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| 3GPP TR 38.869 V0.2.0 (2023-05) | |
| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access Network;  Study on low-power wake up signal and receiver for NR  (Release 18) | |
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| ***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 |
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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

The present document …

# 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-222644: " Study on low-power wake up signal and receiver for NR".

# 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].

**example:** text used to clarify abstract rules by applying them literally.

## 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 format (EW)

<ABBREVIATION> <Expansion>

# 4 Introduction

5G systems are designed and developed targeting for both mobile telephony and vertical use cases. Besides latency, reliability, and availability, UE energy efficiency is also critical to 5G. Currently, 5G devices may have to be recharged per week or day, depending on individual’s usage time. In general, 5G devices consume tens of milliwatts in RRC idle/inactive state and hundreds of milliwatts in RRC connected state. Designs to prolong battery life is a necessity for improving energy efficiency as well as for better user experience.

Energy efficiency is even more critical for UEs without a continuous energy source, e.g., UEs using small rechargeable and single coin cell batteries. Among vertical use cases, sensors and actuators are deployed extensively for monitoring, measuring, charging, etc. Generally, their batteries are not rechargeable and expected to last at least few years as described in TR 38.875. Wearables include smart watches, rings, eHealth related devices, and medical monitoring devices. With typical battery capacity, it is challenging to sustain up to 1-2 weeks as required.

The power consumption depends on the configured length of wake-up periods, e.g., paging cycle. To meet the battery life requirements above, eDRX cycle with large value is expected to be used, resulting in high latency, which is not suitable for such services with requirements of both long battery life and low latency. For example, in fire detection and extinguishment use case, fire shutters shall be closed and fire sprinklers shall be turned on by the actuators within 1 to 2 seconds from the time the fire is detected by sensors, long eDRX cycle cannot meet the delay requirements. eDRX is apparently not suitable for latency-critical use cases. Thus, the intention is to study ultra-low power mechanism that can support low latency in Rel-18, e.g. lower than eDRX latency.

Currently, UEs need to periodically wake up once per DRX cycle, which dominates the power consumption in periods with no signalling or data traffic. If UEs are able to wake up only when they are triggered, e.g., paging, power consumption could be dramatically reduced. This can be achieved by using a wake-up signal to trigger the main radio and a separate receiver which has the ability to monitor wake-up signal with ultra-low power consumption. Main radio works for data transmission and reception, which can be turned off or set to deep sleep unless it is turned on.

The power consumption for monitoring wake-up signal depends on the wake-up signal design and the hardware module of the wake-up receiver used for signal detecting and processing.

The study should primarily target low-power WUS/WUR for power-sensitive, small form-factor devices including IoT use cases (such as industrial sensors, controllers) and wearables. Other use cases are not precluded, e.g.XR/smart glasses, smart phones.

As opposed to the work on UE power savings in previous releases, this study will not require existing signals to be used as WUS. All WUS solutions identified shall be able to operate in a cell supporting legacy UEs. Solutions should target substantial gains compared to the existing Rel-15/16/17 UE power saving mechanisms. Other aspects such as detection performance, coverage, UE complexity, should be covered by the evaluation.

**The study item includes the following objectives:**

- Identify evaluation methodology (including the use cases) & KPIs [RAN1]

- Primarily target low-power WUS/WUR for power-sensitive, small form-factor devices including IoT use cases (such as industrial sensors, controllers) and wearables

- Other use cases are not precluded

- Study and evaluate low-power wake-up receiver architectures [RAN1, RAN4]

- Study and evaluate wake-up signal designs to support wake-up receivers [RAN1, RAN4]

- Study and evaluate L1 procedures and higher layer protocol changes needed to support the wake-up signals [RAN2, RAN1]

- Study potential UE power saving gains compared to the existing Rel-15/16/17 UE power saving mechanisms, the coverage availability, as well as latency impact of low-power WUR/WUS. System impact, such as network power consumption, coexistence with non-low-power-WUR UEs, network coverage/capacity/resource overhead should be included in the study [RAN1]

- Note: The need for RAN2 evaluation will be triggered by RAN1 when necessary.

Use the following terminology for future discussion,

- Main radio (MR): the Tx/Rx module operating for NR signals/channels apart from signals/channel related to low-power wake-up

- LP-WUR (LR): The Rx module operating for receiving/processing signals/channel related to low-power wake-up.

# 5 Use cases & KPI

*Editor’s note: The following SI Objective is included in this clause.*

- Identify evaluation methodology (including the use cases) & KPIs [RAN1]

- Primarily target low-power WUS/WUR for power-sensitive, small form-factor devices including IoT use cases (such as industrial sensors, controllers) and wearables

- Other use cases are not precluded

The following characteristics for target use cases are considered in the study item:

- IoT cases including e.g., industrial wireless sensors, controllers, actuators and etc, including the following characteristics,

- FFS: latency

- primary for small form devices

- power-sensitive

- static, nomadic or limited mobility

- Wearable cases including e.g., smart watches, rings, eHealth related devices, and medical monitoring devices etc.,

- FFS: latency

- primary for small form devices,

- power-sensitive

- low/medium speed, FFS: high speed

- eMBB cases including e.g., XR/smart glasses, smart phones and etc.,

- FFS: latency

- devices form is various and not restricted

- power-sensitive

- low/medium speed, FFS: high speed

Note: other use cases/characteristics are not precluded if any.

Both RRC IDLE/INACTIVE and CONNECTED modes are to be studied as part of the LP-WUS/WUR SI.

- FFS: Further prioritization if needed during the study item.

# 6 Evaluation methodology

*Editor’s note: The clause includes evaluation methodology for this SI*

## 6.1 General performance metrics

For system impact analysis, the following performance metrics are considered to be provided,

Table 6.1-1: Performance metrics for system impact analysis

|  |  |
| --- | --- |
| Performance Metric | Note |
| System overhead | expressed as percentage of used part of all REs for LP-WUS (including guard band or time or others resource used for LP-WUR if any) among all resources  Other assumptions related to the system overhead analysis can be reported, e.g., the LP-WUR raw data rate evaluated in the coverage evaluations. |
| Capacity impact | Evaluate the system capacity impact due to introducing of LP-WUS  Note: it is for UEs which are in connected mode. Definition is the same as in XR TR. |
| FFS: NW power consumption / Energy Efficiency | [Impact of LP-WUS/WUR operation on gNB energy consumption as performance metric in system impact analysis.] |

For power and latency evaluation of the LP-WUS, the following performance metrics definitions provided for future study

Table 6.1-2: Performance metrics for power and latency evaluation

|  |  |
| --- | --- |
| Performance Metric | Note |
| Power consumption | Relative power consumption in units. The power consumption includes main radio and LP-WUR. For comparison, the relative power consumption and evaluation period for baseline schemes should also be provided, as well as the power saving gain (i.e., percentage of power consumption reduction of the proposed power saving scheme from the baseline scheme). |
| Latency | For IDLE/INACTIVE state,  - the latency is the time interval between the data arrival time at the gNB and the time of the first PO UE can monitor the paging message  - alternatively, if UE is not required to monitor a PO after wake-up, company to report detailed procedure and definition of the latency. In RAN1#111, there are no definitions being precluded  - sync/re-sync for main radio is included |
| UPT | The definition is the same as in [TR38.840]  Note: it is for connected mode purpose. |

- Companies to report baseline scheme, e.g., PO monitoring with i-DRX, e-DRX, with or without PEI

- Companies to report the power consumption / power saving gain considering the FAR impact, latency considering MDR impact

- Other performance metrics (e.g., mobility) can be reported by companies (if any)

## 6.2 Evaluation assumptions

### 6.2.1 General evaluation assumptions

RRC IDLE/INACTIVE evaluation assumptions

The following is assumed for RRC IDLE/INACTIVE evaluation,

Table 6.2.1-1: RRC IDLE/INACTIVE evaluation assumptions

|  |  |
| --- | --- |
| Parameters | Value |
| i-DRX cycle length | 1.28s and other values not precluded and reported by companies, consider both with PEI/ without PEI |
| e-DRX cycle length | 20.48s, 61.44s and other values not precluded, company to report which value(s) are used.  *Note: ‘ultra-deep sleep’ state can be assumed for eDRX whenever necessary for baseline UE* |
| Number of POs in Paging Frame | 1 |
| Number of DRXs per PTW | 4 |
| Number of SSB before PO / PEI | 1, 2 or 3, (used for e.g., AGC adjustment, T/F tracking, serving cell and intra-F measurement)  company to report which value(s) are used  Note: the assumptions is for MR wakes from ‘Deep sleep’ |
| Sync/re-sync after ultra-deep sleep | companies to report the timeline of sync/re-sync and X value, X is the time for sync/re-sync |
| RRM Measurement | Company to report whether and how the RRM measurement is assumed, e.g., whether RRM performed by main radio or LP-WUR, whether RRM is relaxed or not. |
| LP-WUS monitoring | Option 1: continuously monitoring  Option 2: discontinuously monitoring, with [T] ms as the period for complete an on-and-off cycle, and [D] ms as the active time for monitoring LP-WUS every cycle. |
| Traffic | Option 1 (baseline):  - The traffic arrival is modeled as a Poisson Arrival Process where inter-arrival times are exponentially distributed, the mean arrival time is P = YREF / RE, REF, where  - RE, REF= 1%, 0.1%, 0.01% or 0.001% and YREF = 1.28s  - Per group paging probability RG = 1 – (1 – RE)N, where N is the number of UEs in the group  - FFS: Value of N  - For LP-WUS  - Both per group and UE paging can be assumed.  Note:  - For i-DRX with cycle duration Y second,  - Per UE paging probability RE = 1 – (1 – RE, REF )Y/YREF  - For e-DRX with K i-DRX cycles duration, PTW duration of L i-DRX cycles, and an i-DRX cycle duration Y second  - Per UE paging probability is  - RE = 1 – (1 – RE, REF )(K-L+1)Y/YREF for the first i-DRX cycle within the PTW  - RE = 1 – (1 – RE, REF )Y/YREF for each of the remaining L-1 i-DRX cycles within the PTW  - L=4  Other options are not precluded can be reported by companies. |
| Others | Reported by companies |

The period of synchronization signal that LP-WUR used for at least power evaluation can be

- Existing SSB periodicity can be used from gNB transmission perspective for evaluations assuming SSB, companies to report how often used for LP-WUR

- For evaluations assuming LP-SS

- {320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms}

- Companies to report other important assumptions if any, e.g., durations of LP-SS to achieve enough T/F accuracy

- Other values are not precluded

Note: companies to report the purpose of the synchronization signal along with evaluations, e.g. can be for LR synchronization (i.e., time and/or frequency tracking) and/or measurement.

RRC CONNECTED mode evaluation assumptions

For R18 LP-WUS/WUR power evaluation in RRC connected mode, the following can be considered,

- XR traffic model with evaluation methodologies and assumptions captured in TR 38.838.

- eMBB traffic model with evaluation methodologies and assumptions captured in TR 38.840

- Heartbeat traffic models in TR 38.875.

- Other models are not precluded.

Company to further provide the followings,

- Parameters (e.g., frame rate, data rate, jitter range, DRX configurations and etc if needed.)

- How to use LP-WUS, e.g., LP-WUS to trigger/adapt PDCCH monitoring

- Other details if any

### 6.2.2 Coverage evaluation assumptions

For evaluation of the coverage of LP-WUS, the methodology and assumptions in R17 CovEnh SI (described in TR38.830) is reused as baseline.

- MIL is used as the metric for LP-WUS coverage evaluation

- urban (2.6GHz/4GHz), rural(700MHz) scenario for FR1 are considered to be evaluated, others (e.g., FR2) are not precluded.

Note: For IoT/wearables devices, refer to R17 Redcap SI TR38.875 if the assumptions differ from TR38.830.

Companies report any other assumptions which differ from the TR38.875/ TR38.830, e.g., Tx and Rx loss

Companies are encouraged to compare LP-WUS with at least PDCCH for paging, PUSCH, others are not precluded. FFS: Target coverage of LP-WUS

For LP-WUS coverage evaluation, the noise figure of LP-WUR is

- Options : [9, 12, 15, 18, 21, 24], Other values can be reported by companies

FFS: how to determine the NF option.

The values provided is for the purpose of studying coverage of LP-WUS, and it can be further revisited depending on the receiver architecture discussion.

For evaluation, 1 Rx chain for LP-WUS receiver is baseline.

For coverage evaluation, the following is used,

Table 6.2.2-1: Coverage evaluation assumptions

|  |  |
| --- | --- |
| Number of RX chains at the UE’s MR | Case 1: 1 Rx for Redcap  Case 2: 2 Rx  Case 3: 4 Rx  Company to report which case is being used. Further decision on antenna assumption for coverage is FFS. |
| Number of RX chains for LP-WUR | 1 Rx  Note: agreed in RAN1#110bis |
| Scenario and frequency | Urban: 4GHz (TDD), 2.6GHz (TDD)  Rural: 700MHz (FDD) |
| Reference data rates for MR | Urban: PDSCH 10Mbps, PUSCH 1Mbps  Rural: PDSCH 1Mbps, PUSCH 100kbps |
| Reference PDCCH configuration | |  |  | | --- | --- | | SCS | 30kHz for TDD, 15kHz for FDD. | | Aggregation level | 8, 16  Company to report which case is being used. Further decision on aggregation level for coverage is FFS. | | Payload | 40 bits | | CORESET size | 2 symbols, 48 PRBs | | Tx Diversity | Reported by companies | | BLER | 1% BLER, | |
| Pathloss model (select from LoS or NLoS) | Urban: NloS  Rural: NloS |
| Bandwidth | 100MHz for 4GHz and 2.6GHz.  20MHz (optional for 10MHz) for 700MHz. (FDD) |
| Channel model for link-level simulation | TDL-C for NLOS |
| Delay spread | Urban: 300ns, optional: 1000ns and companies to provide descriptions for such scenarios  Rural: 300ns |
| UE velocity | Urban: 3km/h  Rural: 3km/h, FFS: 120km/h (optional 30km/h) for outdoor |
| Number of antenna elements for BS | - Urban: 192 antenna elements for 4GHz and 2.6GHz,  (M,N,P,Mg,Ng) = (12,8,2,1,1)  (optional) 128 antenna elements for 4GHz,  (M,N,P,Mg,Ng) = (8,8,2,1,1)  - Rural: 16 antenna elements for 700MHz  (M,N,P,Mg,Ng) = (4,2,2,1,1) |
| Number of TxRUs for BS | gNB architectures to study:  - 2 or 4 TXRUs for700 MHz  - 64TxRUs for 2.6 and 4 GHz. |

### 6.2.3 Link performance evaluation assumptions

For the performance evaluations of LP-WUS candidate designs, it is assumed that

- The miss-detection rate (MDR) of LP-WUS [1%],

- The false-alarm rate (FAR) of LP-WUS

- 0.1%, 1%

- Other values are not precluded for studying reported by companies

- Note: if LP-WUS for wake-up indication consists of two parts or even multiple parts, the proposed MDR/FAR should take into account the reception performance of the two or more parts jointly

- The above values applied in both RRC CONNECTED and IDLE/INACTIVE mode.

- FFS FAR requirement based on the study outcome of the impact of FAR on power consumption / power saving gain / system overhead

- FFS: Note: FAR should be evaluated both in the absence of gNB transmissions and in the presence of transmissions from gNB. Proponent to provide the details.

The FAR definition does NOT include the impact of the falsely alarmed for wake-up due to the detection of a LP-WUS which is intended to wake-up/alarm the LP-WUR of another UE within the same UE group

For evaluation purpose, FAR target is determined across a reference time duration T of one or multiple LP-WUS attempts/trials,

- UE have N attempts within T,

- Company to report (FAR target, T, N)

- For example,

- if UE makes a single decision based on multiple correlations for a sequence in the monitor occasion, these correlations are considered as UE implementation in ONE trial/attempt.

- if UE performs decoding in a monitor occasion, a single decoding is considered as ONE trial/attempt.

- If UE performs N non-overlap attempts within the reference time duration, the false alarm event for the attempts are assumed as independent.

Companies to provide the assumed side conditions to attain the used FAR over T or per one attempt e.g. CRC/sequence length in LP-WUS design.

For link-level simulation of LP-WUS, the following table is used as starting point,

- FFS for other assumptions if any

- Note: The assumptions are not intended to limit the scope of the study or the design.

Table 6.2.3-1: Simulation assumptions for LP-WUS

|  |  |
| --- | --- |
| Attributes | Assumptions |
| Carrier Frequency | 2.6GHz/4GHz/700MHz |
| Waveform | OOK , FSK , OFDM  Company to report which option for OOK /FSK /OFDM is used |
| Channel structure | - Option 1: Sync signal /sequence+ payload + CRC,  - Option 2: Sequence only,  - Option 3: Payload+CRC,  - Other options are not precluded  - Company to report the sequence length, payload size, CRC length (may or may not be presence). |
| SCS of OFDM generator for NR signal | 30kHz/15KHz |
| Configuration for LP-WUS signal | For OOK/FSK waveform,  - Option 1a: M=1 and SCSs = 15kHz (same as NR signal)  - Option 1b: M=1 and SCSs = 30kHz (same as NR signal)  - Option 2a: M =2/4/8 for SCS = 15KHz (same as NR signal)  - Option 2b: M =2/4/8 for SCS = 30 kHz (same as NR signal)  - Option 3: M=1 and SCSs = 60kHz/120kHz/240kHz  - Note: M is referred to the definition of “M” in the agreements for OOK-1/2/3/4 and FSK-1/2  For OFDM: FFS, e.g., ZC sequence  Other options are up to companies to report |
| WUS duration | Number of OFDM symbols: e.g., 1,2,4, 8, 16,24 symbols |
| MDR/FAR assumption | The miss-detection rate (MDR) of LP-WUS 1%,  The false-alarm rate (FAR) of LP-WUS  - [0.1%, 1%]  - Other values are not precluded for studying, reported by companies  - Further discuss on the following alternatives for FAR target  - Alt 1: FAR target is determined per single WUS attempt/trial,  - Alt 2: FAR target is determined across a reference time duration of one or multiple WUS attempts/trials  - FFS: possible values for reference time durations  - Companies to report details, e.g., receiver behaviour, how to compute MDR, detection threshold  - Companies to report the selected reference time duration values and the associated number of WUS attempts/trials |
| Code scheme | Companies to report, if any, the coding scheme (e.g., Manchester code or any other schemes) and the code rate (e.g., 1/2, 1/4, ….) |
| gNB Channel BW | 20MHz, FFS other values |
| LP-WUS BW | Option 1:  - 5MHz including subcarriers for guard band  - 4.32MHz (i.e.,12 RBs) for LP-WUS transmission for 30kHz SCS  Option 2:  - {2.16, 4.32} MHz including subcarriers for guard band  - 1.44MHz, 2.88MHz (i.e.{4, 8} RBs) for LP-WUS transmission for 30kHz SCS  FFS: other options are up to companies to report  GB is symmetrically placed on each side of LP-WUS |
| Filter | X-th Order filter (e.g. Butterworth, Chebyshev, …) with Y MHz bandwidth,  - X = {3, 5}  - Companies to report Y  Companies to report any other assumptions if needed |
| Adjacent subcarrier interference | PDSCH mapped on resources other than that for WUS and guard band;  EPRE of LP-WUS / EPRE of PDSCH =ρ, where ρ=0 dB as baseline, ρ= {3, 6} dB as optional |
| Sampling Rate | Companies to report. |
| ADC bit width | 1-bit, 4-bit, 8-bit, ideal and other options are not precluded |
| Channel Model | See link coverage assumption table (will copy and paste here) |
| Impairment modelling | - FFS: Frequency and time error model  - Phase noise up to company report, e.g. the modelling used for 802.11ba  - Other cell interference is up to company to report |

For evaluation of LP-WUR frequency and time errors, the following is used,

Table 6.2.3-2: Frequency error/drifting

|  |  |
| --- | --- |
| ****Parameter**** | ****Value**** |
| **Oscillator max frequency error [ppm], Oscillator frequency drift [ppm/s]** | option 1: (200, 0.1)  option 2: (50, 0.1)  option 3: (10, 0.05)  option 4: (5, 0.05)  Other values are not precluded for studying, reported by companies |
| **RTC max frequency error [ppm],**  **FFS: RTC frequency drift [ppm/s]** | (20, FFS:[0.1]) |

- Company to report how to use the clocks for LR on/off state**s**

- The above clock assumptions for LR assumes the MR is in ‘ultra-deep sleep’ power state.

- Note: Assumptions important for achieving performance by option 1/2/3/4 clock for LR should be declared, including active on/off power, transition energy/ ramp-up time TLR, ramp-up for LR and etc.

- If MR is in other state than ‘ultra-deep sleep state’, the clock running for MR can be used for LR.

- assumptions important for achieving performance by using MR clock for LR should be declared

- Other clock accuracy options are not precluded. Companies to report options based on a feasibility analysis of clock power consumption and UE power consumption to use the clock accuracy option

- Company to report the frequency error assumption for the detection of LP-WUS/synchronization signal,

- The following are examples for consideration, other approaches are not precluded,

- Model 1:

- The relationship between a drifted frequency error(ΔF), frequency drift ( F’) over a time (T1) is ΔF = ±F’ \* T1

- When frequency displacement [Fd] reaches max frequency error, it is assumed to be equaled to max frequency error

- T1 is the time from the previous frequency synchronization. T1 may take different values depending on the chosen frequency synchronization approach.

- For Model 1 of frequency error, Frequency displacement (Fd), defined as the difference between ideal frequency and frequency due to 1) clock drifting (ΔF); and 2) residual frequency error from previous synchronization/calibration (Fr), is given as Fd (ppm)=ΔF (ppm) +Fr(ppm),

- Companies to report Fr and important assumptions for achieving Fr, e.g., if MR can assist to calibrate LP-WUR to correct the frequency error or if LP-WUR can only correct the frequency error based on LP-WUS synchronization signal

- Model 2: random frequency drifting, FFS details

- Company to report the timing drifting error assumption for the detection of LP-WUS/synchronization signal,

- The following are examples for consideration, other approaches are not precluded,

- Model 1 [R1-2301438] [R1-2301558][R1-1714993]:

- The relationship between the maximum frequency error(Fe) and corresponding timing drift( ΔT) over a time(T) is ΔT = ±Fe \* T (linear region)

- The relationship between a frequency drift( F’), and corresponding timing drift(ΔT) over a time(T) is ΔT = Fr\*T ±0.5 \* F’ \*T2 (transient region)

- The transition between transient and linear region (from synchronization or calibration point/time) occurs at time [Ts= (Fe-Fr)/( F’)]



- T is the time from the previous time synchronization. T may take different values depending on the chosen synchronization approach

- FFS: Time error (Te) before detection of a current sync signal is defined as the difference between ideal time of the current sync signal and the time error due to 1) clock time drift (ΔT); and 2) residual time error from previous synchronization/calibration (Tr); Te= ΔT+ Tr

- Model 2: random time drifting, FFS details

- FFS: Phase noise model

**The following for usage of the clock is assumed for LP-WUR OFF/ON**

|  |  |
| --- | --- |
| Assumption on LP-WUR OFF power | Assumptions on the clock usage |
| 0.001 | When LP-WUR is OFF  - Time offset cumulated in the off period cannot be calculated based on the parameters of the oscillator option 1/2/3/4. RTC should be used(Only RTC is running during sleep.)  When LP-WUR is ON, frequency offset and time offset calculation can follow the parameters of the oscillator option 1/2/3/4 [Note2] (cumulating based on the frequency drift and not exceed maximum frequency error)  - The initial frequency offset when LP-WUR switches on can be set to the [FFS: maximum frequency error or a random value within the maximum frequency error] following the parameters of the oscillator option 1/2/3/4[Note2].  - When LP-WUR is synced with LP-SS/SSB or MR is used to assist to calibrate LP-WUR to correct the time/frequency error, residual frequency error Fr is assumed at the time when the synchronization/calibration is done. |
| TBD: value(s) | For both LP-WUR OFF and ON  - Time offset cumulated in the off period can be calculated based on the parameter of the oscillator option 1/2 or option 3/4[Note2]. RTC can be used too.  - Frequency offset calculation can follow the parameter of the oscillator option 1/2 or option 3/4[Note2] (cumulating based on the second value in the value pair and not exceed maximum frequency error).  When at the time point after LP-WUR is synced with LP-SS/SSB or if MR can assist to calibrate LP-WUR to correct the frequency error  - Frequency offset is the Fr, which is residual frequency error from previous synchronization/calibration |

[Note1: Any additional LO/FLL/PLL could start running during LP-WUR On duration. The power consumption of any of those LO/FLL/PLL is captured in LP-WUR On power]

FFS: Note2: option 3/4 can only be assumed when LP-WUR ON power value and LP-WUR OFF power value>=TBD2, option 1/2 can only be assumed when LP-WUR ON power value and LP-WUR OFF power value>=TBD1

Note3: The clock error (of both RTC and LO) could be improved to be less than max ppm error of option 1,2,3,4 with clock calibation based on sync signal such as LP-SS or preamble.

## 6.3 Power consumption model

### 6.3.1 Power model for Main Radio (MR)

Take the following power model for main radio for evaluation in LP-WUS/WUR SI,

- For IoT and wearable cases, reuse TR38.875 power model as baseline.

- For eMBB and other cases, reuse TR38.840 power model as baseline.

- Introduce ‘*Ultra-deep sleep*’ power state for main radio of UEs with LP-WUS receiver

The following power models are used for ‘*Ultra-deep sleep*’ power state for main radio for evaluation

Table 6.3.1-1: Power model for Main Radio

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Power State | Relative Power (unit) | Ramp-up and down transition energy (Note1):  (unit multiplied by ms) | Ramp-up time | Time for sync/re-sync |
| Ultra-deep sleep | [0.015] | For evaluation, at least for FR1 MR ultra-deep sleep state, (Ramp-up and down transition energy, ramp-up time) is as follows,  - Alt 1: (15000, 400ms) as baseline  - Alt 2: (40000, 800ms)  Company to report which alternative they use for which use cases. | | For MR, at least for FR1 evaluation,  - Number of SSBs for sync/re-sync for MR is up to 10  - Companies to report timeline and energy consumption |

Note1:

- Ramp-up time may consist of the procedure for [main radio hardware tune on e.g., boot, memory load and etc.],

- Time for sync/re-sync consists of the procedure for [main radio to re-synchronization with the serving gNB etc.],

- FFS: X and whether/how to have different values depending on other factors, e.g., signal-to-noise ratio

- Companies can report the assumption of X in the initial evaluation.

- Ramp up and down energy includes power for ramp-up and ramp-down. Energy consumption for sync/re-sync is separately calculated.

- The total time for main radio transition from ultra-deep sleep to active/micro sleep state is the sum of ramp-up time and time for sync/re-sync.

- FFS whether/how to define ramp-down time, whether to separately describe the ramp-down energy consumption

Note 2: The power state transitions in this table refer to transitions between ultra deep sleep state and active / micro sleep state.

Note 3: The values inside of ‘[ ]’ are to be used as starting point of future study on LP-WUS.

### 6.3.2 Power model for LP-WUR (LR)

The following power model for LP-WUR is used for evaluation for FR1,

Table 6.3.2-1: Power model for LP-WUR

|  |  |  |  |
| --- | --- | --- | --- |
| Power State | Relative Power (unit) | Additional transition energy:  (unit multiplied by ms) | Ramp-up time TLR, ramp-up (ms) |
| Off[1] | 0.001 | [TLR, ramp-up \*(PON-POFF)/2]  Note: this assumes the power consumption during the transition time is sum of additional transition energy and LP-WUR OFF energy, e.g., similar definition as the additional transition energy in TR38.840 | TLR, ramp-up = FFS, and company to report TLR, ramp-up    FFS: Relation between Receiver architecture and its relative power and value of TLR, ramp-up |
| On[2] | 0.01/0.05/0.1/0.5/1/2/4  FFS: If other values are needed |

- FFS: whether further categorization/sub-categorization is needed and how.

- FFS: Mapping from values to a LP-WUR architecture or LP-WUR mode of operation

- FFS: LP-WUR power consumption values for FR2.

Note1: A unit of power is defined to be the same for main receiver and LP-WUS receiver.

Note2: The values provided is for the purpose of studying power saving gain, and the values can be further revisit and categorization depending on the receiver architecture discussion.

Note3: For LP-WUR ‘on’ state, more than one values within the above range may be used for evaluation (e.g. for a single LP-WUR architecture)

[1] Relative power unit for LP-WUR ‘off’ state, i.e., the LP-WUR does not perform monitoring

[2] Relative power unit for LP-WUR ‘on’ state, i.e., the LP-WUR performs monitoring

# 7 LP-WUR and LP-WUS Design

## 7.1 LP-WUS receiver architectures

*Editor’s note: The following SI Objective is included in this clause.*

- Study and evaluate low-power wake-up receiver architectures [RAN1, RAN4]

This clause includes the studies for LP-WUR architectures. It does not intend to mandate the implementation of any specific type(s) of LP WUR architecture at the UE. Note this does not prevent RAN4 from defining requirements for LP WUR in the normative phase.

For the study on LP WUR architecture, power consumption relative to the deep sleep state of the MR is provided.

- Deep sleep state of non-RedCap UE should be assumed

### 7.1.1 General description of receiver types

*Editor’s note: Any general description of the receiver types from RAN 1/RAN4 related conclusions*

Study at least the following three types of receiver architectures for LP-WUR:

- Architecture with RF envelope detection

- Heterodyne architecture with IF envelope detection

- Homodyne/zero-IF architecture with baseband envelope detection

- Note: The details of each type of receiver architecture are discussed separately.

- Note: Above receiver architectures are considered suitable for OOK modulation. Some of the architectures

- can be applicable for other modulations such as FSK.

#### 7.1.1.1 RF envelope detection

The architecture with RF envelope detection based on at least the following diagram for LP-WUR.

- The RF signal is converted into baseband signal directly via an RF envelope detector.

- There is no Local Oscillator (LO) and no Phase-Locked Loop (PLL).

- 1 bit or multi-bit ADC is applied.

- Some component(s), e.g., RF LNA and/or BB AMP, can be optionally applied.

- High-Q matching network and/or RF BPF [and/or BB LPF] can be used to suppress adjacent channel interference or interference from legacy NR signals and/or other LP WUS on adjacent subcarriers.

- FFS the support of band and/or carrier tuning

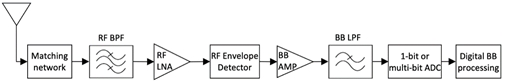


Figure 7.1.1-1: RF envelope detection based LP-WUR diagram

For the architecture with RF envelope detection,

- It can achieve relatively low power consumption due to the removal of LO/PLL.

- Interference suppression for adjacent channel interference requires very high-Q matching network and/or RF BPF, which is challenging due to the high Q values and may require off-chip components.

- Interference suppression for interference from legacy NR signals and/or other LP WUS on adjacent subcarriers, if performed in RF, requires very high-Q matching network and/or RF BPF, which is challenging due to the high Q values and may require off-chip components.

- The support of multiple bands and/or carriers may require multiple high-Q matching networks and/or RF BPFs or multiple off-chip components.

- RF LNA can be applied to improve sensitivity, with the cost of additional power consumption.

- The noise figure can be relatively high.

#### 7.1.1.2 Heterodyne architecture with IF envelope detection

The heterodyne architecture with IF envelope detection based on at least the following diagram for LP-WUR.

- The RF signal is down converted into IF signal via an RF mixer with a LO. The IF signal is converted into baseband signal via an IF envelope detection.

- There may be one or multiple IF stages depending on design.

- The choice of the LO is one of the major factors that determines the power consumption.

- Lower power consumption can be achieved by relaxing the accuracy and stability requirements of the LO. However, such increased frequency offset and phase noise should be taken into account in the design and evaluation.

- FLL (frequency locked loop) may replace PLL for non-coherent detection.

- 1-bit or multi-bit ADC is applied.

- High-Q matching network and/or RF BPF and/or IF BPF [and/or BB LPF] can be used to suppress adjacent channel interference or interference from legacy NR signals and/or other LP WUS on adjacent subcarriers.

- Some component(s), e.g., RF LNA and/or IF AMP and/or BB AMP, can be optionally applied.

- Image rejection filter or an image rejection mixer is required.

- FFS the support of band and/or carrier tuning

- FFS the choice of IF frequency range

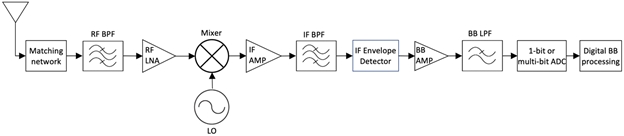


Figure 7.1.1-2: Heterodyne architecture with IF envelope detection based LP-WUR diagram

For heterodyne architecture with IF envelope detection,

- For the support of band and/or carrier tuning, the band and/or carrier tuning can be achieved via tuning the LO frequency.

- The matching network and RF BPF for LP WUR may or may not reuse those of the main radio.

- It is more effective and less complex to use IF BPF instead of high-Q matching network and/or RF BPF to suppress adjacent channel interference or interference from legacy NR signals and/or other LP WUS on adjacent subcarriers.

- Using FLL instead of PLL consumes less power, but it may result in larger frequency error.

- The IF frequency can be properly selected to avoid LO leakage (DC offset) and flicker (1/f) noise.

- Image rejection can be done via either image rejection filter or image rejection mixer.

- Image rejection filter can be done in either RF or IF, which may require high-Q filter.

- Image rejection mixer requires two-branch (I/Q) mixing with good matching in gain and phase, which consumes additional power.

- RF LNA and/or IF AMP can be applied to improve sensitivity, with the cost of additional power consumption.

#### 7.1.1.3 Homodyne/zero-IF architecture with baseband envelope detection

The homodyne/zero-IF architecture with baseband envelope detection based on at least the following diagram for LP-WUR.

- The RF signal is directly down converted into baseband signal via an RF mixer with a LO.

- Baseband envelope detection can be done either in analog domain or in digital domain depending on design, which is not explicitly shown in the diagram.

- The choice of the LO is one of the major factors that determines the power consumption.

- Lower power consumption can be achieved by relaxing the accuracy and stability requirements of the LO. However, such increased frequency offset and phase noise should be taken into account in the design and evaluation.

- FLL (frequency locked loop) may replace PLL for non-coherent detection.

- 1-bit or multi-bit ADC is applied.

- High-Q matching network and/or RF BPF and/or BB BPF [and/or BB LPF] can be used to suppress adjacent channel interference or interference from legacy NR signals and/or other LP WUS on adjacent subcarriers.

- No image rejection filter is required.

- Some component(s), e.g., RF LNA and/or BB AMP, can be optionally applied.

- FFS the support of band and/or carrier tuning

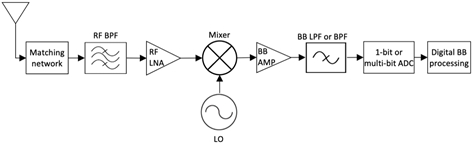


Figure 7.1.1-3: Homodyne/zero-IF architecture with baseband envelope detection based LP-WUR diagram

For homodyne/zero-IF architecture with baseband envelope detection,

- For the support of band and/or carrier tuning, the band and/or carrier tuning can be achieved via tuning the LO frequency.

- The matching network and RF BPF for LP WUR may or may not reuse those of the main radio.

- It is more effective and less complex to use BB BPF/LPF instead of high-Q matching network and/or RF BPF to suppress adjacent channel interference or interference from legacy NR signals and/or other LP WUS on adjacent subcarriers.

- Using FLL instead of PLL consumes less power, but it may result in larger frequency error.

- It can suffer from LO leakage (DC offset) and flicker (1/f) noise. The impact may be alleviated by using BB BPF in some cases.

- RF LNA can be applied to improve sensitivity, with the cost of additional power consumption.

- The baseband envelope detection can be done in either analog domain (before ADC) or digital domain (after ADC).

#### 7.1.1.4 FSK receiver

Two examples for FSK receiver architectures are shown below:

- Example 1: parallel OOK receivers and a comparator circuit, e.g.,

- Each path can be implemented using either of [the architecture with RF envelope detection,] heterodyne architecture with IF envelope detection, or homodyne/zero-IF architecture with baseband envelope detection.

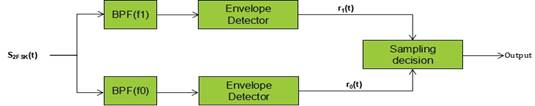
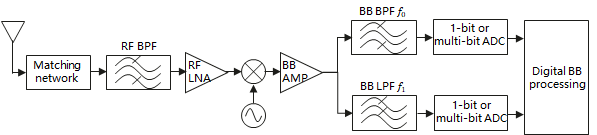


Figure 7.1.1-4: FSK receiver with parallel OOK receivers and a comparator circuit based LP-WUR diagram

Study the parallel receiver architectures (as examples that can be captured in the TR) for FSK based on the following diagrams:

- Parallel homodyne architecture



- The observations made for homodyne/zero-IF architecture with baseband envelope detection in RAN1#110b/111 are also applicable here.

- Parallel heterodyne architecture

A picture containing text, night sky

Description automatically generated

- The observations made for heterodyne architecture with IF envelope detection in RAN1#110b/111 are also applicable here.

- Note: Other architectures are not precluded.

- The OOK receiver architectures agreed for study in RAN1#110bis-e are also examples that can be captured in the TR

- Example 2: using an FM-to-AM detector [or an FM detector]

- Alt 1: Use an analog FM-to-AM detector with a similar architecture as for OOK (e.g. heterodyne or zero-IF architecture), except that the envelope detector is replaced by a FM-to-AM detector.

- Analog FM-to-AM detector can be implemented at least in BB or low-IF.

C:\Users\11048224\AppData\Local\Temp\ksohtml34372\wps6.jpg

Figure 7.1.1-5: FSK LP-WUS receiver with FM-AM detector- Alt 1

- Alt 2: Use a FM-to-AM detector [or an FM detector] implemented in digital domain after ADC, with a heterodyne or zero-IF architecture.

- Digital FM-to-AM detector implementation can be considered as part of digital baseband processing.

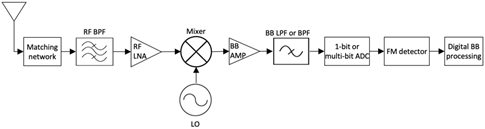
- Here is an example of using zero-IF architecture: ****

Figure 7.1.1-6: FSK LP-WUS receiver with FM-AM detector - Alt 2

- The FM-AM detector can be implemented using a frequency discriminator, which converts frequency variations into amplitude changes. It can be implemented in either analog domain (as in Alt 1) or digital domain (as in Alt 2).

- One example, as shown in the figure below, is a conventional quadrature FM discriminator. It multiplies received frequency modulated signal with a phase shifted version, followed by a low pass filter. The amplitude of the output signal is proportional to the frequency of the input signal.

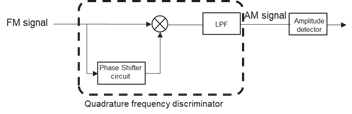


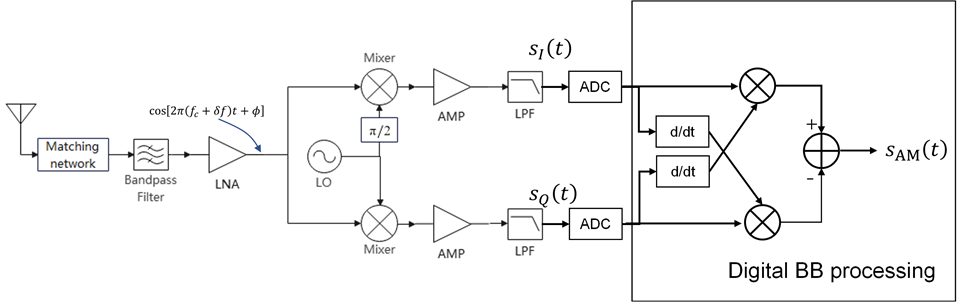
Figure 7.1.1-7: FSK LP-WUS receiver with FM-AM detector by using a frequency discriminator

- Note: Other architectures are not precluded.

Study the receiver architectures (as examples that can be captured in the TR) for FSK with frequency to amplitude conversion based on the following diagrams:

- Homodyne architecture with frequency to amplitude conversion

- I/Q branches are required for frequency to amplitude conversion in digital BB.



- Heterodyne architecture with frequency to amplitude conversion

Diagram

Description automatically generated

- Companies provide the exact type of frequency to amplitude conversion being ~~is~~ studied.

- Note: Other architectures are not precluded.

Observation for FSK with frequency to amplitude conversion:

- The FSK architectures with frequency to amplitude conversion is applicable to single-SC FSK, but it may be challenging to make the frequency to amplitude conversion work well with multi-subcarrier FSK.

- Note: single-SC FSK refers to the waveform where each frequency segment has a single subcarrier, and multi-subcarrier FSK refers to the waveform where each frequency segment has multiple subcarriers, as described in the agreements for FSK-1 and FSK-2.

#### 7.1.1.5 OFDMA-based signals/channels detection

For OFDMA-based signals/channels, study the receiver architectures based on the following diagrams:

- I/Q branches are required for digital BB processing.

- Digital BB processing may or may not include FFT (companies to provide details on how).

- For sequence-based OFDM signals/channels, digital BB processing includes sequence correlation in either time domain (without FFT) or frequency domain (after FFT).

- Proponent companies should at least provide details on power consumption reduction compared to the MR regarding the RF and digital BB processing.

- Companies are encouraged to provide the break-down for the components.

- The potential power reduction compared to the main radio may come from e.g.:

- Lower performance LNA/amplifier

- Oscillator/PLL with relaxed performance requirements

- ADC with lower sampling rate and smaller bit-width

- Reduced BB processing complexity compared to the MR

- Companies are encouraged to provide the performance analysis corresponding to the considered power consumption considering the impact of e.g. phase noise, I/Q mismatch.

- Companies to report whether the LP WUR is assumed to share components with MR. In case of component sharing, the potential impact on the MR ultra-deep sleep state should be considered.

- Companies to report the possible number of information bits

- In addition, companies should consider the power consumption in the OFF state and the transition energy.

Diagram

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### 7.1.2 [RAN4 studies of the receiver]

*Editor’s note: RAN4 related conclusions*

## 7.2 LP-WUS design and L1 procedure

*Editor’s note: The following SI Objective related to LP-WUS design and L1 procedure is included in this clause.*

- Study and evaluate wake-up signal designs to support wake-up receivers [RAN1, RAN4]

- Study and evaluate L1 procedures and higher layer protocol changes needed to support the wake-up signals [RAN2, RAN1]

- When evaluating and/or comparing link performance of MC-ASK, MC-FSK, and CP-OFDMA waveforms of LP-WUS at least

- raw information bit-size

- Alt 1:

- average EPRE within the [time]/frequency resources used for LP-WUS (including any guard bands)

- time/frequency resources used for LP-WUS (including any guard bands)

- Alt 2:

- average EPRE within the [time]/frequency resources used for LP-WUS (including any guard bands)

- FFS: false alarm probability/rate

- FFS: misdetection probability/rate

are kept [comparable or fixed].

- Study at least

- impact of timing error

- impact of frequency error

- impact of phase noise and I/Q imbalance, if applicable

- impact of ADC resolution and sampling rate

- impact of interference

- impact of delay spread

- impact of doppler spread

- Companies to report

- how they modelled SINR

- SNR is calculated as average EPRE divided by power of noise [and interference].

- whether and how power pooling across and within MR OFDMA symbols is used.

- FFS: PAPR applicable to LP-WUS

- time/frequency resources (including any guard bands) for the scheme

- false alarm probability/rate and misdetection probability/rate

- receiver architecture type and its relative power consumption

- When comparing waveforms of LP-WUS, consider the impact to gNB for each of the waveform generation schemes. Consider whether there is impact to PAPR and a need for additional hardware for WUS.

### 7.2.1 Signal design

#### 7.2.1.1 Waveform

- Study generation and link performance of multi-carrier (MC)-ASK (including OOK) waveform

- Study techniques to generate waveform by modulating sub-carriers of CP-OFDM symbol, consider up to M bits transmitted per OFDM symbol, where M is FFS.

- Note that above does not preclude DFT-S-OFDMA

- Study generation and link performance of multi-carrier (MC)-FSK waveforms

- Study techniques to generate waveform by modulating sub-carriers of CP-OFDM symbol symbol, consider up to M bits transmitted per OFDM symbol, where M is FFS.

- Study link performance of OFDMA-based signals/channels considering at least the existing signal/channel structure (e.g. CSI-RS, SSS)

- Other signal/channel structures are not precluded

For MC-ASK or MC-FSK waveform generation, SCS of a CP-OFDM symbol used for LP-WUS generation can be the same as SCS used for other NR transmissions in CP-OFDM symbol overlapping in time with, study whether SCS can be different, also study

- FDM/TDM multiplexing with other NR transmissions

- link performance

- impact to legacy UEs

- impact on gNB

##### 7.2.1.1.1 MC-ASK waveform

For MC-ASK waveform generation, where K is size of iFFT of CP-OFDMA, N is number of SCs used by LP-WUS including potential guard-bands, study further

- Option OOK-1: Single-bit in 1 OFDM symbol, SCs of LP-WUS are

- OOK=1 means all SCs are modulated

- OOK=0 means all SCs are zero power (from base-band point of view)



- Option OOK-2: Parallel M-bit OOK in frequency domain,

- N SCs of LP-WUS is further separated into M segments (M=2 in Figure) possibly with guard-bands in-between and/or around

- OOK=1 means all SCs in segment are modulated

- OOK=0 means all SCs in segment are zero power (from base-band point of view)

- FFS architecture.



- Option OOK-3: Multi-tone single-bit OOK

- N SCs of LP-WUS is separated into L segments (L=2 on Figure) without guard-bands in-between segment, but possibly around

- OOK=1 means 1 sub-carrier (known by UE) of each segment is modulated, rest of SC is zero power (from base-band point of view)

- OOK=0 means all SCs in all segments are zero power (from base-band point of view)

- FFS architecture



- Option OOK-4: Transform M-bit OOK in time domain

- N SCs of OOK-1 are generated by a transformation (DFT/Least square)

- N’ samples are generated from M-bits

- signal modification may or may NOT be used

- truncation or other additional modification may or may NOT be used, if not used, N is the same as N’

- N’ can be the same as K



- FFS modulated SCs are e.g. QAM symbols, sequences or other signals

- Companies to report their assumptions

- potential guard-band SCs are zero power (from base-band point of view)

- [optionally, 2 additional segments, one always modulated and one always zero power (from base-band point of view) can be transmitted]

- Other options are not precluded (e.g. OOK-1 with multiple bits in one OFDM symbol)

OOK-2 can be received using the agreed receiver architectures for OOK with parallel envelope detection.

Study further methods to modulate input signal of the DFT/Least-Square block for OOK-4, and methods to modulate input signal of N SCs for other MC-ASK/FSK schemes

- Study methods with respect to

- improving frequency diversity by flattening the spectrum, frequency repetition and frequency hopping

- impact to dynamic range of RE power in frequency domain

- FFS: impact to PAPR of generated time domain modulated MC-ASK/FSK symbol

- improving robustness to timing error necessary spectrum adjustment for compatibility with CP-OFDM generation

##### 7.2.1.1.2 FSK waveform

For M-bit MC-FSK generation study further the following options

- Option FSK-1: N SCs of LP-WUS are separated to M pairs of segments with potential guard-bands in-between and around.

- segment comprises one sub-carrier or multiple contiguous SCs

- in a pair of segments one segment is modulated, other segment is zero power (from base-band point of view)

- Option FSK-2: N SCs of LP-WUS are separated to 2^M segments with potential guard-bands in-between and around.

- segment comprises one sub-carrier or multiple contiguous SCs

- one segment from 2^M segments is modulated, other segments of SCs are zero power (from base-band point of view)

- M >0

- N >1

- Study how to generate segment in time domain, e.g. OOK-1 or OOK-4

- Other options are not precluded.

#### 7.2.1.2 Bandwidth and location

For the purpose of study, the BW of one LP-WUS is not greater than X (FFS X is 5 or 20) MHz for FR1, study further

- whether BW of LP-WUS is configurable (implicitly or explicitly)

- size of guard band [FFS: within or outside of BW X], if any

- whether there is different X for Idle, Connected, Inactive modes

FFS: Whether FR2 is included in the scope of LP-WUS SI

- From RAN1 perspective, LP-WUS and signals/channels used by MR can be within the same FR1 band.

- At least LP-WUS and signals/channels by MR can be on the same carrier in the band

- Study further

- Whether LP-WUS and signals/channels used by MR can be different carriers in the band

- Details on the LP-WUS location within a carrier

- Band can be different than band of signals/channels used by MR

- LP-WUS association with BWP

- LP-WUS can be configurable within guard-band of a band (like NB-IoT)

- Study RRC connected mode LP-WUS BW, whether same as IDLE/Inactive mode or different

At least for IDLE/Inactive mode, at least one BW-size <=5MHz is recommended to be supported for FR1

- Other BW sizes are not precluded

- if additional BW-size(s) are recommended to be supported, BW-size can be up to 20MHz

- LP-WUS bandwidth size (including guard-bands) is assumed to be an integer number of PRBs

#### 7.2.1.3 LP-WUS content

- For IDLE/INACTIVE mode study at least following candidates for content of LP-WUS

- information on which user(s) is/are targeted by the LP-WUS

- e.g. UE-group, -subgroup or -ID

- FFS: cell information

- FFS: SI change and ETWS/CMAS information, tracking area information, and RAN area information

- For CONNECTED mode, study at least following candidates for content of LP-WUS

- information on which user(s) is/are targeted by the LP-WUS

- e.g UE-group, -subgroup or -ID

- indication to wake-up to PDCCH monitoring.

- Other information candidates are not precluded

- Study pros and cons of including above information to LP-WUS.

- Note: the information may be explicitly or implicitly indicated.

- Study further following alternatives to carry the LP-WUS information using:

- Alt 1: by sequence(s) detection/selection

- FFS sequence type

- Alt 2: by encoded bits

- FFS: what type of encoding scheme

- FFS: with or without other bits (e.g. CRC/FCS)

- Other alternatives are not precluded

- Study whether LP-WUS information needs to be preceded by known one or more sequence(s).

### 7.2.2 L1 procedures

#### 7.2.2.1 RRM measurements

Study potential measurement metric used for RRM measurements performed by LP-WUR.

- examples of measurement metric are signal quality, signal power, detection rate of LP-WUS/synch signal

- companies to report assumption of signal used for measurements

**RRC IDLE/INACTIVE mode**

For a UE support LP-WUR in IDLE/INACTIVE mode,

- Study how to reduce UE power consumption due to existing RRM measurement requirements at least for mobility support,

- study feasibility of RRM measurements performed by LP-WUR, at least for serving/camping cell, based on signals detected by LP-WUR

- FFS: measurement metric

- FFS: whether and how to identify cell/ tracking area

- FFS: need for neighbouring cells

- FFS: need for relaxation of existing RRM measurement requirements (for UE)

**RRC CONNECTED mode**

- For RRC connected mode, the following is assumed for LP-WUS study in RAN1

- RLM/BFD/CSI are performed by UE Main Radio (MR)

- RRM measurements are performed by UE Main Radio (MR)

- Ultra-deep sleep state is not allowed for MR.

- Study additional support of RRM measurement by LP-WUR for RRC connected mode

#### 7.2.2.2 Synchronization of LP-WUR

Study synchronisation signal used by LP-WUR, if needed, based on

- Option 1: aperiodic signal transmitted as part of LP-WUS

- FFS: Whether the signal can additionally be transmitted separately from LP-WUS

- Option 2: periodic signal transmitted separately from LP-WUS

- Option 3: Option1 + Option2

#### 7.2.2.3 LP-WUS monitoring

Study further pros and cons of the following monitoring behaviours of LP-WUR

- Option1: Duty cycle, corresponds to LP-WUR switches between ON/OFF states

- Option2: Continuous monitoring, corresponds to LP-WUR is ON all the time

#### 7.2.2.4 Activation/Deactivation procedures of LP-WUS

Study RRC connected mode LP-WUS activation/deactivation procedures.

#### 7.2.2.5 Coverage

- Study techniques/mechanisms to enhance coverage performance of LP-WUS

- Study potential gains available as well as drawback(s) of the technique(s)/mechanisms(s), e.g. system overhead, increased complexity network energy consumption etc…

- Study potential issues and corresponding solutions for the case when LP-WUS coverage is insufficient

- At least study fallback mechanisms where the Main Radio switches to legacy operation in case the channel condition of LP-WUS is not sufficient, e.g. below threshold.

#### 7.2.2.6 void

#### 7.2.2.7 void

#### 7.2.2.8 void

#### 7.2.2.9 Others

- Study RRC connected mode LP-WUS functionality/purpose/procedures

- In RRC connected, study the relationship between LP-WUS and legacy UE power saving techniques.

## 7.3 Higher-layer aspects

*Editor’s note: The following SI Objective related to higher layer aspects is included in this clause.*

- Study and evaluate L1 procedures and higher layer protocol changes needed to support the wake-up signals [RAN2, RAN1].

### 7.3.1 RRC\_IDLE/INACTIVE mode

#### 7.3.1.1 IDLE/INACTIVE mode procedures

In RRC\_IDLE and RRC\_INACTIVE states, UEs shall perform idle/inactive mode procedures defined in TS 38.304 and TS 38.331, which specify how UEs shall monitor paging, keep system information up to date, receive ETWS/CMAS information, and perform RRM measurements and corresponding cell selection/re-selection to ensure that UE is camping on the strongest cell. These procedures may need to be modified to accommodate operation using LP-WUS/WUR. To avoid unnecessary control signalling overhead, Idle/Inactive mode procedures should not rely on signalling between UE and gNB unless there is paging for the UE. *[The same principle should apply for LP-WUS/WUR operation…]*

Editor's Notes: FFS whether there is need for the network to be aware of whether the UE is monitoring LP-WUS or not.

The corresponding pros/cons for whether there is necessarity for the network/gNB to be aware of whether an Idle/Inactive UE is monitoring LP-WUS or not are listed as below:

**Table X: Pros and Cons for network awareness of using LP-WUS**

|  |  |  |
| --- | --- | --- |
|  | Network knows whether UE monitors LR or MR | Network does not know whether UE monitors LR or MR |
| Pros | Reduce Uu resource consumption:  NW only sends LP-WUS when the target UE is monitors LP-WUS;  Lower false wake-up rate:  When LP-WUS is not sent, the other UE monitoring LP-WUS, which is in the same group with the target paging UE, will not be waken up as a result of false wake up. | Since the UE needs not to inform the NW whether its MR is monitoring or not, the  signalling overhead, Uu resource consumption, UE power consumption caused by MR state report does not exist. |
| Cons | More signalling overhead:  UE needs to inform the NW when it starts/stops monitoring with MR.  Uu resource consumption caused by more signalling overhead.  More UE power consumption caused by more signalling overhead. | More Uu resource consumption：NW always send LP-WUS signal given it always assume the target UE is monitoring the LP-WUS.  More alarm rate of LP-WUS: in case the target UE is not monitoring LP-WUS, the other UE (monitoring the same LP-WUS as the target UE) will be waken up. |

#### 7.3.1.2 Power saving state

With LP-WUS/WUR, the Main Receiver (MR) of a UE could enter ultra-deep sleep state, which denotes a state when the MR may sleep or turn off. Such ultra-deep sleep state could be entered when predefined condition (e.g. quality of LP-SS and/or SSB is better than the threshold ) is fulfilled. In principle, a new (sub-)state, RRC or other, for operation using LP-WUS/WUR could be introduced. A sub-state to RRC\_IDLE like the one used for Mobile Initiated Communication Only (MICO), where both monitoring of the downlink and RRM measurements are stopped until there is a subsequent uplink transmission, is however not feasible for LP-WUS/WUR. This since the point with LP-WUS/WUR is to reduce UE power consumption while maintaining some downlink monitoring functionality, and this is not possible if either the UE stops monitoring in downlink or if the UE does not detect that it has moved into a new cell/area and therefore apply the incorrect configuration for downlink monitoring. According to TS 38.300, the functionality to be supported over Uu interface in RRC\_IDLE and RRC\_INACTIVE includes PLMN selection, SI reception, cell re-selection mobility, and paging, etc. Therefore, it is feasible to introduce LP-WUS/WUR as a power saving feature for RRC\_IDLE and RRC\_INACTIVE, while ultra-deep sleep state as a power saving state for RRC\_IDLE and RRC\_INACTIVE.

#### 7.3.1.3 LP-WUS monitor and wake up procedure

Paging reception in RRC\_IDLE and RRC\_INACTIVE is supported both with discontinuous reception (DRX), and from Rel-17 and Rel-18, respectively, with extended DRX (eDRX). LP-WUS/WUR could also be supported with or without duty-cycled operation, i.e., as ‘continuous’ or as ‘duty-cycled’. Since the LP-WUS/WUR feature is introduced to lower the UE energy consumption, it is for these two options feasible to introduce support for the LP-WUR option which can introduce the greatest UE energy consumption reduction compared to baseline as discussed above in section 6. If the gain is similar, the magnitude of implementation complex, specification impact, and latency impact should be the determining factors for which LP-WUR option to support.

Currently, the paging monitoring in Idle/Inactive mode is based on the configured I-DRX, as well as PEI is also designed as ‘duty-cycled’ associated with legacy PO. There may be more specification impact on TS 38.304 for ‘continuous’ than ‘duty-cycled’ (for which PEI text could be considered as to be reused). While, a potential benefit of ‘continuous’ is shorter downlink latency. That is, since the UE monitors the downlink continuously the downlink latency could potentially be shorter.

Due to the transition time to start up the main receiver however, LP-WUR operation may always have worse latency performance than legacy, i.e., comparing to legacy continuous monitoring or DRX. ‘Continuous’ could still provide shorter downlink latency compared to ‘duty-cycled’, comparing at the same UE energy consumption reduction gain. This however depends on the UE procedure triggered by LP-WUS and the LP-WUS payload content and size. *[FFS That is, if a unique UE identifier can be included in the LP-WUS payload, e.g., the 48-bit 5G-S-TMSI or 24/40-bit I-RNTI, a UE need not monitor paging in the PO after waking up via LP-WUS but can directly from the WUS reception determine that it is being paged and immediately trigger access establishment. For ‘continuous’, the achievable downlink latency is in this case therefore determined by the PRACH resource periodicity, and if this periodicity is shorter than the periodicity for downlink monitoring applied for ‘duty-cycled’, there could be latency gain proportional to this difference. However, including such a large payload in LP-WUS can be challenging for LP-WUS link performance and coverage.]* *[If a unique UE identifier cannot be included in the LP-WUS payload, the UE cannot directly from the LP-WUS reception determine that itself, and not another UE, is being paged].*

Editor's Notes: FFS Alt 2: UE could perform random access directly, FFS on whether and what condition/requirement is needed. R2 assumes that this require that LP-WUS includes UE\_ID or equivalent. (Depends on LP-WUS capacity to carry information)

On one hand, after waking up by LP-WUS, the legacy paging monitoring procedure should be triggered for the main receiver. That is, if the UE detects LP-WUS it would start up its main receiver to monitor legacy paging, i.e., the PDCCH scheduling of the paging message on PDSCH, and at first after finding its own *PagingRecord* in the paging message the UE could determine that it is being paged (similar to Rel-15 WUS for NB-IoT/LTE-M or Rel-17 PEI). In this case, the downlink latency will be determined by the periodicity of the legacy paging occasions (POs).

* In some case, ‘continuous’ may not have latency benefit compared to ‘duty-cycled’. That is, even if LP-WUS is immediately received using ‘continuous’ the UE might anyway need to wait for the subsequent PO (i.e., maybe a same PO as if ‘duty-cycled’ is used).
* In some other case, the beneficial part comes from the margin that LP-WUS could be received earlier in case ‘continuous’ than ‘duty-cycled’, which would wake up the main receiver earlier and an earlier PO will be monitored by main receiver after waking up by LP-WUS.

On the other hand, after waking up by LP-WUS, the main receiver could also monitor legacy PEI defined in Rel-17, if it is configured by network and it is supported by UE. Especially for the case that LP-WUS doesn’t have full coverage as legacy signalling, e.g. SSB, main receiver needs to wake up to perform legacy operation out of LP-WUS coverage. In this case, network could still configure PEI for the use of fallback mechanism to save UE power consumption for paging monitoring. It means, the network would configure and transmit both LP-WUS and PEI for the UE, especially when the network is not aware of UE’s entry/exit of LP-WUS monitoring. From UE perspective, LP-WUS could be used together with PEI if both LP-WUS and PEI are configured, to achieve more power saving gain.

Editor's Notes: FFS details on using LP-WUS and PEI together, e.g. subgrouping

After waking up from LP-WUS, in case UE needs to monitor PO, the time offset between LP-WUS and the PO should be long enough to include the transition time to start up the main receiver to be ready for PDCCH monitoring, which depends on the design of LP-WUR and the detailed procedure after waking up. Besides, in order to monitor PO after waking up from LP-WUS, the mapping of LP-WUS (or LP-WUS occasion) to PO may need to be defined. In the simplest case, similar as Rel-17 PEI, a LP-WUS (or monitoring occasion) could be associated with each PO. Alternatively, a LP-WUS (or monitoring occasion) could be configured to trigger the UE to monitor multiple POs, or even an entire paging time window (PTW) when using eDRX. Such mapping could increase the network flexibility and reduce signalling overhead when paging several UEs but could at the same time have a negative impact on UE energy consumption and the LP-WUR gain since upon each LP-WUS reception, false alarm, or false paging the UE would have to keep the main receiver on for a longer time. For reference, Rel-17 PEI supports mapping of up to 8 POs (configured the parameter po-*NumPerPEI)*, and Rel-15 WUS and Rel-16 GWUS for NB-IoT/LTE-M supports mapping of up to 4 POs, but only when the UE is configured with eDRX.

Furthermore, after waking up from LP-WUS, either all UEs could be triggered to wake up to monitor paging in associated PO(s), or just a subset of the UEs sharing the PO, so called LP-WUS UE subgrouping. The latter can be used to reduce the negative impact from false alarm rate for paging, i.e., unnecessary energy consumption in the UE caused by paging intended for another UE. In the latter case, LP-WUS UE subgrouping information corresponding to 2 bits or more, *[e.g. x bits]*, would have to be included in the LP-WUS payload or from the use of multiple LP-WUS signals corresponding to different subgroups, depending on the design of LP-WUS. For reference, both Rel-17 PEI and Rel-16 GWUS for NB-IoT/LTE-M support up 8 subgroups per PO (configured by the parameters *subgroupsNumPerPO* and *GWUS-NumGroups*, respectively).

Editor's Notes: The number of subgroups depends on the decision on payload of LP-WUS in RAN1.

Both these features rely on DRX and UEs already being distributed over the different POs in the cell, and the UE subgrouping therefore refers to further subgrouping of the UEs already divided into the same PO. This would be the same for ‘duty-cycled’ operation. However, for ‘continuous’, false paging could apply to all UEs in the cell since all UEs are monitoring the downlink continuously. False paging would therefore be much more severe for ‘continuous’ and a larger number of LP-WUS/WUR UE subgroups would be required to achieve the same false paging rate.

A summary of the impact from carrying a unique UE identifier in the LP-WUS payload or UE subgroup indication in the LP-WUS is given in Table 1.

**Table x: Impact from the inclusion of a unique UE\_ID or UE subgroup information in the LP-WUS payload.**

|  |  |  |
| --- | --- | --- |
|  | Unique UE\_ID in LP-WUS payload: | UE subgroup indication in LP-WUS: |
| Procedure triggered by LP-WUS reception: | *[FFS Random Access]* | Legacy monitoring of paging in PO or PEI |
| gNB transmission upon paging: | WUS  Or LP-WUS and legacy paging (PDCCH+PDSCH) e.g. in partial LP-WUS coverage | LP-WUS and legacy paging (PDCCH+PDSCH). |
| False paging: | No false paging. | False paging among all UEs in the cell using ‘Continuous’, and among all UEs sharing a PO using ‘duty-cycled’.  False paging is reduced by use of UE subgrouping and an increasing number of UE subgroups. |
| Latency impact: | *[FFS DL latency determined by PRACH resource periodicity]* | DL latency determined by DRX cycle length and PRACH periodicity. |

In Rel-17 PEI, two subgrouping methods were introduced, which includes: CN assigned and UE\_ID based subgrouping. For CN assigned subgrouping, UE's subgroup is assigned by CN taking into account the UE's characters, such as mobility pattern, paging probabilities, etc. While for UE\_ID based subgrouping, UE's subgroup is formed based on UE\_ID and the subgroup number in RAN. UE supporting CN assigned subgrouping in RRC\_IDLE or RRC\_INACTIVE state can be assigned a subgroup ID by AMF through NAS signalling. The UE belonging to the assigned subgroup ID monitors its associated PEI which indicates the paged subgroup(s). Paging with UE\_ID based subgrouping is used in the cell which supports UE\_ID based subgrouping. It is up to network configuration to determine which subgrouping should be used.

Similar as PEI, the subgrouping methods for LP-WUS could include the CN assigned, and UE\_ID based subgrouping. Details, e.g. which one/both should be supported, how to support/provide the configuration, etc., could be further determined during WI phase.

#### 7.3.1.3 LP-WUS coverage and trigger condition

The Rel-17 PEI and Rel-15 WUS for NB-IoT/LTE-M procedure works for LP-WUR if there is full LP-WUS coverage in the cell. However, LP-WUS link performance is considerably worse than legacy physical channels (e.g., PDCCH or PUSCH) there would only be partial LP-WUS coverage in the cell and the complexity of the solution will be considerably higher. That is, UE and gNB may need to keep track of when the UE moves in and out of LP-WUS coverage in the cell, this to be able to fall back to monitoring paging using the main receiver when the coverage of LP-WUS is not sufficient. The UE could determine this based on the measured RSRP, e.g., compared to an RSRP threshold in system information.

That is, UE’s MR could stay in ultra-deep sleep power state only when UE is in the coverage of LP-WUS. When UE moves out of the coverage of LP-WUS, the network cannot wake up UE’s MR via LP-WUS. Hence, UE should start up its MR when it moves out of the coverage of LP-WUS to avoid missing the paging message. In this way, one of the exit conditions for using LP-WUS or ultra-deep sleep power state should be that the UE is out of LP-WUS coverage. A quality threshold of target Reference Signal can be pre-configured to UE to define the exit condition for using LP-WUS. With this threshold, UE can stop using LP-WUS and exit the ultra-deep sleep power state when the quality of target Reference Signal is lower than the threshold.

During ultra-deep sleep or when using LP-WUS, UE’s MR may not perform measurement as legacy. Thus, in order to be applicable for all cases, the pre-configured exit condition should be based on the measurement of target Reference Signal by LR.

Editor's Notes: FFS exit condition(s) based on the measurement on MR.

Similarly, the measurements and trigger conditions would need to be defined for using LP-WUS. A most straightforward way is to define a quality threshold for the target Reference Signal measurement to determine the coverage. One entry condition for using LP-WUS could be configured to UE based on this quality threshold. From network perspective, the threshold could be set based on the coverage of LP-WUS. With this threshold, LP-WUS could be used, and UE’s MR could enter ultra-deep-sleep power state when the quality of target Reference Signal is better than the threshold.

Before entry condition is fulfilled, UE should perform legacy measurement on serving cell based on legacy SSB, e.g. for cell (re)selection purpose. Hence, it is straightforward to use the legacy SSB as the target Reference Signal for pre-configured entry condition. That is, when the quality of the serving cell’s SSB measured by MR is better than a pre-configured threshold, UE considers the entry condition is fulfilled, then, LP-WUS could be used and MR could enter ultra-deep-sleep power state for power saving. Alternatively, LP-SS could be introduced for LR measurement, the pre-condition could be also defined based on the measurement on LP-SS via LR. In this way, the target Reference Signal could be the LP-SS sent by the serving cell, i.e. when the quality of the LP-SS measured by LR is better than a pre-configured threshold, UE considers the entry condition for using LP-WUS is fulfilled. The solution requires the UE to perform measurement on LP-SS via LR before using LP-WUS. In this way, the UE needs to turn on its LR before entering ultra-deep- sleep power state, which may lead to extra power consumption, but it is not an issue as the power consumption of LR is very low.

Editor's Notes: FFS the entry/exit condition(s) of using LP-WUS is configured via RRC dedicated signalling, e.g. by RRC release.

Editor's Notes: FFS on other entry/exit condition(s) of using LP-WUS.

Editor's Notes: FFS the serving cell quality measurement on LR is based on LP-SS and/or SSB (pending RAN1 decision).

From the network perspective, if a unique UE identifier (e.g., 48-bit 5G-S-TMSI or 24/40-bit I-RNTI) is not carried in the LP-WUS payload, a gNB anyway need to always transmit both LP-WUS and the associated legacy PDCCH and PDSCH for the paging message. In this case, the gNB would in principle not need to consider whether the UE is within LP-WUS coverage in the cell or not, but in case it is not there would be some unnecessary control signalling overhead from the transmission of LP-WUS. If instead a unique UE identifier is carried in the LP-WUS payload, the gNB could either transmit LP-WUS or legacy paging depending on if the UE is within LP-WUS coverage or not. However, without any signalling from the UE upon LP-WUS coverage change, or from being in the cell or not, this would have to be done blindly and would be left to the gNB implementation (similar to paging the UE in two different cells, i.e., up to trial and error). With partial coverage, the most severe error case would be if the UE from inaccurate measurements incorrectly concludes that it is in LP-WUS coverage when it is not, and therefore becomes unreachable in the downlink (the UE only monitors using LP-WUR but is outside LP-WUS coverage).

#### 7.3.1.4 Configuration

Regarding the LP-WUS configuration, both UE and gNB must have a common understanding of when LP-WUS should be applied to avoid that UEs become unreachable in the downlink, as mentioned above in 7.2.3.1.3. Both UE and gNB could apply LP-WUS if LP-WUS has been configured in the cell in SI. This would further determine the conditions for entering and leaving LP-WUS monitoring operation as being tied to the monitoring of paging in a cell: A UE enables LP-WUS monitoring if it is configured with LP-WUS and camp on a cell in RRC\_IDLE or RRC\_INACTIVE state in which LP-WUS is configured, for example when re-selecting a cell in in which LP-WUS is configured or being released from RRC\_CONNECTED in a cell in which LP-WUS is configured. Regarding the conditions leaving LP-WUS monitoring operation, a UE would continue to apply LP-WUS monitoring until it either is de-configured with LP-WUS, the cell de-configures LP-WUS in SI, or the UE re-selects to another cell in which LP-WUS is not configured.

#### 7.3.1.5 System information update and PWS

Reception of system information (SI) broadcast and ETWS/CMAS is another Idle mode procedure which must be supported with LP-WUS/WUR. When the UE initiates the acquisition of SI, for example when SI has become outdated or upon cell change, the UE anyway needs to start up the main receiver for the reception of the SI message(s). However, this is not the case for a gNB notification of SI update and it must be possible to notify also UEs with LP-WUR about an upcoming SI change in the cell. For reference, in Rel-16 GWUS for NB-IoT/LTE-M this is done by a subgroup common to all UEs (configured by the parameter *commonSequence*), whereas for Rel-17 PEI the gNB must transmit PEI to all subgroups separately and upon the reception of PEI UEs continue to, as in legacy operation, monitor for the *systemInfoModification* and *systemInfoModification-eDRX* in the Short Messages transmitted on PDCCH using P-RNTI.

Editor's Notes: FFS to what extent UE maintains valid SI in case UE’s MR is in ultra-deep sleep state.

ETWS/CMAS is regulatory requirement for UEs supporting ETWS/CMAS. Therefore, even for UE in ultra-deep sleep, the ETWS/CMAS messages should be ensured to be reachable if the UE is capable of ETWS/CMAS. As in legacy, the gNB would upon ETWS/CMAS information need to wake up UE by LP-WUS from ultra-deep sleep.

Editor's Notes: FFS whether indicate the notification of ETWS/CMAS or SI change in LP-WUS.

#### 7.3.1.6 Mobility and RRM

To ensure a UE in RRC\_IDLE or RRC\_INACTIVE is camping on the strongest cell it needs to perform mobility measurements as specified in TS 38.304. RRM measurement for mobility includes serving cell measurements and neighbour cell measurements, which can be intra-frequency or inter-frequency (including inter-RAT) measurements. In general, the neighbour cell measurements however only need to be performed by the UE if the serving cell is not strong enough, i.e., when the intra-frequency cell re-selection criterion (Srxlev> SIntraSearchP and Squal > SIntraSearchQ) or the inter-frequency cell re-selection criterion (Srxlev > SnonIntraSearchP and Squal > SnonIntraSearchQ) is not fulfilled. For the majority of UEs, and in a well deployed network without coverage holes, it is therefore the serving cell measurements that need to be performed the most frequently, and therefore they will also have the biggest impact on UE energy consumption.

For a UE operating with LP-WUR, infrequently starting up the main receiver (MR) for neighbour cell measurements is not expected to have any significant impact on UE energy consumption. However, using the MR for serving cell measurements has a significant impact on UE energy consumption and reduce the LP-WUS/WUR gain according to the observations from the study evaluation results. This since according to Clause 4.2.2.2 in TS 38.133, serving cell measurements must be performed every or every second DRX cycle in FR1 (and somewhat more relaxed in FR2). Starting the main receiver for RRM measurements every DRX cycle removes a large part of the UE energy consumption reductions from LP-WUS/WUR.

In order to achieve the UE power saving gain by LP-WUS/WUR, the RRM measurement on serving cell and neighbouring cell via MR is relaxed or may be stopped when UE is using LP-WUS or MR is in ultra-deep sleep. In Rel-16/17 PowSav and RedCap WI, RRM measurement relaxation on neighbouring cell was introduced. But here, more relaxation or even no measurement could be considered. The relaxation on RRM measurement may impact the performance of mobility performance in RRC\_IDLE or RRC\_INACTIVE. In order to avoid or minimize such impact, the RRM measurement on LP-WUR could be considered. Thus, the above RRM measurement relaxation on serving cell and neighbouring cell should be premised on the feasibility or support of RRM measurement on LR.

Editor's Notes: FFS the details on how to perform RRM measurement relaxation on serving cell and/or neighbouring cell when UE is monitoring LP-WUS or MR is in ultra-deep sleep.

Editor's Notes: FFS the details on in which condition RRM measurement relaxation is allowed on serving cell and neighbouring cell when UE is monitoring LP-WUS or MR is in ultra-deep sleep.

Editor's Notes: FFS RRM measurement for neighbouring cell by LR as well as corresponding cell (re-) selection.

### 7.3.2 RRC\_CONNECTED mode

# 8 Evaluation results

*Editor’s note: The following SI Objective is included in this clause.*

- Study potential UE power saving gains compared to the existing Rel-15/16/17 UE power saving mechanisms and their coverage availability, as well as latency impact. System impact, such as network power consumption, coexistence with non-low-power-WUR UEs, network coverage/capacity/resource overhead should be included in the study [RAN1]

- Note: The need for RAN2 evaluation will be triggered by RAN1 when necessary.

# X Conclusions

Annex <A>:  
Simulation assumptions

Annex <X>:  
Change history

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2022-10 | RAN1#110bis | R1-2208666 |  |  |  | Baseline TR skeleton | 0.0.0 |
| 2022-10 | RAN1#110bis | R1-2210430 |  |  |  | Baseline TR skeleton after discussion | 0.0.1 |
| 2023-02 | RAN1#112 | R1-2302236 |  |  |  | Update TR and incorporating agreements for evaluation and receiver architecture from RAN1#110bis and RAN1#111 | 0.1.0 |
| 2023-05 | RAN1#113 | R1-2305954 |  |  |  | Update TR and incorporates agreements from RAN1#112 and RAN1#112bis | 0.2.0 |