3GPP TSG RAN WG1#110bis-E R1-22XXXXX

eMeeting, October 10th – 19th, 2022

Source: Moderator (vivo)

Title: FL summary#1 of evaluation on low power WUS

Agenda Item: 9.13.1

Document for: Discussion and Decision

# Introduction

This document summarizes the contributions [1 - 25] for AI 9.13.1 and email discussions.

The issues in this document are tagged and color coded with [H] or [M].

The previous FL summaries can be found in section 7.

**Please consider entering contact info below for this email discussion.**

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# Discussion

## Issue 1: Use cases and KPIs

### 1A-v1: Use case descriptions

**Use cases can be considered for the study are as follows,**

**IoT cases (supported according to SID), e.g,** Actuator control, On-demand sensing application (the case age of sensed information matters), On-demand location tracking

* power-sensitive,
	+ Huawei, vivo(last at least few years), Nokia
* small form devices,
	+ Huawei
* latency-insensitive
	+ vivo (several or tens of seconds)
* latency-sensitive
	+ vivo (1 or 2 seconds), Nokia, Sony
* Mobility
	+ Vivo (static or nomadic)

**Wearable cases (supported according to SID)**

* power-sensitive,
	+ Huawei, vivo (last a few weeks), MediaTek (multiple days (up to 1-2 weeks)), Qualcomm
* small form devices,
	+ Huawei, Sony
* Latency-sensitive
	+ Vivo (several seconds), MediaTek (Hundreds of milliseconds), Qualcomm (low latency and low power), Sony(delay requirement or device reachability in time is short)
* Mobility
	+ Vivo (low/medium speed)

**eMBB cases, e.g., XR, smartphone,**

* General support
	+ Huawei, vivo, Nokia(can be considered), ZTE, MediaTek, Apple, Samsung, Ericsson, Qualcomm
* Higher power saving gain,
	+ Huawei, vivo, MediaTek (device's battery should last multiple hours. (up to 1-2 days))
* Low latency,
	+ Huawei, vivo(in the order of milliseconds), MediaTek (Several milliseconds), Ericsson(tight delay requirements (e.g., XR))
* Mobility
	+ Vivo (low/medium speed)

#### [H] Proposals 1A-v1:

The following 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,
	+ latency sensitive
	+ small form devices
	+ power-sensitive, e.g., the battery should last at least few years for standby.
	+ targeting for limited data activity
	+ static, normadic or limited mobility
* Wearable cases including e.g., smart watches, rings, eHealth related devices, and medical monitoring devices etc.,
	+ Latency sensitive
	+ small form devices,
	+ power-sensitive, the battery should last multiple days (up to 1-2 weeks) for standby.
	+ targeting for limited data activity
	+ low/medium speed
* eMBB cases including e.g., XR/smart glasses, smart phones and etc.,
	+ Latency sensitive
	+ provide even higher power saving gains compared to the legacy solutions with acceptable latency impact of some typical NR services
	+ targeting for intensive traffic arrival with delay requirements (e.g., XR)
	+ low/medium speed

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| **Company** | **Comments** |
| Nordic | regarding eMBB use-case, it is not clear whether target is IDLE or RRC connected, or more precisely which of sub-bullets of eMBB are IDLE and which RRC connected. This should be clarified. |
| Futurewei | We agree with the proposal with prioritization of IoT/Wearable use case and one clarification that for a power-sensitive use case, it can be latency-insensitive unless indicated that it can also be latency-sensitive. |
| ZTE, Sanechips | According to the SID, the IoT cases and wearable should have higher priority. As for the medium speed and Latency sensitive, more details should be clarified, e.g., the specific value for latency and speed. |
| Xiaomi | OK with the proposal |
| Vivo | Regarding Nordic’s comments, for our understanding, it should be connected state for eMBB case. We are open to clarify this in this section or any other places.Since it is for study purpose, we think all use cases can be equally studied during the SI. It can be based on contribution driven. |
| Panasonic | We share similar view on the target use cases with the top down priority order in general. However, we are not sure about the usage of term “latency sensitive” in each use cases. As per the SID, the context of latency sensitivity is to compare with the cycle of eDRX. In addition, considering the LP-WUR/WUS design and procedure, we would like to clarify the latency range, e.g. at least not the same level as URLLC. |
| Intel | Agree with Futurewei that a power-sensitive use case may not necessarily be latency-insensitive |

### 1B-v1: target power for LP-WUR

* vivo (30-500uW),
* CATT(<100uW),
* Intel(active: 100uW-1000uW, inactive: 1-10uW),
* MediaTek (100 to 500 $μ$W),
* Apple (sub-mW level)
* Rakuten Symphony (500uW)
* Samsung (hundreds of uW or below)
* Qualcomm (1mW)

#### [H] Proposals 1B-v1:

The targeting maximum power consumption of low power-wake up receiver for active state is [100 ~ 500] $μW$.

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| **Company** | **Comments** |
| Nordic  | < 1mW should be the target. And need FFS on “how to map to relative power units” |
| Futurewei | We would like to know the purpose of this proposal in light of the discussed power model for LP-WUR in Proposal 2C-v1. |
| Spreadtrum1 | Less or equal to 1mW |
| ZTE, Sanechips | Considering the different requirement for coverage, power saving gain, data rate from different types of devices, 100uW~1 mW can be considered in the early stage for study. |
| vivo | We are OK with the target power consumption of LP-WUR ON. As we analyzed in our contribution [R1-2208668], the average power consumption of a legacy UE in idle/inactive mode is on several to tens of mW. To achieve substantial power saving gain, a reasonable target power consumption of LP-WUR need to be at the level of 1/100~1/1000 of the main receiver, corresponding to tens to hundreds of μW. Besides, according to our simulation verification, if the LP-WUR power consumption is 30μW~500μW, UE battery life can be increased by 3~7 times compared with legacy UEs. Thus, no more than 500μW LP-WUR power consumption is a reasonable target. |
| Panasonic | We are open to starting point of around or below 1mW. |
| Intel | It is a bit earlier to conclude upper bound of 500uW. However, we expect it can be commonly agreed that the target must be <1mW. Agree with Nordic to add an FFS for relative power unit determination |

### 1C-v1: target coverage for LP-WUR

* FutureWei (limited coverage scenario)
* Vivo (NR bottleneck channel, e.g., PUSCH)
* CATT (Receiver sensitivity of Low-power wakeup receiver – [-80] dBm or maximum coupling loss at [126 dB])
* ZTE (equal or better than that of the limited channel evaluated in NR Rel-15/16/17)
* Rakuten Symphony (sensitivity of -80 dBm or better)
* Lenovo (Consider similar coverage level for the LP-WUR implemented in a supplementary chip and the main NR receiver)
* Samsung (Coverage of LP-WUS/WUR should be similar to that of main radio, PUSCH or PDSCH)
* Rakuten Mobile (Coverage by LP-WUS should be kept to the same level as existing cell coverage by NR)
* Ericsson (candidate LP-WUS/WUR designs should be compared to that of NR-PDCCH link budget for various deployment scenarios (e.g., those identified in TR 37.910))
* Sony (LP-WUS coverage target is based on the coverage analysed in the Rel-17 coverage enhancements SI, RAN1 considers fallback mechanisms for UEs that are out of coverage of the LP-WUS.)
* InterDigital(As shown in Fig. 1 [3], a trend line with a slope of -1 decade / 20dBm of power consumption vs. receiver sensitivity is observed. The trend line implies that there is 20 dB degradation in sensitivity for every 10x power consumption reduction.)



* OPPO(Same/close to NR DL control channels)
* Apple(Coverage of LP WUS can be evaluated and compared in two ways: 1 ) Compare the link budget of LP WUS vs PDCCH. 2 )Compare the link budget of LP WUS vs the weakest channel in the system. The same coverage for WUS and PDCCH would be ideal, and it can simplify the design a lot. However, depending on the power consumption and performance target, it may or may not be feasible to achieve such target. In this case, the 2nd approach can be taken.)
* Nordic (In our opinion LP-WUS should target the same coverage as R17 NR. However, what the R17 coverage is should be further discussed)

#### [M] Proposals 1C-v1:

The targeting coverage of LP-WUS is comparable to that of the NR bottleneck channel.

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| **Company** | **Comments** |
| Nordic  | OK |
| Futurewei | There is a clear trade-off between ability to achieve full coverage, resource utilization, and achievable power saving gain, therefore we think that the target can be the outcome of the feasibility study considering the different use cases and potentially multiple LP-WUR architecture categories. |
| Spreadtrum | Fine, although it seems DL channel always needs a margin of target coverage compared to UL channel. Also, from cell (re-)selection and RLM perspective, DL signal/channel quality should be guaranteed at first. |
| Xiaomi | OK with the proposal |
| vivo | Support this proposal |
| Panasonic | We agree with Futurewei that tradeoff needs to be considered for at least system resource overhead, power value of LP-WUR and sensibility. It is also good to make it clear that the intention of the proposal is to match the LP-WUS coverage to the NR bottleneck channel of **downlink or uplink.** Our current position is it seems sufficient to match to NR bottleneck channel of downlink for LP-WUS. |
| Intel | In the typical case of LP-WUS, i.e., idle/inactive mode, UE doesn’t transmit PUSCH at all, so using PUSCH of main radio as a reference needs some discussions. In idle/inactive mode, the UE will still monitor SSB, SIB1, OSI, Type0/0A/1/2 CSS, paging PDSCH, and maybe RACH msg1/2/3/4 and common PUCCH if being paged. Therefore, it seems a reference can be selected from the above listed channel.If two or multiple parts of LP-WUS is defined, the target coverage should consider the performance of the two or multiple parts jointly.  |

### 1D-v1: target BW for LP-WUS

* Vivo (1.4MHz ~ 4MHz)
* Lenovo (Consider candidate LP-WUS bandwidth similar to RedCap bandwidth, SSB bandwidth)
* Sharp (The system configurations used to evaluate R16 power saving can be reused and should be extended with the configuration with 20MHz system bandwidth extended.)

#### [M] Proposals 1D-v1:

The design target of the maximum LP-WUS bandwidth should be no more than X MHz, where X<=20.

* FFS value of X and whether more than one value can be considered.

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| **Company** | **Comments** |
| Nordic | OK, but this is more an 9.13.3 topic, in our opinion |
| Futurewei | This can be discussed after the LP-WUR architecture study.  |
| Spreadtrum1 | OK. Too narrow bandwidth may lead to low power if PSD is constant, i.e. no power boosting. |
| ZTE, Sanechips | Better to wait for further study, especially considering the difference between FR1 and FR2 or SCS design for LP-WUS. Additionally, why this proposal with Med priority is highlighted with yellow? |
| Vivo | We are open to be discussed in 9.13.3 |
| Panasonic | Agree with Nordic. |
| Intel | Not sure the proposal (up to 20MHz) is for evaluation or target design. Due to the impact of channel delay spread, an OOK symbol duration cannot be too short, otherwise, there will be inter-OOK symbol interference that the power of OOK-ON symbol leaks to an OOK-OFF symbol. That is, the capability to carry wake-up information in time domain will be limited. Therefore, we expect that the BW of LP-WUS should not be large, otherwise it consumes much resource overhead. Our preference is to use 4MHz for evaluation purpose.  |

### 1E-v1: applicable RRC states

* Alt 1 (prioritize RRC idle/inactive mode): Huawei, Lenovo,Apple
* Alt 2 (study for both RRC idle and connected mode): **MTK, vivo, Nokia, CATT (only mentioned), Intel, ZTE (if consider XR use case), xiaomi**
* Alt 3 (need to study feasibility in RRC connected mode): Ericsson

#### [H] Proposals 1E-v1:

Both RRC IDLE/INACTIVE and CONNECTED mode are considered for study in the LP-WUS/WUR SI.

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| **Company** | **Comments** |
| Nordic | We are OK with studying also Connected mode, but IDLE/Inactive should have more priority. For example, when it comes to optimization of LP-WUS. Or would connected mode have separate LP-WUS design? |
| Futurewei | We are OK with the proposal but would like to prioritize RRC IDLE/INACTIVE states in the study. |
| Spreadtrum1 | Because of study item, there is no need to exclude any state. |
| ZTE, Sanechips | Considering the different requirement for coverage, power saving gain, data rate from different types of devices, 100uW~1 mW can be considered in the early stage for study. |
| Xiaomi | OK with the proposal |
| vivo | We agree with the proposal since there are target use cases for both RRC idle/inactive and connected scenarios. Since it is for study purpose, we think all use cases can be equally studied during the SI. It can be based on contribution driven. |
| Panasonic | We would like to prioritize RRC IDLE/INACTIVE and okay to study also CONNECTED mode. |
| Intel | We support the proposal  |

### 1F-v1: more deisgn targets

* FutureWei
	+ a model capturing LP-WUR’s limited coverage scenario and the behavior/protocol of LP-WUR/Main Radio need to be defined for proper evaluation of the LP-WUS/WUR power saving gain
* Vivo
	+ Around 100kbps data rate can be considered as design target for LP-WUS
	+ The overall design target of coexistence is to support multiplexing between LP-WUS with legacy NR signals/channels and to allow reuse of unused LP-WUS resources for other DL transmissions
* Nokia
	+ Down prioritize the sidelink related studies for time being
	+ LP-WUS design and LP-WUR architecture support flexible placement in frequency domain.
	+ The wake-up signal design and wake up receiver architecture defined, allows efficient reuse of gNB hardware for signal generation.
	+ The LP-WUS signal design and LP-WUR architecture should be defined so that efficient multiplexing with existing NR signals and channels is possible to limit the resource reservation.
	+ Coverage and mobility implications should be accounted for in LP-WUS design and LP-WUR architecture assumptions.
	+ Consider in LP-WUS design and LP-WUR architecture the possibility to accommodate use cases with some degree of limited mobility.
* CATT
	+ Minimum achievable data rate – [160] bps
* Samsung
	+ The design of LP-WUS should strive to minimize the impact to the gNB.
* Rakuten Mobile
	+ For the assumption of framework of LP-WUS, minimum impact to the network deployment should be assured.
	+ Regarding frequency assumption, in-band operation can be the baseline.
* Ericsson, following general framework should be used as starting point for WUS evaluations:
	+ transmission of LP-WUS should not require new gNB hardware and should not trigger new emissions/compliance requirements for gNBs
	+ it should be possible to dynamically reuse unused LP-WUS resources for other NR transmissions (i.e., dedicated time/frequency resource reservation for WUS should be avoided)
	+ it should be possible to multiplex LP-WUS with other NR transmissions in time or frequency domain without causing interference
	+ LP-WUS is transmitted on Uu interface from gNB to UE
* Sony
	+ RAN1 considers fallback mechanisms for UEs that are out of coverage of the LP-WUS

#### [M] Proposals 1F-v1:

The following design targets of LP-WUS/WUR should be taken into account,

* Flexible placement of the LP-WUS in frequency domain,
* Reuse of existing gNB hardware to generate LP-WUS related signals
* Allow in-band operating with legacy NR system.
* Allow multiplex with legacy NR signals/channels, e.g., TDM/FDM.
* Down prioritize the sidelink related studies.

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| **Company** | **Comments** |
| Nordic  | These topics belong more to 9.13.3 AI. In addition main bullet should be reformulated. to “**At least** the following ……”  |
| Futurewei | The third and fourth bullets can be combined as allowing in-band operation already implies multiplexing with legacy NR signals/channels whether in time or frequency domain. For example:Allow in-band multiplexing with legacy NR signals/channel, e.g., TDM/FDM.We would also like to suggest including handling of inter-cell interference in the evaluation. |
| Spreadtrum1 | Fine. Regarding the data rate mentioned by companies, we fail to understand how to calculate it, if we do not have modulation order, OFDM symbol duration or the number of modulation symbols per OFDM symbol (1 modulation symbol per OFDM symbol). May I ask a question that what the data rate of eMBB in NR is? We can answer it only if we have SCS, bandwidth, modulation order and code rate etc. It seems a complicated equations in peak data rate shown in 38.306(?). |
| Xiaomi | Generally OK with the proposal. Also think these topics belong more to 9.13.3 AI.  |
| vivo | In principle, we agree with the proposed design targets. Besides, allow reuse of unused LP-WUS resources for other DL transmissions can also be considered. BTW, we are OK with Futurewei’s suggestion on combining the third and fourth bullets. |
| Panasonic | Agree with Futurewei. |
| Intel | Similar to deprioritize sidelink operation, unlicensed operation should also be deprioritized, otherwise, due to LBT, UE cannot assume LP-WUS always happen in a configured timing. Alternatively, if UE is configured to monitor multiple LP-WUSs in a window which is similar to DRS transmission window in NR-U, it increases the power consumption for of LP-WUR .Further, as commented by Futurewei, inter-cell interference may need to be included.  |

### 1G-v1: Terminology

* **vivo:** terminology

**Proposal 14: Adopt the following terminology for future discussion,**

* **Main radio: the Tx/Rx module operating for legacy system**
* **LP-WUR: The Rx module operating for receiving/processing LP-WUS**

#### [M] Proposals 1G-v1:

Adopt the following terminology for future discussion,

* Main radio: the Tx/Rx module operating for legacy signals/channels.
* LP-WUR: The Rx module operating for receiving/processing LP-WUS.

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| **Company** | **Comments** |
| Nordic | OK |
| Futurewei | We agree with the proposal |
| Spreadtrum | Partial Yes. Main receiver may be better. Radio seems we only talk about the RF frontend, but indeed we may pay lots of efforts on baseband, which is the reason for RAN1 lead instead of RAN4 lead. |
| Xiaomi | OK |
| Vivo | Support |
| Panasonic | We are basically okay but just need to clarify that it is not prevented that Main radio (or part of) is capable of receiving LP-WUR as per implementation on modem design. Thus we propose the below change:Main radio: the Tx/Rx module **capable of** operating for legacy signals/channels. |
| Intel | Support |

## Issue 2: Power evaluation related assumptions

### 2A-v1: General: performance metrics

#### [H] Proposals 2A-v1:

For Power evaluation of the LP-WUS, the following performance metrics are considered to be provided.

|  |  |
| --- | --- |
| **Performance Metric** | **Note** |
| Power consumption | Relative power consumption in units per ms. The power consumption includes main radio and LP-WUR. For comparison, the relative power consumption for baseline schemes should also be provided. |
| System overhead | Expressed as percentage of used part of all REs for LP-WUS among all resources. |
| Latency | For IDLE/INACTIVE state, the latency is the time interval between the data arrival time and the time of the PO it is paged.For CONNECTED state, the latency is the time interval between the data arrival time and the time of the first PDCCH for PDSCH scheduling. |
| FFS: Capacity impact | [Evaluate the system capacity impact due to introduce of LP-WUS] |

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| **Company** | **Comments** |
| Nordic | Need some text updateFor IDLE/INACTIVE state, the latency is the time interval between the data arrival time and the time of the first PO UE can monitor.For CONNECTED state, the latency is the time interval between the data arrival time and the time of the first PDCCH monitoring occasion a UE can monitor  |
| Futurewei | We agree with the metrics considered for the evaluation but would like to have the following suggestions on the notes/definitions.* For power consumption, this metric is dependent on the considered traffic model, so for reporting we can consider the relative power consumption in a transaction cycle, i.e., average inter-arrival time.
* For latency, the definition for RRC IDLE/INACTIVE state might be limiting if we consider existing/legacy definition of a PO. The evaluation of latency should be able to capture the impact of LP-WUR always monitoring operation and potential of considering unique addressing via the LP-WUS.New definition/note: For RRC IDLE/INACTIVE state, latency is the time interval between data arrival time and time a unique identifier is determined.

BTW, we suggest changing the title of section 2.2 to be more than power evaluation related. |
| Spreadtrum1 | For system overhead, it should be coverage and resource overhead. Mentioning about resource overhead without the coverage requirement is meaningless. In R17 PEI discussion, the resource overhead is coupled with the coverage requirement.Mobility should be addressed. Many companies mentioned a large portion of power saving comes from the skipping of measurement. |
| ZTE, Sanechips | For latency part, we share similar view with Nordic.For system overhead part, text update is needed:Expressed as percentage of used part of all REs for LP-WUS among all resources in a time interval. |
| Xiaomi | As to the time unit of relative power consumption, slot unit is adopted in TR 38.840 “*Power values are averaged over the operations within a slot*” .We think it is better to keep the same as TR 38.840 |
| vivo | We think Futurewei’s proposal is valid, it can be general performance metrics, for example, the overhead may not related to power evaluation. Proposal 2A-v1, 3A-v1, 3B-v1 includes the related to power, coverage or link-level simulation. For better understanding, the following categorization can be made, For Power evaluation of the LP-WUS, the following metrics are considered,* Power consumption (power saving gain)
* Latency

For coverage evaluation (i.e., link-budget) , the following metrics are considered,* MIL, compared with other bottleneck channel

For link-level simulation, the following metrics are considered,* FAR, MDR target should be considered

For other evaluation, the following metrics are considered,* System overhead
* Capacity
 |
| Panasonic | We are okay with the proposal. |
| Intel | On power consumption for LP-WUR, it is preferred to clarify both absolute and relative power consumption of LP-WUR. For the definition of latency, depending on LP-WUS design, UE may not need to monitor a PO at all. Therefore, the first sentence needs modification |

### 2B-v1: Power model for main radio

* **Futurewei:** relative power: 0.015 [0.05]---transition time: 200 ms [25 ms]----transition energy: 10000 [1250]

Table 1: UE Power Consumption Model for Main Radio.

|  |  |  |  |
| --- | --- | --- | --- |
| **Power State** | **Characteristics** | **Relative Power [100 MHz BW]** | **Relative Power [20 MHz BW]** |
| Standby | Power consumption of the main radio when LP-WUR is used for LP-WUS monitoring | 0.015 [0.05] | 0.015 [0.05] |
| Deep Sleep | Time interval for the sleep should be larger than the total transition time entering and leaving this state. Accurate timing may not be maintained. | 1 (Optional: 0.5) | 1 (Optional: 0.5) |
| Light Sleep | Time interval for the sleep should be larger than the total transition time entering and leaving this state.  | 20 | 20 |
| Micro sleep | Immediate transition is assumed for power saving study purpose from or to a non-sleep state | 45 | 45 |
| PDCCH-only | No PDSCH and same-slot scheduling; this includes time for PDCCH decoding and any micro-sleep within the slot.  | 100 | 50 |
| SSB or CSI-RS processing | SSB can be used for fine time-frequency sync. and RSRP measurement of the serving/camping cell. TRS is the considered CSI-RS for sync.  | 100 | 50 |
| PDCCH + PDSCH | PDCCH + PDSCH.  | 300 | 120 |

Table 2: UE Power Consumption for Main Radio during the State Transition.

|  |  |  |
| --- | --- | --- |
| **Sleep type** | **Additional transition energy:****(Relative power x ms)**  | **Total transition time**  |
| **Standby** | 50x200ms [25ms] = 10000 [1250] | 200 ms [25 ms] |
| **Deep sleep**  | 450 | 20 ms |
| **Light sleep**  | 100 | 6 ms |
| **Micro sleep**  | 0 | 0 ms\* |
| \* Immediate transition is assumed for power saving study purpose from or to a non-sleep state |

* **Huawei:** relative power: [0]---transition time: 1 or several seconds----transition energy: need to be discussed.
1. ***For evaluation purposes, capture the following table in the TR and reuse other power states of main receiver in TR 38.840.***

|  |  |  |
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| **Power state** | **Relative Power** | **Note** |
| **Ultra-deep sleep (main receiver)** | **[0]** | **The main receiver sleeps deeper than ‘Deep sleep’, and the power consumption is ultra-low.**  |

1. **Current power model defined in TR 38.840 does not account for how to model the transition for a new deeper sleep state.**
2. ***RAN1 to investigate how to model the transition energy for ultra-deep sleep state of main receiver for evaluation purpose.***
3. ***For evaluation purposes, the transition time of main receiver for ultra-deep sleep is assumed to be about one to several seconds.***
* **Spreadtrum:** no new state define for main radio

***Proposal 1: The power model for the main receiver can reuse that defined in TR 38.840.***

* **vivo:** relative power: 0.015---transition time: 400ms ----transition energy: [2000-20000]

**Proposal 15: For R18 LP-WUS/WUR power evaluation, the following power model of the ultra-deep sleep state agreed in R18 positioning SI for LPHAP is reused for main radio.**

* + **Note: the value of additional transition energy can be updated based on further agreement made in R18 positioning SI.**

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| **Power State** | **Relative Power** | **Additional transition energy:****(Relative power x ms)** | **Total transition time** |
| Ultra-deep sleep | 0.015 | [2000-20000] | 400ms |

* **Nokia:** relative power: [0.015]---transition time: [200ms]----transition energy: [10000]

**Table 1. UE power consumption model**

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| --- | --- |
| Power State | Power model(Idle/inactive-mode operation with reception bandwidth 20 MHz) |
| **Relative power** | **Transition time and energy****(if applicable)** |
| *Main receiver* |  |  |
| Power off $(P\_{off}^{†})$ | [0.015] \* | {[200ms], [10000]} \* |
| Note: Power scaling to 20MHz reception bandwidth follows the rule in Section 8.1.3 of TR 38.840, i.e., max{reference power \* 0.4, 50}.[]\* : Values are preliminary and to be considered further based on the LP-WUR architecture discussion.$x^{†}:$ Power accounted only for boot-up and sub-systems bring-up including internal calibration. Ramp down transition not considered.  |

* **CATT:** relative power: “zero”; ---transition time: [2250]; ----transition energy: [100 ms]

**Proposal 5: The power model for the low-power wakeup receiver should include the following assumptions**

* **The power consumption of low-power wakeup receiver is independent to that of NR receiver.**
* **The power consumption of NR receiver should be negligibly low and assumed to be “zero” relative to the deep sleep mode value “1”.**
* **The power model of the low-power wakeup receiver is defined relative to the power state of deep sleep mode with the assumption of the negligible power consumption of NR receiver.**

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| **Sleep type** | **Additional transition energy:****(Relative power x ms)** | **Total transition time** |
| LP-WUR | [2250] | [100 ms] |

* **Intel:** relative power: [0.015]---transition time: [400ms]----transition energy: [2000]

**Table 2: Power consumption and transition time for deeper sleep mode**

|  |  |  |  |
| --- | --- | --- | --- |
| **Power State** | **Relative Power** | **Additional transition energy** | **Total transition time** |
| Deeper Sleep | [0.015] | 2000 | [400] ms |

* **ZTE:** need study but no suggest values

***Proposal 6: The power off state of main radio should be introduced for power consumption evaluation.***

* ***The characteristics of power off state, the value of relative power and UE power consumption during the state transition should be defined.***
* **MTK:** two set of values for main radio of normal and redcap devices:

For normal UE: relative power: 0.015---transition time: 400ms----transition energy: [20000]

For redcap UE: relative power: 0.015---transition time: 400ms----transition energy: 14000

**Table 4: Rel-15 Ref UE power consumption model for FR1 (TR 38.840)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Power State** | **Relative Power** | **Additional transition energy:****(Relative power x ms)** | **Total transition time** |
| Power off | 0.015 | 50 x 400ms = 20000 | 400 ms |

**Table 5: Rel-17 RedCap UE power consumption model for FR1 (TR 38.875)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Power State** | **Relative power**  | **Additional transition energy:****(Relative power x ms)** | **Total transition time** |
| Power off | 0.015 | 35 x 400ms = 14000 | 400 ms |

Note that Rel-15 reference UE shall at least stay 20.3s in “power off.” Otherwise, staying in “deep sleep” will consume

1. For UE power and latency evaluation, introduce a power consumption model for LP-WUR, including WUR on/off power states and transition time/energy.$ $
2. For UE power and latency evaluation, introduce a new power state of "power off" for the Rel-15 reference UE and Rel-17 RedCap UE.
* **Ericsson:** need study but no suggest values
1. For the main radio power model
* Use existing models in TR 38.840 and TR 38.875 as starting point for evaluations
* Study whether any updates are needed for the power model (including any updates to scaling factors, transition time) when the main radio is operated in conjunction with LP-WUR
* Consider additional energy (if any) consumed to acquire synchronization
1. For power saving evaluations, consider impact of DRX/Paging configuration assumptions for the UE and impact of false wake-up of main radio due to LP-WUR false alarms.
* **Qualcomm:** [0.015\*] [20000\*] [400 ms\*]

Table 1 Power Model for Deep Sleep and ULPS



* **OPPO**: relative power[0.01] --- transition time: [200ms]----transition energy: [5000]

**Table 2: UE power consumption model for LP-WUS/WUR**

|  |  |  |
| --- | --- | --- |
| **Power State**  | **Characteristics**  | **Relative Power**  |
| **Main radio** |
| [Quasi] Power Off | Main radio can keep power off when LP-WUR not wake-up main radio. | [0.01] |

**Table 3: UE power consumption during the state transition**

|  |  |  |
| --- | --- | --- |
| **Sleep type**  | **Additional transition energy:** **(Relative power x ms)**  | **Total transition time**  |
| [Quasi] Power Off | [5000] | [200 ms] |
| Deep sleep  | 450  | 20 ms  |
| Light sleep  | 100  | 6 ms  |
| Micro sleep  | 0  | 0 ms\*  |
| Immediate transition is assumed for power saving study purpose from or to a non-sleep state |

* **Apple:**
* Main radio
	+ The power consumption of the main radio in ultra-deep sleep state
	+ The transition time and transition energy for the main radio to go from non-sleep state to ultra-deep sleep state
	+ The transition time and transition energy for the main radio to go from ultra-deep sleep state to non-sleep state
	+ Note that these depends on the assumptions on what information is maintained at the main radio during the ultra-deep sleep state, and what steps the main radio needs to take before performing regular operation (such as acquisition, synchronization, etc).
	+ There may be different implementations that allow the main radio to go into different levels of ultra-deep sleep state. Multiple models can be potentially considered.

***Proposal 4: For WUS evaluation, use the evaluation methodology and power model defined in TR 38.840 as the baseline. Additionally, define the following parameters for UE power model:***

* **The power consumption of the main radio in “ultra-deep sleep state”**
* **The transition time and transition energy for the main radio to go from/to non-sleep state to/from ultra-deep sleep state**
* **The power consumption of WUR during active monitoring**
* **The power consumption of WUR when it is not actively monitoring**
* **Apple:**
* **CMCC:**

***Proposal 2: The transient period between “main radio turned on” and “main radio turned off/deep sleep” shall be taken into consideration in the evaluation methodology.***

Ultra-deep sleep state power model,

Transition time in the order of hundreds of milliseconds (100ms-400ms),

* relative power: 0.015 [0.05]; transition time: 200 ms [25 ms]; transition energy: 10000 [1250]: FutureWei, Nokia
* relative power: 0.015; transition time: 400ms; transition energy: [2000-20000]: vivo, Intel, MTK, Qualcomm
* relative power: “0”; transition time: [100 ms]; transition energy: [2250]: CATT
* relative power[0.01]; transition time: [200ms]; transition energy: [5000]: OPPO

Transition time in the order of several seconds (1 or several seconds),

* relative power: [0]; transition time: 1 or several seconds; transition energy: need to be discussed: Huawei

#### [H] Proposals 2B-v1:

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

* For IoT and Wearable cases, reusing TR38.875 power model as baseline.
* For eMBB cases, reusing TR38.840 Power model as baseline.
* Introduce ‘*Ultra-deep sleep*’ power state for main radio and reusing power model option 1 value of ‘*Ultra-deep sleep*’for LPHAP evaluation, i.e.,

|  |  |  |  |
| --- | --- | --- | --- |
| Power State | Relative Power (unit/ms) | Additional transition energy(Note1):(Relative power x ms) | Total transition time |
| Ultra-deep sleep | **0.015** | **[2000-20000]\*** | **400ms** |

* Note1: transition time /energy consists of the procedure for [main radio hardware tune on, coarse sync, cell search…]

|  |  |
| --- | --- |
| **Company** | **Comments** |
| FL | Considering transition time and outcome of LPHAP, 400ms is proposed. |
| Nordic  | No, in our opinion LPWA power model should be used as baseline for IOT. This because it could be easily used as WUR. WUR should do better than LPWA paging |
| Futurewei | We agree with FL proposal. |
| Spreadtrum | Too early to draw conclusion. The main receiver behavior after wakeup is unclear and has different understandings across companies, in our view. |
| ZTE, Sanechips | If coarse sync is included in the transition time, the exact sync accuracy should be clarified. Additionally, why cell search is included in the transition time also needs to be clarified. |
| Xiaomi | OK with the proposal. |
| Vivo | In RAN-97, it is agreed that,**Conclusion:** * The Rel-18 study on low-power WUS/WUR is for NR only and LTE NB IoT/MTC is not in scope of the SI, no need for SID update.
* Endorse a revised SID with the following editorial changes.

|  |
| --- |
| * Study potential UE power saving gains compared to the existing Rel-15/16/17 UE power saving mechanisms ~~and their~~ , 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.
 |

Hence, using RedCap power model is preferred from our understanding. |
| Panasonic | We support the proposal of reusing power state for low power high accuracy positioning evaluation. |
| Intel | The value for additional transition energy should be further down selected.  |

### 2C-v1: Power model for LP-WUR

* **Futurewei:**

Table 3: UE Power Consumption Model for LP-WUR.

|  |  |  |
| --- | --- | --- |
| **Power State** | **Characteristics** | **Relative Power**  |
| Off | WUR power consumption when turned off | 2e-5 [up to 0.003]\* |
| On | WUR power consumption when turned on | 0.005 [up to 0.15]\* |
| \* Exact value will be dependent on the studied architecture |

* **Huawei:**

|  |  |  |
| --- | --- | --- |
| **Power state** | **Relative Power** | **Note** |
| **LP-WUR working state** | **0.01 ~ 0.02** | **The architectures proposed in [2] can achieve such a power consumption range, where the one without LO usually consumes more power than the one with LO.** |
| **LP-WUR non-working state** | **0** | **The wakeup receiver is turned off.** |

* **Spreadtrum:** depends on WUR architecture, transition time of LP-WUR should be defined.

***Proposal 2: The power consumption of detection of the LP-WUS can be defined.***

***Proposal 3: At least one type of sleep mode can be defined for the LP-WUR.***

***Proposal 4: The number of categories of power model for the LP-WUR depends on the outcome of discussion of architectures of the LP-WUR.***

***Proposal 5: The transition energy/time should be defined for transition between a sleep mode and active mode for the LP-WUR.***

* **vivo:**

**Proposal 16: For R18 LP-WUS/WUR power evaluation, the following power model of LP-WUR is considered.**

* **Note: these value in brackets can be further confirmed based on the progress of LP-WUR architecture.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Power State** | **Absolute Power** | **Relative Power** | **Additional transition energy** | **Total transition time** |
| LP-WUR sleep | [2] μW | **[0.002]** | **0** | **0** |
| LP-WUR monitoring | [30~500] μW | **[0.03~0.5]** | **-** | **-** |

* **Nokia:**

|  |  |
| --- | --- |
| Power State | Power model(Idle/inactive-mode operation with reception bandwidth 20 MHz) |
| **Relative power** | **Transition time and energy****(if applicable)** |
| *LP-WUR* |  |  |
| LP-WUS monitoring (LNA ON) | [0.1]\* | [TBD] |
| *LP-WUS monitoring (LNA Off)* | [0.05]\* | [TBD] |
| LP-WUR sleep | [TBD] | [TBD] |

* **CATT:** two types of LP-WUR

**Table 1: Power model for LP-WUR**

|  |  |  |
| --- | --- | --- |
| Power State | Characteristics | Relative Power  |
| Periodic low power WUS | Front end wakeup receiver is configured to detect the wakeup signals periodically associated with C-DRX or PO.  | [0.01 – 0.1] |
| On-demand low-power WUS | Front end wakeup receiver with free-running clock in the active device or passive device monitoring of wakeup signals continuously | [0.001 – 0.01] |

* **Intel:**

**Table 3: Power consumption of LP-WUR**

|  |  |  |
| --- | --- | --- |
| **Power State** | **Active state** | **Inactive state** |
| Deeper Sleep | [100uW – 1mW] | [1-10uW] |

* **ZTE:** need study but no suggest values

***Proposal 7: For LP-WUS, the relative power of WUR on state, WUR off state and the power consumption of WUR on-off transition state should be defined.***

* **MTK:**

**Table 3: LP-WUR power consumption model for FR1**

|  |  |  |  |
| --- | --- | --- | --- |
| **Power State** | **Power (mW)**  | **Additional transition energy:****(Relative power x ms)** | **Total transition time** |
| WUR off | 2 $μ$W |  |  |
| WUR on | 100-500 $μ$W | 0 | 0 ms |
| The reference configurations: frequency = 2.6 GHz, BW = 4MHz |

* **Ericsson:** need study but no suggest values
1. For each LP-WUR architecture considered in the study, consider at least the below aspects as part of the LP-WUR power model
* LP-WUR active power when monitoring LP-WUS
* LP-WUR sleep power when not monitoring LP-WUS (when a duty cycle for LP-WUS detection is applicable for the LP-WUR)
* Transition energy and transition time (if any) between above two states
* Transition time and transition energy (if any) for triggering the main radio from a given main-radio sleep state.
* Additional energy (if any) consumed to acquire synchronization for detecting LP-WUS
* **Scaling factors if variable BW operation is supported**
* **Qualcomm:** need study, LP-WUR transition energy and time are assumed to be zero.

 **Table 2 WUR Power Model**

|  |  |  |  |
| --- | --- | --- | --- |
| Sleep type | Relative power | Transition energy:(Relative power × ms) | Total transition time |
| LP-WUR monitoring power | TBD | 0 | 0 |
| LP-WUR sleep power | TBD |

* **OPPO:**

|  |
| --- |
| **LP-WUR** |
| LP-WUS monitor | Monitoring of low power wake-up signals.[Two possible working mechanism, i.e., monitor lower power wake-up signals by always on or periodically on manner.] | [0.5] |
| [LP-WUR sleep] | Lower power wake-up radio keeps sleep state when no lower power wake-up signals.[Monitoring LP-WUS by periodically manner] | [0.01] |

* **Apple:**
* LP WUR
	+ The power consumption of WUR during active monitoring
		- It can be further discussed whether the power consumption needs to be differentiated between continuous monitoring and periodic monitoring.
	+ The power consumption of WUR when it is not actively monitoring
	+ The power consumption of WUR greatly depends on the WUR architecture (related to WUS design) and the performance requirements. Multiple models can be potentially studied to cover different levels of trade-off between power consumption and performance.
* Alt 1 (WUR on: 0.005 [up to 0.15]\*; WUR OFF: 2e-5 [up to 0.003]\*): FutureWei
* Alt 2 (WUR on: 0.01 ~ 0.02; WUR OFF: 0): Huawei
* Alt 3 (WUR on: [0.03~0.5]; WUR OFF: [0.002]): vivo
* Alt 4 (WUR on: [0.1 or 0.05]; WUR OFF: [TBD]): Nokia
* Alt 5 (WUR on: [100uW – 1mW]; WUR OFF: [1-10uW]): Intel
* Alt 6 (WUR on: [100uW – 500uw]; WUR OFF: [2uW]): MTK
* Alt 7 (WUR on: [0.5]; WUR OFF: [0.01]): OPPO

#### [H] Proposals 2C-v1:

* The following power model for LP-WUR/WUS evaluation is considered,
	+ Relative power unit for LP-WUR ‘off’ state, i.e., the LP-WUR does not perform monitoring:
		- [0.001]
	+ Relative power unit for LP-WUR ‘on’ state, i.e., the LP-WUR performs monitoring:
		- Option 1: [0.01]
			* *Editor’s Note: adding details if needed*
		- Option 2: [0.5]
			* *Editor’s Note: adding details if need*
	+ No additional transition energy and transition time between ‘on’ and ‘off’ state.

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

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic | if 100uW - 1mW should be 0.01unit then PDCCH monitoring according to 38.840 would consume 1-10W corresponding to 100units?This does not sound correct. As we pointed out PSM floor in LPWA could be 2.7uA\*3.7V=10uW (there was typo in our contribution). This corresponding to 0.1unit. So 100uW = 1unit, and PDCCH monitoring would then be 10mW which is more realistic.  |
| Futurewei | We can consider the evaluation of few LP-WUR architecture categories and their fitness to the different considered use cases.For example, we can consider the following:***Consider evaluation of three receiver architecture categories with active state power consumption*** $P\_{C}$ ***defined as******LP-WUR-cat1:*** $P\_{C}\in $ ***[0.5, 1] mW*** ***LP-WUR-cat2:*** $P\_{C}\in $ ***[0.1, 0.5[ mW*** ***LP-WUR-cat3:*** $P\_{C}\in $ ***[0.03, 0.1[ mW*** Note: exact power consumption value for each category is to be determined. |
| Spreadtrum1 | It is tightly coupled with the architecture. Due to the first meeting, we may not draw any conclusion of power model, but we can provide the absolute values of power consumption of the LP-WUR. |
| ZTE, Sanechips | It depends on the outcome of proposal 1B and the mapping relationship between relative power and absolute power should be clarified. |
| vivo | In principle we are fine with FutureWei’s proposal. Perhaps it’s better to provide relative power unit/ms value this meeting in order that companies can perform power analysis. We consider 1 relative power unit corresponds to 1 mW.  |
| Panasonic | Just to clarify the relation between the LP-WUR ’on’ state and Ultra-deep sleep [0.015] for main radio. So the option 1 [0.01] means that when LP-WUR monitors LP-WUR, the power consumption is still lower than the ultra-deep sleep for main radio? |
| Intel | We think Nordic had a good observation. 0.01 unit is too optimistic for LP-WURWe are fine with Futurewei proposal to evaluation multiple power level of LP-WUR |

### 2D-v1: Assumptions for RRC IDLE/INACTIVE

**a) parameters setting, including paging rate, paging cycle, eDRX cycle, traffic model, RRM, cell search, sync procedure**

* paging DRX cycle (1.28s): Futurewei, vivo, spreadtrum
* paging rate (1% or 10%): Huawei, spreadtrum, vivo
* eDRX cycle (48 DRX cycles = 61.44s): Futurewei, vivo, Nokia
* PTW duration (8 DRX cycles =10.24s): Futurewei, vivo, Nokia
* Traffic model (reuse that of 38.875 or 38.840):
	+ 38.875 traffic models including heartbeat or instant messaging: vivo, Futurewei, MTK, Ericsson , OPPO
	+ 38.840 traffic models including FTP3 or VoIP: CATT, sharp
	+ Qualcomm (IoT traffic model: inter-arrival time: [tens of min to hours])
	+ interD (FTP 3: mean arrival🡪 200ms or 2s)
* RRM measurement: Nokia, Apple, ZTE
* Cell search: Nokia, spreadtrum,
* Sync procedure: Nokia, Ericsson
* Other assumptions: R17 PEI assumptions. 38.802, 38.840—Apple, CATT, Ericson, QUALCOMM

**b) Total latency introduced by LP-WUS or LP-WUS processing timeline related assumptions:**

* depends on whether UE should do PO monitoring after wakeup—Huawei; spreadtrum, Nokia, Intel, ZTE, vivo (PO need to be monitored), Xiaomi (consider both legacy PO or enhanced PO monitoring)
* depends on RRM measurement—spreadtrum (relaxed if or not), ZTE (should be assumed)
* depends on whether the main receiver needs to perform cell search after wakeup.—spreadtrum
* depends on LP-WUR always-on vs. periodically-on –spreadtrum, CATT, OPPO, vivo
* depends on whether LP-WUS can be used to support/assist re-synchronization or time/frequency tracking—Nokia, Ericsson
* **Futurewei:**

**Table 4: List of Initial Evaluation Parameters and Values**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Definition / Description** | **Value** |
| *T* | Transaction Cycle – average inter-arrival time. | 60 (s) |
| *A* | DRX Cycle. | 1.28 (s) |
| *B* | eDRX Cycle. | 61.44 (s) |
| *PTW* | Paging Time Window - on period/duration of eDRX cycle when eDRX cycle is $>1024$ radio frames. | 10.24 (s) |
| $$P\_{RRC}$$ | Total relative power for each RRC connection duration. | 3000 (unit.ms) |
| *BW* | System Bandwidth. | 20 (MHz) |
| *D* | Total time required to process a LP-WUS and wake-up the main radio (i.e., from standby power state). | 101 (ms) |

***Proposal 4: A set of use cases and corresponding traffic models and power saving schemes parameters needs to be defined for proper evaluation/comparison with power consumption and latency of LP-WUS.***

* **Huawei:** paging rate per UE =1%, total latency introduced by LP-WUS depends on whether it should do PO monitoring.
1. ***For evaluation purposes, the per-UE paging rate is assumed to be 1%, which is the same as in earlier releases.***

Depending on the detailed design of LP-WUS, the total latency introduced by LP-WUS and its subsequent procedures is different. For example, if LP-WUS carries per UE paging information, the latency is just the transition time above. As another example, if LP-WUS carries per UE group paging information, after turning on the main receiver the UE may need to receive legacy PO, then latency includes transition time and legacy paging reception.

1. ***RAN1 needs to agree assumptions for the total latency introduced by LP-WUS, depending on the information the signal conveys, i.e. depending on the subsequent procedures assumed in the UE.***
* **Spreadtrum: need to consider the following four assumptions:**
1. whether the main receiver should still monitor PO after wakeup,
2. whether the measurement is relaxed or not at the main receiver, and
3. whether the main receiver needs to perform cell search after wakeup.
4. LP-WUR always-on vs. periodically-on
* Paging rate is 1%
* Group-paging-rate is 10% (assuming 10 UEs in a group)
* Paging cycle is 1280ms or above

***Proposal 8: The baseline evaluation assumptions should be determined, e.g.***

* ***paging rate,***
* ***group-paging-rate,***
* ***paging cycle,***
* ***link-level performance requirement for the LP-WUR, and***
* ***CFO requirement and the number of SS bursts to be processed for the main receiver.***

***Proposal 9: The additional evaluation assumptions should be studied and determined as much as possible, e.g.***

* ***always-on vs. periodically-on,***
* ***whether the LP-WUS supports beam sweeping or not,***
* ***whether the main receiver should still monitor PO after wakeup,***
* ***whether the measurement is relaxed or not at the main receiver, and***
* ***whether the main receiver needs to perform cell search after wakeup.***

***Observation 6: Assumption of always-on or periodically-on impacts KPIs widely.***

***Observation 7: Assumption of whether the LP-WUS supports beam sweeping or not impacts at least the resource overhead and the coverage.***

***Observation 8: Assumption of whether the main receiver should still monitor PO after wakeup impacts KPIs widely.***

***Observation 9: Assumption of whether the measurement is relaxed or not at the main receiver at least impacts the mobility.***

***Observation 10: Assumption of whether the main receiver needs to perform cell search after the main receiver is turned on at least impacts the latency and the power saving gain.***

***Observation 11: If the main receiver needs to perform cell search after wakeup, the main receiver can stay in a completely-off state before wakeup.***

* **vivo:**

**Table 5. Key evaluation assumptions for I-DRX paging and PEI**

|  |  |
| --- | --- |
| **Parameters** | **Value** |
| Paging cycle length | 1.28s |
| Number of SSB before PO | 1, 2 or 3, (used for AGC adjustment, T/F tracking, serving cell and intra-F measurement) |
| Number of SSB after PO | 1, (used for inter-F measurement); 0, (for High SINR case). |
| Number of SSB before PEI | 1, (used for PEI PDCCH receiving) |

**Table 6. Evaluation assumptions for traffic model or paging rate**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Option 1: Traffic model**(based on TR 38.875[4]) | Heart beat traffic model

|  |  |
| --- | --- |
| **Model** | FTP3 |
| **Packet size** | 100 Bytes |
| **Mean inter-arrival time** | 60s (per UE paging rate≈2%) |

 |
| **Option 2:****Per PO/UE paging rate** | 10%; 1% |

**Table 7. eDRX configuration**

|  |  |
| --- | --- |
| **Parameters** | **Value** |
| PTW length | 8 paging cycles, i.e. 10.24 s |
| eDRX cycle length | 48 paging cycles, i.e. 61.44s |

**Proposal 18: The evaluation assumptions given in Table 4~7 should be considered for R18 LP-WUS/WUR power evaluation in RRC idle/inactive mode.**

* **Nokia**: detect a number of SSBs for re-synchronization; serving cell evaluations; Beacon, Paging procedure

**Table 2. Power saving evaluation assumptions.**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| *Numerology* |
| Subcarrier spacing | 30 kHz |
| Bandwidth | 20 MHz |
| TDD frame structure | 6 DL : 4 UL, repeated every 5 ms |
| Number of beams | 8 |
| *Paging* |
| DRX cycle | 1.280 seconds (2560 slots) |
| eDRX cycle | 48 DRX cycles |
| PTW | 8 DRX cycles |
| Paging probability per DRX cycles | [10/48] % (unless noted otherwise) |
| Number of PDCCHs/PDSCHs/EPI received per PEI-O/PO | 8 |
| Number of EPI slots used for detection | 1 |
| Number of subgroups  | 1 (unless noted otherwise) |
| *Synchronization* |
| SSB periodicity | 20 ms |
| SSB burst duration | 2 ms (4 slots) |
| Number of SSB bursts received prior to PO  | 1/2/3 for high/med/low SINR |
| Time duration for serving cell SSS acquisition if main receiver was in power off state Note1 | 4(80)/8(160)/12(240) SSB periods (slots)  |
| Number of SSB bursts received prior to PEI-O | 1 |
| Offset from SSB to PO | 10 ms |
| Offset from SSB to PEI-O | 2 ms |
| *Measurements* |
| SMTC window for intra-frequency RRM measurements | 2 ms (4 slots) |
| SMTC window for inter-frequency RRM measurements | 5 ms (10 slots) |
| Time to switch frequency layer | 0.5ms (1 slot) |
| Cell search rate $P\_{search}$ | 25 % |
| Note1: Power based on neighbor cell search power per freq. layer, Pinter, search-only, per slot is assumed for the duration. |



Figure 1: Timeline of set of process followed by 5G modem upon receiving wake-up interrupt from LP-WUR.

**Observation 3: The power consumption model developed in Rel-16 and Rel-17 would need to be updated to account LP-WUR power consumption, based on the selected LP-WUR reference architecture**

**Observation 4: For Idle/Inactive mode enhancements, if main receiver is assumed to be in power off state deep sleep for the duration of inactivity, the time line would need to accommodate the time taken to detect a number of SSBs for re-synchronization prior full reception capabilities are resumed.**

The minimum time for PSS/SSS detection, SSB index acquisition and SSB measurement (Tidentify\_intra\_with\_index = (TPSS/SSS\_sync\_intra + TSSB\_measurement\_period\_intra + TSSB\_time\_index\_intra)) is 600ms+120ms+200ms(=960ms), or greater if SMTC period is long. However, these requirements are only for the situation that UE is already synchronised to a (serving) cell in CONNECTED mode and searching for a new neighbouring cell. Hence, it is assumed that the UE already has a fine synchronisation to the network. **Thus, it would seem that rather long time may need to be reserved for the main receiver to re-acquire synchronisation.** This would of course depend on for example on the LP-WUR architecture and LP-WUS design, if they can facilitate e.g. tracking the timing and oscillator accuracy.

**Observation 5: If power off state (below deep sleep state) is considered for the main receiver, sufficient time would need to be assumed to allow the (main) receiver to acquire synchronization. This would be dependent on the time tracking capability/support of the LP-WUR/WUS.**

**Observation 6: For both, Idle/Inactive and Connected mode evaluations, the needed serving cell evaluations would need to be accounted.**

**Proposal 8: Account the evaluation assumptions presented in Table 1 and Table 2 for definition of power saving evaluation assumptions including the timeline for re-synchronisation after main receiver wake-up from power off.**

Re-Synchronisation Signal

**Proposal 11: Consider the feasibility of using the LP-WUS to support/assist re-synchronization or time/frequency tracking.**

Beacon style signal

**Proposal 12: Consider the feasibility of using the LP-WUS to support coverage determination.**

Paging procedure

**Proposal 13: Consider the feasibility of different paging procedures for LP-WUS.**

* **CATT:**  38.802+38.840 simulation assumptions; continuously or with duty-cycle of LP-WUR monitoring.

**System level simulation assumptions: 38.802**

**Traffic model used for the low-power wakeup receiver**

**Table 5: Parameters of Traffic model used for the evaluation of LP-WUR**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **FTP traffic** | **Instant messaging** | **VoIP** |
| Model | FTP model 3 | FTP model 3 | 40 bytes payload (AMR12.2 kbps) with inter-arrival time of 20 ms50% activity factor; |
| Packet size | 0.5 Mbytes | 0.1 Mbytes |
| Mean inter-arrival time | 200 ms | 2 sec |
| DRX setting | Period = 160 msInactivity timer = 100 ms | Period = 320 msInactivity timer = 80 ms | Period = 40 msInactivity timer = 10 ms |

Note: For ON duration setting, following reference DRX configurations as previously agreed.

**System Configurations:**

**Table 6: Reference DRX configuration for the evaluation of LP-WUR**

|  |  |
| --- | --- |
| **Parameter** | **Configuration** |
| DRX Cycle | On duration | Inactivity Timer |
| DRX configuration | 320msec | FR1: 10 msecFR2: 5 msec | {200, 80} |
| 160 msec | FR1: 8 msFR2: 4 ms | {100, 40} |
| 40 ms | FR1: 4 msFR2: 2 ms | {25, 10} |
| eDRX configuration | 10.24 sec | Paging Occasion |  |
| 40.96 sec | Paging Occasion |  |

**Proposal 2: The wakeup receiver could be configured to monitor wake up signals continuously for on-demand access or with duty-cycle to align with the periodicity of DRX for CONNECTED mode UE or PO for IDLE/Inactive mode UE**

* **Intel:** LP-WUS is assumed to replace PEI, further LP-WUS carry more information than PEI such as PO information.



Figure 2: LP-WUS to replace PEI PDCCH

* In Figure 2A, the UE detects a valid indication of the LP-WUS (ON) that the paging sub-group for the UE is triggered. Then, the UE can wake up the main receiver for the detection in the associated paging occasion (PO). The UE may need to detect multiple SSBs for serving cell RRM and/or fine time/frequency synchronization which are required prior to the reception of paging PDSCH.
* In Figure 2B, the difference from Figure 2A is the availability of TRS for IDLE/INACTIVE state. After the main receiver is turned on, UE may detect one SSB for RRM and one additional TRS for fine time/frequency synchronization for the reception of paging PDSCH.
* If LP-WUS can provide a RRM measurement or no RRM is necessary in the current paging cycle, the UE may detect only the TRS for fine time/frequency synchronization for the reception of paging PDSCH in Figure 2C.
* Finally, if a UE doesn’t detect a wake-up signal for the UE in Figure 2D, the UE may not wake up the main receiver at all.

**Proposal 1:** For idle/inactive mode

* Performance metrics include ratio of power consumption reduction, latency reduction
* In the modeling, LP-WUS is assumed to replace PEI PDCCH
* Study LP-WUS to provide more information than PEI PDCCH
* **ZTE:** RRM measurement should be assumed. paging latency: data arrival time to its PO.

***Proposal 8: For LP-WUS, RRM measurement assumptions should be determined.***

***Proposal 10: For LP-WUS latency evaluation, paging arrival time, position relationship between LP-WUS and corresponding PO, and LP-WUS monitoring mechanism should be determined.***



Figure 2 Paging delay

* **MTK:** reuse the traffic model in TR 38.875 including heartbeat and instant messaging.

**Table 6: baseline traffic models for FR1**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Instant messaging** | **Heartbeat** | **VoIP** |
| Model | FTP model 3 | FTP model 3 | As defined in R1-070674. Assume max two packets bundled. |
| Packet size | 0.1 Mbytes | 100 Bytes |
| Mean inter-arrival time | 2 seconds | 60 seconds |
| DRX setting | Period = 320 msInactivity timer = **20** ms'On' duration: 10 ms | C-DRX cycle 640 msInactivity timer **80** ms'On' duration: 10 ms | Period = 40 msInactivity timer = **10** ms'On' duration: 4 ms |

Details of SLS parameters are in the appendix.

1. For UE power and latency evaluation, reuse the traffic model in TR 38.875 as the baseline.
* **Ericsson:** reuse **TR 38.875 traffic models; reuse TR 38.838 and TR 38.840 traffic models;** **Additional energy (if any) consumed to acquire synchronization; paging latency (define from traffic arrival time to its PO) for both RRC idle and RRC connected modes.**

**Proposal 1 For evaluating IoT and wearable use cases, consider the mMTC traffic model in ITU M.2412, and the heartbeat and instant messaging traffic models in 3GPP TR 38.875. For evaluating other use cases (e.g., XR/smart glasses, smart phones), the corresponding traffic models in TR 38.838 and TR 38.840 can be considered.**

1. For each LP-WUR architecture considered in the study, consider at least the below aspects as part of the LP-WUR power model
* LP-WUR active power when monitoring LP-WUS
* LP-WUR sleep power when not monitoring LP-WUS (when a duty cycle for LP-WUS detection is applicable for the LP-WUR)
* Transition energy and transition time (if any) between above two states
* Transition time and transition energy (if any) for triggering the main radio from a given main-radio sleep state.
* Additional energy (if any) consumed to acquire synchronization for detecting LP-WUS
* **Scaling factors if variable BW operation is supported**
1. For power saving evaluations, consider impact of DRX/Paging configuration assumptions for the UE and impact of false wake-up of main radio due to LP-WUR false alarms.
2. For RRC-Idle mode evaluations, impact of LP-WUS/WUR operation on paging latency (e.g., time between the arrival of paging message at gNB and the reception of PDCCH with P-RNTI and any associated PDSCH by the UE) should be considered.
3. For RRC-Connected mode evaluations, impact of LP-WUS/WUR operation on scheduling latency (e.g., time between arrival of DL data at gNB and the corresponding PDCCH scheduling the data to UE) should be considered.
* **Qualcomm:** reuse 38.840; IoT traffic model

**Proposal 3: Use existing 38.840 power model and discuss/agree on additional assumptions based on evaluation done during Rel-17 UE power saving WI as starting point.**

**Additional assumptions made during R17 power saving (UEPS) WI include**

* + **Idle mode wakeup timeline in low/high SNR**
	+ **SSB monitoring for RRM (serving cell / neighbor cell)**
	+ **PO monitoring**

**Proposal 7: Introduce IoT traffic model with very sparse traffic arrival.**

**Group paging**

**Poisson page arrival with average paging inter-arrival time: [tens of min to hours]**

**Latency requirements to be considered.**

* + **E.g., [0.5]sec for actuator control/wearable, [1-60]sec for location tracking and on-demand sensing**
* **Samsung:** latency defined as from gNB transmits LP-WUS to main radio receives the PDSCH
* **OPPO:** reuse 38.875 traffic models; LP-WUR monitor LP-WUS by always on or periodically manner;

Traffic model used for the UE power saving scheme evaluation

|  |  |  |  |
| --- | --- | --- | --- |
|   | Instant messaging | Heartbeat | VoIP |
| Model | FTP model 3 | FTP model 3 | As defined in R1-070674 [7]. Assume max two packets bundled. |
| Packet size | 0.1 Mbytes | 100 Bytes |
| Mean inter-arrival time | 2 seconds | 60 seconds |
| DRX setting | Period = 320 msInactivity timer = 80 ms | C-DRX cycle 640 ms Inactivity timer {200, 80} ms | Period = 40 msInactivity timer = 10 ms |

**Proposal 2: Working mechanism for LP-WUR should be determined first, i.e. it need to determine LP-WUR monitor LP-WUS by always on or periodically manner**

* **InterDigital:** use FTP traffic and Instant messaging

Traffic model

* + FTP traffic and Instant messaging used for power saving (Table 3) can be used as baseline. Other traffic models can be considered as optional if needed.

Table 3 Traffic model

|  |  |  |
| --- | --- | --- |
|  | FTP traffic | Instant messaging |
| Model | FTP model 3 | FTP model 3 |
| Packet size | 0.5 Mbytes | 0.1 Mbytes |
| Mean inter-arrival time | 200 ms | 2 sec |
| DRX setting | Period = 160 msInactivity timer = 100 ms | Period = 320 msInactivity timer = 80 ms |

***Proposal 5: FTP traffic and Instant messaging used for power saving (Table 3) can be used as baseline.***

* **Xiaomi:** whether consider PO after detected LP-WUS: 1, legacy PO monitoring, 2, enhanced PO monitoring.



Fig.1 Case 1, LP WUS and legacy paging mechanism



Fig.2 Case 2, LP WUS and enhanced paging mechanism

***Proposal 1: For RRC idle/inactive state, two use cases can be considered for evaluation:***

***Case 1, LP WUS combined with legacy paging mechanism;***

***Case 2, LP WUS combined with enhanced paging mechanism***

* **Sharp:** reuse 38840 FTP 3 traffic model
* **Traffic model**

In the R16/R17 UE power saving study, the mandatory traffic model is FTP model 3 with 0.5Mbyte payload and mean inter-arrival time of 200 milliseconds.

**Observation 4: The traffic model can use the same assumptions as the R16 power savings study.**

* **Apple: 38.840 assumptions,** RRM measurements enhancement need to be considered.

***Proposal 4: For WUS evaluation, use the evaluation methodology and power model defined in TR 38.840 as the baseline. Additionally, define the following parameters for UE power model:***

***Proposal 6: RRM measurement enhancements should be considered as part of LP WUS/WUR evaluation.***

* **Nordic:** R16 LPWA is a power consumption reference

The WID states that LP-WUS power saving should be compared with the “existing Rel-15/16/17 UE power saving mechanisms”. We think that benchmark should not be R17 NR PEI, but R16 LPWA, such as NB-IoT or LTE-M.

***Proposal-3: R16 LPWA is a power consumption reference for LP-WUS.***

**c) baseline schemes setting, e.g. paging I-DRX and/ or eDRX; with PEI or not.**

* Alt 1 (paging DRX and eDRX, w/wo PEI): FutureWei, vivo, ZTE, OPPO, Nokia
* Alt 2 (R17 PEI and TRS for paging): Huawei, spreadtrum, CATT (R16 CDRX+DCP for connected mode),
* **Futurewei:**

|  |
| --- |
| **Power Saving Scheme** |
|
| *LP-WUS* | - |
| *DRX* | w/o PEI |
| w/ PEI |
| *eDRX* | w/o PEI |
| w/ PEI |

* **Huawei:** Rel-17 PEI and potential TRS occasions are taken as baseline mechanism
1. ***Rel-17 PEI and potential TRS occasions are taken as baseline mechanism for power saving gain evaluation.***
* **Spreadtrum:**  R17 PEI

***Proposal 7: The power saving gain can be the additional power saving gain compared with R17 UE power saving techniques, e.g. R17 PEI.***

* **vivo:** I-DRX paging and eDRX

**Table 4. The evaluation power saving schemes for RRC idle/inactive mode.**

|  |  |
| --- | --- |
| **Schemes** | **Description** |
| **Baseline 1-1: I-DRX Paging without PEI** | Assume low, medium, high SINR cases |
| **Baseline 1-2: I-DRX Paging with PEI** | Assume low, medium, high SINR cases |
| **Baseline 2-1: eDRX without PEI** | Assume low, medium, high SINR cases |
| **Baseline 2-2: eDRX with PEI** | Assume low, medium, high SINR cases |
| **LP-WUS/WUR** | After receiving the LP-WUS, UE’s main radio will be turned on and the UE is required to monitoring its PO. |

**Proposal 17: For comparison with R18 LP-WUS/WUR, both I-DRX paging and eDRX can be taken as baseline schemes.**

* **CATT:**  R17 paing+PEI; R16 CDRX+DCP for connected mode

**Proposal 7: The baseline configuration for the study of low-power wakeup receiver should be the latest power saving techniques as follows,**

* **CONNECTED mode: Rel-16 DRX adaptation with UE wakeup indication from DCI format 2\_6**
* **IDLE/Inactive mode: Rel-17 paging enhancement with Paging Early Indication from DCI format 2\_7**
* **ZTE:**  reuse 38.840. eDRX configuration

Table 2 Paging rate

|  |  |  |
| --- | --- | --- |
| paging rate per PO | Paging rate per group | Paging rate per UE |
| 4 | 8 |
| 10% | 2.6% | 1.3% | 0.3% |

***Proposal 9: System configurations including paging rate and DRX cycle configuration in TR38.840 can be reused. eDRX configuration(s) can be chosen from existing eDRX configurations.***

* **OPPO:**  Paging cycle with PEI and eDRX with PEI can be the baseline scheme.

#### [H] Proposals 2D-v1:

For RRC IDLE/INACTIVE, the i-DRX and eDRX are considerd as baseline schemes. The following is assumed for evaluation,

|  |  |
| --- | --- |
| **Parameters** | **Value** |
| i-DRX cycle length | 1.28s, consider both with PEI/ without PEI |
| e-DRX cycle length | 20.48s, 61.44s, company to report which value(s) are used |
| # POs  | 1 |
| # PTW | 4 |
| i-DRX cycle length | 1.28s |
| 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 |
| Number of SSB after PO | 1, (used for inter-F measurement); 0, (for High SINR case). |
| RRM Measurement | Company to report how the RRM measurement is assumed, e.g., RRM performed by main radio or LP-WUS receiver.  |
| LP-WUS monitoring | Option 1: continuously monitoringOption 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: Per PO/UE paging rate = ([10%], [1%])Option 2:Reusing TR 38.875 heart beat traffic model

|  |  |
| --- | --- |
| Model | FTP3 |
| Packet size | 100 Bytes |
| Mean inter-arrival time | 60s (per UE paging rate≈2%) |

Model RRC connection phase power consumption as follows,

|  |  |
| --- | --- |
| RRC connection duration | 30ms |
| Relative enery consumption of RRC connection block (Relative power x ms) | 30ms\*100 =3000 |

 |

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic | for baseline study only the case with PEI (if NR is the choice of baseline ). And only Option 1 traffic model. OK to make “without PEI” and “Option 2 traffic model” as optional.  |
| Futurewei | We are in general OK with the listed assumptions but would like to clarify the behavior of the main radio in conjunction with LP-WUR as the main radio’s behavior and the content of the LP-WUS can have an impact on the power consumoption and latency evaluation results. For example, if the LP-WUS contains the paged UE’s unique address, the main radio does not have to monitor the PO and the per PO paging rate is irrelevant. So, we suggest considering the following options for the evaluation:LP-WUS Option 1: Uniquely-addressedLP-WUS Option 1: Group-addressed and a group paing rate XMain Radio Option 1: Monitors legacy PO after wake-upMain Radio Option 2: Monitors newly configured PO after wake-upMain Radio Option 3: Does not need to monitor any POs after wake-up |
| Spreadtrum1 | Generally agree. Share the similar view as Futurewei, some assumptions needs multiple options before we have consensus. More assumptions:Measurement relaxation Option 1: Measurement relaxed by the main receiver.Measurement relaxation Option 2: Measurement is not relaxed by the main receiver.Beam sweeping of the LP-WUS Option 1: YesBeam sweeping of the LP-WUS Option 2: No |
| ZTE, Sanechips | Some basic assumptions for RRM measurement should be listed. If it is up to company report, the simulation results would be quite different. For example, following assumptions can be considered1. No RRM measurement
2. Measurement based on LP-WUS
3. Relaxed RRM measurement

For the traffic part, * RRC IDLE/INACTIVE in assumed for this proposal. Model of RRC connection phase power consumption is not related to this proposal. It is better to be removed.
* The relationship between paging rate and traffic should be clarified., i.e., how to obtain ‘per UE paging rate≈2%’

Additionally, how to calculate the time for LP-WUS and time for main radio may need further clarification. For example, whether LP-WUS is turned off when main radio is turned on, the power consumption for SSB sync is included in transition energy or additionally added, whether the transition energy during transition time includes the power consumption for LP-WUS and main radio. |
| Xiaomi | About the main radio part, share similar views as Futurewei |
| vivo | Support. For the UE behavior after woke up by LP-WUS, we think the legacy UE behavior, i.e. UE need to monitor legacy PO after woke up by LP-WUS should be considered as a baseline assumption at least. And other proposed UE behaviors after wake up can be left to company report. Since there is no related reference modelling for other UE behaviors, company needs to provide detailed assumptions accordingly. |
| Panasonic | We are okay with the proposal. |
| Intel | We share Futurewei’s view to evaluate different cases with assumption that LP-WUS identifies a paging group, paging sub-group (as PEI) or a single UE with different behavior for main radio. b.t.w., there are two rows of ‘i-DRX cycle length’ in the proposal. It would be helpful if the FL can clarify the difference of these two rows.  |

### 2E-v1: Assumptions for RRC CONNECTED

* **vivo:** reuse 38.838 assumption and additional jitter model

**Proposal 19: For R18 LP-WUS/WUR power evaluation in RRC connected mode, R17 evaluation methodologies and assumptions captured in TR 38.838 (for XR) should be reused as baseline. And the jitter model (jitter range is [-8, +8]ms and jitter STD is 5ms) should be considered.**

**Proposal 20: For R18 LP-WUS/WUR power evaluation in RRC connected mode, during the LP-WUS monitoring by separate receiver, the power state of main radio can be micro or light sleep.**

* **Ericsson:**  the evaluation methodology in TR 38.838 can be reused.
* **Intel:**  for XR or FTP traffic; LP-WUS function is similar to DCP. Monitoring LP-WUS during DRX on.

**Proposal 2:** For connected mode

* Two modes can be considered for evaluations
	+ Model 1: LP-WUS detection in DRX ON for XR operation having periodic traffic with jitter in packet arrival time
	+ Model 2: LP-WUS to trigger active PDCCH monitoring or SSSG switching assuming aperiodic traffic, e.g., ftp traffic is configured to the UE
* Performance metrics include ratio of power consumption reduction, latency reduction
* LP-WUS may provide a function that is similar to DCI format 2\_6
* Monitoring LP-WUS is further extended in the DRX ON time.
* **ZTE:**  the evaluation methodology in TR 38.838 can be reused.

***Proposal 4: If XR service is considered in LP-WUS study, the evaluation methodology in TR 38.838 can be reused.***

* ***FFS parameters, such as jitter range, need to be updated.***
* **Xiaomi:**

*For RRC connected state, three use cases can be considered for evaluation:*

*Case 1, LP WUS used as DCP;*

*Case 2, LP WUS used during C-DRX on duration;*

*Case 3, LP WUS used without C-DRX.*



Fig.3 Case 1, LP WUS used as DCP



Fig.4 Case 2, LP WUS used during C-DRX on duration



Fig.5 Case 3, LP WUS used without C-DRX

***Proposal 2: For RRC connected state, three use cases can be considered for evaluation:***

***Case 1, LP WUS used as DCP;***

***Case 2, LP WUS used during C-DRX on duration;***

***Case 3, LP WUS used without C-DRX.***

Reuse 38.838 assumptions: vivo (with additional jitter model ), Ericsson, Intel (mentioned XR traffic), ZTE (with additional jitter model), xiaomi (mentioned XR traffic)

#### [H] Proposals 2E-v1:

For R18 LP-WUS/WUR power evaluation in RRC connected mode, evaluation methodologies and assumptions captured in TR 38.838 (for XR) should be reused as baseline. Company can further report the followings,

* Parameters (e.g., frame rate, data rate, jitter range, DRX configurations and etc.)
* How to use LP-WUS, e.g., LP-WUS to trigger/adapt PDCCH monitoring

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Futurewei | We are OK with proposal. |
| Spreadtrum1 | Fine |
| ZTE, Sanechips | System level simulation is expected for the evaluation of RRC connected mode . We are OK with this proposal.Power consumption for LP-WUS and main radio state,e.g.,light sleep or micro sleep, in connected mode may need further clarification. |
| Xiaomi | OK with the Proposal |
| vivo | Support. Besides, the evaluation methodologies and assumptions agreed in R18 XR study can also be reused, if any. |
| Panasonic | We are okay. |
| Intel | The FL proposal means to simulate LP-WUS only in DRX ON duration. Then our question is whether/how to evaluate the operation in DRX OFF or when DRX is not configured? |

## Issue 3: Link Performance related assumptions

### 3A-v1: Performance metric in LLS

* Metric 1: FAR
	+ Supported by Huawei, spreatrum, vivo, interdigital, intel, ZTE, samsung, sony
	+ Reported by companies: Huawei
	+ 0.1%: vivo, Xiaomi, E///
	+ 1%: intel (often used for PUCCH detection and other channels)
	+ <<0.1%: Qualcomm
	+ Determined based on the power consumption: Samsung, E///
* Metric 2: MDR
	+ Supported by Huawei, vivo, spreatrum, interdigital, intel, ZTE, Samsung, sony
	+ 1%: Huawei, vivo, E///, Qualcomm
	+ 0.1% : intel (miss detection is even more harmful to the communication), Xiaomi
	+ Determined based on their impact on the latency: Samsung

#### [H] Proposal 3A-v1:

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

* The miss-detection rate (MDR) of LP-WUS should be no worse than [1%],
* The false-alarm rate (FAR) of LP-WUS should be no large than [0.1%]

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic | It depends, if LP-WUS would replace paging, 1% MDR would be enough.  |
| Futurewei | We agree on MDR $\leq 1\%$ but suggest relaxing the requirement on FAR to $\leq 1\%$ and evaluate the impact on power consumption and coverage. |
| Spreadtrum1 | It related to SINR required, and also related to sensitivity required. If we draw a conclusion, the architecture should provide the sensitivity required, or equivalently the coverage target is fixed with a given architecture. |
| ZTE, Sanechips | OK.  |
| vivo | 1% MDR is preferred which is usually used for PDCCH. For FAR, 1% are also acceptable for trade-off between power consumption and coverage especially when the LP-WUS is monitored discontinuously |
| Panasonic | We agree on the proposal. |
| Intel | If false alarm happens, it means waste some UE power. On the other hand, if miss detection happens, it means further delay to UE connection. We believe the impact on other functionalities should be minimized by the introduction of LP-WUS. This is the reason we prefer low MDR. In our understanding, if LP-WUS 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. We prefer to explicitly clarify it in the proposal.  |

In R17 PEI discussion, we set the coverage requirement at first in form of miss-detection rate (MDR) and false-alarm rate (FAR), and then evaluate the resource overhead of different designs of the PEI. The similar methodology can be reused.

### 3B-v1: Performance metric for coverage and methodology

For coverage evaluation, there are many assumptions should be provided, e.g., frequency bands, channel model, data rates for data channels (e.g., PUSCH, PDSCH), gNB antenna structures. Several companies proposed to reuse the basic assumptions defined in TR38.830, which is the outcome of Rel-17 CovEnh SI, as the starting point. And some companies propose to reuse the assunptions defined in TR 38.875(Redcap), which also largely reuse the assumptions agreed in Rel-17 CovEnh SI.

* Reuse R17 CovEnh: Huawei, vivo, Qualcomm
* Reuse R17 Redcap: ZTE(TR 38.875, deployment scenario similar to redcap), MTK
* Reuse assumptions including channel model in TR38.901: Samsung
* Reuse assumptions in TR37.910(ITU self evaluation): E///
* Reuse the evaluation assumptions for defined in TR 38.802: interDigital

Most companies proposed to reuse the coverage evaluation metric and methodoly in TR38.840 (TR of R17 CovEnh SI) or TR 38.875 (TR of R17 RedCap SI). Except for limited parameters, e.g., channel BW and UE Rx numbers, and data rates for DL channels are separated discussed in Redcap SI, other assumptions and methodology in Redcap SI are directly reused from CovEnh SI. Besides, a limited set of scenarios, e.g. dense urban at 2.6GHz for FR1, is prioritized in coverage evaluation in R17 Redcap.

For coverage evaluation for LP-WUS, moderate suggest to reuse the assumptions and methodology in TR38.830 or TR 38.875, which are well discussed in last release. We can further discuss subset of the metrics and assumptions to be prioritized for evaluation in this SI.

**Discussion point 1: Metrics for coverage evaluation.**

Coverage is one of the important evaluation aspects for LP-WUS. There are company proposals on the metric for coverage evaluation. The following metrics are raised by companies.

* Alt 1: MCL.
	+ Huawei,…
* Alt 2: MIL
	+ Huawei, vivo, intel, MTK, Nordic, [E///],

**Discussion point 2: Reference NR channels for coverage comparison.**

The coverage of LP-WUS should be compared to existing NR channels. The comparison of coverage between existing NR channels and LP-WUS is a good way to evaluate the coverage of LP-WUS. For the existing NR channels used as reference for comparison, company proposals are summarized as follows.

Alt-1: PUSCH with certain data rates.

* vivo, intel, ZTE(Equal or better than PUSCH), Nordic, Samsung

Alt-2: Paging PDCCH/CSS PDCCH

* Nokia, OPPO(Same/close to NR DL control channels, -80~-60dBm Receiver sensitivity), ZTE (FFS), E///, Nordic

Alt-3: SSS

* Nokia

Alt-4: PDSCH

* Samsung

#### [H] Proposal 3B-v1:

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;
* LP-WUS should be compared with NR bottle neck channel, i.e., PUSCH [1Mbps].

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic  | If not mistaken PUSCH bottle neck depends on Scenario, excerpt from 38.830Urban: DL 10Mbps, UL 1MbpsRural: DL 1Mbps, UL 100kbpsRural with long distance: DL 1Mbps, UL 100kbps, 30kbps (optional) |
| Futurewei | We are OK with proposal. |
| Spreadtrum1 | Need further discussion |
| ZTE, Sanechips | As Nordic mentioned, the data rate is related to the scenarios. Additionally, the following aspects should be taken into account for the link budget.* Noise figure
* Amplification factor
 |
| vivo | Support the proposal. According to TR 38.830, PUSCH has worst coverage in almost all scenarios evaluated. Thus, existing NR deployments is limited by PUSCH coverage. Hence, we suggest coverage of PUSCH, with certain data rates reused from TR 38.830, is used as reference channel to compare with LP-WUS. |
| Panasonic | We think it needs further discussion on which channel (DL and also UL) should be compared with LP-WUS. Also agree with Nordic that the details are scenario dependent. |
| Intel | The second bullet seems overlap with proposal 1C-v1. We think it is more proper to select a channel from SSB, SIB1, OSI, Type0/0A/1/2 CSS, paging PDSCH, RACH msg1/2/3/4 and common PUCCH of NR |

### 3C-v1: LLS common assumptions

* **Huawei**

Depending on detailed design of the LP-WUS, which shall impact the link budget calculation.

Comparing the coverage of different design, the data rate should be aligned or reported to fulfill the requirement to get fair comparison.

* **Intel**

**Table 4: Common evaluation assumptions**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameters**  | **FR1, Urban** | **FR1, Urban** | **FR1, Rural** |
| Carrier Frequency | 2.6 GHz (TDD) | 4 GHz (TDD)(Low priority) | 0.7 GHz (FDD) |
| SCS | 30 kHz | 30 kHz | 15 kHz |
| Frame structure for TDD | DDDDDDDSUU (S: 6D:4G:4U) | DDDSUDDSUU (S: 10D:2G:2U) | N/A |
| # of gNB TX chains | 4 | 4 | 2  |
| # of gNB RX chains | 4 | 4 | 2 |
| Channel Model | TDL-C, NLOS | TDL-C, NLOS | TDL-C, NLOS |
| UE antenna correlation | low | low | low |
| delay spread | 300 ns | 300 ns | 300 ns |
| UE velocity | 3 km/h | 3 km/h | 3 km/h |
| Modulation  | MC-OOK, MC-FSK |
| Initial error of LO frequency or sampling clock | Up to [200ppm] |
| Main Radio of UE |
| BW | 100MHz (273 PRBs)20MHz (51 PRBs)5MHz (11 PRBs) | 100MHz (273 PRBs)20MHz (51 PRBs)5MHz (11 PRBs) | 20MHz (106 PRBs)5MHz (25 PRBs) |
| # of TX chains  | 1 | 1 | 1 |
| # of RX chains | 4, 1 | 4, 1 | 2, 1 |
| LP-WUR of UE |
| BW | [4MHz] | [4MHz] | [4MHz] |
| # of UE RX chains | [4, 1] | [4, 1] | [2, 1] |

* **MTK**

**Figure 1: general baseband model for LP-WUR LLS evaluation**

|  |  |  |
| --- | --- | --- |
| **Name** | **Definition** | **Reference**  |
| 3GPP channel | TDL-C, NLOS | TR 38.875 |
| Intra-cell Interference | NR data is sent with LP-WUS in the frequency domain. Interference power level depends on guild band and LPF. | R1-1902940R1-2109954 |
| Inter-cell interference | An interference cell shares the same RE with LP-WUS. Interference power level = 10.45 dB (for single interfering cell). | TR 38.833 |
| Low-pass Filter | Use a 2nd order Butterworth low-pass filter with cutoff frequency at approximately 2.5 MHz | IEEE 802.11-17/0188r10 |
| Carrier frequency offset | The tx oscillator has an inaccuracy of 20ppm, and the Rx oscillator has an inaccuracy of 180ppm. The total frequency offset is 200 ppm. | IEEE 802.11-17/0188r10 |

**Table 7: WIFI-like configurations**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Comments** |
| Total carrier bandwidth | 4 MHz | The same as IEEE 802.11ba  |
| Receiver noise figure | 18 dB | 8 dB margin to a WIFI main receiver [9] |
| Occupied channel bandwidth | 3.6 MHz | 2RB/4RB margin for guard bands |
| Number of received chains | 1 | The same as NR Rel-17 RedCap |
| Required SNR | 3.7 dB | 32 bits payload without the use of I/Q [9]  |

* **Rakuten Symphony**

Table 1 WUS/WUR evaluation assumptions

|  |  |
| --- | --- |
| **Features** | **Assumptions** |
| Waveform  | MC-OOK, MC-FSK |
| Carrier frequency  | 2.4 GHz, 5 GHz (TBD) |
| SCS | 15 kHz, 30 kHz |
| WUS bandwidth  | [4] MHz |
| Simulation type | Link level, system level (optional) |
| Channel model | AWGN, TDL-A, TDL-C |
| Packet size | TBD |
| WUS frequency location | In-band |
| Channel bandwidth | 20 MHz |
| Adjacent channel interference | WUS and NR legacy channels adjacent in the same channel (Guard band TBD) |
| Frequency offset | 200 ppm |
| Phase noise model | [802.11ba model] |
| UE mobility | 0 km/h and 3 km/h |

**Channel models:**

**Reuse that in 38.830 as starting point:** Huawei, vivo

**TDL-C 300ns:** vivo, Nokia, qualcomm, Eurecom

**AWGN:** vivo, Nokia, Eurecom

**Others:**

* TDL-C-30ns, TDL-C-100ns, TDL-D 30ns
* CDL-C and TDL-A (for FR2)

**Interference modeling:**

**ZTE:** FDMed LP-WUS

**vivo:** PDSCH mapped on RBs not used for LP-WUS and guard band; EPRE of LP-WUS vs EPRE of PDSCH = 1:1.

**MTK:** NR data is sent with LP-WUS in the frequency domain. Interference power level depends on guild band and LPF.

**Qualcomm:** placement of other DL signals on both sides of the LP-WUS BW to evaluate interference rejection capability of different receiver architectures

**Filter**

**Nokia:** 6-th order butterworth.

**Vivo:** 5-th order butter worth.

**MTK:** 2nd order Butterworth low-pass filter with cutoff frequency at approximately 2.5 MHz(IEEE 802.11-17/0188r10)

**ZTE：**should be considered.

**Eurecom:** 3rd order Butterworth (LPF Cut-off Frequency: 2\*(K/2+0.5)\*SCS Hz assuming WUS BW is 64 subcarriers)

**Guard band**

* Nokia: company report.
* MTK: should consider in LLS baseband model
* Vivo: should consider

**Co-channel interference**

* **Nokia:** NR (OFDM signal) channel transmitted before and after the LP-WUS and also instead the LP-WUS signal for false alarm and robustness evaluation.
* **ZTE:** DL signal/LP-WUS of neighboring cell.

#### [H] Proposal 3C-v1:

The following should be described for the link-level evaluation:

* Structure of LP-WUS signals/channels
* Information conveyed by the LP-WUS
* Modulation and coding schemes if any
* ACI modelling: DL channels FDMed with LP-WUS, including Resource allocation, power and guardband, etc.
* ACI rejection methods: e.g., parameter of the filters

The following assumptions for link performance evaluation for LP-WUS is used,

**Assumptions for link performance evaluation for LP-WUS**

|  |  |
| --- | --- |
| **Attributes** | **Assumptions** |
| Channel structure | Company to report, e.g., Preamble +data +CRC: 32 chips+ 32 bits +8 CRC bits |
| Coding scheme | Company to report |
| LP-WUS raw data rate | Company to report |
| SCS | 30kHz |
| gNB Channel BW  | 20MHz, 100MHz  |
| WUS Bandwidth | Compay to report, e.g., 12RB ~ 4.32MHz, 5RB ~ 1.8MHz |
| Guard band | [N] RB on each side of LP-WUS bandwidth, company to report N |
| ACI | PDSCH mapped on RBs not used for LP-WUS and guard band;EPRE of LP-WUS vs EPRE of PDSCH = Q, company to report Q, |
| Filter | [X]-th order Butterworth low-pass filter with cutoff frequency at [Y] MHz, company to report |
| Sampling Rate | S = [1/4, 1/2, 1, 2, 4,…] times of LP-WUS raw data rate, company to report S |
| ADC | D = 1bit (comparator), or D = 2bits / 4bits ADC, subject to company report D |
| Channel Model | TDL-C 300ns |
| Number of Rx for LP-WUS | 1 Rx |
| UE speed | 3 km/h |

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic | This is good starting point, but we believe it will be difficult to compare results, there is too much freedom. We assume we will be able to refine above assumption in later rounds.  |
| Futurewei | We would like to clarify that specified SCS is for the generation of PDSCH for ACI and that details on how to generate the LP-WUS, i.e., the utilized SCS and considered TX architecture {OFDM, DFT} are to be reported by company. We also suggest including additional channel model, e.g., TDL-C 30ns, for the evaluation.Further, we would appreciate if you can elaborate on how we can consider a sampling rate defined as a fraction of raw data rate for the evaluation.  |
| ZTE, Sanechips | The following parameters also should be captured:* Duplex mode
* gNB antenna configuration
* Waveform
* Frequency drift

It should be clarified whether the SCS is for LP-WUS or gNB. For the SCS of LP-WUS, other configurations also should not be precluded.Additionally, does coding scheme mean OOK, FSK or other coding scheme, or just mean waveform, e.g., Manchester? |
| vivo | Support these assumptions as starting point. We can further refine these assumptions later. |
| Panasonic | We are basically okay but think it is not necessary to mandate the SCS as just 30 kHz. We can make 30kHz as baseline and companies may report the SCS used. |
| Intel | Thanks for good summary/proposal. we should align a proper payload size for LP-WUS. Then, the time duration of LP-WUS should be aligned too. suggest to add SCS 15kHz for low frequency  |

### 3D-v1: Frequencies and scenarios

**Frequencies**

The Frequency range/band directly impacts the coverage of the LP-WUS. Some companies provided some initial proposals on Frequency range/band.

**Huawei:** [assumptions in TR38.830 as starting point]

**vivo:** [900MHz and 2GHz]

**Interdigital:** Focus on FR1 for evaluation in Rel-18 and study FR2 later if needed.

* Most receivers consuming low power operate at frequencies below 3 GHz as required power consumption generally increases as carrier frequency increases.

**Nokia:** 4GHz

**Intel/Nordic:** 2.6GHz/4GHz for Urban, 0.7GHz for Rural.

**MTK:** 2.6GHz for Urban, 0.7GHz for Rural.

**Lenovo:** Consider FR1

* Since most of the frequencies deployed in IoT scenarios are in the C-band i.e., 3.5GHz carrier frequency or even lower frequency band, i.e., 700MHz-800MHz, which should be prioritized compared to higher mmWave frequencies in FR2.

**Qualcomm:** 700MHz, 4GHz

**Urban/dense/indoor/rural**

Huawei

1. ***The deployment scenarios of LP-WUS at least include dense urban, rural macro and indoor hotspot.***

Vivo

**About -80 dBm Receiver sensitivity is required for LP-WUS, to achieve same coverage as PUSCH with 1Mbps data rates in Urban scenario.**

CATT

* Proposal 4: The study of low-power wakeup receiver should prioritize the single layer dense urban and indoor hotspot scenarios

ZTE

***Proposal 3: The deployment scenarios for LP-WUS includes Urban, Rural and Indoor.***

* ***Further discuss and decide which deployment can be optionally evaluated.***

Nordic

RAN1 to study and decide what target MIL should be for LP-WUS in the following scenarios; (i) Rural (700MHz), (ii) Urban scenario (2.6 GHz) and (iii) Urban scenario (4GHz).

#### [H] Proposal 3D-v1:

For evaluation of LP-WUS, the frequencies / scenarios in TR38.830 are baseline.

* Priortize urban (2.6GHz?4GHz?) scenario for FR1,
* Others not precluded.

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic  | not OK, 700MHz is must for IoT use-case, not sure why TDD bands should be prioritized. |
| Futurewei | We are open but prefer to be more inclusive at this stage. |
| ZTE, Sanechips | All the 0.7G, 2.6G, and 4G frequencies should be considered. |
| vivo | Support the proposal.We are also fine to include other scenarios, e.g. 700MHz carrier frequency. However, the number of scenarios to be evaluated should be limited. We can down select in the scenarios evaluated in TR 38.830.  |
| Panasonic | Agree with Futurewei. |
| Intel | 700MHz should be included which is proposed by companies too |

### 3E-v1: impairments

**Frequency error:**

* **Uniform distribution in the range [-X, +X]ppm:** Nokia
* **[200] PPM:** vivo, intel, MTK
* **Should be considered:** E///

MTK: (The tx oscillator has an inaccuracy of 20ppm, and the Rx oscillator has an inaccuracy of 180ppm. The total frequency offset is 200 ppm.)

Qualcomm: Introduce clock error parameters, e.g.,

* + Clocks frequency drift (ppm/s) [X, Z].
	+ Clocks maximum frequency error (ppm) [Y, L].

#### [M] Proposal 3E-v1:

Maximum LO frequency error for LP-WUR, when not relying on DL synchronization signals is assumed to be [200ppm] for evaluation.

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic  | LC-DCO / LC-VCO should do better. Those were not yet ruled out, per se. For ring oscillator 200ppm sound right. |
| Futurewei | We are OK with proposal which should cover all potential evaluated LP-WUR architecture categories. |
| vivo | Support this proposal. |
| Panasonic | Just to clarify our understanding, we think it is +/- 100ppm error drifting, which is intended for 200ppm error. Or the intention is +/- 200 ppm? |
| Intel | We support the FL proposal.  |

### 3F-v1: Noise Figure

Noise figure is one of the parameters used in link budget for coverage evaluation. Due to WUR is separated from the main radio for low power consumption, the RF components e.g., LNA, used for WUR is not as good as that for the main radio. The noise figure assumed for the WUR may be worse than that in the main radio, which is 7dB assumed in [TR38.830]. Companies provided initial proposals on the value for the noise figure, which are summarized as follows.

* 18 dB: Huawei(for architecture with LO), MTK (8dB higher than wifi main receiver)
* 23 dB: Huawei(for architecture without LO)
* 15 dB: vivo (8 dB higher than NR main receiver with 7dB NF.)
* Depending on Rx architectures/ Company report/FFS: Nordic, Ericsson, Qualcomm

**Huawei:** To keep a low power consumption, usually a lower power LNA would be used and the corresponding noise figure is larger than that of main receiver. A larger noise figure would cause a worse sensitivity, which impacts the coverage of the receiver. More analysis can be found in [2].

#### [M] Proposal 3F-v1:

For evaluation,

* the noise figure is [15-18]dB for mixer-first LP-WUS receiver.
* the noise figure is [23]dB for rectifier-first LP-WUS receiver without LO.

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic  | This suggests that these two architecture are further studied. We should first make progress in 9.13.2  |
| vivo | Noise figure for LP-WUR should be different from that of main radio. We supported this proposal, and also open to other values if justified in 9.13.2. |
|  |  |
| Intel | Fine with proposal for evaluation purpose. The value can be updated after a progress in 9.13.2 as proposed by Nordic |

### 3G-v1: LP-WUR Rx

Rx number is one of the parameters that has impacts on coverage. For NR DL channels, 2 or 4 antennas are required for different bands. For LP-WUS channel, how many antennas are used can be further discussed. Companies provided initial proposals on the number of receiving antennas, which are summarized as follows.

* Alt 1：1Rx
	+ Huawei, vivo, [intel], [MTK], Lenovo(the baseline can be taken from that of RedCap), Qualcomm
* Alt 2: 4Rx
	+ [intel]

#### [M] Proposal 3G-v1:

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

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Nordic | Support |
| Futurewei | We agree with the proposal. |
| Xiaomi | OK with the Proposal |
| vivo | Support. |
| Panasonic | We are okay. |
| Intel | We are OK with the proposal  |

### 3H-v1: Others

**Other proposal related to coverage evaluation** are summarized as follows:

**Spreadtrum:** Assumption of whether the LP-WUS supports beam sweeping or not impacts at least the resource overhead and the coverage.

**ZTE:** it is suggested to **simplify the evaluation for each deployment to reduce the workload** if all the scenarios, Urban, Rural and Indoor deployment scenario, are considered for study.

The deployment scenarios for LP-WUS includes **Urban, Rural and Indoor.**

* Further discuss and decide which deployment can be optionally evaluated.
* The system level simulation for NW capacity can be deprioritized.

**CMCC**

With the existing Rel-15/Rel-16/Rel-17 5G NR network deployment, compared with the sensitivity of the main radio, low-power WUR with worse sensitivity has less applicable areas.

**Other proposal related to coverage evaluation**

**Nokia**

We assumed TDL-C-300ns channel, with 3kmh and 30kHz sub-carrier spacing. SSS was defined as per TS38.211 and PDCCH was assuming 48RB CORESET with 1 symbol (AL8, 41 bits + 24 CRC bits). As a LP-WUS signal a 14 OFDM symbols long MC-OOK sequence **(seven on/off symbol pairs) was used,** where ‘on’-durations were SSS signals (127-len). For LP-WUS a time domain envelope detector was considered with 6th order Butterworth filter followed by down sampling and averaging to determine the threshold. The sequence envelope is illustrated in Figure 6.



**ZTE:** The parameters should be selected based on the actual LP-WUS receiver architectures;

**Qualcomm:** FFS Receiver model based on receiver architecture study; prefer to have a unified receiver model for different low-power receiver architectures for non-OFDM based LP-WUS

# Summary of the previous agreements

## RAN1#110bis-e

# Proposals from companies’ submitted contributions

## FUTUREWEI

**R1-2208378 Evaluation of Low Power WUS and initial performance results FUTUREWEI**

Performance Metrics and Models

***Proposal 1: A set of relative power values and corresponding low-power receiver characteristics, e.g., sensitivity, needs to be defined for proper evaluation of power saving gains/losses.***

***Proposal 2: If LP-WUR’s full coverage is not a target design, a model capturing LP-WUR’s limited coverage scenario and the behavior/protocol of LP-WUR/Main Radio need to be defined for proper evaluation of the LP-WUS/WUR power saving gain.***

***Proposal 3: A set of signal design options and corresponding time/frequency resource requirements needs to be defined for proper evaluation of the network resource overhead in support of LP-WUS/WUR***

Assumptions and Use Case

***Proposal 4: A set of use cases and corresponding traffic models and power saving schemes parameters needs to be defined for proper evaluation/comparison with power consumption and latency of LP-WUS.***

Initial Results for Power Consumption and Latency

***Observation 1: LP-WUS can provide a significant power saving gain of*** $\left(80.9\% to 88.4\%\right)$ ***compared to DRX but may provide a power saving loss of*** $\left(-18.4\% to-4.7\%\right)$ ***compared to eDRX.***

***Observation 2: Despite the slight power saving loss, LP-WUS can provide a significant latency reduction of*** $(96.1\% to 99.5\%)$ ***compared to eDRX power saving scheme.***

***Observation 3: LP-WUS may suffer latency increase/penalty of*** $\~30\%$ ***for a DRX cycle-restricted main radio but can provide latency reduction of*** $\~84\%$ ***for a non DRX cycle-restricted main radio compared to DRX power saving scheme.***

***Observation 4: LP-WUS/WUR can enable a new power consumption vs. latency trade-off region that may not be achievable by either of the DRX and the eDRX power saving schemes.***

## Huawei, HiSilicon

**R1-2208417 Evaluation methodology for LP-WUS Huawei, HiSilicon**

1. **LP-WUR allows the main receiver to change between off/ultra-deep sleep state, and ‘on’ state.**
2. **The average power consumption of LP-WUR should be lower than the deep sleep power consumption of the main receiver to provide significant power saving gain.**
3. **Current power model defined in TR 38.840 does not account for how to model the transition for a new deeper sleep state.**
4. ***Evaluations should include traffic models applicable to smartphones.***
5. ***LP-WUS for RRC IDLE/INACTIVE mode is prioritized at first.***
6. ***The deployment scenarios of LP-WUS at least include dense urban, rural macro and indoor hotspot.***
7. ***The power saving gain is evaluated by***

$$power saving gain=1-\frac{\sum\_{i}^{}P\_{i, enh}}{\sum\_{i}^{}P\_{i, base}}$$

***where i is the slot index,*** $P\_{i, enh}$ ***is the power consumption of enhanced scheme in slot i, and*** $P\_{i, base}$ ***is the power consumption of baseline scheme in slot i.***

1. ***For system level simulation, the assumptions specified in Table A2.1-1 in TR 38.802 can be the starting point, with necessary updates.***
2. ***For evaluation purposes, capture the following table in the TR and reuse other power stables of main receiver in TR 38.840.***

|  |  |  |
| --- | --- | --- |
| Power state | Relative Power | Note |
| LP-WUR working state | 0.01 ~ 0.02 | The architectures proposed in [2] can achieve such a power consumption range, where the one without LO usually consumes more power than the one with LO. |
| LP-WUR non-working state | 0 | The wakeup receiver is turned off. |
| Ultra-deep sleep (main receiver) | [0] | The main receiver sleeps deeper than ‘Deep sleep’, and the power consumption is ultra-low.  |

1. ***RAN1 to investigate how to model the transition energy for ultra-deep sleep state of main receiver for evaluation purpose.***
2. ***For evaluation purposes, the per-UE paging rate is assumed to be 1%, which is the same as in earlier releases.***
3. ***Rel-17 PEI and potential TRS occasions are taken as baseline mechanism for power saving gain evaluation.***
4. ***For coverage evaluation of LP-WUS, link budget, e.g. MCL or MIL, can be used as the metric.***
5. ***The following link simulation assumption is used for LP-WUS coverage evaluation***

***1 receive chain for LP-WUS***

***Noise figure is [18] dB / [23 ]dB for wakeup receiver with/without LO***

***Missed detection rate: 1%***

***False alarm rate: reported by companies***

***Other parameters are dependent on detailed design and reported by companies***

1. ***For evaluation purposes, the transition time of main receiver for ultra-deep sleep is assumed to be about one to several seconds.***
2. ***RAN1 needs to agree assumptions for the total latency introduced by LP-WUS, depending on the information the signal conveys, i.e. depending on the subsequent procedures assumed in the UE.***
3. ***Evaluations assuming the same SCS for legacy NR signal and LP-WUS transmitted by gNB are mandatory and the baseline. Evaluations with different SCSs for legacy NR and LP-WUS transmitted by gNB are optional, and companies to report the SCSs used.***
4. ***For evaluation purpose, the resource overhead of LP-WUS occupying*** $N\\_RE\_{LP-WUS}$ ***REs is evaluated by*** $O=\frac{N\\_RE\_{LP-WUS}}{N\\_RE\_{total}}$***, in a carrier of*** $N\\_RE\_{total}$ ***REs***

## Spreadtrum Communications

**R1-2208572 Discussion on evaluation on low power WUS Spreadtrum Communications**

KPI

***Observation 1: Using R17 PEI as baseline for the additional power saving gain of the LP-WUR can make comparison easy.***

***Observation 2: The latency may a key benefit of the LP-WUR.***

***Observation 3: The resource overhead to meet the coverage requirement may be a tradeoff for the power saving gain.***

***Observations 4: The coexistence between the legacy signal/channel and the LP-WUS may cause increase of the resource overhead.***

***Observation 5: The mobility may be affected by turning off the main receiver.***

Evaluation assumptions

***Observation 6: Assumption of always-on or periodically-on impacts KPIs widely.***

***Observation 7: Assumption of whether the LP-WUS supports beam sweeping or not impacts at least the resource overhead and the coverage.***

***Observation 8: Assumption of whether the main receiver should still monitor PO after wakeup impacts KPIs widely.***

***Observation 9: Assumption of whether the measurement is relaxed or not at the main receiver at least impacts the mobility.***

***Observation 10: Assumption of whether the main receiver needs to perform cell search after the main receiver is turned on at least impacts the latency and the power saving gain.***

***Observation 11: If the main receiver needs to perform cell search after wakeup, the main receiver can stay in a completely-off state before wakeup.***

We have the following proposals.

Evaluation methodology

***Proposal 1: The power model for the main receiver can reuse that defined in TR 38.840.***

***Proposal 2: The power consumption of detection of the LP-WUS can be defined.***

***Proposal 3: At least one type of sleep mode can be defined for the LP-WUR.***

***Proposal 4: The number of categories of power model for the LP-WUR depends on the outcome of discussion of architectures of the LP-WUR.***

***Proposal 5: The transition energy/time should be defined for transition between a sleep mode and active mode for the LP-WUR.***

KPI

***Proposal 6: The following KPIs for the LP-WUR can be used, e.g.***

* ***the power saving gain,***
* ***the latency,***
* ***the resource overhead to meet the coverage requirement, and***
* ***the mobility in terms of the measurement relaxation at the main receiver.***

***Proposal 7: The power saving gain can be the additional power saving gain compared with R17 UE power saving techniques, e.g. R17 PEI.***

Evaluation assumptions

***Proposal 8: The baseline evaluation assumptions should be determined, e.g.***

* ***paging rate,***
* ***group-paging-rate,***
* ***paging cycle,***
* ***link-level performance requirement for the LP-WUR, and***
* ***CFO requirement and the number of SS bursts to be processed for the main receiver.***

***Proposal 9: The additional evaluation assumptions should be studied and determined as much as possible, e.g.***

* ***always-on vs. periodically-on,***
* ***whether the LP-WUS supports beam sweeping or not,***
* ***whether the main receiver should still monitor PO after wakeup,***
* ***whether the measurement is relaxed or not at the main receiver, and***
* ***whether the main receiver needs to perform cell search after wakeup.***

## vivo

**R1-2208668 Evaluation methodologies for R18 LP-WUS/WUR vivo**

**Observation 1: For RRC connected mode, the additional latency by adopting LP-WUS/WUR is up to 3ms**

**Observation 2: For RRC idle/inactive UEs, the average UE power consumption is currently on several to tens of mW.**

**Observation 3: To achieve substantial power saving gain, a reasonable target power consumption of LP-WUR need to be at the level of 1/100~1/1000 of the main receiver, corresponding to tens to hundreds of μW.**

**Observation 4: When the LP-WUR power consumption is 30μW~500μW, UE battery life can be increased by 3~7 times compared with legacy UEs.**

**Observation 5: When the LP-WUR power consumption is 30μW~500μW, the standby time of IoT devices can be extended to up to 10 years with the use of a button battery for power supply.**

**Observation 6: The main contribution of latency comes from the LP-WUS monitoring cycle and the transition time of main radio.**

**Observation 7: With the assistance of a separate receiver i.e., LP-WUR, the main radio has the opportunity to enter an ultra-deep sleep state (i.e., deeper than the existing deep sleep).**

**Observation 8: Compared with existing deep sleep mode, the main radio in ultra-deep sleep state consumes longer transition time and more energy for the transition from the ultra-deep sleep state to normal operation.**

**Observation 9: Comparing with I-DRX paging, LP-WUR/WUS can largely reduce the UE power consumption (5x or 7x), with similar latency performance.**

**Observation 10: Comparing with eDRX, LP-WUR/WUS can largely reduce the latency (26x), with even lower UE power consumption.**

**Observation 11: Comparing with I-DRX paging and eDRX, LP-WUR/WUS provides a much better trade-off between latency and power consumption.**

**Observation 12: Comparing with Always-On LP-WUS monitoring, duty-cycled LP-WUS monitoring can further reduce power consumption while sacrificing latency performance.**

**Observation 13: The motivation to study LP-WUS/WUR in RRC connected mode for XR service is to reduce the excessive PDCCH monitoring due to unpredictable jitter.**

**Observation 14: Compared to the existing R15/16/17 power saving schemes, LP-WUS monitoring combined with main receiver micro sleep can bring {6%~15%} additional UE power saving gain with no capacity loss in both low load and high load cases.**

**Observation 15: Compared to the existing R15/16/17 power saving schemes, LP-WUS monitoring combined with main receiver light sleep can bring {10%~22%} additional UE power saving gain, with acceptable capacity loss at least in low load case.**

**Observation 16: About -80 dBm Receiver sensitivity is required for LP-WUS, to achieve same coverage as PUSCH with 1Mbps data rates in Urban scenario.**

**Observation 17: The bandwidth of the filter for suppressing ACI may be wider than the signal bandwidth to accommodate the frequency error at WUR.**

**Proposal 1: Study the following use cases for LP-WUS/WUR:**

1. **For IoT devices (e.g., sensors and controllers): The battery should last at least few years; Latency would be within several or tens of seconds; For latency sensitive sensors/actuators, the latency requirement is 1 or 2 seconds; The mobility would be stationary or nomadic.**
2. **For wearable devices: The battery should last a few weeks; Latency need to be within several seconds; Support of low/medium speed is required.**
3. **For XR devices or smart phones: power saving in CONNECTED mode is desirable; Latency which is critical for RRC CONNECTED state need to be in the order of milliseconds; Support of low/medium speed is required.**

**Proposal 2: Study the application of LP-WUS/WUR in both RRC idle/inactive mode and RRC connected mode.**

**Proposal 3: The target KPI for LP-WUR power consumption should be tens to hundreds of μW.**

**Proposal 4: The latency introduced by LP-WUR/WUS needs to consider two parts: wake-up delay and transition time of main radio.**

**Proposal 5: Target KPI of latency should be as follows.**

* **Depends on the length of LP-WUS monitoring cycle for RRC idle/inactive mode**
* **Wake up delay: depends on the length of LP-WUS monitoring cycle, e.g. hundreds of milliseconds**
* **Transition time: hundreds of milliseconds**
* **Several milliseconds for RRC connected mode**
* **Wake up delay: 0 (assuming continuous monitoring of LP-WUS)**
* **Transition time: up to 3ms**

**Proposal 6: Coverage of the LP-WUS should be comparable to the NR bottleneck channel.**

**Proposal 7: Around 100kbps data rate can be considered as design target for LP-WUS.**

**Proposal 8: The overall design target of coexistence is to support multiplexing between LP-WUS with legacy NR signals/channels and to allow reuse of unused LP-WUS resources for other DL transmissions.**

**Proposal 9: Adopt the following power consumption evaluation methods for R18** **LP-WUS/WUR study:**

* **For RRC idle/inactive mode, the simulation assumptions for R17 Power saving paging enhancement evaluation can be reused.**
* **For RRC connected mode, the simulation assumptions for R17/18 XR power evaluation can be reused.**

**Proposal 10: The latency can be roughly caculated as 1/2 LP-WUS monitoring cycle length + transition time of main radio.**

**Proposal 11: FAR and MDR is used as the performance metric for LP-WUS in link level simulation,**

* **{FAR, MDR}: {0.1%, 1%} can be assumed as starting point.**

**Proposal 12:**  **MIL metric defined in Coverage Enh SI can be reused as the metric for relative comparison between coverage of LP-WUS and NR channels.**

**Proposal 13: Resource overhead and network power consumption are evaluated by numerical analysis, using the outcome of NW energy saving study. Capacity impact is evaluated by system level simualtion using XR evaluation methodlogy for RRC CONNECTED.**

**Proposal 14: Adopt the following terminology for future discussion,**

* **Main radio：the Tx/Rx module operating for legacy system**
* **LP-WUR: The Rx module operating for receiving/processing LP-WUS**

**Proposal 15: For R18 LP-WUS/WUR power evaluation, the following power model of the ultra-deep sleep state agreed in R18 positioning SI for LPHAP is reused for main radio.**

* + **Note: the value of additional transition energy can be updated based on further agreement made in R18 positioning SI.**

|  |  |  |  |
| --- | --- | --- | --- |
| Power State | Relative Power | Additional transition energy:(Relative power x ms) | Total transition time |
| Ultra-deep sleep | 0.015 | [2000-20000] | 400ms |

**Proposal 16: For R18 LP-WUS/WUR power evaluation, the following power model of LP-WUR is considered.**

* **Note: these value in brackets can be further confirmed based on the progress of LP-WUR architecture.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Power State | Absolute Power | Relative Power | Additional transition energy | Total transition time |
| LP-WUR sleep | [2] μW | **[0.002]** | **0** | **0** |
| LP-WUR monitoring | [30~500] μW | **[0.03~0.5]** | **-** | **-** |

**Proposal 17: For comparison with R18 LP-WUS/WUR, both I-DRX paging and eDRX can be taken as baseline schemes.**

**Proposal 18: The evaluation assumptions given in Table 4~7 should be considered for R18 LP-WUS/WUR power evaluation in RRC idle/inactive mode.**

**Proposal 19: For R18 LP-WUS/WUR power evaluation in RRC connected mode, R17 evaluation methodologies and assumptions captured in TR 38.838 (for XR) should be reused as baseline. And the jitter model (jitter range is [-8, +8]ms and jitter STD is 5ms) should be considered.**

**Proposal 20: For R18 LP-WUS/WUR power evaluation in RRC connected mode, during the LP-WUS monitoring by separate receiver, the power state of main radio can be micro or light sleep.**

**Proposal 21: For evaluation of the coverage of LP-WUS, the methodology and assumptions in R17 CovEnh SI should be reused.**

* **MIL is used as the metric for coverage evaluation;**
* **LP-WUS should be compared with NR bottle neck channel, i.e., PUSCH.**
* **PUSCH coverage is evaluated with the certain data rates as in CovEnh SI, e.g., 1Mbps for urban;**
* **LP-WUS specific evaluation assumptions and parameter, can be further discussed in the study.**

**Proposal 22: 15dB noise figure can be assumed for MIL calculation for LP-WUS.**

**Proposal 23: OOK/ASK based waveform, which are widely used for ultra-lower power receiver, can be assumed in link level simulation.**

**Proposal 24: Channel structure/coding/data rate should be reported in link level simulation,**

* **Channel Structure like {[Sync field] + information bits + [CRC]} can be assumed;**
* **Simple coding scheme, e.g., Manchester coding, can be used as starting point;**
* **~10 to ~100kbps raw data rate can be evaluated in the simulation.**

**Proposal 25: For frequency domain resources for LP-WUS, following can be assumed in link level simulation**

* **Around 1.4MHz ~ 4MHz channel bandwidth can be assumed as stating point;**
* **[1~2] RB Guard band reserved on each side of LP-WUS bandwidth can be assumed as starting point.**

**Proposal 26: For modeling adjacent interference, PDSCH can be mapped on RBs not used for LP-WUS and guard band.**

**Proposal 27:** **Around [4/2/1/0.5] MHz sampling rate can be considered in evaluation.**

**Proposal 28: [1] receiving antennas can be assumed for WUR in evaluation.**

**Proposal 29: 1-bit comparator or 2/4-bits ADC can be assumed for WUR in LLS.**

## InterDigital, Inc.

**R1-2208686 Discussion on evaluation on LP-WUS InterDigital, Inc.**

***Observation 1:*** *Most receivers consuming low power operate at frequencies below 3 GHz as required power consumption generally increases as carrier frequency increases.*

***Observation 2:*** *Link level simulation is a tool for evaluating coverage as well as false alarm rate and misdetection rate.*

***Proposal 1:*** *Focus on FR1 for evaluation in Rel-18 and study FR2 later if needed.*

***Proposal 2:*** *Support link level evaluation as baseline evaluation for LP-WUS.*

***Proposal 3:*** *Link level evaluation assumptions used for power saving (Table 4 in Appendix) can be a starting point for further discussion.*

***Proposal 4:*** *To evaluate power saving gain from LP-WUS, relative power, additional transition energy and total transition time should be additionally defined with a newly defined power state for LP-WUS*.

***Proposal 5:*** *FTP traffic and Instant messaging used for power saving (Table 3) can be used as baseline.*

***Proposal 6:*** *For system level simulation, the evaluation assumptions used for power saving (Table 5 in Appendix) can be a starting point for further discussion.*

## Nokia, Nokia Shanghai Bell

**R1-2208698 Low power WUS Evaluation Methodology Nokia, Nokia Shanghai Bell**

In section 2 we discussed study item scope and raised following observations and proposals:-

Observation 1: Many of the target use cases for the new WUS, are the same as those for the Reduced Capability devices developed for Release 17 and the being developed for Release 18.

Proposal 1: The SI considers the constraints of RedCap devices.

Proposal 2: Down prioritize the sidelink related studies for time being.

In section 3 we looked at the different deployment scenarios and make following proposals:-

Proposal 3: LP-WUS design and LP-WUR architecture support flexible placement in frequency domain.

Proposal 4: The wake-up signal design and wake up receiver architecture defined, allows efficient reuse of gNB hardware for signal generation.

Proposal 5: The LP-WUS signal design and LP-WUR architecture should be defined so that efficient multiplexing with existing NR signals and channels is possible to limit the resource reservation.

Proposal 6: Coverage and mobility implications should be accounted for in LP-WUS design and LP-WUR architecture assumptions.

Proposal 7: Consider in LP-WUS design and LP-WUR architecture the possibility to accommodate use cases with some degree of limited mobility.

Simulation and evaluation assumptions are addressed in section 4, with focus on the power saving and link level assumptions. In section 4 we observe following on the key performance indicators:-

Observation 2: Different key performance indicators need to be considered in the study should cover: power consumption, latency, coverage, selectivity/robustness data rate/capacity (from LP-WUS and system perspective).

Further in section 4.1 and 4.2 we discuss the assumptions related to the power saving evaluations, together with preliminary results and conclude:-

Observation 3: The power consumption model developed in Rel-16 and Rel-17 would need to be updated to account LP-WUR power consumption, based on the selected LP-WUR reference architecture

Observation 4: For Idle/Inactive mode enhancements, if main receiver is assumed to be in power off state deep sleep for the duration of inactivity, the time line would need to accommodate the time taken to detect a number of SSBs for re-synchronization prior full reception capabilities are resumed.

Observation 5: If power off state (below deep sleep state) is considered for the main receiver, sufficient time would need to be assumed to allow the (main) receiver to acquire synchronization. This would be dependent on the time tracking capability/support of the LP-WUR/WUS.

Observation 6: For both, Idle/Inactive and Connected mode evaluations, the needed serving cell evaluations would need to be accounted.

Observation 7: The latency involved with LP-WUR reception of LP-WUS is ≈5ms. However, the overall service/paging latency including sub-systems boot-up, calibration, and re synchronization, incurs the average delay of 960ms, which is bit more than DRX latency of 640ms.

Proposal 8: Account the evaluation assumptions presented in Table 1 and Table 2 for definition of power saving evaluation assumptions including the timeline for re-synchronisation after main receiver wake-up from power off.

Link level simulation assumptions, together with preliminary results are discussed in section 4.3 with a proposal:-

Proposal 9: Account assumptions presented in Table 3 in definition of the link level simulation assumptions

In Section 4.4 we discuss on the system level simulation assumptions:-

Observation 8: Overhead analysis should be considered for different LP-WUS designs and LP-WUR architectures, accounting any guard needed. Detailed system level simulation assumptions should be discussed once there is consensus on the focus use cases and related assumptions.

Finally in section 5 we touch upon on some other potential use cases for LP-WUS:-

Proposal 10: Consider the possible use cases of the LP-WUS in Connected mode.

Proposal 11: Consider the feasibility of using the LP-WUS to support/assist re-synchronization or time/frequency tracking.

Proposal 12: Consider the feasibility of using the LP-WUS to support coverage determination.

Proposal 13: Consider the feasibility of different paging procedures for LP-WUS.

## OPPO

**R1-2208843 Evaluation discussion on lower power wake-up signal OPPO**

***Observation 1****: Rel-18 lower power WUS/WUR could apply in many use cases, such as Industrial Wireless Sensor Network, Smart Wearable, Smart Home, Medical Health, etc.*

***Proposal 1: KPIs in table1, such as power consumption of LP-WUR, power saving gain, latency, coverage of LP-WUS, resource overhead, UE receiver sensitivity, etc. should be considered when study LP-WUS/WUR.***

***Proposal 2: Working mechanism for LP-WUR should be determined first, i.e. it need to determine LP-WUR monitor LP-WUS by always on or periodically manner.***

***Proposal 3: New power states and power consumption values should be defined in UE power consumption model for main radio and LP-WUR, respectively.***

***Proposal 4: UE power consumption model in TR38.840 can be modified as table 2 for Rel-18 LP-WUR/WUS.***

Table 2: UE power consumption model for LP-WUS/WUR

|  |  |  |
| --- | --- | --- |
| **Power State**  | **Characteristics**  | **Relative Power**  |
| **Main radio** |
| [Quasi] Power Off | Main radio can keep power off when LP-WUR not wake-up main radio. | [0.01] |
| Deep Sleep  | Time interval for the sleep should be larger than the total transition time entering and leaving this state. Accurate timing may not be maintained.  | 1 (Optional: 0.5)  |
| Light Sleep  | Time interval for the sleep should be larger than the total transition time entering and leaving this state.  | 20  |
| Micro sleep  | Immediate transition is assumed for power saving study purpose from or to a non-sleep state  | 45  |
| PDCCH-only  | No PDSCH and same-slot scheduling; this includes time for PDCCH decoding and any micro-sleep within the slot.  | 100  |
| SSB or CSI-RS proc.  | SSB can be used for fine time-frequency sync. and RSRP measurement of the serving/camping cell. TRS is the considered CSI-RS for sync. FFS the power scaling for processing other configurations of CSI-RS.  | 100  |
| PDCCH + PDSCH  | PDCCH + PDSCH. ACK/NACK in long PUCCH is modeled by UL power state.  | 300  |
| **LP-WUR** |
| LP-WUS monitor | Monitoring of low power wake-up signals.[Two possible working mechanism, i.e., monitor lower power wake-up signals by always on or periodically on manner.] | [0.5] |
| [LP-WUR sleep] | Lower power wake-up radio keeps sleep state when no lower power wake-up signals.[Monitoring LP-WUS by periodically manner] | [0.01] |

***Proposal 5: The power consumption and transition time during the state transition which main radio goes into power off should be considered.***

***Proposal 6****:* ***Following******Performance metrics should be evaluation.***

* + - ***UE power saving gain,***
		- ***Latency and Scheduling delay***
		- ***Overhead for reception of the LP-WUS***
		- ***Coverage performance***
		- ***False alarm rate and miss-detection rate***

## CATT

**R1-2208960 Deployment scenarios and evaluation methodologies for low-power WUS CATT**

* Proposal 1: The UE power consumption of preparation and detection of wakeup signal/channel should be significantly lower comparing to the wakeup indication by DCI formats 2\_6 and 2\_7 in the target study of low power wakeup receiver.
* Proposal 2: The wakeup receiver could be configured to monitor wake up signals continuously for on-demand access or with duty-cycle to align with the periodicity of DRX for CONNECTED mode UE or PO for IDLE/Inactive mode UE
* Proposal 3: The target requirements of UE power consumption, the receiver sensitivity and the minimum achievable data rate of Low-power wakeup should be defined as follows,
	+ UE power consumption < [100] µW
	+ Receiver sensitivity of Low-power wakeup receiver – [-80] dBm or maximum coupling loss at [126 dB]
	+ Minimum achievable data rate – [160] bps
* Proposal 4: The study of low-power wakeup receiver should prioritize the single layer dense urban and indoor hotspot scenarios
* Proposal 5: The power model for the low-power wakeup receiver should include the following assumptions
	+ The power consumption of low-power wakeup receiver is independent to that of NR receiver.
	+ The power consumption of NR receiver should be negligibly low and assumed to be “zero” relative to the deep sleep mode value “1”.
	+ The power model of the low-power wakeup receiver is defined relative to the power state of deep sleep mode with the assumption of the negligible power consumption of NR receiver.
* Proposal 6: The link and system level simulation assumptions are based on the system parameters of selected deployment scenarios of those scenarios with limited inter-site distance in Rel-16 UE power saving in TR38.840.
* Proposal 7: The baseline configuration for the study of low-power wakeup receiver should be the latest power saving techniques as follows,
	+ CONNECTED mode: Rel-16 DRX adaptation with UE wakeup indication from DCI format 2\_6
	+ IDLE/Inactive mode: Rel-17 paging enhancement with Paging Early Indication from DCI format 2\_7
* Proposal 8: The key performance index of LP-WUR study should include the UE power saving gain, system performance and overhead, the miss-detection/false alarm of the wakeup signaling detection.

## Intel Corporation

**R1-2209075 Discussion on evaluations on LP WUS Intel Corporation**

**Proposal 1:** For idle/inactive mode

* For the deeper sleep mode of main radio, the power consumption, additional transition energy and transition time can be respectively assumed as 0.015, 2000 and 400ms for the evaluation of power saving and latency reduction.
* The power consumption for the active or inactive state of LP-WUR is assumed to 100uW – 1mW and 1-10uW for the evaluation of power saving and latency reduction
* Performance metrics include ratio of power consumption reduction, latency reduction
* In the modeling, LP-WUS is assumed to replace PEI PDCCH
* Study LP-WUS to provide more information than PEI PDCCH

**Proposal 2:** For connected mode

* Two modes can be considered for evaluations
	+ Model 1: LP-WUS detection in DRX ON for XR operation having periodic traffic with jitter in packet arrival time
	+ Model 2: LP-WUS to trigger active PDCCH monitoring or SSSG switching assuming aperiodic traffic, e.g., ftp traffic is configured to the UE
* Performance metrics include ratio of power consumption reduction, latency reduction
* LP-WUS may provide a function that is similar to DCI format 2\_6
* Monitoring LP-WUS is further extended in the DRX ON time.

**Proposal 3:**

* Two performance metrics, false alarm rate of 1% and mis detection rate of 0.1% can be used in LP-WUS evaluation.
* If LP-WUS consists two parts, the link performance of the two parts need to be jointly considered to derive the final performance metrics
* The sensitivity for LP-WUS can be derived by the required SINR for LP-WUS detection

**Proposal 4:**

* Adopt Table 4 as a start point for the detailed link-level simulation assumptions for LP-WUS detection.

## ZTE, Sanechips

**R1-2209199 Evaluation on LP-WUS ZTE, Sanechips**

***Proposal 1: The following aspects should be considered for any studied use case for LP-WUS***

* ***Traffic model***
* ***Power consumption ratio of idle mode and connected mode***

***Proposal 2: The following KPIs of LP-WUS should be considered***

* ***For UE side***
* ***Power saving gain***
* ***Latency***
* ***Complexity increase***
* ***For gNB side***
* ***Coverage***
* ***Co-existence***
* ***Network power consumption/resource overhead/capacity***
* ***For LP-WUS***
* ***False alarm rate***
* ***Miss detection rate/BLER***
* ***Sync performance***

***Proposal 3: The deployment scenarios for LP-WUS includes Urban, Rural and Indoor.***

* ***Further discuss and decide which deployment can be optionally evaluated.***

***Proposal 4: If XR service is considered in LP-WUS study, the evaluation methodology in TR 38.838 can be reused.***

* ***FFS parameters, such as jitter range, need to be updated.***

***Proposal 5: The method to calculate the total power consumption can be based on the power consumption of main radio, the power consumption for LP-WUS receiver, and the power consumption for RRM measurement.***

$$E\_{total}=E\_{}^{MR}+E\_{}^{WUR}+E\_{measurment}^{}$$

***Where,***

$$E\_{}^{MR}=E\_{SSB}^{MR}+E\_{PDCCH+PDSCH}^{MR}+E\_{sleep}^{MR}+E\_{off}^{MR}+E\_{state transition}^{MR}$$

$E\_{}^{WUR}=E\_{on}^{WUR}+E\_{off}^{WUR}+E\_{state transition1}^{WUR}$ **or** $E\_{}^{WUR}=E\_{on}^{WUR}+E\_{state transition2}^{WUR}$

$$E\_{measurment}^{}=E\_{measurement}^{MR}+E\_{measurement}^{WUR}$$

***Proposal 6: The power off state of main radio should be introduced for power consumption evaluation.***

* ***The characteristics of power off state, the value of relative power and UE power consumption during the state transition should be defined.***

***Proposal 7: For LP-WUS, the relative power of WUR on state, WUR off state and the power consumption of WUR on-off transition state should be defined.***

***Proposal 8: For LP-WUS, RRM measurement assumptions should be determined.***

***Proposal 9: System configurations including paging rate and DRX cycle configuration in TR38.840 can be reused. eDRX configuration(s) can be chosen from existing eDRX configurations.***

***Proposal 10: For LP-WUS latency evaluation, paging arrival time, position relationship between LP-WUS and corresponding PO, and LP-WUS monitoring mechanism should be determined.***

***Proposal 11: Regarding network coverage evaluation for LP-WUS, the parameters/simulation assumptions of the deployment scenarios defined in TR38.875 can be used as references.***

***Proposal 12: Regarding network coverage evaluation for LP-WUS, its coverage performance should be equal or better than that of the limited channel evaluated in NR Rel-15/16/17.***

* ***Whether its coverage performance is consistent with that of paging message needs to be further considered.***

***Proposal 13: The following aspects need to be considered in LP-WUS design.***

* ***Network resource overhead, network power consumption can be evaluated and compared with NR signal, e.g., SSB.***
* ***Coexistence with non-low-power-WUR UEs can be further analyzed based on the outcome of LP-WUS design***
* ***The system level simulation for NW capacity can be deprioritized.***

***Proposal 14: Regarding LLS assumptions for LP-WUS receiver, the aspects such as system configuration, LP-WUS transmission configuration, LP-WUS receiver configuration and performance metrics should be considered and studied.***

* ***For system configurations, LLS /link budget parameter in TR38.875 can be used as reference.***
* ***For LP-WUS transmission configuration, LP-WUS receiver configuration and performance metrics, they depend on LP-WUS designs and corresponding LP-WUS receiver architectures.***

## xiaomi

**R1-2209270 Evaluation on low power WUS xiaomi**

***Proposal 1: For RRC idle/inactive state, two use cases can be considered for evaluation:***

***Case 1, LP WUS combined with legacy paging mechanism;***

***Case 2, LP WUS combined with enhanced paging mechanism.***

***Proposal 2: For RRC connected state, three use cases can be considered for evaluation:***

***Case 1, LP WUS used as DCP;***

***Case 2, LP WUS used during C-DRX on duration;***

***Case 3, LP WUS used without C-DRX.***

***Proposal 3:*** ***For RRC idle/inactive state, numerical calculation or statistics to evaluate power consumption and latency.***

***Proposal 4:*** ***For RRC connect state, system level or link level simulation to evaluate power consumption, latency and throughput.***

***Proposal 5:*** ***Link level simulation to evaluate miss detection rate/false detection rate of LP WUS sequence, and set the target miss detection rate/false detection rate as 10-3.***

***Proposal 6: Reuse power model/traffic model and simulation assumptions for power saving defined in TR 38.840 as much as possible. And extra model for LP WUS monitoring power consumption and the related wake up delay should be developed.***

## CMCC

**R1-2209361 Discussion on evaluation methodology and applicable scenarios for low power WUR CMCC**

**Observation 1: In the real world outside lab, “assisted parts” also need to be considered for low-power WUR. And the total power consumption of low-power WUR might be high up to the order of hundreds of uW or even mW, which is much higher than the power consumption of the “core parts” only.**

**Proposal 1: When evaluating the power consumption of low-power WUR, both the power consumption of the “core parts” and the “assisted parts” shall be taken into consideration, including VCO/Oscillator, IF Amp, Envelop Detector, BB Amplifier, Digital Circuit, Bias, PMIC, Bandgap voltage reference, GPIO, etc.**

**Observation 2: The transient period may be high up to the order of 10ms when the main radio to be turned on from the status of “turned off” or “deep sleep”.**

**Proposal 2: The transient period between “main radio turned on” and “main radio turned off/deep sleep” shall be taken into consideration in the evaluation methodology.**

**Observation 3: With the existing Rel-15/Rel-16/Rel-17 5G NR network deployment, compared with the sensitivity of the main radio, low-power WUR with worse sensitivity has less applicable areas.**

**Observation 4: To balance among the die area/benefits of power saving/complexity/cost, etc., the less bands supported, the more benefits can be obtained from the low-power WUR solution.**

**Proposal 3: Observation 3 and Observation 4 shall be taken into consideration when analyzing the applicable scenarios for low-power WUR.**

## MediaTek Inc.

**R1-2209502 Evaluation on low power WUS MediaTek Inc.**

**Proposal 1 Use cases can at least include wearables and XR for LP WUR/S.**

**Proposal 2 KPI can includes power consumption, data latency, coverage (MIL), and robustness (MDR and FAR) for LP WUR/S.**

**Proposal 3 For UE power and latency evaluation, introduce a power consumption model for LP-WUR, including WUR on/off power states and transition time/energy.**

**Proposal 4 For UE power and latency evaluation, introduce a new power state of "power off" for the Rel-15 reference UE and Rel-17 RedCap UE.**

**Proposal 5 For UE power and latency evaluation, reuse the traffic model in TR 38.875 as the baseline.**

**Proposal 6 For coverage evaluation, at least consider carrier frequencies of 700MHz and 2.6GHz.**

**Proposal 7 For coverage evaluation, reuse a template in R1-2009293 for Rel-18 RedCap.**

**Proposal 8 For coverage evaluation, LP WUR/WUS link-level simulation (LLS) is essential to evaluate the required SNR and the occupied LP-WUS bandwidth.**

**Proposal 9 For LP WUR/WUS LLS evaluation, consider a general baseband model including interference, low-pass filter, and frequency error.**

**Proposal 10 L1 signal and procedure design for LP WUR/WUS should consider coexistence and overhead impact.**

## Apple

**R1-2209605 On performance evaluation for low power wake-up signal Apple**

**Proposal 1: All the use cases can be considered for the study.**

**Proposal 2: RRC idle/inactive mode can be prioritized for the study.**

**Proposal 3: For performance evaluation of LP WUS/WUR for idle/inactive UEs, the following KPIs should be considered:**

* **WUS detection performance, including missed detection rate and false alarm rate**
* **Coverage**
* **UE power saving gain**
* **Paging latency**
* **WUS overhead**

**Proposal 4: For WUS evaluation, use the evaluation methodology and power model defined in TR 38.840 as the baseline. Additionally, define the following parameters for UE power model:**

* **The power consumption of the main radio in “ultra-deep sleep state”**
* **The transition time and transition energy for the main radio to go from/to non-sleep state to/from ultra-deep sleep state**
* **The power consumption of WUR during active monitoring**
* **The power consumption of WUR when it is not actively monitoring**

**Proposal 5: Set a preliminary target of sub-mW level power consumption for WUR during active monitoring.**

**Proposal 6: RRM measurement enhancements should be considered as part of LP WUS/WUR evaluation.**

## Rakuten Symphony

**R1-2209621 Discussion on low power WUS evaluation Rakuten Symphony**

**Proposal 1: Consider MC-OOK and MC-FSK waveforms as candidates for the low power WUS.**

**Proposal 2: Assume maximum power of 0.5 mW and sensitivity of -80 dBm or better.**

**Proposal 3: Consider the parameters in Table 1 for simulation analysis.**

Table 1 WUS/WUR evaluation assumptions

|  |  |
| --- | --- |
| **Features** | **Assumptions** |
| Waveform  | MC-OOK, MC-FSK |
| Carrier frequency  | 2.4 GHz, 5 GHz (TBD) |
| SCS | 15 kHz, 30 kHz |
| WUS bandwidth  | [4] MHz |
| Simulation type | Link level, system level (optional) |
| Channel model | AWGN, TDL-A, TDL-C |
| Packet size | TBD |
| WUS frequency location | In-band |
| Channel bandwidth | 20 MHz |
| Adjacent channel interference | WUS and NR legacy channels adjacent in the same channel (Guard band TBD) |
| Frequency offset | 200 ppm |
| Phase noise model | [802.11ba model] |
| UE mobility | 0 km/h and 3 km/h |

## Lenovo

**R1-2209665 Discussion on the evaluation methodology for low power WUS Lenovo**

Proposal 1: RAN1 study prioritize latency tolerant low sensitive use case for evaluation

* IIoT use case: Sensor and actuator control, condition monitoring sensors in factories, environmental monitoring sensors such as temperature, pressure etc.,, and low power asset tracking applications
* Commercial use case: Wearable devices such as smart watch, smart meter etc.,

Proposal 2: Prioritize duty cycle-based LP-WUR application compared to always-on LP-WUR

Proposal 3: Prioritize studying the LP-WUR for idle/inactive mode UEs

Proposal 4: Consider FR1 and single receive antenna for coverage evaluation

Proposal 5: Consider similar coverage level for the LP-WUR implemented in a supplementary chip and the main NR receiver

Proposal 6: Consider both in-band and out of band combination to evaluate the cost, complexity, and coverage of LP-WUR and LP-WUS

Proposal 7: LP-WUR device capabilities can include receive-only LP-WUR and transmit-receive LP-WUR. For evaluation framework, consider the evaluation of receive-only LP-WUR at the beginning

Proposal 8: Consider candidate waveform based on MC-OOK and FSK with their respective receiver architecture to evaluate power consumption, coverage, data rate, sensitivity and selectivity

Proposal 9: Consider candidate LP-WUS bandwidth similar to RedCap bandwidth, SSB bandwidth

Proposal 10: Consider LP-WUS to be FDMed with the existing NR signal/channel including the requirement for guard resource blocks

Proposal 11: Consider reporting the latency from the successful reception of the LP-WUS in the supplementary chip to the waking up of the main receiver to successfully receive PDCCH

Proposal 12: Consider reporting paging reception delay with and without LP-WUR

## Sharp

**R1-2209685 Discussion on evaluation for low power WUS Sharp**

**Observation 1**: The power consumption models for R16 power saving can be reused for LP-WUS evaluation.

**Observation 2**: The power consumption model for LP-WUS receive can include two states at least, and the details need more study.

**Observation 3:** The system configurations used to evaluate R16 power saving can be reused and should be extended with the configuration with 20MHz system bandwidth extended.

**Observation 4:** The traffic model can use the same assumptions as the R16 power savings study.

## Samsung

**R1-2209756 Evaluation on LP-WUS/WUR Samsung**

**Proposal 1: Add XR, smart glasses and smartphones as target use cases.**

**Proposal 2: Power consumption of LP-WUR should target to achieve hundreds of uW or below.**

**Proposal 3: The design of LP-WUS should strive to minimize the impact to the gNB.**

**Proposal 4: Power consumption model defined in TR38.840 is reused with the following enhancements for LP-WUR/WUS evaluation:**

* **Power unit needs to be defined for the cases that LP-WUR is on, LP-WUR detects LP-WUS, and LP-WUR wakes up the main radio;**
* **A new state for the main radio needs to be defined for the case that the main radio is turned off;**
* **Transition time and power unit need to be defined for transition between the off state of the main radio and other states.**

**Proposal 5: Target probabilities of false alarm and misdetection should be determined based on their impact on the latency and the power consumption.**

**Proposal 6: Coverage of LP-WUS/WUR should be similar to that of main radio.**

**Proposal 7: Latency is defined as the time duration from the point that the gNB transmits LP-WUS to the point that main radio receives the PDSCH.**

**Proposal 8:  Evaluation assumptions in TR38.901 are reused for link level simulation.**

**Proposal 9: Evaluation assumptions in TR38.840 are reused for evaluation of UE power saving gain.**

## Rakuten Mobile, Inc

**R1-2209766 Initial view on evaluation of low-power WUS Rakuten Mobile, Inc**

**Proposal 1**
Power consumption reduction gain of LP-WUS should be evaluated.

**Observation 1**
Overall framework of application of LP-WUS needs to be clarified to evaluate overall power consumption gain.

**Proposal 2**

For the assumption of framework of LP-WUS, minimum impact to the network deployment should be assured.

**Proposal 3**For the evaluation of the power consumption gain of LP-WUS, power consumption modelling of the Rel-16/17 WUS can be utilized.

**Proposal 4**Link level performance should be evaluated.

**Proposal 5**

Coverage by LP-WUS should be kept to the same level as existing cell coverage by NR.

**Proposal 6**System-level evaluation should be conducted.

**Proposal 7**
Regarding frequency assumption, in-band operation can be the baseline.

## Ericsson

**R1-2209862 Evaluation framework for low power WUS Ericsson**

[Proposal 1 For evaluating IoT and wearable use cases, consider the mMTC traffic model in ITU M.2412, and the heartbeat and instant messaging traffic models in 3GPP TR 38.875. For evaluating other use cases (e.g., XR/smart glasses, smart phones), the corresponding traffic models in TR 38.838 and TR 38.840 can be considered.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442420)

[Proposal 2 For evaluating use cases with tight delay requirements (e.g., XR), feasibility of LP-WUR waking up the main radio with low latency should be studied also considering the associated power consumption for the main radio.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442421)

[Proposal 3 Following general framework should be used as starting point for WUS evaluations:](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442422)

[· transmission of LP-WUS should not require new gNB hardware and should not trigger new emissions/compliance requirements for gNBs](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442423)

[· it should be possible to dynamically reuse unused LP-WUS resources for other NR transmissions (i.e., dedicated time/frequency resource reservation for WUS should be avoided)](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442424)

[· it should be possible to multiplex LP-WUS with other NR transmissions in time or frequency domain without causing interference](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442425)

[· LP-WUS is transmitted on Uu interface from gNB to UE](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442426)

[Proposal 4 For the main radio power model](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442427)

[· Use existing models in TR 38.840 and TR 38.875 as starting point for evaluations](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442428)

[· Study whether any updates are needed for the power model (including any updates to scaling factors, transition time) when the main radio is operated in conjunction with LP-WUR](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442429)

[· Consider additional energy (if any) consumed to acquire synchronization](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442430)

[Proposal 5 For each LP-WUR architecture considered in the study, consider at least the below aspects as part of the LP-WUR power model](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442431)

[· LP-WUR active power when monitoring LP-WUS](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442432)

[· LP-WUR sleep power when not monitoring LP-WUS (when a duty cycle for LP-WUS detection is applicable for the LP-WUR)](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442433)

[· Transition energy and transition time (if any) between above two states](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442434)

[· Transition time and transition energy (if any) for triggering the main radio from a given main-radio sleep state.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442435)

[· Additional energy (if any) consumed to acquire synchronization for detecting LP-WUS](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442436)

[Proposal 6 For power saving evaluations, consider impact of DRX/Paging configuration assumptions for the UE and impact of false wake-up of main radio due to LP-WUR false alarms.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442437)

[Proposal 7 For coverage evaluations, link-budget for candidate LP-WUS/WUR designs should be compared to that of NR-PDCCH link budget for various deployment scenarios (e.g., those identified in TR 37.910)](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442438)

[· LP-WUS/WUR designs should strive to match the coverage for NR PDCCH](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442439)

[Proposal 8 Network overhead should be evaluated for each LP-WUS design proposal considering the time/frequency resources used for LP-WUS transmission (including any guard-bands) and any additional resources used for synchronization.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442440)

[Proposal 9 For RRC-Idle mode evaluations, impact of LP-WUS/WUR operation on paging latency (e.g., time between the arrival of paging message at gNB and the reception of PDCCH with P-RNTI and any associated PDSCH by the UE) should be considered.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442441)

[Proposal 10 For RRC-Connected mode evaluations, impact of LP-WUS/WUR operation on scheduling latency (e.g., time between arrival of DL data at gNB and the corresponding PDCCH scheduling the data to UE) should be considered.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442442)

[Proposal 11 Impact of LP-WUS/WUR operation on NW Energy Efficiency should be considered especially if LP-WUS transmissions require significantly more time/frequency resources compared to PDCCH or require additional always-on transmissions from gNB.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442443)

[Proposal 12 For link-level evaluation of LP-WUS](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442444)

[· Target a joint missed detection probability of LP-WUS and paging/scheduling PDCCH to be ~ 10-2](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442445)

[· Evaluate false alarm probability both in the absence of gNB transmissions, and in the presence of other gNB transmissions, e.g., random QAM symbols](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442446)

[o False alarm probability value can be assumed to be 1e-3 or alternately determined during the evaluations to optimize power saving gain (in which case the assumption should be reported)](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442447)

[· Minimum SNR required to achieve required mis-detection performance should be reported](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442448)

[Proposal 13 Impact of LP-WUR characteristics/impairments (e.g., oscillator error/drift) should be considered for link-level evaluations.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442449)

[Proposal 14 Noise figure assumed for a particular LP-WUR architecture should be reported.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442450)

[Proposal 15 Following KPIs should be considered for LP-WUS/WUR evaluations.](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115442451)

|  |  |  |
| --- | --- | --- |
| **KPI** | **Idle mode evaluations** | **Connected mode evaluations** |
| UE Energy consumption | Energy consumption for paging reception | Energy consumption for data reception |
| Latency/UPT | Paging delay: Time between the paging message arrives at gNB and the reception of PDCCH with P-RNTI and any associated PDSCH by the UE. | Scheduling delay: Time between the arrival of DL data to be scheduled at gNB and the corresponding PDCCH reception at the UE. Scheduling delay impact on UPT. |
| Coverage | Link-budget for candidate LP-WUS/WUR designs compared to that of NR-PDCCH (e.g., using assumptions in TR 37.910) |
| Network overhead and Network energy consumption | Time/frequency resources used for WUS transmission (including any guard-bands) and any additional resources used for synchronization.Impact of LP-WUS/WUR operation on energy consumption. |
| Link level aspects to ealuate LP-WUS/WUR | * Minimum SNR required to achieve required mis-detection performance
	+ Noise figure and other receiver impairments (e.g., clock accuracy/drift) assumed for LP-WUR should be reported
* Mis-detection rate
	+ ~1e-02 (Joint missed detection probability of LP-WUS and paging/scheduling PDCCH)
* False alarm rate
	+ 1e-03 or alternately determined during the evaluations to optimize power saving gain (in which case the assumption should be reported). Should be studies both in the absence of gNB signals, and in the presence of other gNB signals (e.g., random QAM symbols can be considered)
 |

We also make the following observation based on initial evaluation results

[Observation 1 WUR power saving gains are larger especially for cases where shorter DRX cycles are needed and is therefore most beneficial for use cases with tighter requirements on DL latency (e.g., actuators, alarms, sirens).](file:///D%3A%5CMy%20Documents%5C002.Report%5C5G%20NR-vivo%5CRel-18%5CAZP%E6%8E%A5%E6%94%B6%E6%9C%BA%5C3GPP%5CRAN1%23110bis-e%5Ccontributions%5Cdocs%5CEricsson_R1-2209862_lpwus_eval_v0.docx#_Toc115432099)

## Qualcomm Incorporated

**R1-2210010 Evaluation methodology for LP-WUS Qualcomm Incorporated**

**Proposal 1: RAN1 considers following use cases for the evaluation of LP-WUR.**

* IoT use cases with low latency and low power requirement, e.g.,
	+ Actuator control
	+ On-demand sensing application (the case age of sensed information matters)
	+ On-demand location tracking
	+ Wearable device
* IoT use case with low power requirement, e.g.,
	+ Sensing
	+ Metering
* Other use cases: eMBB/XR

**Proposal 2: Include following KPIs: power consumption, latency, sensitivity, data rate, false wakeup probability (due to grouping and false alarm), and misdetection probability.**

**Proposal 3: Use existing 38.840 power model and discuss/agree on additional assumptions based on evaluation done during Rel-17 UE power saving WI as starting point.**

* Additional assumptions made during R17 power saving (UEPS) WI include
	+ **Idle mode wakeup timeline in low/high SNR**
	+ **SSB monitoring for RRM (serving cell / neighbor cell)**
	+ **PO monitoring**

**Proposal 4: Introduce ULPS state with** **power consumption, transition time and energy as shown in Table 1.**

**Proposal 5: Introduce LP-WUR monitoring and sleep state.**

* Power numbers for each state are part of study.
* LP-WUR transition energy and time are assumed to be zero.

**Proposal 6: Introduce clock error parameters, e.g.,**

* Clocks frequency drift (ppm/s) [X, Z].
* Clocks maximum frequency error (ppm) [Y, L].

**Proposal 7: Introduce IoT traffic model with very sparse traffic arrival.**

* Group paging
* Poisson page arrival with average paging inter-arrival time: [tens of min to hours]
* Latency requirements to be considered.
	+ E.g., [0.5]sec for actuator control/wearable, [1-60]sec for location tracking and on-demand sensing

**Observation 1**

* Sensitivity is a function of receiver’s noise figure, required SNR, and data rate.

**Proposal 8: Study potential values for WUR’s NF, including the case when the WUR’s NF is similar to MR.**

**Proposal 9: Adopt the above link-level simulations assumptions.**

## EURECOM

**R1-2210051 Discussion on Evaluation on Low power WUS EURECOM**

**Observation 1: Manchester coding significantly improves performance of ED.**

**Observation 2: For MC-OOK, the number of allocated sub-carriers is a trade-off between SNR gain and multi-path diversity gain.**

**Observation 3: Jointly encoding multiple bits results in significant performance gain.**

**Observation 4: More elaborate coding strategies significantly increase spectral efficiency while maintaining moderate decoding complexity.**

## NTT DOCOMO, INC.

**R1-2210169 Discussion on evaluation methodology for low power WUS NTT DOCOMO, INC.**

**Proposed 1: Mobility and measurement procedure with LP-WUS/WUR should be further studied.**

**Proposed 2: Reuse the following UE power model in Rel-17 agreement.**

**Proposed 3: New power consumption should be modelled for deep sleep mode at least.**

* + Transition from/to deep sleep mode
	+ monitoring LP-WUS by WUR

## Nordic Semiconductor ASA

**R1-2210197 On LP-WUS evaluation Nordic Semiconductor ASA**

***Proposal-1:*** *RAN1 to study and decide what target MIL should be for LP-WUS in the following scenarios; (i) Rural (700MHz), (ii) Urban scenario (2.6 GHz) and (iii) Urban scenario (4GHz).*

***Proposal-2:*** *For considered LP-WUS architectures, estimate the achievable Noise Figures.*

***Proposal-3:*** *R16 LPWA is a power consumption reference for LP-WUS.*

***Proposal-4:*** *To rigorously benchmark LP-WUS, discuss how to map LP-WUS power consumption to 3GPP relative power units. Consider conversion ratio of 1unit =10uW.*

***Proposal-5:*** *Target that LP-WUS power consumption with T/10 latency is better than that of (e)DRX with latency T.*

## Sony

**R1-2210222 Evaluation for low power WUS Sony**

The following observation is made:

***Observation 1 – When designing a low-power WUR, there is a trade-off between WUR power consumption and its level of noise figure and sensitivity.***

The following proposals are made:

***Proposal 1 – Support to target low-power WUS/WUR for power-sensitive, low-traffic, small form factor devices such as RedCap devices addressing IoT use cases (such as industrial sensors, controllers) and wearables where delay requirement or device reachability in time is short.***

***Proposal 2 – Update the NR power model and include low-power WUR characteristics in terms of power consumption and transition times.***

***Proposal 3 – The power model for LP-WUR should cater for different LP-WUR architectures.***

***Proposal 4 – LP-WUS coverage target is based on the coverage analysed in the Rel-17 coverage enhancements SI.***

***Proposal 5 – RAN1 considers fallback mechanisms for UEs that are out of coverage of the LP-WUS.***

***Proposal 6 – Update performance evaluation assumption and include latency, coverage and mobility requirement as well as requirements on low-power WUS probabilities of miss-detection and false-alarm into list of assumptions.***

***Proposal 7 – LP-WUS power saving performance is compared against reference power saving mechanisms that are applicable to RedCap devices.***

# SID

[*RP-222644*](https://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_97e/Docs/RP-222644.zip)

**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.

# Reference

**The following contributions are submitted in RAN1#110bis-E in AI 9.13.1,**

1. [R1-2208378](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208378.zip) Evaluation of Low Power WUS and initial performance results FUTUREWEI
2. [R1-2208417](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208417.zip) Evaluation methodology for LP-WUS Huawei, HiSilicon
3. [R1-2208572](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208572.zip) Discussion on evaluation on low power WUS Spreadtrum Communications
4. [R1-2208668](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208668.zip) Evaluation methodologies for R18 LP-WUS/WUR vivo
5. [R1-2208686](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208686.zip) Discussion on evaluation on LP-WUS InterDigital, Inc.
6. [R1-2208698](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208698.zip) Low power WUS Evaluation Methodology Nokia, Nokia Shanghai Bell
7. [R1-2208843](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208843.zip) Evaluation discussion on lower power wake-up signal OPPO
8. [R1-2208960](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2208960.zip) Deployment scenarios and evaluation methodologies for low-power WUS CATT
9. [R1-2209075](file:///C%3A%5CUsers%5Cyounsun%5CDocuments%5C3GPP%20documents%5CRAN1%20tdocs%5CTSGR1_110b-e%5CDocs%5CR1-2209075.zip) Discussion on evaluations on LP WUS Intel Corporation
10. [R1-2209199](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209199.zip) Evaluation on LP-WUS ZTE, Sanechips
11. [R1-2209270](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209270.zip) Evaluation on low power WUS xiaomi
12. [R1-2209361](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209361.zip) Discussion on evaluation methodology and applicable scenarios for low power WUR CMCC
13. [R1-2209502](file:///C%3A%5CUsers%5Cyounsun%5CDocuments%5C3GPP%20documents%5CRAN1%20tdocs%5CTSGR1_110b-e%5CDocs%5CR1-2209502.zip) Evaluation on low power WUS MediaTek Inc.
14. [R1-2209605](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209605.zip) On performance evaluation for low power wake-up signal Apple
15. [R1-2209621](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209621.zip) Discussion on low power WUS evaluation Rakuten Symphony
16. [R1-2209665](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209665.zip) Discussion on the evaluation methodology for low power WUS Lenovo
17. [R1-2209685](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209685.zip) Discussion on evaluation for low power WUS Sharp
18. [R1-2209756](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209756.zip) Evaluation on LP-WUS/WUR Samsung
19. [R1-2209766](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209766.zip) Initial view on evaluation of low-power WUS Rakuten Mobile, Inc
20. [R1-2209862](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2209862.zip) Evaluation framework for low power WUS Ericsson
21. [R1-2210010](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2210010.zip) Evaluation methodology for LP-WUS Qualcomm Incorporated
22. [R1-2210051](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2210051.zip) Discussion on Evaluation on Low power WUS EURECOM
23. [R1-2210169](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2210169.zip) Discussion on evaluation methodology for low power WUS NTT DOCOMO, INC.
24. [R1-2210197](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2210197.zip) On LP-WUS evaluation Nordic Semiconductor ASA
25. [R1-2210222](file:///C%3A%5CUsers%5C11048224%5CAppData%5CLocal%5CDocs%5CR1-2210222.zip) Evaluation for low power WUS Sony

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