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| Technical Report |
| 3rd Generation Partnership Project;Technical Specification Group Radio Access Network;Study on support of reduced capability NR devices(Release 17) |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

This document captures the findings from the study item "Study on support of reduced capability NR devices" [2].

The study includes identification and study of potential UE complexity reduction techniques and UE power saving and battery lifetime enhancements for reduced capability UEs in applicable use cases, functionality that will enable the performance degradation of such complexity reduction to be mitigated or limited, principles for how to define and constrain such reduced capabilities, and functionality that will allow devices with reduced capabilities to be explicitly identifiable to networks and networks operators and allow operators to restrict their access if desired.

The scope of the study includes support for all FR1/FR2 bands for FDD and TDD and coexistence with Rel-15/16 UEs. This study focuses on SA mode and single connectivity. The scope of the study does not include LPWA use cases.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP RP-193238: "New SID on support of reduced capability NR devices".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

**RedCap UE:** For convenience only, a RedCap UE refers to an NR UE with reduced capabilities with details described herein.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

<ABBREVIATION> <Expansion>

# 4 Introduction

The usage scenarios that have been identified for 5G are *enhanced mobile broadband* (eMBB), *massive machine-type communication* (mMTC), and *Ultra-Reliable and Low Latency communication* (URLLC). Yet another identified area is *time sensitive communication* (TSC). In particular, mMTC, URLLC and TSC are associated with novel IoT use cases that are targeted in vertical industries. It is envisaged that eMBB, mMTC, URLLC and TSC use cases may all need to be supported in the same network.

In the 3GPP study on "*self-evaluation towards IMT-2020 submission*" it was confirmed that NB-IoT and LTE-M fulfil the IMT-2020 requirements for mMTC and can be certified as 5G technologies. For URLLC support, URLLC features were introduced in Release 15 for both LTE and NR, and NR URLLC is further enhanced in Release 16 within the enhanced URLLC (eURLLC) and Industrial IoT work items. Rel-16 also introduced support for Time-Sensitive Networking (TSN) and 5G integration for TSC use cases.

1. One important objective of 5G is to enable connected industries. 5G connectivity can serve as catalyst for next wave of industrial transformation and digitalization, which improve flexibility, enhance productivity and efficiency, reduce maintenance cost, and improve operational safety. Devices in such environment include e.g. pressure sensors, humidity sensors, thermometers, motion sensors, accelerometers, actuators, etc. It is desirable to connect these sensors and actuators to 5G radio access and core networks. The massive industrial wireless sensor network (IWSN) use cases and requirements described in TR 22.804, TS 22.104, TR 22.832 and TS 22.261 include not only URLLC services with very high requirements, but also relatively low-end services with the requirement of small device form factors, and/or being completely wireless with a battery life of several years. The requirements for these services are higher than LPWA (i.e. LTE-M/NB-IoT) but lower than URLCC and eMBB.

2. Similar to connected industries, 5G connectivity can serve as catalyst for the next wave smart city innovations. As an example, TR 22.804 describes smart city use case and requirements for that. The smart city vertical covers data collection and processing to more efficiently monitor and control city resources, and to provide services to city residents. Especially, the deployment of surveillance cameras is an essential part of the smart city but also of factories and industries.

3. Finally, wearables use case includes smart watches, rings, eHealth related devices, and medical monitoring devices etc. One characteristic for the use case is that the device is small in size.

As a baseline, the requirements for these three use cases are:

Generic requirements:

- Device complexity: Main motivation for the new device type is to lower the device cost and complexity as compared to high-end eMBB and URLLC devices of Rel-15/Rel-16. This is especially the case for industrial sensors.

- Device size: Requirement for most use cases is that the standard enables a device design with compact form factor.

- Deployment scenarios: System should support all FR1/FR2 bands for FDD and TDD.

Use case specific requirements:

1. Industrial wireless sensors: Reference use cases and requirements are described in TR 22.832 and TS 22.104: Communication service availability is 99.99% and end-to-end latency less than 100 ms. The reference bit rate is less than 2 Mbps (potentially asymmetric e.g. UL heavy traffic) for all use cases and the device is stationary. The battery should last at least few years. For safety related sensors, latency requirement is lower, 5-10 ms (TR 22.804)

2. Video Surveillance: As described in TR 22.804, reference economic video bitrate would be 2-4 Mbps, latency < 500 ms, reliability 99%-99.9%. High-end video e.g. for farming would require 7.5-25 Mbps. It is noted that traffic pattern is dominated by UL transmissions.

3. Wearables: Reference bitrate for smart wearable application can be 5-50 Mbps in DL and 2-5 Mbps in UL and peak bit rate of the device higher, up to 150 Mbps for downlink and up to 50 Mbps for uplink. Battery of the device should last multiple days (up to 1-2 weeks).

The intention is to study a UE feature and parameter list with lower end capabilities, relative to Release 16 eMBB and URLLC NR to serve the three use cases mentioned above.

# 5 Study objectives

The study includes the following objectives:

1) Identify and study potential UE complexity reduction features, including [RAN1, RAN2]:

- Potential features:

- Reduced number of UE RX/TX antennas

- UE bandwidth reduction

- Half-duplex FDD

- Relaxed UE processing time

- Relaxed UE processing capability

- Notes:

- Rel-15 SSB bandwidth should be reused and L1 changes minimized.

- The work defined above should not overlap with LPWA use cases.

- The lowest data rate and bandwidth capability considered should be no less than an LTE Category 1bis modem.

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

2) Study UE power saving and battery lifetime enhancement for reduced capability UEs in applicable use cases (e.g. delay tolerant) [RAN2, RAN1]:

- Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits [RAN1].

- Extended DRX for RRC Inactive and/or Idle [RAN2]

- RRM relaxation for stationary devices [RAN2]

3) Study functionality that will enable the performance degradation of such complexity reduction to be mitigated or limited, including [RAN1]:

- Coverage recovery to compensate for potential coverage reduction due to the device complexity reduction.

- For FR1, coverage analysis for wearables can include consideration of potential reduced antenna efficiency due to device size limitations as part of the antenna gains. The extent of additional recovery of coverage loss due to reduced antenna efficiency is to be limited to 3 dB.

- The study includes evaluations of the impact to network capacity and spectral efficiency.

- Note: Potential overlap with coverage enhancements study is discussed and resolved in RAN#87 or later.

4) Study standardization framework and principles for how to define and constrain such reduced capabilities – considering definition of a limited set of one or more device types and considering how to ensure those device types are only used for the intended use cases [RAN2, RAN1].

5) Study functionality that will allow devices with reduced capabilities to be explicitly identifiable to networks and network operators, and allow operators to restrict their access, if desired [RAN2, RAN1].

Additional notes:

- Coexistence with Rel-15 and Rel-16 UE should be ensured.

- This SI should focus on SA mode and single connectivity.

# 6 Evaluation methodology

## 6.1 Evaluation methodology for UE complexity reduction

For cost/complexity evaluation of UE complexity reduction techniques, the methodology used in TR 36.888 was used as a starting point.

Reference NR devices were defined as follows for FR1 FDD, FR1 TDD and FR2, respectively.

* All mandatory Rel-15 features (with or without capability signaling)
* Single RAT
* Operation in a single band at a time
* Maximum bandwidth:
	+ For FR1: 100 MHz for DL and UL
	+ For FR2: 200 MHz for DL and UL
* Antennas:
	+ For FR1 FDD: 2Rx/1Tx
	+ For FR1 TDD: 4Rx/1Tx
	+ For FR2: 2Rx/1Tx
* Power class: PC3
* Processing time: Capability 1
* Modulation:
	+ For FR1: support 256QAM for DL and 64QAM for UL
	+ For FR2: support 64QAM for DL and 64QAM for UL
* Access: Direct DL/UL access between UE and gNB

Detailed cost breakdown for the reference NR devices according to Table 6.1-1 was assumed in the study. The RF-to-baseband cost ratio was assumed to be 40:60 for an FR1 UE and 50:50 for an FR2 UE.

The study considered impacts on cost/complexity reduction from the studied UE complexity reduction techniques for a UE that supports multiple RF bands through operation in a single band at a time, where it was assumed that support of multiple RF bands may affect the RF cost but not the baseband cost significantly.

NOTE: This study assesses, from a 3GPP standpoint, the technical feasibility of reduced-capability NR devices for industrial wireless sensors, video surveillance and wearables use cases. Given that factors outside 3GPP responsibility influence the cost of a modem/device, this study item (and this study report) cannot guarantee, or be used as a guarantee, that such modem/device will be low-cost in the market.

**Table 6.1-1: Detailed cost breakdown for the reference NR devices**

|  |  |  |  |
| --- | --- | --- | --- |
| **Functional block** | **FR1 FDD (2Rx)** | **FR1 TDD (4Rx)** | **FR2** |
| **RF** |
| Antenna array for FR2 |  |  | ~33% |
| Power amplifier  | ~25% | ~25%  | ~18% |
| Filters | ~10% | ~15% | ~8%  |
| RF transceiver(including LNAs, mixer, and local oscillator) | ~45%  | ~55% | ~41% |
| Duplexer / Switch | ~20% | ~5% | ~0% |
| **Baseband** |
| ADC / DAC | ~10% | ~9% | ~4% |
| FFT/IFFT | ~4% | ~4% | ~4% |
| Post-FFT data buffering | ~10% | ~10% | ~11% |
| Receiver processing block | ~24% | ~29% | ~24% |
| LDPC decoding | ~10% | ~9% | ~9% |
| HARQ buffer | ~14% | ~12% | ~11% |
| DL control processing & decoder | ~5% | ~4% | ~5% |
| Synchronization / cell search block | ~9% | ~9% | ~7% |
| UL processing block | ~5% | ~5% | ~7% |
| MIMO specific processing blocks | ~9% | ~9% | ~18% |

## 6.2 Evaluation methodology for UE power saving

## 6.3 Evaluation methodology for coverage recovery

## 6.4 Evaluation methodology for performance impacts

# 7 UE complexity reduction features

## 7.1 Introduction to UE complexity reduction features

## 7.2 Reduced number of UE Rx/Tx antennas

### 7.2.1 Description of feature

The antenna configurations for RedCap UEs that were considered in the study are:

* For FR1: 1Rx/1Tx and 2Rx/1Tx
* For FR2: 1Rx/1Tx and 2 Rx/1Tx

The evaluation of cost/complexity reduction has been performed with respect to a reference NR UE. The reference NR UE has the following antenna configuration:

* For FR1 FDD: 2Rx/1Tx
* For FR1 TDD: 4Rx/1Tx
* For FR2: 2Rx/1Tx

### 7.2.2 Analysis of UE complexity reduction

The reduction of number of UE Rx branches, relative to that of the reference NR device, may be beneficial in terms of reducing the device size in FR1. It is unclear whether the reduction of number of UE Rx branches, relative to that of the reference NR device, may be beneficial in terms of reducing the device size in FR2. This does not imply that a non-RedCap NR UE cannot be used in a compact or small form factor in FR1 or FR2.

### 7.2.3 Analysis of performance impacts

**Coverage:**

In general, degradation of downlink performance is expected when reducing the number of Rx branches, which may affect the coverage. The amount of degradation depends on the number of Rx branches. Quantitative evaluation results are provided in clause 9.

**Network capacity and spectral efficiency:**

A loss in network capacity and spectral efficiency is expected when reducing the number of UE Rx branches. The magnitude of the loss depends on the proportion of RedCap UEs, the traffic characteristics, as well as on the number of Rx branches. Quantitative evaluation results are provided in clause X.

**Data rate:**

Reducing the number of Rx branches at the UE will lower the downlink peak data rate. This is due to the reduction in number of downlink MIMO layers that can be supported when the number of Rx branches is reduced.

* Reduction from 2 Rx branches to 1 Rx branch decreases the downlink peak rate by ~50%.
* Reduction from 4 Rx branches to 2 Rx branches decreases the downlink peak rate by ~50%.
* Reduction from 4 Rx branches to 1 Rx branch decreases the downlink peak rate by ~75%.

Despite this reduction in peak data rate, a UE with reduced number of Rx branches and downlink MIMO layers will be able to sufficiently fulfil the peak data rate requirements for the RedCap use cases. For peak rate impacts from other combinations of UE complexity reduction techniques, see clause 7.8.3.

**Latency and reliability:**

Reducing the number of UE Rx branches has limited impact on the latency in most cases. However, if the UE is near the cell edge, the latency can increase. Nevertheless, the latency requirements of RedCap use cases can be sufficiently fulfilled, in both FR1 and FR2.

The reliability requirements for the RedCap use cases can still be fulfilled with reduced number of UE Rx branches. However, in some cases, the reliability can only be maintained at the cost of downlink spectral efficiency loss.

**PDCCH blocking probability:**

In order to compensate for the performance degradation resulting from a reduced number of UE Rx branches, higher aggregation levels may need to be used. This can lead to increase in PDCCH blocking probability if the amount of PDCCH resources is not increased.

### 7.2.4 Analysis of coexistence with legacy UEs

### 7.2.5 Analysis of specification impacts

## 7.3 UE bandwidth reduction

### 7.3.1 Description of feature

In the study, the main UE bandwidth reduction options considered are:

* For FR1: 20 MHz
* For FR2: 50 MHz or 100 MHz

The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with maximum bandwidth capability shown below.

* For FR1: 100 MHz for DL and UL
* For FR2: 200 MHz for DL and UL

For the baseline UE bandwidth capability of RedCap UEs, the same maximum UE bandwidth in a band applies to both RF and baseband. It is also primarily assumed that this maximum UE bandwidth applies to both data and control channels and that this maximum UE bandwidth is assumed for both DL and UL. A few contributions analyze other mixes of bandwidths.

### 7.3.2 Analysis of UE complexity reduction

The estimated cost for a device with reduced maximum UE bandwidth, relative to the reference NR device (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.3.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by reducing the UE bandwidth from 100 MHz to 20 MHz is ~32% for FR1 FDD and ~33% for FR1 TDD. For FR2, the average estimated cost reduction achieved by reducing the UE bandwidth from 200 MHz to 100 MHz and 50 MHz is ~16% and ~23%, respectively.

By comparing Table 7.3.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:

* Baseband: ADC/DAC
* Baseband: FFT/IFFT
* Baseband: Post-FFT data buffering
* Baseband: Receiver processing block
* Baseband: LDPC decoding
* Baseband: HARQ buffer

Although the results from most sourcing companies do not show PA cost reduction from bandwidth reduction, some sourcing companies indicate that PA cost can be reduced due to Tx bandwidth reduction from 100 MHz to 20 MHz in FR1.

Furthermore, ~75% of sourcing companies indicated that the cost savings do not accumulate across supported bands.

Table 7.3.2-1: Estimated relative device cost for reduced maximum UE bandwidth

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Reduced UE bandwidth** | **FR1 FDD** | **FR1 TDD** | **FR2 (200 MHz 🡪 100 MHz)** | **FR2 (200 MHz 🡪 50 MHz)** |
| RF: Antenna array | - | - | 33.0% | 33.0% |
| RF: Power amplifier  | 24.1% | 23.8% | 17.9% | 17.8% |
| RF: Filters | 10.0% | 14.7% | 8.0% | 8.0% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 43.7% | 53.0% | 40.6% | 40.3% |
| RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% | 0.0% |
| **RF: Total relative cost** | **97.7%** | **96.4%** | **99.5%** | **99.0%** |
| BB: ADC / DAC | 2.8% | 2.0% | 2.0% | 1.0% |
| BB: FFT/IFFT | 1.1% | 1.0% | 1.9% | 0.9% |
| BB: Post-FFT data buffering | 2.3% | 2.1% | 5.6% | 2.8% |
| BB: Receiver processing block | 9.1% | 9.9% | 14.2% | 9.1% |
| BB: LDPC decoding | 3.8% | 3.5% | 5.4% | 3.8% |
| BB: HARQ buffer | 4.2% | 3.3% | 6.0% | 3.5% |
| BB: DL control processing & decoder | 4.5% | 3.7% | 4.7% | 4.5% |
| BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% | 7.0% |
| BB: UL processing block | 3.5% | 3.6% | 5.5% | 4.9% |
| BB: MIMO specific processing blocks | 8.2% | 8.4% | 17.0% | 16.5% |
| **BB: Total relative cost** | **48.5%** | **46.6%** | **69.3%** | **54.0%** |
| **RF+BB: Total relative cost** | **68.2%** | **66.5%** | **84.4%** | **76.5%** |

### 7.3.3 Analysis of performance impacts

**Coverage:**

The impact of reduced bandwidth on the coverage of downlink and uplink channels would not be large, although a small loss may be observed due to reduced frequency diversity.

For PDCCH coverage, one important aspect is whether the larger aggregation levels (AL), e.g. 8 and 16, can be supported after bandwidth reduction. In FR1, UE bandwidth 20 MHz is enough for supporting AL 16 for any CORESET#0 configuration. In FR2, UE bandwidth 100 MHz is also enough for supporting AL 16 for any CORESET#0 configuration. However, reducing the UE bandwidth to 50 MHz in FR2 will have impact on PDCCH coverage when CORESET#0 is configured to have 69.12 MHz bandwidth. The loss is assessed to be ~1.5-3.0 dB. Reducing the UE bandwidth to 50 MHz will have impact on PBCH coverage if the SSB is configured with 240 kHz SCS. The loss is assessed to be within 1 dB. Furthermore, reducing the UE bandwidth to 50 MHz may also impact the coverage of initial access messages if CORESET#0 is configured to have 69.12 MHz bandwidth.

**Network capacity and spectral efficiency:**

Bandwidth reduction in FR1 will not have a significant impact on capacity and spectral efficiency, although there may be some minor degradation due to the loss in frequency selective scheduling gain.

Bandwidth reduction in FR2 may be associated with more noticable loss in capacity and spectral efficiency if analog beamforming is being used. In this case, the loss will be larger for 50 MHz UE bandwidth than for 100 MHz UE bandwidth.

**Latency and reliability:**

All the latency and reliability requirements for the RedCap use cases can be satisfied by all the bandwidth options (20 MHz in FR1, and 50 MHz or 100 MHz in FR2)

In FR2, UE bandwidth reduction may result in a longer SSB/SIB1 acquisition time for certain configurations for SSB/CORESET multiplexing patterns 2 and 3. To minimize the SSB/SIB1 acquisition time, it may be beneficial to support an FR2 RedCap UE bandwidth of 100 MHz.

**PDCCH blocking probability:**

If CORESET is configured according to the RedCap UE capability and shared by both RedCap and non-RedCap UEs, this may result in increased PDCCH blocking probability. In that case, the impact of an FR2 RedCap UE bandwidth of 50 MHz would be greater than for 100 MHz.

### 7.3.4 Analysis of coexistence with legacy UEs

### 7.3.5 Analysis of specification impacts

## 7.4 Half-duplex FDD operation

### 7.4.1 Description of feature

Half-duplex operation allows the UE to receive and transmit on different frequencies, but not at the same time. Half-duplex mode allows for removing a duplexer and instead use a switch and an additional filter.

The RedCap study includes both HD-FDD operation Type A and Type B, as defined in LTE, where study of Type A is prioritized.

### 7.4.2 Analysis of UE complexity reduction

The estimated cost for an HD-FDD only device, relative to the reference NR device (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.4.2-1.

For Type A HD-FDD, a high proportion of the cost saving occurs because the duplexer can be replaced with a switch and a lowpass filter.

For Type B HD-FDD, uplink and downlink can share one local oscillator, therefore, some additional saving on RF transceiver can be obtained.

By comparing Table 7.4.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributor of the cost reduction is the duplexer/switch block. Depending on the implementation, as indicated by some sourcing companies, removing the duplexer may also reduce the insertion loss in both the Rx and Tx chains and as a result, the PA power can be reduced, and the LNA sensitivity requirement can be relaxed which allows for potential UE complexity reduction.

As can be seen in the last row for the total cost, the average estimated cost reduction achieved by Type A and Type B HD-FDD is approximately ~7% and ~10%, respectively.

Furthermore, all sourcing companies indicated that the RF cost savings (but not the baseband cost savings) accumulate across supported bands.

It is unclear whether the HD-FDD operation may be beneficial in terms of reducing the device size in FR1 FDD.

Table 7.4.2-1: Estimated relative device cost for an HD-FDD device

|  |  |  |
| --- | --- | --- |
| **Half-duplex FDD operation** | **HD-FDD operation (Type A)** | **HD-FDD operation (Type B)** |
| RF: Antenna array | - | - |
| RF: Power amplifier  | 24.1% | 23.9% |
| RF: Filters | 10.6% | 10.7% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 44.4% | 37.8% |
| RF: Duplexer / Switch | 4.8% | 4.9% |
| **RF: Total relative cost** | **83.9%** | **77.3%** |
| BB: ADC / DAC | 10.0% | 10.0% |
| BB: FFT/IFFT | 3.8% | 3.7% |
| BB: Post-FFT data buffering | 9.9% | 9.9% |
| BB: Receiver processing block | 24.0% | 24.0% |
| BB: LDPC decoding | 10.0% | 10.0% |
| BB: HARQ buffer | 14.0% | 14.0% |
| BB: DL control processing & decoder | 4.8% | 4.8% |
| BB: Synchronization / cell search block | 9.0% | 9.0% |
| BB: UL processing block | 4.8% | 4.8% |
| BB: MIMO specific processing blocks | 9.0% | 9.0% |
| **BB: Total relative cost** | **99.4%** | **99.2%** |
| **RF+BB: Total relative cost** | **93.2%** | **90.4%** |

### 7.4.3 Analysis of performance impacts

**Coverage:**

If there are no stringent requirements on latency and data rate, then HD-FDD will not result in coverage loss, otherwise a coverage loss can be expected.

**Network capacity and spectral efficiency:**

HD-FDD operation has minor impact on spectral efficiency and capacity.

**Power consumption:**

The lower insertion loss of an HD-FDD UE may enable a higher power efficiency in the transmit chain and reduce power consumption. Furthermore, compared to the reference NR modem, half-duplex operation means some components can work in a reduced power state until required. However, on the other hand, HD-FDD may have a negative impact on UE average power consumption because the UE will be active for a longer time before being able to return to a lower power light sleep or deep sleep state. The impact on power consumption of HD-FDD depends on implementation and traffic characteristics.

**PDCCH blocking probability:**

HD-FDD operation may potentially reduce the available PDCCH monitoring occasions when the UE is transmitting rather than receiving.

### 7.4.4 Analysis of coexistence with legacy UEs

### 7.4.5 Analysis of specification impacts

## 7.5 Relaxed UE processing time

### 7.5.1 Description of feature

In the RedCap study item, relaxed UE processing time is considered in terms of more relaxed N1/N2 values compared to those of UE processing time capability 1.

In the study, for the purpose of evaluation, the relaxed UE processing time in terms of N1/N2 are assumed to be doubled compared to those of capability 1, i.e.,

* N1 = 16, 20, 34, and 40 symbols for 15, 30, 60, and 120 kHz SCS (assuming only front-loaded DMRS)
* N2 = 20, 24, 46, and 72 symbols for 15, 30, 60, and 120 kHz SCS

In the study, for the purpose of evaluation, relaxed CSI computation time was also considered, assuming doubled Z/Z' compared to the values defined in TS 38.214 clause 5.4.

### 7.5.2 Analysis of UE complexity reduction

The estimated cost for a device with relaxed UE processing time (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.5.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction is ~6% for FR1 FDD, ~6% for FR1 TDD, and ~6% for FR2 TDD.

Relaxed UE processing time in terms of N1/N2 potentially reduces UE complexity by allowing a longer time for the processing of PDCCH and PDSCH and preparing PUSCH and PUCCH. By comparing Table 7.5.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the cost of the following functional blocks can be reduced:

* Baseband: Receiver processing block
* Baseband: LDPC decoding
* Baseband: DL control processing & decoder
* Baseband: UL processing block

Whether the relaxed UE processing time may reduce the cost/complexity in the ‘DL control processing & decoder’ block depends on the UE implementation.

Furthermore, all sourcing companies indicated that these cost savings do not accumulate across supported bands.

Table 7.5.2-1: Estimated relative device cost for relaxed UE processing time

|  |  |  |  |
| --- | --- | --- | --- |
| **Relaxed processing time (doubled N1 and N2)** | **FR1 FDD** | **FR1 TDD** | **FR2 TDD** |
| RF: Antenna array | - | - | 33.0% |
| RF: Power amplifier  | 25.0% | 25.0% | 18.0% |
| RF: Filters | 10.0% | 14.7% | 8.0% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 45.0% | 54.3% | 41.0% |
| RF: Duplexer / Switch | 20.0% | 6.0% | 0.0% |
| **RF: Total relative cost** | **100.0%** | **100.0%** | **100.0%** |
| BB: ADC / DAC | 10.0% | 9.0% | 4.0% |
| BB: FFT/IFFT | 4.0% | 4.0% | 4.0% |
| BB: Post-FFT data buffering | 10.0% | 10.0% | 11.0% |
| BB: Receiver processing block | 20.3% | 24.6% | 19.5% |
| BB: LDPC decoding | 6.6% | 5.9% | 5.9% |
| BB: HARQ buffer | 14.0% | 12.0% | 11.0% |
| BB: DL control processing & decoder | 4.1% | 3.3% | 4.0% |
| BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% |
| BB: UL processing block | 3.7% | 3.6% | 5.0% |
| BB: MIMO specific processing blocks | 8.8% | 8.8% | 17.5% |
| **BB: Total relative cost** | **90.5%** | **90.1%** | **88.9%** |
| **RF+BB: Total relative cost** | **94.3%** | **94.1%** | **94.4%** |

### 7.5.3 Analysis of performance impacts

**Network capacity and spectral efficiency:**

Depending on the gNB scheduler implementation, there may be no or minor impact on network capacity or spectral efficiency from a more relaxed UE processing time.

### 7.5.4 Analysis of coexistence with legacy UEs

### 7.5.5 Analysis of specification impacts

## 7.6 Relaxed maximum number of MIMO layers

### 7.6.1 Description of feature

In the study, the following relaxation options for maximum number of DL MIMO layers were studied and evaluated:

* For FR1 FDD: 1 MIMO layer
* For FR1 TDD: 1 and 2 MIMO layers
* For FR2: 1 MIMO layer

The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with the maximum number of DL MIMO layers support shown below.

* For FR1 FDD: 2 MIMO layers
* For FR1 TDD: 4 MIMO layers
* For FR2: 2 MIMO layers

It is primarily assumed that this maximum number of MIMO layers applies to DL data channel only.

### 7.6.2 Analysis of UE complexity reduction

The estimated cost for a device with relaxed maximum number of MIMO layers (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.6.2-1. As can be seen in the last row for the total cost, the average estimated cost reduction achieved by relaxing the maximum number of MIMO layers from 2 to 1 layer is ~12% for FR1 FDD, from 4 to 2 layer is ~11% for FR1 TDD, from 4 to 1 layer is ~17% for FR1 TDD, and from 2 to 1 layer is ~11% for FR2.

By comparing Table 7.6.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:

* Baseband: Receiver processing block
* Baseband: LDPC decoding
* Baseband: HARQ buffer
* Baseband: MIMO specific processing block

Furthermore, all sourcing companies indicated that these cost savings do not accumulate across supported bands. Finally, it can be noted that for an FR1 UE supporting multiple bands, the baseband cost/complexity reduction may be limited by the case with the highest maximum number of MIMO layers among the supported bands.

Table 7.6.2-1: Estimated relative device cost for relaxed maximum number of MIMO layers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Relaxed maximum number of MIMO layers** | **FR1 FDD****(2 🡪 1 layer)** | **FR1 TDD****(4 🡪 2 layers)** | **FR1 TDD****(4 🡪 1 layer)** | **FR2****(2 🡪 1 layer)** |
| RF: Antenna array | - | - | - | 33.0% |
| RF: Power amplifier  | 25.0% | 25.0% | 25.0% | 18.0% |
| RF: Filters | 10.0% | 15.0% | 15.0% | 8.0% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 45.0% | 55.0% | 55.0% | 41.0% |
| RF: Duplexer / Switch | 20.0% | 5.0% | 5.0% | 0.0% |
| **RF: Total relative cost** | **100.0%** | **100.0%** | **100.0%** | **100.0%** |
| BB: ADC / DAC | 10.0% | 9.0% | 9.0% | 4.0% |
| BB: FFT/IFFT | 3.9% | 4.0% | 4.0% | 4.0% |
| BB: Post-FFT data buffering | 9.8% | 10.0% | 10.0% | 11.0% |
| BB: Receiver processing block | 19.7% | 24.4% | 22.3% | 19.9% |
| BB: LDPC decoding | 5.2% | 4.6% | 2.4% | 4.7% |
| BB: HARQ buffer | 7.2% | 6.1% | 3.3% | 5.7% |
| BB: DL control processing & decoder | 4.9% | 4.0% | 4.0% | 5.0% |
| BB: Synchronization / cell search block | 8.8% | 9.0% | 9.0% | 7.0% |
| BB: UL processing block | 5.0% | 5.0% | 5.0% | 7.0% |
| BB: MIMO specific processing blocks | 4.8% | 5.0% | 3.0% | 9.5% |
| **BB: Total relative cost** | **79.3%** | **81.1%** | **71.9%** | **77.8%** |
| **RF+BB: Total relative cost** | **87.6%** | **88.7%** | **83.2%** | **88.9%** |

### 7.6.3 Analysis of performance impacts

**Coverage:**

Reducing the maximum number of MIMO layers does not impact the coverage.

**Network capacity and spectral efficiency:**

Since reducing the maximum number of MIMO layers reduces the peak data rate, it degrades the network capacity and spectral efficiency. Especially, the reduction of maximum number of MIMO layers mainly degrades the spectral efficiency for UEs in good channel conditions.

**Data rate:**

Reducing the maximum number of downlink MIMO layers will lower the downlink peak data rate.

* Reduction from 2 layers to 1 layer decreases the downlink peak rate by ~50%.
* Reduction from 4 layers to 2 layers decreases the downlink peak rate by ~50%.
* Reduction from 4 layers to 1 layer decreases the downlink peak rate by ~75%.

Despite this reduction in peak data rate, the UE with reduced number of downlink MIMO layers will be able to sufficiently fulfil the peak data rate requirements for the RedCap uses cases. For peak rate impacts from combinations of UE complexity reduction techniques, see clause 7.8.3.

**Latency and reliability:**

Reducing the number of MIMO layers does not impact the latency and reliability significantly. The reduction of the maximum number of MIMO layers is only expected to affect the achievable latency for UEs in good channel conditions. The latency requirements of most RedCap use cases can still be sufficiently fulfilled.

### 7.6.4 Analysis of coexistence with legacy UEs

### 7.6.5 Analysis of specification impacts

## 7.7 Relaxed maximum modulation order

### 7.7.1 Description of feature

Relaxation of maximum mandatory modulation orders reduces complexity through reducing the amount of RF and baseband processing required.

In the study, the main options for relaxation of maximum mandatory modulation orders considered are:

* UL:
	+ FR1: 16QAM instead of 64QAM
	+ FR2: 16QAM instead of 64QAM
* DL
	+ FR1: 64QAM instead of 256QAM
	+ FR2: 16QAM instead of 64QAM

The study uses a legacy NR UE as a reference. The evaluation of cost/complexity reduction is with respect to a reference UE with the maximum modulation orders shown below.

* UL:
	+ FR1: 64QAM
	+ FR2: 64QAM
* DL
	+ FR1: 256QAM
	+ FR2: 64QAM

It is primarily assumed that these maximum modulation orders apply to data channels only.

### 7.7.2 Analysis of UE complexity reduction

The estimated cost for a device with relaxed maximum modulation order (see evaluation methodology described in clause 6.1) and averaged over the results provided by the sourcing companies, is summarized in Table 7.7.2-1 and Table 7.7.2-2.

As can be seen in the last row for the total cost in Table 7.7.2-1, the average estimated cost reduction achieved by relaxing the maximum UL modulation order from 64QAM to 16QAM is ~2% for FR1 FDD, FR1 TDD, and FR2.

By comparing Table 7.7.2-1 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:

* RF: Power amplifier
* RF: Transceiver
* Baseband: ADC/DAC
* Baseband: UL processing block

Furthermore, ~50% of sourcing companies indicated that the RF cost savings (but not the baseband cost savings) accumulate across supported bands.

Table 7.7.2-1: Estimated relative device cost for relaxed maximum UL modulation order

|  |  |  |  |
| --- | --- | --- | --- |
| **Relaxed maximum UL modulation order** | **FR1 FDD****(64QAM 🡪 16QAM)** | **FR1 TDD****(64QAM 🡪 16QAM)** | **FR2****(64QAM 🡪 16QAM)** |
| RF: Antenna array | - | - | 33.0% |
| RF: Power amplifier  | 22.6% | 22.6% | 16.1% |
| RF: Filters | 10.0% | 15.0% | 8.0% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 44.3% | 54.2% | 40.4% |
| RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% |
| **RF: Total relative cost** | **96.9%** | **96.7%** | **97.5%** |
| BB: ADC / DAC | 9.1% | 8.2% | 3.6% |
| BB: FFT/IFFT | 4.0% | 4.0% | 4.0% |
| BB: Post-FFT data buffering | 10.0% | 10.0% | 11.0% |
| BB: Receiver processing block | 24.0% | 29.0% | 24.0% |
| BB: LDPC decoding | 10.0% | 9.0% | 9.0% |
| BB: HARQ buffer | 13.9% | 11.9% | 10.9% |
| BB: DL control processing & decoder | 5.0% | 4.0% | 5.0% |
| BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% |
| BB: UL processing block | 4.3% | 4.3% | 5.8% |
| BB: MIMO specific processing blocks | 9.0% | 9.0% | 18.0% |
| **BB: Total relative cost** | **98.2%** | **98.4%** | **98.4%** |
| **RF+BB: Total relative cost** | **97.7%** | **97.7%** | **97.9%** |

From Table 7.7.2-2, the average estimated cost reduction achieved by relaxing the maximum DL modulation order from 256QAM to 64QAM is ~6% for both FR1 FDD and TDD bands. For FR2, the average estimated cost reduction achieved by relaxing the maximum DL modulation order from 64QAM to 16QAM is ~6%.

By comparing Table 7.7.2-2 with the reference NR device cost breakdown in clause 6.1, it can be observed that the main contributors of the cost reduction are the following functional blocks:

* RF: Transceiver
* Baseband: ADC/DAC
* Baseband: Receiver processing block
* Baseband: LDPC decoding
* Baseband: HARQ buffer

Furthermore, more than 70% of sourcing companies indicated that these cost savings do not accumulate across supported bands.

Table 7.7.2-2: Estimated relative device cost for relaxed maximum DL modulation order

|  |  |  |  |
| --- | --- | --- | --- |
| **Relaxed maximum DL modulation order** | **FR1 FDD****(256QAM 🡪 64QAM)** | **FR1 TDD****(256QAM 🡪 64QAM)** | **FR2****(64QAM 🡪 16QAM)** |
| RF: Antenna array | - | - | 33.0% |
| RF: Power amplifier  | 24.5% | 24.1% | 17.5% |
| RF: Filters | 10.0% | 14.8% | 8.0% |
| RF: Transceiver (including LNAs, mixer, and local oscillator) | 43.0% | 52.1% | 39.1% |
| RF: Duplexer / Switch | 20.0% | 5.0% | 0.0% |
| **RF: Total** | **97.5%** | **96.0%** | **97.6%** |
| BB: ADC / DAC | 8.9% | 7.8% | 3.6% |
| BB: FFT/IFFT | 4.0% | 4.0% | 4.0% |
| BB: Post-FFT data buffering | 9.4% | 9.4% | 10.1% |
| BB: Receiver processing block | 23.0% | 27.8% | 22.7% |
| BB: LDPC decoding | 7.6% | 6.8% | 6.3% |
| BB: HARQ buffer | 11.0% | 9.3% | 8.1% |
| BB: DL control processing & decoder | 5.0% | 4.0% | 5.0% |
| BB: Synchronization / cell search block | 9.0% | 9.0% | 7.0% |
| BB: UL processing block | 5.0% | 5.0% | 7.0% |
| BB: MIMO specific processing blocks | 8.7% | 8.7% | 17.3% |
| **BB: Total** | **91.7%** | **91.8%** | **91.0%** |
| **RF+BB: Total**  | **94.0%** | **93.5%** | **94.3%** |

### 7.7.3 Analysis of performance impacts

**Coverage:**

Relaxation of maximum mandatory modulation orders does not impact the coverage.

**Data rate:**

Reducing the maximum modulation orders will lower the downlink peak data rate.

* Reduction from 256QAM to 64QAM decreases the downlink peak rate by ~25%.
* Reduction from 64QAM to 16QAM decreases the downlink peak rate by ~33%.

Despite this reduction in peak data rate, the UE will be able to sufficiently fulfil the peak data rate requirements for the RedCap uses cases. For peak rate impacts from combinations of UE complexity reduction techniques, see clause 7.8.3.

**Latency and reliability:**

Relaxing the maximum modulation orders may increase the latency slightly. Nevertheless, all the latency and reliability requirements for the RedCap use cases can be satisfied by all the studied options for relaxed maximum modulation orders.

**Power consumption:**

Relaxation of maximum modulation orders can reduce power consumption of the RF and baseband modules marginally during transmission and reception.

### 7.7.4 Analysis of coexistence with legacy UEs

### 7.7.5 Analysis of specification impacts

## 7.8 Combinations of UE complexity reduction features

### 7.8.1 Description of feature combinations

### 7.8.2 Analysis of UE complexity reduction

### 7.8.3 Analysis of performance impacts

### 7.8.4 Analysis of coexistence with legacy UEs

### 7.8.5 Analysis of specification impacts

# 8 UE power saving features

## 8.1 Introduction to UE power saving features

## 8.2 Reduced PDCCH monitoring

### 8.2.1 Description of feature

### 8.2.2 Analysis of UE power saving

### 8.2.3 Analysis of performance impacts

### 8.2.4 Analysis of coexistence with legacy UEs

### 8.2.5 Analysis of specification impacts

## 8.3 Extended DRX for RRC Inactive and/or Idle

### 8.3.1 Description of feature

### 8.3.2 Analysis of UE power saving

### 8.3.3 Analysis of performance impacts

### 8.3.4 Analysis of coexistence with legacy UEs

### 8.3.5 Analysis of specification impacts

## 8.4 RRM relaxation for stationary devices

### 8.4.1 Description of feature

### 8.4.2 Analysis of UE power saving

### 8.4.3 Analysis of performance impacts

### 8.4.4 Analysis of coexistence with legacy UEs

### 8.4.5 Analysis of specification impacts

# 9 Coverage recovery features

## 9.1 Introduction to coverage recovery features

## 9.2 Coverage recovery feature X

### 9.2.1 Description of feature

### 9.2.2 Analysis of coverage recovery

### 9.2.3 Analysis of performance impacts

### 9.2.4 Analysis of coexistence with legacy UEs

### 9.2.5 Analysis of specification impacts

# 10 Definition and constraining of reduced capabilities

## 10.1 Definition of reduced capabilities

### 10.1.1 Description of feature

### 10.1.2 Analysis of coexistence with legacy UEs

### 10.1.3 Analysis of specification impacts

## 10.2 Constraining of reduced capabilities

### 10.2.1 Description of feature

### 10.2.2 Analysis of coexistence with legacy UEs

### 10.2.3 Analysis of specification impacts

# 11 UE identification and access restrictions

## 11.1 UE identification

### 11.1.1 Description of feature

### 11.1.2 Analysis of coexistence with legacy UEs

### 11.1.3 Analysis of specification impacts

## 11.2 Access restrictions

### 11.2.1 Description of feature

### 11.2.2 Analysis of coexistence with legacy UEs

### 11.2.3 Analysis of specification impacts

# 12 Conclusions

[Editor’s Note: The following RAN1 agreements will be captured in this section:

* Capture the recommendation that maximum bandwidth of an FR1 RedCap UE is 20 MHz during and after initial access.
	+ FFS: Whether an FR1 RedCap UE can optionally support a maximum bandwidth larger than 20 MHz after initial access
* Support that the maximum bandwidth of an FR2 RedCap UE is 100 MHz during initial access and 100MHz after initial access.
* For FR1 FDD bands where a non-RedCap UE is required to be equipped with a minimum of 2 Rx branches,
	+ The minimum number of Rx branches supported by specification for a RedCap UE is 1.
	+ Specification also supports of 2 Rx branches for a RedCap UE.
* For FR1 TDD bands where a non-RedCap UE is required to be equipped with a minimum of 4 Rx branches, the minimum number of Rx branches supported by specification for a RedCap UE is N. To be down-selected during the WI phase or at RAN plenary:
	+ Alt 1: N=2
	+ Alt 2: N=1, where N=2 is also supported

/End of Editor’s Note]

Annex <A>:
<Title>

# A.1 <Heading>

Annex <Y>:
Bibliography

The following material, though not specifically referenced in the body of the present document (or not publicly available), gives supporting information.

<Publication>: "<Title>".

Annex <Z>:
Change history

|  |
| --- |
| **Change history** |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2020-06 | RAN1#101-e | R1-2004962 |  |  |  | Skeleton | 0.0.1 |
| 2020-08 | RAN1#102-e | R1-2005233 |  |  |  | Updated skeleton with endorsed clauses 4 & 5 (R1-2005233) and RAN2-led changes (agreed in R2-2007366) | 0.0.2 |
| 2020-11 | RAN1#103-e | R1-2009490 |  |  |  | Updated skeleton with RAN1 endorsed changes (R1-2009490) | 0.0.3 |
| 2020-11 | RAN1#103-e | R1-20xxxxx |  |  |  | Updated with RAN1 endorsed changes (R1-20xxxxx) | 0.0.4 |