade-off, and whether additional components for enabling multiband operation.  A note capturing the above points might be included in the TR. |

# 7 UE complexity reduction features

## 7.2 Reduced number of UE Rx/Tx antennas

### 7.2.1 Description of feature

In RAN1#101-e, the following agreements were made with regards to the study on UE complexity reduction through reduced number of UE Rx/Tx antennas.

|  |
| --- |
| Agreements:   * For FR1, study two antenna configurations for RedCap UEs, namely 1Rx/1Tx and 2Rx/1Tx. * For FR2, study two antenna configurations for RedCap UEs, namely 1Rx/1Tx and 2Rx/1Tx.   Agreements:   * [...] * Cost/complexity breakdowns can be separate for FR1 and FR2 if found beneficial. * Include antenna parts at least in the cost/complexity breakdown for FR2. * 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.   Agreements:  The reference NR device for evaluation of cost/complexity reduction supports the following:   * [...] * Operation in a single band at a time * Antennas:   + For FR1 FDD: 2Rx/1Tx   + For FR1 TDD: 4Rx/1Tx   + For FR2: 2Rx/1Tx * [...]   Note: The study will consider impacts on the cost/complexity reduction from support of multiple RF bands within FR1 or FR2. |

In the following sections, we summarize the findings/observations/proposals in various contributions under AI 8.6.1. We have also provided few questions for companies, intended as a way-forward in the SI for this complexity reduction feature.

The agreements in RAN1#101-e are on the study of reduction in Rx and Tx branches relative to the reference NR device. In FR2, however, the antenna panels can make up a considerable portion of the overall UE cost/complexity. Therefore, the reduction of antenna panels (and elements within the panels) may help to reduce UE cost. However, there would be associated performance and specification impacts. These aspects have not yet been captured in any agreements.

**Q 7.2.1-1: Should the SI study reduced number of UE (physical) antenna elements and panels in FR2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | The question is too open ended with only one meeting to go. Either we have a specific agreement on how to handle, or just skip it. Simple ways to handle may be to increase the RF ratio as in a previous proposal. |
| SONY | We think that it is important to study FR2 RedCap UEs with reduced numbers of panels as well as panels with reduced sets of antenna elements. Reduced set of elements per panel will require a new power class (RAN4). |
| Ericsson | The UE power classes (e.g., power class 3) in FR2 are based on RAN4 requirements on EIRP (min peak, spherical coverage, etc.), which depends on number of antenna panels and number of antenna elements per panel. Therefore, a proper technical study would require RAN4 involvement. There will also be significant performance impacts, both in uplink and downlink, which are not easily captured by link-level simulations. Due to the limited time left to conclude the study item, we do not recommend the study on reduction of UE antenna panels/elements in TR 38.875.  However, we consider reducing antenna elements and panels as an effective UE cost/complexity reduction technique that fits well with stationary devices such as certain industrial sensors and surveillance cameras. It could be a potential candidate in a future RAN4 study item. |

### 7.2.2 Analysis of UE complexity reduction

Most contributions have pointed out that a reduced number of Rx antennas compared to a Rel-15 reference UE enables reduced complexity, e.g. in terms of the required number of RF components and a relaxation of the baseband receiver complexity. The cost/complexity reduction analysis has been done either quantitatively or qualitatively.

For FR1, the quantitative cost reductions reported in different contributions are provided in Table 1.

**Table 1: Estimation of overall relative cost saving from reduced number of UE Rx antennas in FR1**

|  |  |  |  |
| --- | --- | --- | --- |
| **Contribution** | **FR1 FDD**  **2 Rx  1 Rx** | **FR1 TDD**  **(4 Rx  2 Rx)** | **FR1 TDD**  **(4 Rx  1 Rx)** |
| [1] | 15-38% | 15-38% | 22.5-57% |
| [2] | ~20% in RF ~30% in baseband | Complexity reduction for individual RF and baseband components has been provided in Table 3 of [2] | - |
| [3] | ~30% | ~30% | - |
| [5] | Up to 50% in many baseband components/process  Reduction in RF cost | Up to 50% in many baseband components/processes  Reduction in RF cost | - |
| [6] | 31%` | 38% | 57% |
| [9] | 15-38% | - | - |
| [16] | 20%~30% | - | - |
| [17] | 33.2% | 37.5% | 56.2% |
| [20] | - | 26.8% | 37.8% |
| [22, 30] | - | 23% | 34% |
| [25] | - | 25-39% | 37-59% |
| [27] | - | factor of 2 in related parts (antennas, RF/baseband receiver chains) | - |
| [29] | 50% in RF 50% in many baseband components | 50% in RF 50% in many baseband components | - |

For FR1, the contributions [7, 8, 18, 23] have provided a qualitative analysis of cost/complexity reduction associated with different components of the RF part (e.g., Filters, RF transceiver, Duplexer /Switch, etc.) and the baseband part (e.g., ADC, FFT, Receiver processing block, decoding, buffers, Synchronization / cell search blocks, MIMO specific processing blocks, etc.). These contributions have indicated that there will be reduction in the UE complexity/cost when reducing the number of antennas. The contribution [8] have further emphasized that the complexity of transmit RF path, duplexer, frequency synthesizer, DAC, uplink baseband, initial cell search and control channel decoding are unaffected when reducing the number of receive chain, and complexity is reduced in quasi-linear proportion to the number of receiver chains in the receiver RF path.

Additionally, [19] has noted that going from 2 Rx to 1 Rx will have less impact on cost saving. The contribution [13] has stated that reducing the number of antennas will save chipset/module cost but especially if HD-FDD is supported, the cost reduction will not be significant, and that it is more economical to have one hardware variant.

For FR2, relatively fewer companies have provided cost/complexity reduction analysis, either quantitatively or qualitatively.

* [1] has stated that reducing only the Rx branches from 2 to 1 in FR2 will have limited impact on the overall cost and complexity reduction.
* [7] has stated that in FR2 reducing the number of antennas leads to complexity reduction through reduced number of antenna packages.
* [12] has noted that unlike in FR1, where ratio of RF to baseband cost was 40: 60, in FR2 the contribution of RF components to the overall cost/complexity of the reference NR UE modem is higher than 40%, closer to 50% or above.
* [17] has reported 49.64% reduction in complexity when going from for 2 Rx to 1 Rx. This is based on a 60:40 ratio of RF to baseband cost.

**Device size:**

In addition to reduction in cost/complexity benefits, the contributions [1, 2, 3, 4, 5, 7, 8, 9, 12, 15, 16, 17, 21, 25] 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 [27] has indicated that form factor consideration does not justify 1 Rx for RedCap, especially in FR2. It is mentioned in [1] that reducing only the Rx (branches) has limited impact on reducing the device size in FR2. In [29], 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.

**Q 7.2.2-1: Most companies agree that the reduced number of Rx antennas is beneficial in terms of reducing the device size. Should this benefit be captured in TR 38.875?**

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| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | As commented in 6.1-4, this is OK but is low priority. The lower carrier frequencies should be in the statement. |
| Ericsson | FR1: Yes, we agree that benefit in terms of reduced device size can be captured in the TR.  FR2: No. In our view, reducing only the Rx antennas (i.e., branches) will have limited impact on reducing the device size. We are also, however, open to receiving and take into consideration more input from UE vendors on this aspect. |

### 7.2.3 Analysis of performance impacts

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.

The downlink coverage loss reported in the contributions are summarized in Table 2. Some contributions (e.g., [22, 23, 29]) have cited their companion paper under AI 8.6.3 for the quantitative values of coverage loss and have not included them as part of their complexity reduction paper under AI 8.6.1. Those values are, however, not included in Table 2.

**Table 2: Estimation of downlink coverage loss from reduced number of UE Rx antennas in FR1**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Contribution** | **FR1 FDD**  **2 Rx  1 Rx** | **FR1 TDD**  **(4 Rx  2 Rx)** | **FR1 TDD**  **(4 Rx  1 Rx)** | **FR2**  **(2 Rx  1 Rx)** |
| [1] | SSB: 4.7 dB  PDCCH (AL16): 3.7 dB  PDSCH: 4.0 dB | SSB: 3.0 dB  PDCCH (AL16): 3.2 dB  PDSCH: 3.0 dB | SSB: 6.9 dB  PDCCH (AL16): 6.2 dB  PDSCH: 6.2 dB | SSB: 3.7 dB  PDCCH (AL16): 3.9 dB  PDSCH: 3.8 dB |
| [2] | PDCCH (AL16): 3.08 dB  PDSCH (5 Mbps): 4.34 dB  PDSCH (10 Mbps): 5.07 dB | - | - | - |
| [3] | 3-6 dB | 3-6 dB | - | - |
| [5] | - | 3 dB\* (AWGN)  \* loss in fading channels may be larger | 5.5 dB-6 dB\* (AWGN)  \* loss in fading channels may be larger | - |
| [6] | PDSCH: 4.0 dB  PDCCH (AL16): ~4.0 dB | PDSCH: 3.2 dB  PDCCH (AL16): ~3.2 dB | PDSCH: 7.2 dB  PDCCH (AL16): ~7.2 dB | - |
| [8] | PDCCH (AL16): 2.6 dB | PDCCH (AL16): 2.3 dB | PDCCH (AL16): 5.6 dB | - |
| [9] | - | SSB: 2.44 dB  PDCCH: 6.48 dB (AL1); 5.52 dB (AL2); 5.32 dB (AL4); 3.47 dB (AL8); 2.59 dB (AL6)  PDSCH: 3.85dB | SSB: 5.51 dB  PDCCH: 13.83 dB (AL1); 12.12 dB (AL2); 9.58 dB (AL4); 7.28 dB (AL8); 6.09 dB (AL6)  PDSCH: 9.83dB | - |
| [15] | - | - | >6 dB | - |
| [17] | PDCCH (AL16): ~4 dB  PDSCH: ~4dB | - | PDCCH (AL16): ~10dB  PDSCH: ~4dB | PDCCH: ~4 dB |
| [19] | PDCCH: 3.63 dB (AL=16); 4.59 dB (AL=4) | PDCCH: 2.9 dB (AL=16); 3.93 dB (AL=4) | PDCCH: 6.56 dB (AL=16); 8.52dB (AL=4) | - |
| [27] | - | - | ~7dB | - |

The above values for performance loss depend on the exact simulation assumptions used by different companies, including on channel conditions, performance requirement for different channels, etc. These are either provided in the above cited papers, or in their respective companion papers on coverage recovery. In [7, 18, 22, 23, 25], it has also been stated qualitatively that there will be coverage loss due to reduction in Rx antennas. In [4], it is noted that the impact of coverage is limited due to reduced Rx as it is shown in the coverage study that NR is UL coverage limited. In [17], it is also noted that longer acquisition time for SSB detection is expected, and that no coverage impact is expected for PUSCH due to reduction in number of Rx antennas.

Several contributions have also identified other impacts when reducing the number of Rx antennas:

**Data rate/throughput:**

* P1: [1, 2, 5, 7, 9, 18] 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.

**Latency and reliability:**

* P2: In [29], it is observed that for 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 [7], it is observed that reducing the number of receive antennas does not affect latency and reliability.

**Power consumption:**

* P4: [19] has indicated that there is less contribution to power saving for 2 Rx****1 Rx
* P5: [2] and [16] have noted that power consumption is also saved by fewer RF chains and by less complexity of multi-antenna processing
* P6: [1, 5, 6, 7, 20, 23] 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.

**Spectral efficiency/network capacity loss:**

* P7: [1, 2, 3, 4, 6, 7, 9, 13, 17, 19, 20, 23, 25], especially [2], report a loss in spectral efficiency of ~30% for 2 Rx****1 Rx.
* P8: In [6], it has been reported that loss is spectral efficiency (sector/cell edge) is 23-33% for 2 Rx****1 Rx, 39-41% for 2 Rx****2 Rx, and 53-60% for 4 Rx****1 Rx.
* P9: In [4], it is also noted that the impact can be managed by network by access control mechanism.

**PDCCH blocking probability:**

* P10: [7] and [20] 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 [29], 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.

The discussion on bottleneck channels and coverage recovery techniques to compensate for the performance loss can be taken under AI 8.6.3, and are left out of the discussion in this section. Some contributions have also noted the impact of device size limitations on potential reduced antenna efficiency. The resulting performance impact can also be studied under AI 8.6.3, and has not been considered in this section.

**Q 7.2.3-1: Does the list (P1, P2, …, P11) above capture the most important performance impacts that need to be considered for UE antenna reduction? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | The most important observation is the very large number of dB loss, especially from 4 to 1 RX. Perhaps some range in [ ] can be agreed for now, and can be revised by next meeting. Note that the table 2 is incorrect in that it says COVERAGE LOSS, which is not correct. These are performance degradations, but since the system is both UL limited and not designed to exactly match the MCL of the UL limited channel, there may not be coverage loss.  A minor point: it would be helpful, in addition to the numbers in P7/8, to say why the loss occurs. I.e., spectral efficiency will be reduced from having to use more robust MCS, repetitions, etc. |
| Ericsson | Y | Yes, beside coverage impacts and coverage recovery aspects, which are treated under the AI 8.6.3 according to the meeting agenda. |

**Q 7.2.3-2: Which of the identified performance impacts in the list above (P1, P2, …, P11) are the most critical ones to be captured in TR 38.875 for UE antenna reduction?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1, P2 |
| FUTUREWEI | Should capture:P1,P6,P7,P8,P11 (only first sentence)  No strong feeling: P4, P10  Should not capture:  P2 and P3, these are misleading as it misses the main point that latency is increased and reliability is at risk. In some cases maybe can still meet for a single RedCap UE, but in a system with many RedCap and legacy UE not clear.  P5 is part of P6  P9 is more relevant for coexistence, but not really needed in the RAN1 led part of the TR.  P11 second sentence “high number” should not be included |
| Ericsson | P1, P6, P7 (only the first part) and P10 are in our view critical to capture in the TR, and there may already be enough inputs to draft a text proposal for the TR.  Regarding P8 and P11, in our view spectral efficiency/network capacity loss is an important impact that need to be captured in the TR, but this can be quantified after evaluations have been carried out for AI 8.6.3.  Regarding P2 and P3, although important to capture latency and reliability in the TR, more inputs/evaluations are needed to identify the degree of impact. |

### 7.2.4 Analysis of coexistence with legacy UEs

Several contributions [1, 3, 5, 7, 17] 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, 3, 17]
* C2: blocking impacts if RedCap UE need to use higher aggregation levels for PDCCH reception [3].
* C3: there will be coexistence issues if common physical channel is used for both legacy UEs and RedCap UEs [5]
* C4: No coexistence impact [7]

**Q 7.2.4-1: Does the list above (C1, C2, C3, C4) capture the most important coexistence impacts that need to be considered for UE antenna reduction? If not, what other aspects need to be added?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | No. C1 is misleading in that it implies that there is COVERAGE LOSS and that solutions and enhancements will be agreed. It also implies that these solutions themselves will eliminate the coexistence issue which is not correct.  Something like statement C3 should be a first one, that states the system treating the UEs the same will mean conservative handling of all UEs. Then a replacement for C1 can state that early identification can reduce this conservative handling, but the enhancements themselves would also have coexistence impacts (such as from partitioning the PRACH preamble space).  C2 is fine.  ‘no impact’ (C4) should not be considered in the list of impacts. |
| Ericsson | Yes |
|  |  |
|  |  |

**Q 7.2.4-2: Which of the identified coexistence impacts in the list above (C1, C2, C3, C4) are the most critical ones to be captured in TR 38.875 for UE antenna reduction?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | C1, C2 |
| FUTUREWEI | Revised C3, replacement of C1, and C2 need to be included. |
| Ericsson | C2.  Depending on potential solutions, e.g., for UE identification and coverage recovery, C1 and C3 might be coexistence issues to consider. |
|  |  |

### 7.2.5 Analysis of specification impacts

Several contributions [1, 3, 5, 7, 17, 18, 20, 27] also point out the specification impacts from reducing the number of UE Rx antennas. These contributions have mainly highlighted potential RAN4 specification impacts, including RRM, demodulation performance requirements, CSI reporting requirements, RF, receiver sensitivity requirements, and procedure requirements (e.g., cell change, radio link management, beam management, etc.) in all RRC states. 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], it is noted that the impact is more significant, in both FR1 and FR2, when reducing the number of receiver branches to 1.

Potential RAN1 impacts depend on the techniques that may be used to compensate for the coverage and spectral efficiency loss. Some techniques highlighted in different contributions that will have RAN1 specification impacts are:

* S1: PDCCH repetition: [8, 17, 22]
* S2: Additional repetitions for PDSCH: [8, 23]
* S3: AL greater than 16: [6]
* S4: Compact DCI: [17]
* S5: CSI enhancement to improve spectral efficiency: [17]
* S6: Early indication of RedCap UE in random access: [17, 22, 25]

In addition, [7] has indicated that there would be potential RAN2 impact due to signalling of reduced antenna capability.

The discussion on bottleneck channels and coverage recovery techniques is treated under AI 8.6.3.

**Q 7.2.5-1: Does the list above (S1, S2, …, S6) capture the most important specifications impacts that need to be considered for UE antenna reduction? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | The important part to be listed here are the expected RAN4 impacts.  S1 to S6 should not be listed here. First, there may not be COVERAGE LOSS. Second, mitigating performance degradation is a different section of the TR and should not be discussed here. |
| Ericsson | Y | We do not see RAN1 specification impacts beyond potential associated coverage recovery and reduction of number of MIMO layers. |

**Q 7.2.5-2: Which of the identified specification impacts in the list above (S1, S2, …, S6) are the most critical ones to be captured in TR 38.875 for UE antenna reduction?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1, S5 |
| FUTUREWEI | NONE |
| Ericsson | We do not see RAN1 specification impacts beyond potential associated coverage recovery and reduction of number of MIMO layers. |

### 7.2.6 Conclusions

Based on the analysis summarized in previous sections, several companies have explicitly indicated/proposed their preference on the number of UE Rx antennas as baseline support for RedCap. We summarize these preferences below. Superscript is used to indicate the notes.

**FR1:**

* **1 Rx:** [41, 15, 17, 21, 292, 3111]
* **2 Rx:** [2, 33, 18, 194, 274]
* **Both 1 Rx and 2 Rx:** [15, 56, 67, 85,8, 125, 165,9, 255]

**FR2:**

* **2 Rx:** [1, 6, 15, 18, 274]
* **Both 1 Rx and 2 Rx:** [56, 2910]

Notes:

* Note 1: 1 Rx for wearables. For devices types that are not very restricted by form factor, 2 Rx can be considered.
* Note 2: [29] has indicated that 2 Rx can be an optional feature in FR1.
* Note 3: FFS if 1Rx/1Tx should be recommended for some low frequency deployment for size considerations, or for scenarios where range is not an issue (e.g., wearables).
* Note 4: 2 Rx has higher priority than 1 Rx
* Note 5: 1 Rx in lower frequency bands in FR1, and 2 Rx in others.
* Note 6: Capability signaling shall be defined to indicate the number of Rx antennas
* Note 7: Does not recommend going from 4 Rx to 1 Rx in FR1. Reduced capability feature set 1 needs 2 Rx; Reduced capability feature set 2 can have either 2 Rx or 1 Rx (depending on band)
* Note 8: FFS: whether to support RedCap UE’s with 1 Rx in all FR1 bands
* Note 9: When operating in bands n7, n38, n41, n77, n78, n79, the number of Rx can be reduced from 4 to 2 or 1.
* Note 10: Consider two antenna configurations for UE capability, namely 1Rx/1Tx and 2Rx/1Tx
* Note 11: The support of 2 Rx is optional

Contribution [13] states that support for a 1 Rx should be the exception and should be an optional UE capability.

Contribution [28] indicates a preference for 2 MIMO layers (which requires 2 Rx) or 40 MHz in FR1

Contribution [32] mentions that the number of receive antenna for a RedCap UE need to be reported as a UE capability.

## 7.3 UE bandwidth reduction

### 7.3.1 Description of feature

For FR1, most of the contributions under AI 8.6.1 [1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31] consider 20 MHz maximum UE bandwidth in FR1. Contributions [5, 15, 16, 28] consider maximum UE bandwidth larger than 20 MHz as additional options in FR1.

For FR2, contributions [1, 3, 4, 5, 6, 8, 9, 11, 12, 13, 16, 17, 18, 19, 23, 24, 25, 26, 27, 28, 29, 31, 35] discuss 50 MHz and/or 100 MHz maximum UE bandwidth options in FR2. Contributions [4, 5, 8, 12, 16, 29] prefer maximum RedCap UE bandwidth 100 MHz, whereas contributions [1, 6, 11] prefer 50 MHz. Contribution [3] points out it might be desirable to preserve the economy of scale for the “normal” 200 MHz NR UE.”

Contribution [1, 3, 15, 22, 30] explicitly states that same bandwidth is considered for DL and UL. Contribution [1, 5, 20, 22, 30] also consider the same BW for RF and baseband. Contribution [22, 30] further states the same bandwidth for data and control channels. Contribution [8, 15] discusses whether asymmetric DL/UL bandwidth might be considered for certain use cases.

**Q 7.3.1-1: Can TR 38.875 focus on the scenario where the same maximum UE bandwidth applies to both DL and UL, both RF and baseband, and both data and control channels?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y | Including this main case is already agreed. No need to spend time on bandwidth proposals between 20 and 100 MHz for FR1. The target is “up to” and various combinations of modulation and MIMO layers can hit the peak data rate. Other proposals may have been considered in the “888” days but are not so promising for NR. Given the limited time unless most companies want to include we should work on completing other aspects of the study. |
| SONY | N | UL bandwidth could be larger than DL bandwidth as UL bandwidth is not a significant cost driver.  Having a wider RF bandwidth than baseband bandwidth could lead to better coexistence, so we would like this to be further studied.  There could be coexistence benefits for having a different control bandwidth to data bandwidth, so we would like to consider this. |
| Ericsson | Y |  |

**Q 7.3.1-2: Should TR 38.875 include more bandwidth options in FR1 in addition to 20 MHz? If yes, what additional bandwidth options?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N |  |
| SONY | Y | We are basically OK with considering 20MHz bandwidth. However, as per the answer to Q7.3.1-1, we would like to consider wider RF bandwidths and / or control channels having a bandwidth of greater than 20MHz. |
| Ericsson | N |  |

**Q 7.3.1-3: Should TR 38.875 include more bandwidth options in FR2 in addition to 50 MHz and 100 MHz? If yes, what additional bandwidth options?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | Including 50MHz is a sufficient example for the long list of impacts and issues, no need to include another similar value. We had proposed last meeting to include a value just large enough (say in 70-80MHz) to avoid all of the issues with 50MHz, but 100MHz also avoids those issues.  As part of the TR analysis for 50 and 100 MHz we should say something like “a value of X MHz in FR2 will avoid these issues with 50MHz, but would require effort in RAN4 to define a new bandwidth.” (same comment we made in the May meeting GTW when accepting 50 and 100MHz) |
| SONY | Y | We are basically OK with considering 50MHz / 100MHz bandwidth. However, as per the answer to Q7.3.1-1 / Q7.3.1-2, we would like to consider wider RF bandwidths and / or control channels having a bandwidth of greater than 50MHz / 100MHz. |
| Ericsson | N |  |

### 7.3.2 Analysis of UE complexity reduction

Contributions [1, 4, 7, 8, 16, 17, 18, 22, 23, 30] specifically indicate that UE bandwidth reduction has impact on the functional blocks listed below.

* Power amplifier: [1, 8, 18]
* ADC/DAC [1, 7, 8, 16, 17, 18]
* Frontend buffering [8]
* FFT/IFFT [1, 4, 7, 8, 16, 22, 23, 30]
* Post-FFT processing or data buffering [1, 4, 7, 16, 22, 30]
* Channel estimation [7, 8, 23]
* HARQ or decoder buffer [1, 4, 8, 16, 22, 23, 30]
* Decoder [1, 8, 16, 22, 23, 30]
* UL processing block, although some contributions also indicate the benefit is minor [1, 7, 8, 22, 30]

Contributions [1, 3, 5, 6, 7, 17, 20, 22, 30] provide quantitative analysis and contributions [3, 5, 12] provide qualitative analysis on UE cost saving.

The estimates in cost reduction achieved by reducing the maximum UE bandwidth from 100 MHz to 20 MHz in FR1 are:

* Contribution [3]: 20%-30%
* Contribution [17]: 27.6% (FDD), 23.8% (TDD)
* Contribution [20]: 34.5%
* Contribution [1]: 15%-39%
* Contribution [6]: 38%
* Contribution [22, 30]: 67% in baseband cost; with 40:60 RF:baseband cost ratio, this translate to 40.2% cost reduction
* Contribution [7]: 51.4%
* Contribution [5]: significant

Based on these estimates, the cost saving from reducing the UE bandwidth from 100 MHz to 20 MHz is in the range of 15%-51.4% The middle of this range is 33.2%

The estimates in cost reduction achieved by reducing the maximum UE bandwidth from 200 MHz to 100 MHz in FR2 are:

* Contribution [3]: Less benefit compared to that achievable in FR1
* Contribution [17]: 10.5%
* Contribution [1]: <10%
* Contribution [6]: 23%
* Contribution [5]: significant

Based on these estimates, the cost saving from reducing the UE bandwidth from 200 MHz to 100 MHz is no greater than 23%

The estimates in cost reduction achieved by reducing the maximum UE bandwidth from 200 MHz to 50 MHz in FR2 are:

* Contribution [17]: 16.5%
* Contribution [1]: 15%
* Contribution [6]: 32%
* Contribution [3]: Less benefit compared to that achievable in FR1
* Contribution [12]: Complexity reduction benefits from 50 MHz compared to 100 MHz in FR2 may be rather limited

Based on these estimates, the cost saving from reducing the UE bandwidth from 200 MHz to 50 MHz is in the range of 15%-32% The middle of this range is 23.5%

### 7.3.3 Analysis of performance impacts

Contributions [1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 15, 16, 17, 18, 20, 21, 27, 28, 29] analyze the performance impact in FR1 due to bandwidth reduction from 100 MHz to 20 MHz.

**Data rate:**

* P1: There is peak data rate reduction due to bandwidth reduction [7, 18]
* P2: 20 MHz bandwidth can either achieve or sufficiently close to achieve data rate requirements for all targeted use cases [2, 3, 6, 8, 21, 27]
* P3: 64QAM without MIMO achieves greater than 80 Mbps in DL [5, 13, 29, 13]
* P4: 64QAM without MIMO achieves greater than 50 Mbps in UL [13, 29]
* P5: 16QAM without MIMO achieves greater than 40 Mbps in UL [13, 29]
* P6: A UE bandwidth of 20MHz without MIMO cannot achieve DL peak bit rate of 150Mbps. To achieve 150 Mbps in DL, either MIMO, CA, or larger bandwidth than 20 MHz is needed. [3, 5, 9, 12, 15, 16, 27, 28, 29]
* P7: A DL peak rate of 150Mbps is not possible with TDD, 20MHz UE BW, and 64 QAM [13]

**Latency:**

* P8: The latency can be increased if the large messages need to be segmented into multiple transport blocks and sent over multiple slots. But, 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. [7]

**Reliability:**

* P9: Reliability should not be impacted as it is envisaged that BLER targets can still be achieved at a reduced bandwidth. [7]

**Power consumption:**

* P10: Power saving benefit: [4, 5, 6, 15, 20,]

**Spectral Efficiency:**

* P11: Minimal spectral efficiency degradation [6, 7, 17]
* P12: CORESET#0 capacity before RRC connection setup and impact as such on spectral efficiency [17, 20]

**PDCCH blocking probability**

* P13: PDCCH block probability may increase [20]

**Coverage:**

* P14: PDSCH performance degradation (based on the same data rate target) [9]
* P15: Minor or no coverage loss [1, 6, 7, 17]

Some of performance impact identified above can be expected also in FR2

Contributions [1, 4, 5, 6, 9, 12, 16, 18, 19, 23, 26, 27, 28, 29] identify the performance impact due to UE bandwidth reduction in FR2.

Impacts common to 50 MHz and 100 MHz

* P16: In FR2, both maximum UE bandwidth 50 MHz and 100 MHz can meet the peak data rate requirement. [5, 6]
* P17: SSB/CORESET acquisition time can be impacted if the UE bandwidth is reduced [28]
* P18: Misalignment between Redcap UE’s receiving bandwidth and PDSCH scheduling bandwidth [16]
* P19: Severely limiting the gNB scheduler in managing load on the initial DL BWP [12]

Some of performance impact identified above can be expected also in FR2.

Impacts identified specific to 50 MHz UE bandwidth

* P20: UE may not be able to receive AL 8 or 16 for certain CORESET#0 configurations [26]
* P21: PDCCH blocking probability [4, 5, 9, 16, 18, 19, 27, 28, 29]
* P22: Reduce the number of users that can be supported by almost 50% if the maximum UE BW is reduced from 100 MHz to 50 MHz [29]
* P23: Lower mean SINR compared to the 100 MHz case [29]
* P24 Regarding PBCH performance degradation, contributions [1, 6, 23] analyze the loss.
  + very modest [1]
  + < 1 dB [23]
  + 0.6 dB [6]
* P25: Regarding PDCCH performance degradation when CORESET#0 is configured to 69.12 MHz, contributions [1, 6] analyze the loss.
  + 1.5-1.7 dB [1]
  + Not expected to have a significant impact to system performance [6]

**Q 7.3.3-1: Does the list (P1, P2, …, P19) above capture the most important performance impacts that need to be considered for bandwidth reduction in FR1? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y | Was the intent to stop at P15? |
| Ericsson | Y |  |

**Q 7.3.3-2: Which of the identified performance impacts or aspects in the list above (P1, P2, …, P19) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR1?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1, P2 |
| FUTUREWEI | Should capture:  P1, P2, P4, P11/14/15 should probably be combined into a small performance loss statement (no mention of COVERAGE LOSS)  No strong feeling:  P8,9  Should not capture:  P3, 5 as related to another technique which, if included, should be analysed on top of bandwidth reduction  P6,7: The requirements are “up to”, saying “cannot achieve” or “is not possible” may give the impression that it is a hard requirement. CA and BW larger than 20MHz should not be mentioned. p7 belongs in modulation restriction if that technique is included.  P12 seems not a spectral efficiency argument but more a coexistence or system impact  P13 no need to discuss for FR1 |
| Ericsson | P1, P2, P3, P6, P8, P9, P10, P11, P15  Regarding P12 and P13, we agree these performance aspects are important. But further studies are needed. |

**Q 7.3.3-3: Does the list (P1, P2, …, P25) above capture the most important performance impacts that need to be considered for bandwidth reduction in FR2? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y |  |
| Ericsson | Y |  |

**Q 7.3.3-4: Which of the identified performance impacts or aspects in the list above (P1, P2, …, P25) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1, P2 |
| FUTUREWEI | Should capture: P16,P17 (where more impact is expected for 50MHz), P20-22, P24-25 (need to be rewritten to emphasize that there is a degradation, then the dB range (so far).  No strong feeling: P23  Should not capture:  P18 issue not clear  P19 more a coexistence issue |
| Ericsson | P1, P9, P10, P11, P15, P16, P17, P23, P24, P25  Regarding P12, P13, P19, and P21, we agree these performance aspects are important. But further studies are needed. |

### 7.3.4 Analysis of coexistence with legacy UEs

Contributions [1, 3, 4, 5, 7, 11, 20] analyze the coexistence issues with legacy UEs. The findings are:

* C1: Small overall impact [1, 20]
* C2: Fully reusing the legacy procedure for RedCap UEs will potentially impact the performance of legacy UEs during initial access and increase the load of the initial BWP [4, 11]
* C3: Longer processing time for PRS is needed [7]
* C4: Paging capacity may be a concern [5]
* C5: Resource fragmentation and reduced peak data rates available for non-RedCap UEs [3]
* C6: Coexistence with URLLC UEs [11]

**Q 7.3.4-1: Does the list above (C1, C2, …, C6) capture the most important coexistence impacts and findings that need to be considered for bandwidth reduction in FR1? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y |  |
| Ericsson | Y |  |

**Q 7.3.4-2: Which of the identified coexistence impacts in the list above (C1, C2, …, C6) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR1?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | C1, C2 |
| FUTUREWEI | Should capture:  C5. We had a similar statement in 888.  No strong feeling:  Should not capture:  C1: This is not compatible with the other statements. Better to list the impacts. Also, not applicable to FR2.  C2: This seems more an issue for FR2. |
| Ericsson | C1, C3.  Regarding C2, C4, C5, and C6, further discussions are needed. |

Some of the coexistence impacts identified for FR1 above might be relevant for FR2.

Concerning 50 MHz UE bandwidth in FR2, contributions [3, 5, 17, 29] highlight the following issues.

* C7: Restrictions on SSB/CORESET#0 configurations or Type0-PDCCH monitoring [3, 17, 5]
* C8: PDCCH blocking probability increases [29]
* C9: Half capacity compared to 100 MHz with a TDM scheduler [29]
* C10: Reduced SIR compared to 100 MHz [29]

**Q 7.3.4-3: Does the list above (C1, C2, …, C10) capture the most important coexistence impacts and findings that need to be considered for bandwidth reduction in FR2? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | As above, should have a statement like “a value of X MHz in FR2 will avoid these issues with 50MHz, but would require effort in RAN4 to define a new bandwidth.” |
| Ericsson | Y |  |

**Q 7.3.4-4: Which of the identified coexistence impacts in the list above (C1, C2, …, C10) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | C1, C2 |
| FUTUREWEI | Should capture: C7  C2 should be rewritten: For 50MHz, two initial access procedures will have to coexist: one for ‘regular’ UEs, one for RedCap UEs  No strong feeling:C8,C9,C10  Should not capture:  C1 (for at least 50MHz) |
| Ericsson | C3, C7.  Regarding C7: we agree this aspect should be captured in the TR. However, our view is that all the currently defined SSB/CORESET#0 configurations can be reused. One restriction we see is that the UE needs to detect SSB and SIB1 in a sequential manner for certain SSB/CORESET#0 configurations.  All the other coexistence impacts need to be discussed further. |

### 7.3.5 Analysis of specification impacts

Contributions [1, 3, 5, 6, 7, 15, 16, 17, 21, 24, 25, 28] identify problem mitigating or performance enhancing solutions which have specification impacts in FR1.

* S1: Dedicated iBWP for RedCap [15, 16]
* S2: Extending the CORESET duration in time domain to enhance the CORESET capacity [15]
* S3: UE behavior (not expecting resource allocations exceeding the number of PRBs corresponding to the maximum UE bandwidth [3]
* S4: FDMed RACH Occasions: [1, 5, 21, 28,]
* S5: Multiple initial BWPs [17]
* S6: CSI report enhancement [17]
* S7: CORESET#0 enhancement [17]
* S8: Capability signaling defining reduced bandwidth or UE type identification [5, 7]
* S9: Minor performance impacts to be reflected in RAN4 specifications [7]
* S10: DCI optimization [5]
* S11: Dedicated PO configuration [5]
* S12: PUCCH frequency hopping during initial access [1]
* S13: Msg3 frequency hopping [5]
* S14: define RedCap narrowband [24]

Contributions [1, 6, 25] conclude that overall specification impact is minimal.

**Q 7.3.5-1: Does the list above (S1, S2, …, S14) capture the most important specifications impacts that need to be considered for bandwidth reduction in FR1? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | Most of these should not be listed here. The SID is clear that L1 changes should be minimized. Mitigating performance degradation is a different section of the TR and should not be discussed here |
| Ericsson | Y |  |

**Q 7.3.5-2: Which of the identified specification impacts in the list above (S1, S2, …, S14) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR1?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1, S2 |
| FUTUREWEI | Should capture: S3, S9  No strong feeling:  Should not capture:  All others |
| Ericsson | S4, S8, S12 |

Some of the identified specification impacts listed above might be relevant to FR2 as well.

Specification impacts required for supporting 50 MHz maximum UE bandwidth in FR2 are identified in contributions [3, 4, 5, 11, 12, 16, 17, 19, 24, 25, 26, 28, 29, 31, 35].

* S15: Initial access due to {SSB, CORESET#0} together or PBCH or CORESET#0 alone spanning a bandwidth larger than 50 MHz [3, 4, 5, 6, 11, 12, 17, 19, 24, 25, 26, 27, 28, 29, 31]
* S16: Limiting the supported SCS combinations for {SSB, CORESET#0} [19]
* S17: Dedicated initial BWP [26]
* S18: RMSI acquisition or initial access procedure for RedCap [3, 11, 25]
* S19: Mechanism for dealing with misalignment between UE receiving bandwidth and PDSCH scheduling bandwidth [16, 25]
* S20: Cell barring [25]
* S21: The minimum guardband of SCS 240 kHz SSB is not defined for 50 MHz bandwidth in the RAN4 spec

Contribution [25] mentions that mechanism for allowing omitting reception of channel/signal outside of UE supportable maximum bandwidth is also needed for supporting maximum 100 MHz UE bandwidth.

Contribution [28] mentions that a special SSB/CORESET#0 configuration might also be considered for supporting 100 MHz UE bandwidth.

Contribution [6] states that specification impact for supporting 50 MHz or 100 MHz maximum UE bandwidth is small.

**Q 7.3.5-3: Does the list above (S1, S2, …, S21) capture the most important specifications impacts that need to be considered for bandwidth reduction in FR2? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | Many of these should not be listed here. The SID is clear that L1 changes should be minimized. Mitigating performance degradation is a different section of the TR and should not be discussed here. |
| Ericsson | Y |  |

**Q 7.3.5-4: Which of the identified specification impacts in the list above (S1, S2, …, S21) are the most critical ones to be captured in TR 38.875 for bandwidth reduction in FR2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1, S2 |
| FUTUREWEI | Should capture: S3, S9  S15+S19 may be OK if clarified or rewritten  Should not capture:  All others  Restrictions on supported SCS S16/21 is a big restriction for NR systems, we should be extremely hesitant to go down this path especially for a small potential complexity gain that is not significant compared to economies of scale. |
| Ericsson | S4, S8, S12, S19, S21 |

## 7.4 Half-duplex FDD operation

### 7.4.1 Description of feature

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

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

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

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

Contributions [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 20, 21, 22, 23, 25, 26, 27, 29, 30, 31] discuss HD-FDD for UE complexity reduction. Contributions [5, 8, 13, 17, 21, 26, 29] explicitly indicate supportive of introducing or considering HD-FD for RedCap. Contribution [21] suggests to study both Type A and Type B, whereas contributions [1, 4, 6, 8, 13] either suggest no need to study type B further or indicate a preference of type A. Contributions [2, 15] indicate not supportive of introducing HD-FDD or mandating the support of HD-FDD for RedCap, although contribution [15] indicates that HD-FDD can be an optional feature for RedCap.

**Q 7.4.1-1: Regarding HD-FDD, which of the below way-forwards shall be adopted?**

* **A: Both Type A and Type B are studied**
* **B: Only study Type A**
* **C: No need to study HD-FDD further, neither Type A nor Type B**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | We already agreed to study, with type A as a priority. Do you mean whether to include in the TR or not?  B or C are OK. A increases the priority of Type B so not OK.  Overall the antenna reduction and BW reduction are the most important, and this technique is not applicable to TDD. So we can accept not studying further if the group wants to go that way. We are also OK to spend a little time to include the benefits and impacts in the TR, which could (perhaps) help avoid spending time in the WI or in a future release.  Note: there is an outlier 19%, which would be misleading if in the TR. If we state that “most companies see ~5-10%” then should be OK. |
| SONY | A: At this stage, we should study both Type A and Type B, but we think that the eventual conclusion is likely to be that Type A is supported. |
| Ericsson | B |

### 7.4.2 Analysis of UE complexity reduction

Contributions [1, 2, 3, 4, 5, 6, 8, 10, 13, 15, 17, 20, 21, 22, 25, 26, 30] analyze the UE complexity or cost reduction benefits achieved by HD-FDD quantitatively. The findings are:

* 4%-19% [1]
* 4.5% and 8.1% for Type A/B respectively [17]
* 4%-8% [5, 25]
* 5-10% [3]
* 6% [6]
* 8% [20]
* <10% [2]
* 50% saving on RF part [22, 30]

Thus, the range of UE cost saving is from 4% to 19%.

### 7.4.3 Analysis of performance impacts

Contributions [1, 2, 3, 5, 6, 7, 8, 13, 15, 17, 20, 21, 22, 25, 27, 29, 30] analyze the performance impact if HD-FDD is introduced for RedCap UEs. The findings are listed below. Some of the items were identified to be studied further.

* P1: no coverage loss [1, 3, 6, 17, 20, 21, 22, 25, 29, 30]
* P2: lower power consumption, lower maximum power peaks, lower power state, or lower insertion loss [3, 5, 6, 7, 8, 13, 20, 21, 29]
* P3: lower noise figure [1, 6, 7, 17, 29]
* P4: lower (peak) data rates or throughput [2, 3, 5, 6, 7, 15, 27, 29]
* P5: increase PUSCH/PDSCH SINR requirements [2, 21]
* P6: larger number of HARQ processes may be required, which increases the UE buffer occupation and processing complexity [2]
* P7: no impact on spectral efficiency or capacity [3, 6, 7, 17, 20]
* P8: coverage impact for delay sensitive services [27]
* P9: negative impact on latency [2, 7, 15, 27, 29]
* P10: more complicated scheduling at the gNB, more scheduling constraints, or significant impact on network [2, 3, 21, 27]
* P11: Scheduling effectiveness is not jeopardized by supporting Type-A half-duplex UE’s in paired spectrum [8]
* P12: Contributions [1, 5] analyze latency and conclude that an HD-FDD device in RRC\_CON14TED can meet the 5-10 ms latency requirement for safety related sensors.

These performance impacts can be classified as follows:

* Peak data rate: P4
* Latency: P8, P9, P12
* Power consumption: P2, P3,
* Spectral efficiency: P3, P5, P7
* PDCCH blocking probability
* Coverage: P3, P5, P8
* UE buffer and processing complexity: P6
* Scheduling and network: P10, P11

**Q 7.4.3-1: Does the list (P1, P2, …, P12) above capture the most important performance impacts that need to be considered for HD-FDD? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y |  |
| Ericsson | Y |  |

**Q 7.4.3-2: Which of the identified performance impacts in the list above (P1, P2, …, P12) are the most critical ones to be captured in TR 38.875 for HD-FDD?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1, P2 |
| FUTUREWEI | Should include:P1,P2,P4, P6,P7,P8,P9,P10,P11  No strong feeling: P3, P5, P12  Should not include:  P11 |
| Ericsson | P1, P3, P7, P12 |

### 7.4.4 Analysis of coexistence with legacy UEs

Contributions [1, 2, 3, 5, 7, 17, 25] analyze coexistence impacts. The identified issues are listed below.

* C1: significant impact on network [2]
* C2: make scheduler more complex [3]
* C3: need to monitor PI/CI to ensure coexistence with URLLC UEs [7]

Contributions [1, 5, 17, 25] conclude that the impact can be minimal or do not raise a concern.

**Q 7.4.4-1: Does the list above (C1, C2, C3) capture the most important coexistence impacts that need to be considered for HD-FDD? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y |  |
| Ericsson | Y |  |

**Q 7.4.4-2: Which of the identified coexistence impacts in the list above (C1, C2, C3) are the most critical ones to be captured in TR 38.875 for HD-FDD?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | C1, C2 |
| FUTUREWEI | C1, C2 should be included. Not sure about C3. |
| Ericsson | Possibly C2. However, if it is done properly, the impact on scheduler might be minor. |

### 7.4.5 Analysis of specification impacts

Contributions [1, 3, 4, 5, 6, 7, 9, 10, 12, 15, 17, 20, 22, 23, 25, 26, 29, 30] identify specification impacts listed below.

* S1: DL-to-UL and/or UL-to-DL switching time [3, 4, 5, 6, 7, 9, 12, 15, 17, 20, 22, 29, 30]
* S2: rule for handling DL/UL collision [1, 12, 26]
* S3: applicable bands and perf requirements [1, 3, 17]
* S4: capability signaling [5, 7, 25]
* S5: DL pre-emption and UL cancellation; Prioritization between eMBB traffic and URLLC traffic [7]
* S6: definition of HD-FDD operation type [20]
* S7: impact of BWP adaptation [10]
* S8: Type B HD-FDD may result in some necessary changes in the L1 design [23]
* S9: HARQ ACK/NACK bundling [29]
* S10: RRC configuration of UL and DL slots/symbols similar to NR TDD [29]

Regarding DL-to-UL and/or UL-to-DL switching time, contributions [1, 4] state that the transition time and the scheduling restriction defined for a UE not capable of full duplex in Rel-15 can be used as a baseline, whereas contribution [12] suggests that more relaxed switching time may be considered.

Contributions [9, 22, 30] suggest a DL-to-UL switching time may be created by not receiving symbols at the end of the DL slot immediately preceding the uplink transmission slot. Contributions [9, 20, 22, 30] suggest the switching time of uplink-to-downlink transition can be created by properly setting TA value by gNB scheduler for the RedCap devices without the need of special handing. Contribution [26] suggests symbol-level switching time.

Contributions [6, 7, 25] conclude that the overall specification impact is small.

**Q 7.4.5-1: Does the list above (S1, S2, …, S10) capture the most important specifications impacts that need to be considered for HD-FDD? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | Y |  |
| Ericsson | Y |  |

**Q 7.4.5-2: Which of the identified specification impacts in the list above (S1, S2, …, S10) are the most critical ones to be captured in TR 38.875 for HD-FDD?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1, S5 |
| FUTUREWEI | Should include: S1,S3,S4  No strong feeling:S6,S10  Should not include:S2,S5 (not sure), S7, S9  S8 will depend on Type B being included in the TR |
| Ericsson | S1, S2, S3, S4, S6  S8 if Type B is adopted.  S5 deserves further discussion |

## 7.5 Relaxed UE processing time

### 7.5.1 Description of feature

In RAN1#101-e, the agreement was made to study UE complexity reduction through a more relaxed UE processing time in terms of N1/N2.

|  |
| --- |
| Agreements:   * For UE complexity reduction through relaxed UE processing time, study a more relaxed UE processing time in terms of N1/N2 compared to capability #1. |

Many contributions [1, 2, 3, 4, 5, 6, 8, 11, 12, 13, 16, 17, 19, 20, 21, 27, 29, 31] discuss relaxed UE processing time in terms of N1/N2 and provide analyses on different aspects as summarized in the next subsections. For the continued evaluation, it might be useful to agree on what values of N1 and N2 to assume. For example, contribution [6] assumed that N1 and N2 were doubled.

**Q 7.5.1-1: For the evaluation of relaxed UE processing time in terms of N1/N2, what values of N1 and N2 should be assumed?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | Doubling is OK to include as an example. Can also include specifically the Rel-16 cross-slot scheduling as another example, though this will also be mentioned in power savings.  Both have a similarly small benefit in terms of cost reduction, but very different impacts in design effort and specification. |
| SONY | N1 / N2 doubled. We don’t have a strong preference on the scaling factor, but think that we need a concrete scaling factor in order to derive conclusions. |
| Ericsson | For the purpose of evaluation and simplicity, N1 and N2 can be assumed to be doubled from those of capability #1. |

Some contributions [2, 12, 17, 27, 29] also mention that CSI computation time can be included as part of the study on relaxed UE processing time.

**Q 7.5.1-2: In addition to relaxed UE processing time in terms of N1/N2, should the study include analysis of relaxed UE processing time related to CSI computation?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes/No** | **Comments** |
| FUTUREWEI |  | No strong feeling |
| SONY | Yes | We are OK studying this, but it is not a priority for us. |
| Ericsson | No | The CSI processing complexity may anyway be reduced due to other cost reduction aspects, e.g. bandwidth reduction. |

### 7.5.2 Analysis of UE complexity reduction

Many contributions [1, 2, 3, 4, 5, 6, 8, 11, 12, 13, 16, 17, 19, 20, 21, 27, 29, 31] discuss potential UE complexity reduction from relaxed UE processing time in terms of N1/N2. Some arguments are based on possible 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.

Some contributions also provide analysis of the cost reduction based on estimate of the cost breakdown of different processing components [6, 17, 20]. Contributions [1, 6, 17, 20, 27] identify that the cost reduction may come from reduced baseband processing, especially from receiver processing block including LDPC decoding and DL control processing & decoder, and UL processing block.

Some cost reduction estimates for relaxed UE processing time are shown in the table below. As can be seen in the rightmost column, the overall estimated cost reduction is 5% according to [3], around 2% according to [6], 1.5-2.6% for relaxed N2 (doubled) and 6.42-9.63% for relaxed N1 (doubled) according to [17], and up to 7% according to [20]. Contribution [3] further notes that the complexity reduction will not accumulate over multiple bands.

Table 1: Estimate cost/complexity reduction from a more relaxed N1/N2 compared to Capability #1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Contribution** | **Cost reduction in baseband parts** | | | | **Total of Baseband relative cost reduction[[1]](#footnote-2)** | **Overall relative cost reduction[[2]](#footnote-3)** |
| **Receiver processing block** | **LDPC decoding** | **DL control processing & decoder** | **UL processing block** |
| **[3]** |  |  |  |  |  | **<5%** |
| **[6]** | 0% | 20% | 0% | 20% | 3% | **2%** |
| **[17]** | ~50%? | ~50%? | 0% | ~50%? | (19.75%) | **FR1 (FDD): N1: 9.63%, N2: 2.6%**  **FR1 (TDD): N1: 8%, N2: 1.88%**  **FR2 (TDD): N1: 6.42%, N2: 1.5%** |
| **[20]** | 25% | 20% | 40% | 25% | 11.15% | **6.69%** |

Contributions [1, 5, 27] note that the actual complexity/cost reduction may not be clear as it depends on the specific implementation. Some contributions [6, 8] suggest that the complexity/cost reduction might be rather small compared to the required standardization efforts and impacts described in the following sections.

Contributions [1, 8, 17, 27] emphasize that the cost/complexity reduction would be limited or reduced significantly when it is considered on top of other UE complexity reduction features.

### 7.5.3 Analysis of performance impacts

Contributions [1, 2, 3, 4, 5, 6, 8, 11, 13, 16, 17, 20, 27, 29, 31] analyze the performance impact if relaxed UE processing time is introduced for RedCap UEs. The findings are listed below.

**Latency:**

* P1: Contributions [1, 2, 5, 8, 11, 13, 20, 27] mentioned the impact of relaxed UE processing time capability on latency, where [1, 5] provide some numerical examples of the impact on UL and DL latency for the initial transmission and different number of retransmissions.
* P2: Contributions [1, 2, 4, 16, 20, 27, 29, 31] 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, 3, 8, 20, 27] 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.
* P4: Contribution [13] discusses an implication of relaxed UE processing time on latency which can lead to having different hardware variants for RedCap UEs.

**Scheduling flexibility/complexity:**

* P5: Contributions [1, 2, 8, 17] observe negative impacts of relaxed UE processing time on scheduling complexity, especially when taking into account different scheduling timing requirements related to N1/N2 and the fact that there already exist two UE processing time capabilities in NR.

**Data rate:**

* P6: Contributions [2, 3] mention that sustained data rate may be impacted due to longer HARQ RTT because of the relaxed UE processing time.

**Coverage:**

* P7: Contributions [3, 6, 17] note that no significant coverage impact is expected from a more relaxed UE processing time.

**Spectral efficiency/network capacity:**

* P8: Contributions [6, 17] note that no impact on spectral efficiency or network capacity is expected since gNB can schedule other UEs during the UE processing time.

**Power consumption:**

* P9: Contributions [2, 4, 16, 29, 31] mentioned that power saving benefit can be obtained from relaxed UE processing time, particularly from cross-slot scheduling which may lower UE’s working voltage and avoiding unnecessary data buffering.
* P10: Contributions [1, 5, 6, 20, 27] 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 cross-slot scheduling can be supported by gNB implementation without the need to introduce a more relaxed UE processing time capability.

**Q 7.5.3-1: Does the list (P1, P2, …, P11) above capture the most important performance impacts that need to be considered for relaxed UE processing time? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | For cross-slot scheduling, need to state there is no real impact to latency, scheduling, data rate, coverage, spectral efficiency. Plus P9,11 |
| Ericsson | Y |  |

**Q 7.5.3-2: Which of the identified performance impacts in the list above (P1, P2, …, P11) are the most critical ones to be captured in TR 38.875 for relaxed UE processing time?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1, P2 |
| FUTUREWEI | For e.g. doubling N1/N2:  Should include: P3, P4, P5, P6, P10  No strong feeling:P1, P2, P7  Should not include:P8 (scheduling may need to be more conservative), P9 (as P10 is correct)  For cross-slot scheduling: P9, P11 |
| Ericsson | P1-P11 |

### 7.5.4 Analysis of coexistence with legacy UEs

Some contributions [1, 5, 17, 21] 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. Contribution [3] notes that multiple timelines can be very complicated to specify and handle to ensure coexistence with legacy UEs.

In order to support relaxed UE processing time capability during initial access, contributions [5, 12, 21] mention that methods for identifying RedCap UEs, e.g., before Msg3 scheduling may need to be studied.

These identified issues are listed below.

* C1: makes scheduler more complex [1, 5, 17, 21]
* C2: complicated to specify and handle to ensure coexistence with legacy UEs [3]
* C3: identification of RedCap UEs before Msg3 may be needed [5, 12, 21]

**Q 7.5.4-1: Is the list of identified coexistence issues to study for relaxed UE processing time in terms of N1/N2 correct and complete? If not, what changes to the list are needed?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | OK |
| Ericsson | Yes |

**Q 7.5.4-2: Which of the identified coexistence issues in the list above (C1, C2, C3) are the most critical ones to be captured in TR 38.875 for relaxed UE processing time in terms of N1/N2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | C1 |
| FUTUREWEI | Should include C1 and C2. C3 may be ok, FFS. |
| Ericsson | C1-C3 |

### 7.5.5 Analysis of specification impacts

Contributions [1, 2, 3, 6, 17, 20] mention the specification impact of defining a new relaxed UE processing time capability and new values of N1/N2. Contributions [3, 8] 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, 17, 19]. On the other hand, contribution [1] notes that no specification impacts on scheduling timing and HARQ-ACK timing 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, 6, 8, 17, 20]
* S2: scheduling time related to default TDRA tables and HARQ-ACK timing range [5, 17, 19]

**Q 7.5.5-1: Is the list of identified specification impacts to study for relaxed UE processing time in terms of N1/N2 correct and complete? If not, what changes to the list are needed?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | There are likely other impacts that these related to coexistence and handling multiple timelines |
| Ericsson | In addition, some timing aspects during the random access procedure may need to be clarified. |

**Q 7.5.5-2: Which of the identified specification impacts in the list above (S1, S2) are the most critical ones to be captured in TR 38.875 for relaxed UE processing time in terms of N1/N2?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1 |
| FUTUREWEI | S1. S2 (FFS). |
| Ericsson | S1  Regarding S2, TDRA values in the specs can already accommodate relaxed N1/N2. |

## 7.6 Relaxed UE processing capability

### 7.6.1 Description of feature

In RAN1#101-e, consensus could not be reached whether relaxed UE processing capability should be studied and which techniques to study. Several techniques are discussed and proposed again. The main discussions are mostly on restricting the maximum modulation orders, the maximum number of MIMO layers, TB sizes and reducing the maximum number of HARQ processes.

***General***

A few contributions [1, 17] indicate that after bandwidth and antenna reductions, significant cost saving gains would not be expected via other complexity reduction techniques. One contribution [3] notes there will only be little benefit in cost/complexity reduction for reduced TBS or HARQ after bandwidth reduction and modulation order restriction. Another contribution [17] further indicates studies on the four techniques for complexity reduction are not necessary.

Contributions [1, 8, 17] indicate cost saving from bandwidth reduction and antenna reductions should not be double counted in cost saving by restricting the maximum TB sizes and the maximum number of MIMO layers.

A few contributions [13, 19, 27] indicates peak rate impacts due to different TDD patterns.

One contribution [27] proposes to agree on whether peak rates less than 150MHz DL and 50MHz UL can be considered. One contribution [5] states that the maximum modulation order and the maximum number of MIMO layers should be specified based on the requirements of peak data rate.

***Maximum modulation order and maximum number of MIMO layers***

Many contributions [1, 2, 3, 4, 5, 6, 11, 12, 13, 16, 18, 20, 23, 27, 29, 30] indicate reducing restricted modulation order can provide complexity reduction or can be studied. One contribution [3] further notes that the gains from restricting the maximum modulation order would accumulate over the multiple RF bands typically present in a device, in contrast to the other baseband-oriented techniques.

Several contributions [1, 3, 5, 11, 12, 16, 20, 23, 27, 30] also indicate MIMO reductions can be studied.

One contribution [3] further indicates only either restricting the maximum number of MIMO layers or modulation order should be studied, while another contribution [23] notes that both techniques should be studied together to understand the trade-offs between both techniques.

***Restricting the TB sizes***

A few contributions [1, 3, 17, 18] indicate that TBS in NR are calculation based and would be reduced significantly after reduction in bandwidth, antenna and modulation order. Therefore, it is not necessary to study restricting the maximum TB sizes.

Some contributions [2, 12, 16, 23, 29, 30] however indicates TBS reduction can be studied.

***Reducing the maximum number of HARQ processes***

A few contributions [1, 2, 3, 17] indicate soft buffer size saving via reducing the number of HARQ processes are insignificant or the gain is unclear as the HARQ process partition is up to UE implementation in NR. Furthermore, a few contributions [1, 2, 8] argue that reducing the number of HARQ processes will impact sustainable peak rates and the number of HARQ processes should not be reduced for RedCap devices.

One contribution [8] indicate it can be beneficial to cap the maximum soft channel bits without reducing the maximum number of HARQ processes.

Some contributions [4, 11, 16, 20, 29, 30] note that reducing the number of HARQ processes is beneficial for low cost devices and can be studied.

***Other techniques***

Two contributions [12, 27] indicate maximum number of DL CC could be limited and one contribution [27] notes that at least intra-band carrier aggregation shall be studied. One contribution [19] indicate UL MIMO, UL CA or SUL can be studied to achieve higher peak data rate. Contribution [2, 27] note that SUL can be studied to achieve larger coverage and UL CA shall not be supported. One contribution [27] notes that CA/SUL shall be considered together with the maximum BW study. However, contribution [29] highlights certain issues with SUL.

Some other contributions [4, 23, 29] indicate support of carrier aggregation are not required or restricted for RedCap devices or shall be single carrier support only.

A few contributions [5, 12, 16, 27, 29, 30] further indicate other techniques listed below can be studied:

* OFDM as an optional waveform for RedCap devices [12, 30]
* Simplification of CSI measurements/feedback [5, 27, 29]
* Simplified beam management framework [27, 29]
* Simplified BWP switching delay [16]
* Reduced HARQ ACK/NACK bundling [29]
* Reduced PDCCH monitoring capability (i.e. relaxed maximum number of BDs and/or CCEs) [16, 27, 29]
* Reducing the number of PRBs allocated for PDSCH/PUSCH [29]
* Restricting the maximum code rate [29]
* Simplified TA validation for stationary or low-mobility UE [29]
* Simplified RLM/RRM measurements [29]
* Simplified BWP operation [12]
* No support of simultaneous reception [12]
* No support of prioritization of dynamically scheduled PDSCH/PUSCH over SPS/CG PUSCH occasions respectively [12]
* PDSCH reception with receiver side puncturing on configured reserved resources [12]
* Reduced number of CSI-RS antenna ports and number of parallel CSI report processing compared to Rel-15 [12]
* No dynamic indication of TCI state for PDCCH and PDSCH [12]

**Q 7.6.1-1: What, if any, modulation scheme restrictions should be considered?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | Either none, or optional 256QAM in DL and 64QAM in UL for FR1 |
| SONY | Max modulation = 64QAM. Modulation scheme restrictions are not a priority item for us. |
| Ericsson | FR1& FR2: Both UL and DL restricted to QPSK, 16QAM, and 64QAM  Further restriction to QPSK and 16QAM in FR2 might be considered. |

**Q 7.6.1-2: What, if any, MIMO layer restrictions should be considered?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
|  |  |
| FUTUREWEI | Either none, or single layer in a 2RX RedCap UE |
| SONY | Max MIMO layers = number of antennas. |
| Ericsson | 1 or 2 MIMO layers in DL might be considered |

**Q 7.6.1-3: Should any explicit TBS restrictions be considered beyond the implicit TBS restrictions resulting from reduced UE bandwidth and reduced number of antennas?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | No |
| SONY | Yes. We would like to consider a fixed max TBS (rather than one worked out through equations). However, we think that some of the complexity reduction techniques will lead to a TBS that is less than the “fixed max TBS” in any case. |
| Ericsson | No |

**Q 7.6.1-4: What, if any, HARQ restrictions should be considered?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | None |
| SONY | Number of HARQ processes should not be reduced. Can consider reduction of soft buffer sizes. |
| Ericsson | No |

**Q 7.6.1-5: Among all the items mentioned under the heading of “Other techniques”, which ones (if any) should be considered?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | None |
| Ericsson | None |

### 7.6.2 Analysis of UE complexity reduction

|  |  |  |
| --- | --- | --- |
| **Techniques** | **Impacted components** | **Cost saving** |
| Reduced maximum number of MIMO layers | Baseband:  FFT/IFFT [17, 30]  Post-FFT data buffering [17, 30]  Receiver processing block [1, 17, 20, 30]  LDPC decoding [1, 5, 17, 20]  HARQ buffer [1, 17, 20]  Synchronization / cell search block [17, 30]  MIMO specific processing blocks: [1, 5, 17]  DMRS channel estimation [5]  Demodulation with less MIMO layers [5]  No layer de-mapping [5] | Form 2 -> 1 MIMO layer, 4 -> 2MIMO layers  Source 1 [1]: marginal total cost saving  Source 2 [17]: 17.5% - 32.8% total complexity saving  Source 3 [20]: 18.9% total cost saving  Source 5 [30]: 22% baseband cost saving  From 4 -> 1 MMIO layer:  Source 1 [1]: medium to significant total gain.  Source 3 [20]: 28.35% total cost saving |
| Restricted maximum modulation order | RF components:  PA: [1, 6, 17, 20]  RF transceiver [1, 17, 20]  Baseband components:  ADC: [1, 6]  Post-FFT data buffering: [1]  LDCP decoding: [6, 30]  HARQ buffer: [6]  UL processing block: [6] | 256QAM->64QAM:  Source 1 [1]: 0-5% RF cost saving gain and 3-4% baseband cost saving gain  xQAM -> yQAM:  Source 2 [17]: ~1% total cost saving  Source 3 [20]: 9.6% total cost saving  Source 5 [30]: 5% baseband cost saving  256QAM->64QAM in DL and 64QAM->16QAM in UL  Source 4 [6]: 6% total cost saving |
| Reduced number of HARQ process | Baseband components:  HARQ buffer: [1, 17, 20, 30]  UL processing block: [20] | Source 2 [17]: unclear UE implementation  16 -> 8 HARQ processes  Source 1 [1]: ~3-4.5% total cost saving or less due to UE implementation and possibly dynamic buffer sharing  16->4 HARQ processes  Source 3 [20]: 13.95% total cost saving  Source 5 [30]: 6% baseband cost saving |
| Restricted max TBS | Baseband:  LDPC decoding [1, 6, 17, 20, 30]  HARQ buffer [1, 6, 17, 20, 30]  UL processing block [1, 6, 17, 20, 30]  DL processing block [30] | Reducing Max TBS by 10-fold for both UL and DL:  Source 1 [1]: ~90% cost saving in LDPC decoding, HARQ buffer size and UL processing block.  Reducing Max TBS to 1/5 for both UL and DL:  Source 2 [17]: 10~15% total complexity gain but should not be double counted if BW is reduced.  Reducing Max TBS from 10000 bits in DL to 1000 bits and 5000 bits in UL to 1000 bits  Source 5 [30]: up to 16% in DL and 5% in UL total cost saving (based on 36.888)  Reducing maximum TBS by reducing BW from 100 MHz -> 5 MHz  Source 3 [20]: 22.8% total cost saving  Reducing maximum TBS by reducing BW from 100 MHz -> 20 MHz  Source 3 [20]: 19.2% total cost saving  150 Mbps DL -> 10 Mbps DL and 50 Mbps UL-> 5 Mbps UL  Source 4 [6]: 13% total cost saving |

### 7.6.3 Analysis of performance impacts

Contributions [1, 5, 6, 17, 30] analyze the performance impact if the reduced maximum number of MIMO layers, restricted maximum modulation order, restricted maximum TB sizes or reduced maximum number of HARQ processes is introduced for RedCap UEs. The findings are listed below.

***Reduced maximum number of MIMO layers***

* Data rates:
  + P1.1: Reduced maximum data rates [1, 5]
* Coverage:
  + P1.2: No coverage impacts [17, 30]
* Cell spectrum efficiency:
  + P1.3: Reduced cell spectrum efficiency [17]
* Power consumption:
  + P1.4: Power consumption of higher data rate seems larger than that of lower data rate [20]

***Restricted maximum modulation order***

* Data rates:
  + P2.1: Reduced maximum data rates [1, 5]
* Coverage:
  + P2.2: No coverage impacts [17, 30]
* Cell spectrum efficiency:
  + P2.3: Reduced cell spectrum efficiency [6, 17]
* Power consumption:
  + P2.4: Power consumption of higher data rate seems larger than that of lower data rate [20]
  + P2.5: Small reduction in power consumption [6]

***Restricted maximum TB sizes***

* Data rates:
  + P3.1: Reduced maximum data rates [1, 17]
* Coverage:
  + P3.2: Reduced / limited impact on coverage due to loss of channel coding gain [6, 17]
  + P3.3: No coverage impacts [30]
* Cell spectrum efficiency:
  + P3.4: Reduced / limited impact on spectral efficiency due to loss of channel coding gain [6, 17]
* Power consumption:
  + P3.5: Increase slightly for a UE with good SNR due to longer Tx/Rx times [6]

***Reduced maximum number of HARQ processes***

* Data rates:
  + P4.1: Sustainable data rates may not be achieved [1]
* Coverage:
  + P4.2: No coverage impacts [30]

**Q 7.6.3-1: Does the list (P1.1, P1.2, …, P4.2) above capture the most important performance impacts that need to be considered for reduced maximum number of MIMO layers, restricted maximum modulation orders, restricted TB sizes and reduced maximum number of HARQ processes? If not, what other aspects need to be added?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | TBD after agree what to study |
| Ericsson | TBD, depending on the exact scope |

**Q 7.4.3-2: Which of the identified performance impacts in the list above (P1.1, P1.2, …, P4.2) are the most critical ones to be captured in TR 38.875?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | P1.1, P2.2 |
| FUTUREWEI | TBD after agree what to study |
| Ericsson | TBD, depending on the exact scope |

### 7.6.4 Analysis of coexistence with legacy UEs

Five contributions [1, 6, 17, 20, 30] provide coexistence analysis on restricting the maximum modulation orders, the maximum number of MIMO layers, the maximum modulation orders, the TB sizes or reducing the maximum number of HARQ process. Two contributions [1, 17] explicitly indicate there will be no coexistence issues if the four techniques are employed for RedCap UEs. Hence, the identified issues are:

* C1: No identified issues

**Q 7.6.4-1: Does the list above (C1) capture the most important coexistence impacts that need to be considered for reduced maximum number of MIMO layers, restricted maximum modulation orders, restricted TB sizes and reduced maximum number of HARQ processes? If not, what other aspects need to be added?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | TBD after agree what to study |
| Ericsson | TBD, depending on the exact scope |

**Q 7.6.4-2: Shall the identified coexistence impacts in the list above (C1) be captured in TR 38.875?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FUTUREWEI | TBD after agree what to study |
| Ericsson | TBD, depending on the exact scope |

### 7.6.5 Analysis of specification impacts

Contributions [1, 6, 17, 20, 30] indicate that there may be limited specification impacts. Identified specification impacts are listed below:

* S1: DCI optimization [6]
  + due to restricted maximum modulation order
* S2: optimized CQI table
  + due to restricted maximum modulation order [1, 5]
  + due to restricted maximum TBS [1]
* S3: optimized MCS table
  + due to restricted maximum modulation order [1, 5]
  + due to restricted maximum TBS [1]
* S4: UE capability indication to notify the network of UE’s reduced capabilities
  + due to reduced maximum number of HARQ processes, restricted maximum modulation order, maximum number of MIMO layers, TB sizes [1, 20]
* S6: RAN4 demodulation requirements
  + due to reduced maximum number of HARQ processes [1]

One contribution [30] further indicates that restricting the maximum TBS and reducing the maximum number of HARQ processes have least or smaller specification impact compared to other techniques.

**Q 7.6.5-1: Does the list above (S1, S2, …, S6) capture the most important specifications impacts that need to be considered for reduced maximum number of MIMO layers, restricted maximum modulation orders, restricted TB sizes and reduced maximum number of HARQ processes? If not, what other aspects need to be added?**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| FUTUREWEI | N | TBD after agree what to study. Likely none of these included, as L1 changes should be minimized, and reuse of existing DCI/CQI/MCS etc is possible. |
| Ericsson | N | TBD, depending on the exact scope |

**Q 7.6.5-2: Which of the identified specification impacts in the list above (S1, S2, …, S6) are the most critical ones to be captured in TR 38.875?**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Example | S1, S2 |
| FUTUREWEI | TBD after agree what to study. Likely none. |
| Ericsson | TBD, depending on the exact scope |

# References

|  |  |  |  |
| --- | --- | --- | --- |
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| [2] | [R1-2005269](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005269.zip) | Potential UE complexity reduction features | Huawei, HiSilicon |
| [3] | [R1-2005277](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005277.zip) | Complexity reduction features for RedCap UEs | FUTUREWEI |
| [4] | [R1-2005383](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005383.zip) | Discussion on complexity reduction for Reduced Capability NR devices | vivo, Guangdong Genius |
| [5] | [R1-2005474](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005474.zip) | Potential UE complexity reduction features | ZTE |
| [6] | [R1-2005525](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005525.zip) | UE complexity reduction features | Nokia, Nokia Shanghai Bell |
| [7] | [R1-2005580](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005580.zip) | On potential complexity reduction techniques for NR devices | Sony |
| [8] | [R1-2005637](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005637.zip) | On complexity reduction features for NR RedCap UEs | MediaTek Inc. |
| [9] | [R1-2005714](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005714.zip) | Discussion on potential UE complexity reduction features | CATT |
| [10] | [R1-2005770](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005770.zip) | Potential UE complexity reduction features | TCL Communication Ltd. |
| [11] | [R1-2005830](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005830.zip) | On UE complexity reduction features for RedCap | Lenovo, Motorola Mobility |
| [12] | [R1-2005880](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005880.zip) | On complexity reduction for RedCap UEs | Intel Corporation |
| [13] | [R1-2005937](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005937.zip) | Reduced Capability UE Complexity Reduction Features | Sierra Wireless, S.A. |
| [14] | [R1-2005959](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005959.zip) | Rel-16 UE power saving features for RedCap | NEC |
| [15] | [R1-2005968](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2005968.zip) | Discussion on the complexity reduction for reduced capability device | Beijing Xiaomi Software Tech |
| [16] | [R1-2006036](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006036.zip) | Discussion on UE complexity reduction | OPPO |
| [17] | [R1-2006152](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006152.zip) | UE complexity reduction | Samsung |
| [18] | [R1-2006196](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006196.zip) | Discussion on potential UE complexity reduction features | Panasonic Corporation |
| [19] | [R1-2006217](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006217.zip) | Discussion on potential UE complexity reduction features | CMCC |
| [20] | [R1-2006272](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006272.zip) | Discussion on potential UE complexity reduction features | Spreadtrum Communications |
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| [25] | [R1-2006576](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006576.zip) | Discussion on Potential UE complexity reduction features | Sharp |
| [26] | [R1-2006644](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006644.zip) | Discussion on potential UE complexity reduction features | Asia Pacific Telecom co. Ltd |
| [27] | [R1-2006682](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006682.zip) | Complexity reduction features for RedCap UE | Sequans Communications |
| [28] | [R1-2006733](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006733.zip) | Discussion on potential UE complexity reduction features for RedCap | NTT DOCOMO, INC. |
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| [30] | [R1-2006988](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006988.zip) | UE Complexity Reduction Features for RedCap | Apple |
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| [32] | [R1-2006155](http://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_102-e/Docs/R1-2006155.zip) | Framework and Principles for Reduced Capability | Samsung |
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1. **depends on cost breakdown for each baseband part** [↑](#footnote-ref-2)
2. **depends on cost split between RF and baseband parts** [↑](#footnote-ref-3)