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| Technical Report | |
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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

## 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

### 7.2.2 Analysis of UE complexity reduction

### 7.2.3 Analysis of performance impacts

### 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

### 7.3.2 Analysis of UE complexity reduction

### 7.3.3 Analysis of performance impacts

### 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

### 7.4.2 Analysis of UE complexity reduction

### 7.4.3 Analysis of performance impacts

### 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

### 7.5.2 Analysis of UE complexity reduction

### 7.5.3 Analysis of performance impacts

### 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

### 7.6.2 Analysis of UE complexity reduction

### 7.6.3 Analysis of performance impacts

### 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

### 7.7.2 Analysis of UE complexity reduction

### 7.7.3 Analysis of performance impacts

### 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

In LTE connected to EPC, the UE may be configured with an extended DRX (eDRX) cycle. The UE may operate in eDRX only if the UE is configured by NAS and the cell indicates support for eDRX in System Information. Note that there is no System Information indication for NB-IoT. In RRC\_IDLE, the eDRX cycle has the maximum value of 2621.44 seconds (43.69 minutes). For NB-IoT the maximum is 10485.76 seconds or 2.91 hours. Hyper SFN (H-SFN) is broadcasted in System Information and incremented by one when SFN wraps around. The Paging Hyperframe (PH) refers to the H-SFN in which the UE starts to monitors for paging during a Paging Time Window (PTW).

From RAN2 perspective, extended DRX can be specified and configured for RedCap UEs so that eDRX cycles at least up to 10.24 seconds can be used in RRC\_IDLE and in RRC\_INACTIVE states. For RRC\_IDLE, the baseline for possible extension of configurable eDRX cycles is up to 2621.44 seconds. Longer values, e.g. 10485.76 seconds can be considered further.

If extension of the eDRX cycles beyond 10.24 seconds is specified, a feasible extension mechanism is expected to be similar to what is specified for LTE. This mechanism would include the use of H-SFN, PH and PTW.

For RedCap UEs in RRC\_IDLE or RRC\_INACTIVE, if the eDRX cycle is less than 10.24 seconds, the paging monitoring configuration does not use PTW and PH. If the configured eDRX cycle is equal to 10.24 seconds in RRC\_IDLE, one solution option is that the paging monitoring does not use PTW and PH.

Editor’s note: RAN2 agreement says: ”*For UE in RRC IDLE and eDRX cycle is equal to 10.24s, among the solution options, we start from the assumption that paging monitoring does not use PTW and PH.*” Text above can be updated to final form when all options/analysis are present.

Shorter values than 5.12 seconds for the DRX cycles, such as 2.56 s, can also be considered and studied further.

Editor’s note: FFS eDRX mechanisms for RRC\_IDLE / RRC\_INACTIVE and possible RAN2 conclusions and recommendations, updates on above text depending on further progress and text proposals.

### 8.3.2 Analysis of UE power saving

Annex A.1 lists power saving results and analysis provided in R2-2009116 and R2-2009620.

In summary, R2-2009116 finds that an eDRX cycle of 10485.76 seconds (2.91 hours) can result in power saving between 34-80 % for a high SINR case and between 56-91 % for a low SINR using an I-DRX cycle (and PTW length) from 2.56 seconds down to 320 ms. R2-2009620 provides a plot of possible UE battery lifetime against eDRX cycle length. The battery lifetime for a UE with a 2-minute eDRX cycle compared to the same device with 10.24 s eDRX cycle is shown to result in between 0.38 – 340 % improvements for RRC\_IDLE and 1-419 % improvements for RRC\_INACTIVE, respectively. The evaluation has been performed for various use cases and inter-arrival times from 100 ms up to 5 min.

Editor’s note: FFS RAN2 agreed conclusions and possible recommendations and references to other results.

### 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

The study includes an objective on RRM relaxation for stationary RedCap UEs. Considering the mobility of a RedCap UE, the stationarity property is not limited to fixed or immobile UEs, but UEs which are considered stationary can also have low mobility, i.e., be slightly moving.

As a baseline, the RRM relaxation of RedCap UEs is triggered based on measurements.

Other triggering conditions are not excluded, for example triggers for fixed or immobile UEs. For such UEs the possibility to signal stationary property explicitly can be studied further.

Rel-16 NR RRM relaxation procedures are taken as a baseline to study further enhancements of neighbour cell RRM relaxation for RedCap UEs in RRC IDLE and RRC\_INACTIVE. RAN2 will study relaxation of neighbour cells RRM measurements in RRC\_CONNECTED.

Editor’s note: FFS further study on details and solutions for RRM relaxation mechanisms in all RRC states.

### 8.4.2 Analysis of UE power saving

Annex A.2 lists power saving results and analysis provided in R2-2009620.

In summary, R2-2009620 presents plotted results for cases where the DRX cycle is 1.28 seconds, the number of intra- and inter-frequency cells is 8 with an SSB periodicity of 20 ms. The results are presented with the average power consumption plotted against how often the UE measures. The results show that power consumption does not change significantly for measurement relaxation beyond one hour.

Editor’s note: FFS RAN2 agreed conclusions and possible recommendations and references to other results.

### 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

As a baseline, the existing UE capabilities framework is used to indicate the capabilities of RedCap UEs. As currently specified in Rel-16, the UE reports its radio access capabilities at least when the network requests the UE to do so.

The network should be able to control whether RedCap UEs can access the cell and differentiate them from other, non-RedCap UEs. The number of different UE types should be minimised to reduce market fragmentation, and UE types should be introduced only where essential to control UE accesses and differentiate them from other non-RedCap UEs.

The UE capabilities can be categorized as:

* Minimum mandatory capabilities that all RedCap UEs support, if identified.
* Optional capabilities, to be signaled explicitly.

For capability signaling of RedCap UEs, the following scenarios are possible, however feasibility, applicability of the cases and the final division to categories depend on the exact RedCap capabilities (to be defined):

* For the features that are mandatory for non-Redcap UEs:
  + The Redcap UE mandatorily supports the feature with the same value;
  + The Redcap UE mandatorily supports the feature, but with different value (e.g. bandwidth value);
  + The Redcap UE optionally supports the feature;
  + The Redcap UE does not support the feature at all.
* For the features that are optional for non-Redcap UEs:
  + The Redcap UE does not support the feature at all.
  + The Redcap UE supports the feature with a different value;
  + The Redcap UE supports the feature with the same value;
  + The Redcap UE mandatorily supports the feature

Based on the above categorization and possible scenarios, the following capability design principle alternatives can be considered:

Alternative 1:

- The UE capability requirements for a RedCap device type, that are different from those for non-RedCap UEs, are listed in the specifications. That is:

o Mandatory features for non-RedCap UEs that are not applicable for RedCap UEs.

o Mandatory features for non-RedCap UEs that are optional for RedCap UEs.

o Mandatory features for non-RedCap UEs that are supported for RedCap UEs but with different value.

o Optional features for non-RedCap UE that are not applicable for RedCap UE.

o Optional features for non-RedCap UE that are mandatorily supported for RedCap UE.

For a RedCap device type, define new signaling fields in UE capability signalling for the features that are mandatory without capability signaling for non-RedCap UEs but are optional for Redcap UEs, or mandatory with capability signaling for non-RedCap UEs but with different value for RedCap UEs. Such new signalling is only applicable for RedCap UEs.

Alternative 2:

* Directly define the UE capabilities required for RedCap devices, including:

o Mandatory features for RedCap UEs (defined in specification).

o Optional features for Redcap UEs (introduce signaling fields in an independent container defined specifically for Redcap UE).

The network should know whether the UE is a RedCap UE or not in order to handle UE capabilities properly (see also Section 11.1 on UE identification). The following options, which do not need to be mutually exclusive, can be considered for further analysis and down-selection:

Option 1: RedCap device type is indicated as part of the capability signaling.

Option 2: Define a new IE specifically for RedCap UEs containing RedCap-specific capabilities. The IE is included in the signaling only by Redcap UEs.

Option 3: The network identifies RedCap UEs based on identification solution (see Section 11.1), e.g. during Msg1, Msg3, MsgA, etc, (pending RAN1 conclusion). The identification is forwarded it to target gNB during handover.

Option 4: The network identifies RedCap UE based on the reported capabilities, assuming the identification can be done through RedCap-specific capabilities not used by non-RedCap UEs.

Editor’s note: FFS further changes to above options and possible options which are not yet captured.

Editor’s note: The details and numbers of device types is FFS and discussion should be coordinated between RAN1/RAN2.

### 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

The study also includes an objective on how to ensure RedCap UEs are only used for intended use cases, that is, UE identifying as RedCap UE can only use services and resources intended for RedCap UE type. The following potential solutions can be considered (the solutions do not need to be mutually exclusive):

* Option 1: RRC Reject based approach

When the network knows the UE is a RedCap UE and the type of the service requested, RAN can reject an RRC connection establishment attempt if the service the UE requests is not allowed for RedCap UEs. The service type can be known, e.g., based on the establishment cause provided in Msg3, through higher layer mechanisms or other ways.

* Option 2: Subscription validation (Note: SA2, CT1 confirmation is needed)

During the RRC connection setup, the UE indicates that it is a RedCap UE to the core network, e.g.

* + UE includes this indication in NAS signaling message to core network; or
  + UE informs this indication during its RRC connection establishment procedure to RAN; RAN then informs core network of the UE’s RedCap type in the Initial UE Context message to core network.

The network validates UE’s indication against its subscription plan, which includes information such as the set of services allowed for the UE. Network then decides whether to accept or reject UE’s registration request. For example, network may reject UE if UE indicates RedCap but its subscription does not include any RedCap-specific services.

* Option 3: Verification of RedCap UE

Network performs capability match between UE’s reported radio capabilities and the set of capability criteria associated with UE’s RedCap type.

* Option 4: Left up to network implementation to ensure RedCap UE uses intended services and/or resources.

The decision on which option or options to choose will be made during a possible normative phase, and if needed, based on consultation with other working groups (e.g. SA2, CT1).

Editor’s note: FFS further changes to above options and possible options which are not yet captured.

### 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

RedCap UEs need to be identified in order to ensure the network can provide services properly in the cell, e.g., to schedule messages and to possibly restrict the UE’s access to the network.

The necessity on when RedCap UE needs to be identified depends on when the network needs to have information of the UE type in order to properly schedule the UE e.g. during the initial access.

The following options for including an indication of have been discussed:

- Option 1: Msg1 (Separate initial UL BWP for RedCap UEs or PRACH partitioning)

- Option 2: Msg3

- Option 3: Msg5

- Option 4: MsgA for 2 step RA

Editor’s note: FFS on details of options, e.g. feasibility / pros / cons, also waiting for RAN1 conclusion.

Analysis of Option 1: …

Analysis of Option 2: Whether it is needed for the network to identify a RedCap UE during reception of Msg3, or earlier, depends on whether Msg4 and/or Msg5 need special handling and whether there is a need to provide opportunity for the network to reject connection establishment based on that the UE is a RedCap UE.

Analysis of Option 3: …

Analysis of Option 4: …

### 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

NG-RAN supports overload and access control functionality such as RACH back off, RRC Connection Reject, RRC Connection Release and UE based access barring mechanisms.

For RedCap UEs, an indication in broadcast system information can be used to indicate whether a RedCap UE can camp on the cell or not.

The unified access control (UAC) framework is specified in TS 22.261 and it applies to all UEs in RRC\_IDLE, RRC\_CONNECTED and RRC\_INACTIVE. This mechanism should also apply to RedCap UEs to control RedCap UEs accesses to the network.

Editor’s note: FFS on details of above, e.g. explicit or implicit indication in SI, details of UE access identifier and/or access categories for reduced capability UEs.

### 11.2.2 Analysis of coexistence with legacy UEs

### 11.2.3 Analysis of specification impacts

# 12 Conclusions

Editor’s note: RAN2 has not yet agreed on final conclusions or recommendations regarding the features to be specified or other potential contents of normative phase.

Annex A:  
Power saving evaluations

# A.1 Extended DRX for RRC Inactive and/or Idle

## A.1.1 Power saving evaluation in R2-2009116

In order to evaluate the additional power savings that could be achieved by introducing eDRX in NR compared to legacy I-DRX, we use a model based on TR 38.840, scaled to 20MHz for Idle mode operation. We consider two scenarios: 1) High SINR, and 2) Low SINR, as illustrated below:





Figure A.1.1-1: Timeline for I-DRX with high SINR





Figure A.1.1-2: Timeline for I-DRX with high SINR

Relative power during various states can be modelled as below:

Table A.1.1-1: Power state modelling for I-DRX

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Component Description** | **Power notation** | **Relative power** | **Time notation** | **Time (ms)** |
| SSB processing |  | 50 |  | 2/4 |
| Intra-frequency neighbor cell measurement |  | 60 |  | 2 |
| Paging occasion reception |  | 50/120 (without/ with PDSCH) |  | 1/4 (high/ low SINR) |
| Inter-frequency neighbor cell  measurement |  | 60 |  | 5 |
| Micro sleep |  | 31 |  | (\*) |
| Light sleep |  | 18 |  | (\*) |
| Deep sleep |  | 0.8 |  | (\*) |

(\*) The value depends on the power saving scenario adopted

We also define the following energy consumption for the state transition.

|  |  |  |  |
| --- | --- | --- | --- |
| **Component Description** | **Energy notation** | **Energy** | **Occurrence notation** |
| Micro sleep transition |  | 0 |  |
| Light sleep transition |  | 100 |  |
| Deep sleep transition |  | 450 |  |

Based on the above timeline and power model, the power consumption for I-DRX with high SINR is given by:

For low SINR, it is given by:

For eDRX, if we consider the UE to be in deep sleep outside of PTW and consuming power PIDRX (in the formula above) during PTW, the formula for eDRX power consumption becomes:

Where, LPTW is the PTW length.

Some example power savings by introducing eDRX, with different eDRX/I-DRX configurations are summarised in the table below:

Table A.1.1-2: Example power savings that can be achieved with eDRX

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenario** | **TI-DRX (ms)** | **TeDRX (ms)** | **PTW length (ms)** | **% Savings with eDRX compared to I-DRX** |
| High SINR | 2560 | 10,485,760 | 2560 | 33.83 |
| High SINR | 1280 | 10,485,760 | 1280 | 50.56 |
| High SINR | 320 | 10,485,760 | 320 | 80.36 |
| Low SINR | 2560 | 10,485,760 | 2560 | 56.08 |
| Low SINR | 1280 | 10,485,760 | 1280 | 71.86 |
| Low SINR | 320 | 10,485,760 | 320 | 91.08 |

From the evaluation above, it is clear that eDRX brings significant improvements to power consumption, and it is also clear that eDRX concepts and mechanisms such as PTW and extension of paging cycles to hyper-frames that were introduced for LTE/NB-IoT should be re-used in RedCap.

## A.1.2 Power saving evaluation in R2-2009620

## Assumptions

To evaluate the power saving functionality for RedCap, we used assumptions based on the agreements made in RAN1 WG1 meeting#101e and #102e, see SID status report in RP-201676. We considered the power saving model described in TR 38.840 section 8. We considered 20 MHz bandwidth in FR1. We assumed half-duplex RedCap devices that have 1 TX and 2 RX antennas with one MIMO layer in UL where MCS 0 is considered for MSG3 and MSG4. We assumed that the RedCap device is powered with 2 AA batteries (capacity is about 2x2000mAh depending on size current discharge) where self-discharging is negligible. It is assumed that the PDCCH monitoring periodicity is 1 ms. No power consumption due to RRM measurements was considered in the evaluation. Also, no coverage recovery is considered in the evaluation. We assumed the SSB synchronization time, i.e. if the sleep between two wakeup periods is extensively long, so there should be some power consumption accounted for to synchronize. We have taken an optimistic approach in determining the SSB period, MIB and SIB acquisition times, and average synchronization time, assuming the power consumption defined in 8.1.1 and 8.1.3 of TR 38.840 for SSB based synchronization tracking. We considered the packet inter-arrival time to model data traffic generation. In addition to the IAT specified in RP-201676, we have also evaluated battery lifetime for a number of IATs. The Inter-arrival rate is considered for uplink traffic.

## Results

The evaluation results are shown in figure A.1.2-1. Figure A.1.2-1 shows the battery lifetime gain for different eDRX cycles and different inter-arrival times. The inter-arrival time in this figure is represented in the order of minutes. If one looks at the inter-arrival time of 1 min, when the eDRX cycle goes beyond 64 min, further extension of the eDRX cycle lengths does not significantly increase the lifetime. It is worth to note that the length of the eDRX cycle extension gain largely depends on the packet inter-arrival time. The IAT above 300 minutes also has nominal battery lifetime gain. Looking at the result, regardless of the payload’s inter-arrival time, one can see that with a DRX cycle up to 10.24s a battery lifetime of around 6 to 8 months can be achieved for a device in RRC\_IDLE. With an eDRX cycle above 10.24s, RRC\_INACTIVE has 25% higher gain than the RRC\_IDLE state due to the reduced signalling load between gNB and UE. It is worth to note that the presented power saving gains may be optimistic due to the simplistic assumptions made during the evaluation.

Chart

Description automatically generated

Figure A.1.2-1: RedCap UE battery lifetime in RRC\_INACTIVE and RRC\_IDLE state.

In the SID use case with Industrial Wireless Sensor Network (IWSN), the UE battery is expected to last at least a few years. From our result, one can see that eDRX longer than 10.24s is required to have a UE battery life of “at least a few years” for both RRC\_IDLE and RRC\_INACTIVE cases. Based on the results, we recommend RAN2 to extend the eDRX cycle for both RRC\_IDLE and RRC\_INACTIVE beyond 10.24 seconds.

## Analysis

### Length of extension for eDRX in RRC\_IDLE

From the results we can see that it is reasonable to extend the eDRX duty cycle to 64 minutes (1.06 hours). In LTE a 10-bit H-SFN is defined in SI for eDRX. If we adopt the LTE-M mechanism for NR then the H-SFN signalling in SIB1 limits the eDRX cycle length to 10845.76 seconds or 2.91 hours, see table A.1.2-1.

Following agreement was made in RAN2#111-e,

*For RRC\_IDLE and/or RRC\_INACTIVE, if the NR DRX cycle range is extended beyond 10.24s, the LTE ‎eDRX mechanism beyond 10.24s (e.g., PTW, PH, etc.) is used as baseline when NR eDRX cycle is configured beyond 10.24s.*

Table A.1.2-1: SFN and H-SFN bit mapping

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Range | Synchronization Method | Max Time in sec |
| SFN | 0~1023 | MIB(PBCH)r | 10.24 |
| H-SFN | 0~1023 | SIB1 | 10485.76  (=2.91 hour) |

Hence, it is likely to introduce 10 H-SFN bits for NR RedCap as well. In this case, even if the exact use cases would be fine with eDRX extension up to 64 minutes. Unless there is a good technical reason, we should not limit the configuration possibility.

### Length of extension for eDRX in RRC\_INACTIVE

During the state transition RRC\_INACTIVE state can reduce control signalling by 57%~63% compared to RRC\_IDLE. In case the state transition occurs in a new gNB with in an assigned paging area then there is ~88% lower signalling cost with RRC\_INACTIVE compared to RRC\_IDLE (Hailu, Sofonias, Mikko Saily, and Olav Tirkkonen. "RRC State handling for 5G." IEEE Communications Magazine 57.1 (2018): 106-113). On top of that introducing eDRX in RRC\_INACTIVE state can be very effective from battery lifetime perspective. As currently specified, RRC\_INACTIVE with short DRX cycle cannot be considered as a good state if the UE wants to save power e.g., for some RedCap use cases such as IWSN. Moreover, the eDRX cycle length extension for RRC\_INACTIVE beyond 10.24s may bring value for other WIs such as Small data enhancement and future WIs like LPWAN in NR. Hence, we should support the extension of the DRX cycle for RRC\_INACTIVE mode.

Table A1.2-2: RRC\_INACTIVE battery life gain in different use cases.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Use case | Mean IAT | Payload Size | RRC\_IDLE Battery Lifetime gain above 10.24s | RRC\_INACTIVE Battery lifetime gain above 10.24s |
| Video Surveillance | ≤1s | 250 Bytes | up to 3.5% | up to 7% |
| Wearables | ≤2s | 72 Bytes | up to 7% | up to 16% |
| Industrial Wireless Sensor | 100ms | 72 Bytes | up to 0.38% | up to 1% |
| 1 min | up to 180% | up to 297% |
| 5 min | up to 340% | up to 419% |

Table A.1.2-2 illustrates the battery life gain in RRC\_IDLE and RRC\_INACTIVE state, with 2 mins eDRX cycle compared to 10.24s eDRX, for the RedCap SID defined used cases and agreed traffic model in RP-201676. As shown in the table the battery life gain for eDRX above 10.24s in RRC\_INACTIVE shows significant gain compared to RRC\_INACTIVE with same eDRX cycle. For instance, in IWSN case, if we increase the IAT to 1 min up to 65% battery lifetime gain is possible in RRC\_INACTIVE in comparison of RRC\_IDLE with eDRX beyond 10.24s. Additionally, please note that IAT increment to 5 min also shows significantly better battery life gain in RRC\_INACTIVE compared to RRC\_IDLE.

# A.2 RRM relaxation for stationary devices

## A.2.1 RRM relaxation evaluation in R2-2009620

Figure A.2.1-1 shows how the average device power consumption is reduced with increased interval between RRM measurements on neighbour cells. The power calculation is performed with the model in TR 38.840. At some point in time the effect of further Increase of the interval between measurements is insignificant. The red dashed line in Figure A.2.1-1 at one hour represents the condition where a device, which is not at cell edge and low mobility, may skip measurements for an hour. Note that even before an interval of one hour) the power consumption has almost reached its minimum. It is likely that the shape of the curve is not affected by UE’s RRC state, however, the Rel-16 functionality mentioned only refers to a device in RRC\_IDLE or RRC\_INACTIVE.

A picture containing graphical user interface

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Figure A.2.1-1: Effect of relaxation on average power consumption.

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 |