|  |  |
| --- | --- |
| 3GPP TR 38.875 V1.0.0 (2020-12) | |
| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access Network;  Study on support of reduced capability NR devices  (Release 17) | |
|  | |
|  |  |
|  | |
| The present document has been developed within the 3rd Generation Partnership Project (3GPP TM) and may be further elaborated for the purposes of 3GPP. The present document has not been subject to any approval process by the 3GPPOrganizational Partners and shall not be implemented. This Specification is provided for future development work within 3GPPonly. The Organizational Partners accept no liability for any use of this Specification. Specifications and Reports for implementation of the 3GPP TM system should be obtained via the 3GPP Organizational Partners' Publications Offices. | |

|  |
| --- |
|  |
| ***3GPP***  Postal address  3GPP support office address  650 Route des Lucioles - Sophia Antipolis  Valbonne - FRANCE  Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16  Internet  http://www.3gpp.org |
| ***Copyright Notification***  No part may be reproduced except as authorized by written permission. The copyright and the foregoing restriction extend to reproduction in all media.  © 2020, 3GPP Organizational Partners (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC).  All rights reserved.  UMTS™ is a Trade Mark of ETSI registered for the benefit of its members  3GPP™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners LTE™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners  GSM® and the GSM logo are registered and owned by the GSM Association |

Contents

Foreword 6

1 Scope 8

2 References 8

3 Definitions of terms, symbols and abbreviations 8

3.1 Terms 8

3.2 Symbols 9

3.3 Abbreviations 9

4 Introduction 9

5 Study objectives 10

6 Evaluation methodology 11

6.1 Evaluation methodology for UE complexity reduction 11

6.2 Evaluation methodology for UE power saving 12

6.3 Evaluation methodology for coverage recovery 16

6.4 Evaluation methodology for network capacity and spectral efficiency 17

7 UE complexity reduction features 18

7.1 Introduction to UE complexity reduction features 18

7.2 Reduced number of UE Rx/Tx antennas 19

7.2.1 Description of feature 19

7.2.2 Analysis of UE complexity reduction 19

7.2.3 Analysis of performance impacts 21

7.2.4 Analysis of coexistence with legacy UEs 22

7.2.5 Analysis of specification impacts 22

7.3 UE bandwidth reduction 22

7.3.1 Description of feature 22

7.3.2 Analysis of UE complexity reduction 23

7.3.3 Analysis of performance impacts 24

7.3.4 Analysis of coexistence with legacy UEs 24

7.3.5 Analysis of specification impacts 25

7.4 Half-duplex FDD operation 25

7.4.1 Description of feature 25

7.4.2 Analysis of UE complexity reduction 25

7.4.3 Analysis of performance impacts 26

7.4.4 Analysis of coexistence with legacy UEs 26

7.4.5 Analysis of specification impacts 27

7.5 Relaxed UE processing time 27

7.5.1 Description of feature 27

7.5.2 Analysis of UE complexity reduction 27

7.5.3 Analysis of performance impacts 28

7.5.4 Analysis of coexistence with legacy UEs 29

7.5.5 Analysis of specification impacts 29

7.6 Relaxed maximum number of MIMO layers 29

7.6.1 Description of feature 29

7.6.2 Analysis of UE complexity reduction 30

7.6.3 Analysis of performance impacts 30

7.6.4 Analysis of coexistence with legacy UEs 31

7.6.5 Analysis of specification impacts 31

7.7 Relaxed maximum modulation order 31

7.7.1 Description of feature 31

7.7.2 Analysis of UE complexity reduction 32

7.7.3 Analysis of performance impacts 33

7.7.4 Analysis of coexistence with legacy UEs 33

7.7.5 Analysis of specification impacts 34

7.8 Combinations of UE complexity reduction features 34

7.8.1 Description of feature combinations 34

7.8.2 Analysis of UE complexity reduction 34

7.8.3 Analysis of performance impacts 35

7.8.4 Analysis of coexistence with legacy UEs 36

7.8.5 Analysis of specification impacts 36

8 UE power saving features 36

8.1 Introduction to UE power saving features 36

8.2 Reduced PDCCH monitoring 36

8.2.1 Description of feature 36

8.2.2 Analysis of UE power saving 36

8.2.3 Analysis of performance impacts 40

8.2.4 Analysis of coexistence with legacy UEs 49

8.2.5 Analysis of specification impacts 49

8.3 Extended DRX for RRC Inactive and/or Idle 49

8.3.1 Description of feature 49

8.3.2 Analysis of UE power saving 50

8.3.3 Analysis of performance impacts 50

8.3.4 Analysis of coexistence with legacy UEs 50

8.3.5 Analysis of specification impacts 50

8.4 RRM relaxation for stationary devices 50

8.4.1 Description of feature 50

8.4.2 Analysis of UE power saving 51

8.4.3 Analysis of performance impacts 51

8.4.4 Analysis of coexistence with legacy UEs 51

8.4.5 Analysis of specification impacts 51

9 Coverage recovery 51

9.0 Introduction to coverage recovery 51

9.1 Coverage recovery evaluation 51

9.1.1 Urban scenario at 2.6 GHz 51

9.1.2 Rural scenario at 0.7 GHz 53

9.1.3 Urban scenario at 4 GHz 55

9.1.4 Indoor scenario at 28 GHz 57

9.1.5 Summary of coverage recovery evaluation 59

9.2 Coverage recovery for PUSCH 60

9.2.1 Description of coverage recovery features 60

9.2.2 Analysis of coexistence with legacy UEs 60

9.2.3 Analysis of specification impacts 60

9.3 Coverage recovery for PDSCH 61

9.3.1 Description of coverage recovery features 61

9.3.2 Analysis of coexistence with legacy UEs 61

9.3.3 Analysis of specification impacts 61

9.4 Coverage recovery for PDCCH 62

9.4.1 Description of coverage recovery features 62

9.4.2 Analysis of coexistence with legacy UEs 62

9.4.3 Analysis of specification impacts 62

10 Definition and constraining of reduced capabilities 62

10.1 Definition of reduced capabilities 62

10.2 Constraining of reduced capabilities 64

10.2.1 Description of feature 64

10.2.2 Analysis of coexistence with legacy UEs 65

10.2.3 Analysis of specification impacts 65

11 UE identification and access restrictions 65

11.1 UE identification 65

11.1.1 Description of feature 65

11.2 Access restrictions 68

11.2.1 Description of feature 68

11.2.2 Analysis of coexistence with legacy UEs 68

11.2.3 Analysis of specification impacts 68

12 Impact to network capacity and spectral efficiency 69

13 Conclusions and recommendations 69

Annex A: UE power saving results 72

A.1 UE power saving results for FR1 72

A.2 UE power saving results for FR2 75

Annex B: PDCCH blocking rate results 77

B.1 PDCCH blocking rate results for FR1 77

B.2 PDCCH blocking rate results for FR2 84

Annex C: Link budget evaluation results 88

C.1 Urban scenario at 2.6 GHz 88

C.2 Rural scenario at 0.7 GHz 93

C.3 Urban scenario at 4 GHz 98

C.4 Indoor scenario at 28 GHz 102

Annex D: System-level simulation evaluation results 107

Annex E: Company inputs to power saving evaluation in RAN2 116

E.1 Extended DRX for RRC Inactive and/or Idle 116

E.1.1 Power saving evaluation in [8] 116

E.1.2 Power saving evaluation in [9] 117

E.2 RRM relaxation for stationary devices 119

E.2.1 RRM relaxation evaluation in [9] 119

Annex F: Change history 120

# 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-201677: "Revised SID on support of reduced capability NR devices".

[3] 3GPP R1-2009293: "FL summary on RedCap evaluation results".

[4] 3GPP TR 36.888: "Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE".

[5] 3GPP TR 38.830: "Study on NR coverage enhancements".

[6] 3GPP TR 38.840: "Study on User Equipment (UE) power saving in NR".

[7] 3GPP R1-070674: "LTE physical layer framework for performance verification", Orange, China Mobile, KPN, NTT DoCoMo, Sprint, T-Mobile, Vodafone, Telecom Italia.

[8] 3GPP R2-2009116: "Further considerations for eDRX", MediaTek.

[9] 3GPP R2-2009620: "RedCap power saving enhancements", Ericsson.

[10] 3GPP R2-2100459: “TP for TR 38875 on evaluation for RRM relaxation”, vivo, Guangdong Genius.

[11] 3GPP R2-2101257: “RRM measurement relaxation for Redcap UE”, Huawei, HiSilicon.

*\*\*\* skip non-related part \*\*\**

# 8 UE power saving features

## 8.1 Introduction to UE power saving features

The following UE power saving techniques have been studied:

- Reduced PDCCH monitoring by smaller numbers of blind decodes and CCE limits

- Extended DRX for RRC Inactive and/or Idle

- RRM relaxation for stationary devices

The outcomes of the studies of these techniques are captured in clauses 8.2 through 8.4, respectively, and summarized in clause 13.

## 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. Irrespective of RRC state, whether to enable or disable RRM relaxation function for RedCap UEs is within network’s control. 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. The stationary property of some RedCap UEs can also characterized by having confined mobility where these RedCap UEs are not expected to move out of a localized area.

#### 8.4.1.1 RRM relaxation in RRC\_IDLE and RRC\_INACTIVE

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.

For triggering neighbour cell RRM relaxation for RedCap UEs in RRC\_IDLE and RRC\_INACTIVE, based on Rel-16 triggering criterion, following enhancements can be considered (other solutions are not precluded):

* **Enhancement 1:** Introduce additional SsearchDeltaP\_stationary threshold to support 2-level speed evaluation (i.e. stationary and low mobility), for example:
  + Stationary: (SrxlevRef – Srxlev) < SSearchDeltaP\_stationary
  + Low mobility: SSearchDeltaP\_stationary <= (SrxlevRef – Srxlev) < SSearchDeltaP\_low\_mobility

Pros:

* From specification point of view, it is simple and straightforward enhancement based on Rel-16 mechanism;
* It supports 2 levels speed evaluation (i.e. stationary and low mobility), so it provides flexibility of designing different RRM relaxation levels for different mobility scenarios.

Cons:

* Unclear whether UE’s mobility level can be accurately determined;
* **Enhancement 2:** Introduce additional TSearchDeltaP\_stationary to support 2-level speed evaluation (i.e. fixed location and low mobility).

Pros:

* From specification point of view, it is simple and straightforward enhancement based on Rel-16 mechanism;
* It supports 2 levels speed evaluation (i.e. stationary and low mobility), so it provides flexibility of designing different RRM relaxation levels for different mobility scenarios.

Cons:

* Unclear whether UE’s mobility level can be accurately determined.

Note: There can be synergies if Enhancement 1 is combined with Enhancement 2.

* **Enhancement 3:** Take into account of beam switching in speed evaluation, for example:
  + Stationary:
    - number of beam switch < N1 or
    - no beam switch and (SrxlevRef – Srxlev) < SSearchDeltaP\_stationary
  + Low mobility:
    - number of beam switch < N2 or
    - SSearchDeltaP\_stationary <= (SrxlevRef – Srxlev) < SSearchDeltaP\_low\_mobility

Pros:

* Using beam level measurement results can assess UE’s movement more accurately than cell measurement, because UE may move among beams but without changing the cell level results;
* Potentially good for detecting “circular motion” around base station.

Cons:

* Unclear whether UE’s mobility level can be accurately determined;
* Beam level measurement results may fluctuate more than cell-level results, so it might cause misjudgement;
* **Enhancement 4:** UE determines its stationary property based on subscription information (e.g. USIM).

Pros:

* It is simpler and faster than evaluating the quality of serving cell.

Cons:

* Only applicable to limited scenarios, e.g. fixed-location devices or devices with confined mobility;
* Channel or link (RSRP/RSRQ) may change (e.g. may be low) even if UE is fixed-location, RRM relaxation only depends on fixed-location information may impact the performance if the UE is located at cell edge.
* **Enhancement 5:** Introduce an additional SsearchDeltaP\_correction threshold and configure the UE to use it if only it detects that it observes higher received signal power variation that do not violate stationarity, i.e. rotating around itself, dynamically changing multipath.

Pros:

* Can be used to differentiate different stationary cases. E.g. stationary or stationary with rotating around itself.

Cons:

* Covers specific use case where device is rotating around itself.

For neighbour cell RRM relaxation methods for RedCap UEs in RRC\_IDLE and RRC\_INACTIVE, based on Rel-16 NR RRM relaxation methods, following enhancements can be considered (other solutions are not precluded):

* **Enhancement 1:** UE can stop measurements on neighbour cells for T (T>>1) hours.

Pros:

* It is useful to further reduce power consumption for truly stationary UEs.

Cons:

* Based on evaluation scenario in TR, the gain compared to 1 hour measurement interval is not significant.
* **Enhancement 2:** Enabling further relaxation by reducing the number of monitored RS.

Pros:

* Since UE only needs to measure specific beams, the power consumption can be reduced and the time period of measurement can be reduced.

Cons:

* **Enhancement 3:** UE only perform measurements on a number of dedicated intra-frequency, inter-frequency cells.

Pros:

* For stationary UEs, can avoid UE to measure all frequencies/cells broadcast. For UEs whose mobility is confined, the frequencies to be measured can be configurable by the network if the mobility characteristic can be reported by the UE for eg., at Msg5. Also can allow the network to only page in the configured frequencies/cells when the UE is to be paged.

Cons:

* May require additional effort for network planning. May require additional signalling from the network to provide the UE with potential frequencies to be used in IDLE/INACTIVE. And additional signalling to allow/prohibit the UE from re-selecting to other frequencies than provided by the network.
* If the UE actually does moves or radio conditions change enough, there may be impact on cell-reselection.
* **Enhancement 4:** Minimize the number of measured frequencies.

Pros:

* For stationary UEs, can avoid UE to measure all frequencies/cells broadcast. Similar advantage as stated in Enhancement 3.

Cons:

* If the UE actually does moves or radio conditions change enough, there may be impact on cell-reselection.
* **Enhancement 5:** Expand the Rel-16 scenario of performing “stop measurements for 1 hour” for stationary UEs.

Pros:

* It is useful to further reduce power consumption for truly stationary UE.

Cons:

#### 8.4.1.2 RRM relaxation in RRC\_CONNECTED

For neighbour cell RRM relaxation in RRC\_CONNECTED, “fixed or immobile UEs” are considered with higher priority than “slightly moving UEs”.

For assisting triggering neighbour cell RRM relaxation for RedCap UEs in RRC\_CONNECTED, following solutions can be considered (other solutions are not precluded):

* **Solution 1:** UE reports “stationary” status to network in Msg5.

Pros:

* Allows UE to report to network if it is temporarily stationary, so network can change its RRM configuration timely.

Cons:

* Channel or link (RSRP/RSRQ) may change even if UE is purely stationary, so it may impact handover performance if UE cannot cancel RRM relaxing timely.
* **Solution 2:** Network provides (e.g. low mobility, not-at-cell-edge) evaluation parameters to UE via dedicated signalling.

Pros:

* Reusing Rel-16 mechanism in Connected UEs, maximize the commonality with idle/inactive UEs;
* Network can set evaluation parameters to UE, so it is more reliable and impacts on performance can be reduced.

Cons:

* Network needs to configure UE with additional parameters for RRC\_CONNECTED;
* Takes away the control from network in RRC\_CONNECTED to some extent.
* **Solution 3:** AMF sends “stationary” indication to gNB (based on UE subscription).

Pros:

* The information is derived from UE subscription information, such fixed-location UE will not move, so performance impact can be minimized.
* It is useful in potentially reducing the amount of measurements, and can enable network to configure more power-efficient RRM in RRC\_CONNECTED.

Cons:

* Only applicable to limited scenarios, e.g. fixed-location devices.
* Channel or link (RSRP/RSRQ) may change even if UE is purely stationary, so it may impact handover performance if UE cannot cancel RRM relaxing timely.
* **Solution 4:** UE reports “stationary” in UE Assistance Information to network.

Pros:

* Allows UE to report to network if it is temporarily stationary, so network can change its RRM configuration timely.

Cons:

* Channel or link (RSRP/RSRQ) may change even if UE is purely stationary, so it may impact handover performance if UE is located at cell edge and cannot cancel RRM relaxing timely.
* **Solution 5:** Network enables measurement relaxation based on UE’s measurement report.

Pros:

* It keeps the control fully on network side.
* UE measurement report can be based on existing RRM mechanism.

Cons:

* It relies on UE measurement reporting.

For neighbour cell RRM relaxation methods for RedCap UEs in RRC\_CONNECTED, the exact mechanism, if any, will be decided by RAN4. But from RAN2’s perspective, other solution are not precluded (e.g. network does not configure measurements for mobility purpose, UE only performs measurement on single RS type).

### 8.4.2 Analysis of UE power saving

Annex E.2 lists power saving results and analysis.

In summary, one source 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.

In addiiton, one source shows the average power consumption and power saving gain when further expand the measurement interval from using three times scaling factor to stopping measurement for 1 hour. The result shows that for DRX cycle =1280ms, stopping measurement for 1 hour can achieve power saving gain of 25.17% compared to 3-times relaxation. In addition, [11] shows the time reduction and power saving gain when the time duration for detecting/measuring SSBs can be reduced by reducing the number of measured SSBs. The power saving gain is 13.54% and 16.25% respectively if the time for SSBs detection/measurement is reduced by 62.5% and 75%.

### 8.4.3 Analysis of performance impacts

### 8.4.4 Analysis of coexistence with legacy UEs

### 8.4.5 Analysis of specification impacts

*\*\*\* skip non-related part \*\*\**

13 Conclusions and recommendations

UE complexity reduction techniques have been analysed individually in clauses 7.2 through 7.7 as well as in different combinations in clause 7.8 (cost/complexity), clause 9 (coverage recovery), and clause 12 (impact on network capacity and spectral efficiency). The main observations from the coverage recovery evaluations are summarized in clause 9.1.5.

Based on the analysis of the UE complexity reduction techniques, the following is recommended for a RedCap UE.

- Maximum UE bandwidth:

- Maximum bandwidth of an FR1 RedCap UE during and after initial access is 20 MHz

- Whether an FR1 RedCap UE can optionally support a maximum bandwidth larger than 20 MHz after initial access can be discussed during the WI phase or at RAN plenary.

- Maximum bandwidth of an FR2 RedCap UE during and after initial access is 100 MHz

- Number of Rx branches:

- For FR1 FDD or FR2 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. The 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*, where *N* is to be down-selected during the WI phase or at RAN plenary between the following alternatives:

- Alt 1: *N*=2

- Alt 2: *N*=1, where *N*=2 is also supported

- Number of DL MIMO layers:

- For a RedCap UE with 1 Rx branch, the maximum number of DL MIMO layers is 1.

- For a RedCap UE with 2 Rx branches, the maximum number of DL MIMO layers is *M*, where *M* is to be down-selected during the WI phase or at RAN plenary between the following options (where different options may be selected for FR1 FDD, FR1 TDD, and FR2, respectively):

- Option 1: *M*=1, where *M*=2 is also supported

- Option 2: *M*=2

- Half-duplex FDD operation:

- HD-FDD operation type B is not supported for RedCap FR1 FDD UEs in Rel-17.

- Decide at RAN plenary whether to have support FD-FDD or HD-FDD operation type A or both by specification for an FR1 FDD RedCap UE.

- Relaxed UE processing time:

- Decide at RAN plenary whether to support relaxed UE processing time in terms of N1 and N2 by specification for a RedCap UE.

- Relaxed maximum modulation order:

- Support of 256QAM in DL is optional (instead of mandatory) for an FR1 RedCap UE.

- No other relaxations of maximum modulation order are supported by specification for a RedCap UE.

The study of UE power saving through reduced PDCCH monitoring can be summarized as follows:

- The PDCCH monitoring reduction for RedCap UEs has been studied. The study includes the evaluation of power saving benefit, system performance impacts, coexistence impacts, potential schemes, and the corresponding specification impacts.

- The power saving benefit by PDCCH monitoring reduction for RedCap UEs has been evaluated based on the agreed power model and traffic model, with the results and observations captured in clause 8.2.2.

- The system performance impact has been evaluated using PDCCH blocking rate as the metric, with the results and observations captured in clause 8.2.3. In addition, scheduling flexibility and latency impacts have also been studied in clause 8.2.3.

- Three candidate schemes for PDCCH monitoring reduction have been identified and studied with the corresponding coexistence and specification impacts captured in clause 8.2.4 and clause 8.2.5, respectively.

The study of UE power saving on RRM relaxation recommends follows:

- RRM relaxation for neighboring cell in RRC\_IDLE/INACTIVE/RRC\_CONNECTED: Compared to RRC\_CONNECTED E, neighbour cell RRM relaxation in RRC\_IDLE/INACTIV can be considered with high priority.

- Irrespective of RRC state, serving cell RRM relaxation for RedCap UEs is not considered.

*\*\*\* skip non-related part \*\*\**

# E.2 RRM relaxation for stationary devices

## E.2.1 RRM relaxation evaluation in [9]

Figure E.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 E.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

Description automatically generated

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

## E.2.x RRM relaxation in idle/inactive mode for serving cell in [10]

* **Simulation cases:**

To evaluate the power saving gain of serving cell RRM relaxation for RedCap UEs in idle and inactive mode, the following 6 cases are modeled and evaluated, which are classified as three scenarios: Rel-15/Rel-16 paging monitoring mechanism, WUS is applied for paging monitoring, including with or without gap between WUS and SSB.

**Note:** The intention to consider WUS together here is to provide the power saving gain in different scenarios (e.g. with or without WUS). As WUS in idle mode may be introduced in Rel-17 power saving, the following simulation results the power saving gain for RRM relaxation for use cases with and without WUS, which shows that there is still power saving gain even in the case with WUS.

Note 1: No neighbour cell RRM relaxation is performed in this simulation.

Note 2: FFS on whether WUS is applicable to Redcap devices.

* **Scenario 1**: When Rel-15/Rel-16 paging monitoring mechanism is adopted:
* **Case1**: No relaxation on serving cell RRM is applied, i.e. UE needs to measure one SSB and monitor one Paging Occasion (PO) per DRX cycle as legacy.
* **Case2**: RRM relaxation with 4x on serving cell, i.e. UE needs to measure one SSB every four DRX cycles and monitor one PO per DRX cycle. As a result, power consumption can be saved by skipping the monitoring of 75% SSBs and long deep sleep duration per DRX cycle can be achieved.
* **Scenario 2**: WUS is applied for paging monitoring, PO monitoring is only required when WUS is received, which occurs with low probability. It is assumed there is no time interval between WUS and SSB.
* **Case3:** No relaxation on serving cell RRM is applied, i.e. UE needs to measure one SSB and monitor one WUS per DRX cycle.
* **Case4:** RRM relaxation with 4x on serving cell, i.e. UE needs to measure one SSB every four DRX cycles and monitor one WUS per DRX cycle.
* **Scenario 3**: WUS is applied for paging monitoring, PO monitoring is only required when WUS is received, which occurs with low probability. The time interval between WUS and SSB is assumed as 3ms and micro sleep is performed between WUS and SSB.
* **Case5:** No selaxation on serving cell RRM is applied, i.e. UE needs to measure one SSB and monitor one WUS per DRX cycle.
* **Case6:** 4 RRM relaxation with 4x on serving cell, i.e. UE needs to measure one SSB every four DRX cycles and monitor one WUS per DRX cycle.
* **Simulation Assumptions:**
* The paging rate is 10%, referring to that 10% POs indicating UE to receive paging PDSCH.
* The time interval between a SSB and its relative PO is 10ms.
* 𝑃WUS= 𝑃PO = 𝑃SSB =50 power units/slot, where 𝑃WUS , 𝑃PO and 𝑃SSB represent the power consumpation for each WUS, PO and SSB reception respectively. The power consumpation is scaled to a 20MHz receiving bandwidth from the 100MHz power model in TR 38.840.
* *T*WUS= *T*SSB = 2ms, where *T*WUS and *T*SSB denote the duration of WUS and SSB.
* UEs are assumed as “true” stationary.
* More detailed power consumption model could be found in TR 38.840.
* **Simulation Results and Analysis:**

The power saving gain are summarized in Table E.x.1.

**Table E.x.1: Power saving gain of RRM relaxation for serving cell in high SINR case**

|  |  |  |  |
| --- | --- | --- | --- |
| Cases | | Average relative power per slot | Power saving gain or RRM relaxation |
| w/o WUS | Case 1 | 1.6975 | **13.4%**  (case 2 over case 1) |
| Case 2 | 1.4709 |
| w/ WUS  no gap between WUS and SSB | Case 3 | 1.5367 | **3.6%**  (case 4 over case 3) |
| Case 4 | 1.4814 |
| w/ WUS  the gap between WUS and SSB is 3ms | Case 5 | 1.627 | **8.3%**  (case 6 over case 5) |
| Case 6 | 1.4914 |

Most of the gain are achieved by skipping SSB measurement with RRM relaxation. In addition, skipping SSB measurement extends the time interval between adjacent wake-up, leading to more energy efficient sleep, e.g. using one long deep sleep to replace serval micro sleeps.

3.6%~13.4% power saving gain is observed when 4 times RRM relaxation for serving cell is adopted by high SINR for idle/inactive UE.

Note: The impact on PDCCH and PDSCH decoding as a results of not monitoring SSBs are not captured in this simulation.

E.2.x RRM relaxation in connected mode in [10]

RRC\_Connected UEs is required to derive one L3 sample per 200ms at the maximum. Such frequent measurement may not be always necessary for stationary or low mobility RedCap UEs, e.g. some fixed industry sensors. In addition, UE is required to perform measurement on too many inter-frequency layers and cells per frequency layers. Related RRM relaxation enhancements has been evaluated in Rel-16 and the results come from Power saving SI TR [6]:

* By increasing measurement period 4 times for RRC\_Connected UEs, 11.1% - 26.6% power saving gains are observed, at the cost of an increase of handover failure rate from 0% to 0.26% for stationary or low mobility (e.g., 3km/h) case.
* By reducing the number of measured cells for RRC\_Connected UEs, 1.8% - 21.3% power saving gain can be observed. In addition, 26.43% - 37.5% power saving gain is shown by assuming that UE can limit the processing for measurement within a constrained time period and/or with reduced complexity.
* By reducing the number of measured inter-frequency layers can provide 21%~38% power saving gain for RRC\_Connected UEs.

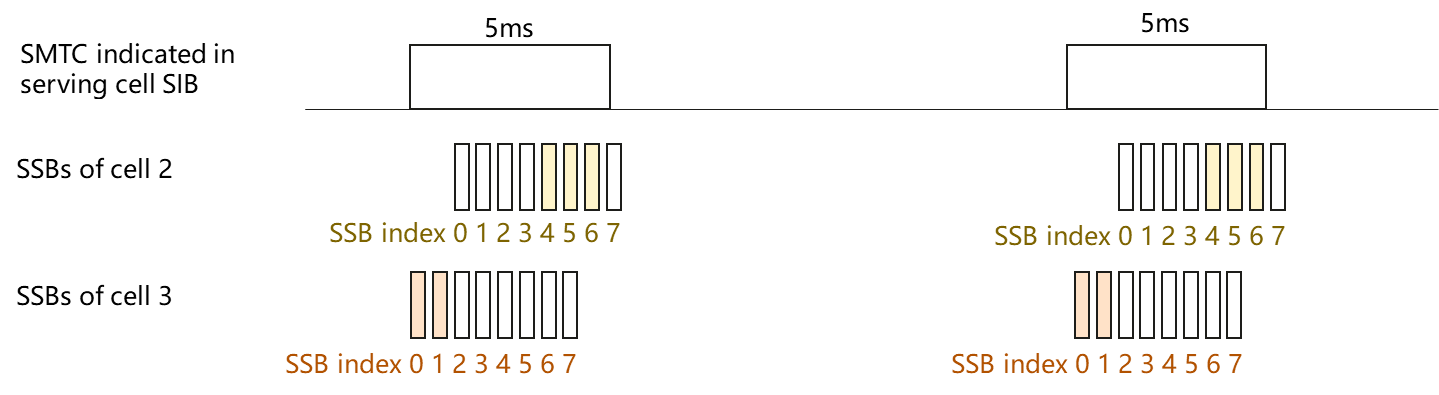
E.2.x RRM relaxation evaluation in [11]

The following table shows the average power consumption and power saving gain when further expand the measurement interval from using three times scaling factor to stopping measurement for 1 hour. The power calculation is performed with the model in TR 38.840. For DRX cycle =1280ms, power saving gain of 25.17% can be achieved.

**Table E.2.x-1 Power saving gain achieved by further expanding the measurement interval.**

|  |  |
| --- | --- |
|  | **DRX cycle = 1280ms** |
| **Relative power consumption:**  **3 times relax [unit]** | 2.0374 |
| **Relative power consumption:**  **stop measurment for 1 hour [unit]** | 1.5246 |
| **Power saving gain** | 25.17% |

The measurement time reduction is further illustrated in Figure E.2.x-2 by reducing the measurement time duration discussed above, with the typical SMTC window with length 5ms (i.e. half frame) and periodicity 20ms. We assume that the maximum number of SS/PBCH blocks per half frame equals to 8, so the average time duration for detecting/measuring one SSB is 0.625ms. The time reduction and power saving gain are given in the Table E.2.x-3 as below. Moreover, the power saving gain can be obtained with few performance degrading since only unnecessary SSBs detection/measurement are avoided.



**Figure E.2.x-2 The measurement time reduction**

**Table E.2.x-3 Time reduction and power saving gain**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Time for measurement within 20ms** | | **Time reduction** | | **Power saving gain**  According to the power model in TR 38.840, the power consumption is calculated during one DRX cycle = 1280ms | |
| Mapping between serving SSB index and the associated measurement time pattern during the SMTC window is not configured  Full SMTC window are measured | | 5ms | | Baseline | | The baseline power consumption is 2284.5 unit (NOTE) | |
| Mapping between serving SSB index and the associated measurement time pattern during the SMTC window is configured | UEs with only 3 neighbor SSBs (Cell 2) to be measured | | 1.875ms | | 62.5% | | Power consumption is 1975.125 unit  Power saving gain is 13.54% | |
| UEs with only 2 neighbor SSBs (Cell 3) to be measured | | 1.25ms | | 75% | | Power consumption is 1913.25 unit  Power saving gain is 16.25% | |
| NOTE: Considering one slot for synchronization, one slot for paging reception, and time duration for serving SSB measurement. The time interval between synchronization and serving SSB measurement is 20ms. The average light sleep time is 19ms. Considering the neighbor SSB measurement is right after the serving SSB measurement, the measurement time is 5ms. The deep sleep time is 1280-0.5-0.5-19-0.5-5=1254.5ms. The power consumption for synchronization, paging reception, serving SSB measurement and measurement for SMTC window is 100 unit per millisecond. The power consumption for light sleep and deep sleep are 20 unit and 1 unit per millisecond respectively. | | | | | | | | |

The following table shows the average power consumption and power saving gain when further expand the measurement interval from using three times scaling factor to stopping measurement for 1 hour. The power calculation is performed with the model in TR 38.840. For DRX cycle =1280ms, power saving gain of 25.17% can be achieved. Therefore, it is proposed to further enhance RRM measurement relaxation by expanding the scenario of performing “stop measurement for 1 hour” for stationary UEs.

**Table E.2.x-4 Power saving gain achieved by further expand the measurement interval.**

|  |  |
| --- | --- |
|  | **DRX cycle = 1280ms** |
| **Relative power consumption:**  **3 times relax [unit]** | 2.0374 |
| **Relative power consumption:**  **stop measurment for 1 hour [unit]** | 1.5246 |
| **Power saving gain** | 25.17% |