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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 is a Technical Report for Rel-19 Radio Frequency (RF) requirements for Low-Power Wake-up Signal and Receiver (LP-WUS/WUR). The purpose is to gather the relevant background information and analysis to address RF requirements for LP-WUS/WUR.

This TR contains discussions and agreements for LP-WUS/WUR RF. The actual RF requirements are added to the corresponding technical specifications.

# 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 TR 38.869: "Study on low-power Wake-up Signal and Receiver for NR".

[3] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone".

[4] 3GPP TS 38.101-2: "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone"

[5] 3GPP TS 38.104: “NR; Base Station (BS) radio transmission and reception”.

# 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].

**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.

## 3.2 Symbols

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

<symbol> <Explanation>

## 3.3 Abbreviations

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

<ABBREVIATION> <Expansion>

ACS Adjacent Channel Selectivity

ADC Analog to Digital Converter

ASCS Adjacent Subcarrier selectivity

BB Base Band

BLER Block Error Rate

BPF Band Pass Filter

BS Base Station

CFO Center frequency offset

FAR False Alarm Rate

FR1 Frequency range 1

FR2 Frequency range 2

ICS In-channel Selectivity

IF Intermediate Frequency

LP-WUS Low Power-Wake Up Signal

LP-WUR Low Power-Wake Up Receiver

LP-SS Low Power- Synchronization Signal

LO Local Oscillator

LNA Low Noise Amplifier

LPF Low Pass Filter

LR LP-WUR

MDR Miss Detection Rate

MR Main Radio

NF Noise Figure

OOB Out-of-band

OOK On-Off keying

OFDM Orthogonal Frequency Division Multiplexing

RE Resource Element

REFSENS Reference Sensitivity

RF Radio Frequency

SINR Signal to Interference plus Noise Ratio

SNR Signal to Noise Ratio

UE User Equipment

Tx Transmitter

# 4 Background

<Editor’s note: general background and considerations, details TBD. >

The present document is a technical report for Rel-19 Radio Frequency (RF) requirements for Low-Power Wake-up Signal and Receiver (LP-WUS/WUR). It covers RF requirements analysis for both UE and BS side. Some initial analysis of RF aspects for LP-WUS/WUR were captured in TR 38.869 [2].

# 5 System parameters

## 5.1 General

The channel arrangements presented in this clause for LP-WUS are based on the operating bands and channel raster defined in sub-clause 5.2 and 5.3 below.

## 5.2 Operating bands

LP-WUS is designed to operate in the operating bands defined in Table 5.2-1 of TS 38.101-1 [3] and TS 38.101-2 [4], excluding bands n46, n47, n96, n102 and SDL bands.

## 5.3 Channel raster

The PRB grid between LR and MR is aligned and the LP-WUS RBs can be flexibly allocated within the wider NR carrier. How to make sure the RB alignment between LP-WUS RB and MR RB grid is aligned is UE implementation specific.

# 6 Simulation assumptions and evaluation

## 6.1 Performance metric

<Editor’s note: performance metric to specify RF requirements. >

For RF requirements and conformance testing, the performance metric is 1% MDR. Meanwhile, the FAR assumption for MDR evaluation is </=1%.

## 6.2 Simulation assumption

### 6.2.1 General

To evaluate the RF performance of LP-WUS/WUR, the link level simulation is performed in this WI. This clause captures the simulation assumption for LP-WUS UE RF and BS RF analysis.

### 6.2.2 Simulation parameters

For RF performance analysis, the following simulation assumptions are considered.

Table 6.2.2-1 General Link level simulation assumption for FR1 LP-WUR

| Attributes | Assumptions |
| --- | --- |
| Waveform | OOK-4 waveform |
| Center frequency | 900MHz, 2.6GHz and 3.5GHz |
| Channel structure | 5 bits |
| RM coding | 8/16/32bit for OOK |
| CRC | NO |
| Chip rate | M=4 |
| overlaid OFDM sequence | 4 candidates overlaid sequences for M=4 |
| WUS duration | OOK：RM coding length\*2/M  OFDM：ceil(5/log2(4)/(M/2)) |
| Coding | 1/2 rate Manchester coding |
| Time error | 0/0.9 us |
| Residual Frequency error | 0/10/20 ppm |
| SCS | 30kHz |
| UE Channel BW | 20MHz (51 RB)-case 1  10MHz (24 RB)-case 2  5MHz (11 RB)-case 3 |
| WUS RB | - Fixed 11RB ~ 3.96MHz for 10MHz and 20MHz cases |
| Position within channel | - For 10/20MHz CBW, Center for ASCS, edge for ACS [assume no ASCS impact]  - For 5MHz CBW, fixed center of channel |
| Guardband of NR channel, both wanted cell and interfer cell (ACS) | - For wanted signal: 505kHz for 5MHz, 665kHz for 10MH, 805kHz for 20Mhz  - For interference cell2 5MHz: fixed 505kHz |
| Guard RB | For ASCS: 0 or 1RB on each side of LP-WUS bandwidth  For ACS: 1/2/3/4 RB |
| Filter | 3th/5th Order lowpass Butterworth matching fixed 3.96MHz RF bandwidth for 10MHz/20MHz case  - Other order lowpass filter is not precluded  The filter bandwidth is adapted with actual WUS RBs, for 5MHz case |
| ASCS | PDSCH mapped on RBs not used for LP-WUS and Guard RB;  EPRE of PDSCH /EPRE of LP-WUS = 0 dB  Same PSD with WUS signal |
| ACS | PDSCH mapped on interference RBs (11RB for 5MHz CBW), one side;  EPRE of PDSCH /EPRE of in-band LP-WUS = [20~33] dB  NOTE: decide the interference level depending on SNR |
| Wanted signal level | For ACS, REFSENS + 14 dB for LP-WUS as baseline, different wanted power level can be also considered |
| Sampling rate | 7.68MHz |
| ADC bit width | 4/8 bits ADC for ASCS/ACS  Encourage companies to provide simulation results with both options for comparison |
| Phase noise | Reciprocal mixing can be optionally considered for ASCS/ACS. Note that actual implementation choice of phase noise is driven by jammer requirement and power consumption target. |
| Non-linearities | Not modelled |
| Power boosting | EPRE ratio: 0dB/3dB for OOK-1/OOK-4  NOTE: 3dB is optional for simulation |
| Channel Model | AWGN |
| Performance metric | - 1% MDR  - false alarm rate 1% as side condition |
| Note: The detailed Receiver algorithm is UE implementation . | |

## 6.3 Simulation evaluation results

<Editor’s note: detailed simulations from each company. FFS detailed structure for each RF requirement>

6.3.1 General

To evaluate some RF performance, link level simulations are performed to collect analysis input.

6.3.2 SNR simulations

In this sub-clause, SNR simulation results from different companies are collected for analysis of target SNR for LP-WUR.

Table 6.3.2-1 SNR simulation summary for FR1 Envelop-detection LP-WUR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Companies Input | SNR | RM coding | ADC | Filter order | Timing error | Note |
| A |  |  |  |  |  |  |
| B |  |  |  |  |  |  |
| C |  |  |  |  |  |  |
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Observations and Summary of SNR simulation outcome for envelop-detection receiver: TBA

Table 6.3.2-2 SNR simulation summary for FR1 OFDM-based LP-WUR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Companies Input | SNR | RM coding | ADC | Filter order | Timing error | Note |
| A |  |  |  |  |  |  |
| B |  |  |  |  |  |  |
| C |  |  |  |  |  |  |
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Observations and Summary of SNR simulation outcome for OFDM-based receiver: TBA

6.3.3 ASCS simulations

In this sub-clause, ASCS simulation results from different companies are collected for analysis of in-band interference performance of LP-WUS. This is for information only, because actual implementation choice of filtering is driven by jammer requirements.

Table 6.3.3-1 ASCS simulation summary for FR1 Envelop-detection LP-WUR

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Companies Input | SNR degradation | Guard RB | RM coding | ADC | Filter order | Timing error | Phase noise | Note |
| A |  |  |  |  |  |  |  |  |
| B |  |  |  |  |  |  |  |  |
| C |  |  |  |  |  |  |  |  |
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Summary of ASCS simulation outcome: TBA

Table 6.3.3-2 ASCS simulation summary for FR1 OFDM-based LP-WUR

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Companies Input | **SNR degradation** | **Guard RB** | **RM coding** | **ADC** | **Filter order** | **Timing error** | **Phase noise** | **Note** |
| A |  |  |  |  |  |  |  |  |
| B |  |  |  |  |  |  |  |  |
| C |  |  |  |  |  |  |  |  |
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6.3.4 ACS simulations

In this sub-clause, ACS simulation results from different companies are collected for analysis of ACS performance of LP-WUR. It was agreed that the interference level of LP-WUR ACS is the same as MR, for both type1 and type 2 LP-WUR. This is for information purpose only, because ACS requirements are driven by agreed coexistence requirements applied to the LR.

Table 6.3.4-1 ACS simulation summary for FR1 Type-1 LP-WUR

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Companies Input | Detection | ACS | Guard RB | Interference level | Wanted signal level | Filter order | Timing error | Phase noise | Note |
| A | Envelop detection |  |  |  |  |  |  |  |  |
| OFDM |  |  |  |  |  |  |  |  |
| B | Envelop detection |  |  |  |  |  |  |  |  |
| OFDM |  |  |  |  |  |  |  |  |
| C | Envelop detection |  |  |  |  |  |  |  |  |
| OFDM |  |  |  |  |  |  |  |  |
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Summary of ACS simulation outcome: TBA

6.3.5 FR2 simulations

6.3.6 Other aspects

# 7 RF requirements

## 7.1 UE RF

<Editor’s note: discussions and analysis for UE RF requirements related. Mainly focus on key aspects and conclusions, rather than detailed simulations from each company>

### 7.1.1 General

The minimum requirements will be determined assuming there is only one receiver. A 1% MDR criterion will be used for verification of all core RF requirements. Following LP-WUS parameters will be used

**Table 7.1.1-1. Common reference channel parameters**

|  |  |  |
| --- | --- | --- |
| Parameter | Unit | Value |
| MR Channel bandwidth | MHz | All CBW |
| LP-WUS bandwidth | RB | 11 |
| Subcarrier spacing | kHz | 15/30kHz |
| RM coding | Bits | 16 |
| CRC |  | No CRC |
| Chip rate |  | M=4 (4 chips in an OFDM symbol) |
| Overlaid OFDM sequence |  | Length 33: generated by 31-length ZC sequence with extension |
| Number of overlaid OFDM sequence per chip to carry information |  | 4 |
| WUS duration for OOK |  | 8 OFDM symbols |
| WUS duration for OFDM |  | 2 OFDM symbols |
| Manchester coding for OOK |  | 1/2 |
| Number of information bits | Bits | 5 |

In the specification, tables will be defined corresponding to 15 KHz and 30 KHz SCS.

### 7.1.2 Rx SNR evaluations

To derive SNR performance of LP-WUS, it was agreed to select OOK-4 M=4 under AWGN channel model with 1% MDR without repetition as worst case.

### 7.1.3 Architecture and NF considerations

The basic architecture considered for the LP\_WUR is a zero-IF architecture for both envelope and sequence based detectors. This assumption is common for both FR1 and FR2. This is just an assumption made to derive parameters which dictate the requirements. This assumption does not preclude any other RF implementations.

In case of FR1, only single RX is assumed. For FR2 requirement derivation, the baseline assumption is an OFDM based receiver with two receiver chains with mutually orthogonally polarized antennas.

In RAN4, there had been no consensus on what IM includes, and no agreement was achieved on individual values of NF and IM, so a joint number was agreed. There are two sets of NF + IM values agreed, and these will be used for REFSENS calculations. The values are,

- Set 1: 18 dB,

- Set 2: 13.5 dB.

The above mentioned numbers are for FR1.

### 7.1.4 REFSENS requirements

It was agreed to derive the REFSENS for LP-WUR in the typical RF manner with AWGN being the channel for which SNR is derived. Thus, the REFSENS for LR is defined as

REFSENSLR (dBm) = -174 + 10log10(BWLR)+ (NFLR + IMLR) + SNRLR.

Here, BWLR corresponds to the bandwidth of the LP-WUS signal in hertz. RAN1 has decided to have 11 RBs for LP-WUS irrespective of SCS, thus the LP-WUS bandwidth will be 1.98 MHz and 3.96 MHz, for 15 and 30 KHz SCS, respectively. Further, there are two set of values for NFLR + IMLR, i.e. 18.0dB and 13.5dB for Type 1 and Type 2 UEs, respectively. There is only single receiver so there is no diversity gain included in the REFSENS.

In the REFSENS test, only the RBs allocated for LP-WUS are populated with the LP-WUS and the rest of the RBs for a given channel bandwidth are left empty. This configuration, however, does not correspond to the real-life case where NR signals in other RBs are generally present and thus can create a coverage shortfall. Separately, the ASCS requirement allows a maximum degradation of 0.5 dB and the side conditions incorporate populated adjacent RBs.

Given the small value of the ASCS degradation factor (0.5 dB), it was agreed not to include this factor in the REFSENS.

For FR1, a SNR value of -4.5 dB for both Type 1 and Type 2 UEs was selected by RAN4 to be used for the REFSENS equation.

### 7.1.5 ASCS requirements

Adjacent subcarrier selectivity (ASCS) is a measure of a receiver's ability to receive an LP-WUS signal at its configured channel frequency in the presence of adjacent in-band NR signal(s). The in-band LP-WUS and NR signal should be same PSD and be separated by a given frequency offset (guard RB) between LP-WUS and NR, and the NR signal occupies the remaining RB resources within the maximum transmission bandwidth configuration, excluding the LP-WUS RBs.

### 7.1.6 ACS requirements

### 7.1.7 IBB requirements

### 7.1.8 OBB requirements

### 7.1.9 other Rx requirements

## 7.2 BS RF

<Editor’s note: discussions and analysis for BS RF requirements related. Mainly focus on key aspects and conclusions, rather than detailed simulations from each company.>

### 7.2.1 General

LP-WUS is transmitted within the NR channel bandwidth and occupies 11 consecutive RBs irrespective of channel bandwidth and SCS. The discussions for the BS RF requirements by introduction of LP-WUS are included in the following sub-clauses.

### 7.2.2 LP-WUS power boosting

Two approaches to define the LP-WUS power boosting are discussed, e.g., legacy dynamic range similar to NB-IoT power boosting and EPRE ratio. The definitions for these two approaches are:

For legacy dynamic range similar to NB-IoT power boosting, the LP-WUS power boosting is defined as the difference between the average power of LP-WUS REs (which occupy certain REs within a NR transmission bandwidth configuration) and the average power over all REs (from both LP-WUS and the NR carrier containing the LP-WUS REs).

For EPRE ratio, the LP-WUS power boosting is defined as the difference between the average power of LP-WUS REs (which occupy certain REs within a NR transmission bandwidth configuration) and the average power over NR REs (the NR carrier excluding the LP-WUS REs).

The above two approaches are mathematically related, and the specific analysis can be found in R4-2407547 and R4-2419482.

RAN4 decides to adopt legacy dynamic range similar to NB-IoT power boosting. The declaration on the support of LP-WUS and support of LP-WUS power boosting should be separate. The minimum power boosting level should be included in the BS manufacturer declaration table, but not defined as a minimum requirement.

### 7.2.3 Regulation relevant spectrum requirements

For transmitted signal with LP-WUS and NR in the same carrier, existing NR regulation relevant spectrum requirements, e.g. spectrum emission mask, spurious emission, are applied.

### 7.2.4 Transmitted signal quality

It is agreed that overlaid OFDM sequence is designed for LP-WUS and the sequence is ZC sequence. This applies in the time domain before the DFT transform for both OOK-1 and OOK-4. RAN1 also agrees on the processing for the OOK signal, and this is illustrated in Figure 7.2.4-1. After the DFT transform, the OOK-4 frequency domain pattern is illustrated in Figure 7.2.4-2.



**Figure 7.2.4-1: OOK-4 signal processing and subcarrier mapping before IFFT**

****

**Figure 7.2.4-2: ZC sequence in frequency domain after DFT processing before IFFT**

### 7.2.5 Other RF requirements

It has been agreed that the BS unwanted emission, and receiver requirements if applicable, in the current release of the specifications should also be applied for LP-WUS.

# 8 Testability

<Editor’s note: discussions and analysis for testability solutions>

## 8.1 Testability for UE Performance verification

### 8.1.1 General Framework

It has been agreed that same LP-WUS RF requirements will apply to all RRC states, but only one RRC state needs to be tested. It is agreed to verify LP-WUR based on 1% MDR of LP-WUS which can be tested based on UE’s response to the NW/TE upon successfully detecting the LP-WUS (e.g. ACK/NACK in CONNECTED state or MSG1/3 in IDLE state or other methods). The ultimate test method including the potential test mode will be decided by RAN5 based on RAN4 input.

For demodulation requirements FAR will also be used.

### 8.1.2 other

Annex A (informative):  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Change history | | | | | | | |
| Date | Meeting | TDoc | CR | Rev | Cat | Subject/Comment | New version |
| 2024-10 | RAN4#112bis | R4-2415778 |  |  |  | draft TR skeleton | 0.0.0 |
| 2024-11 | RAN4#113 | R4-2418215 |  |  |  | TR skeleton  Updated structure | 0.0.1 |
| 2024-11 | RAN4#113 | R4-2418234 |  |  |  | R4-2420392 TP to TR 38.774 on Clause 5 (System parameters)  R4-2420393 TP to TR 38.774 on LP-WUS | 0.1.0 |
| 2025-02 | RAN4#114 | R4-2500753 |  |  |  | R4-2501381 TP for TR 38.774 on LP-WUS  R4-2503027 TP to TR 38.774 on LP-WUS  R4-2500556 TP to TR 38.774 on regulation relevant spectrum requirements (Clause 7.2.3) | 0.2.0 |
| 2025-04 | RAN4#114bis | R4-2503830 |  |  |  | R4-2505236 TP for TR 38.774 on LP-WUS  R4-2505148 TP to TR 38.774 on Clause 5 (System parameters)  R4-2505149 TP to TR 38.774 on LP-WUS  R4-2504743 TP to TR 38.774 on LP-WUS power boosting (Clause 7.2.2) | 0.3.0 |
| 2025-05 | RAN4#115 | R4-2508089 |  |  |  | R4-2508089 TP for TR 38.774 on LP-WUS  R4-2508090 TP to TR 38.774 on testability of LP-WUR  R4-2508117 TP to TR 38.774 on LP-WUS UE RF Simulations  R4-2508739 TP to TR 38.774 on LP-WUS BS RF general part (Clause 7.2.1)  R4-2508769 TP to TR 38.774: Other BS RF requirements for Low-Power Wake-up Signal and Receiver  R4-2508770 TP to TR38.774: BS RF requirement overview for LP-WUS | 0.4.0 |