3GPP TSG-RAN2 Meeting #123-bis R2-231xxxx

Xiamen, China, 9~14 October 2023

Agenda Item: 7.22.3

Source: Qualcomm

Title: Summary of [Post123][060][LPWUS] Low-power receiver in RRC Connected (Qualcomm)

Document for: Discussion and Decision

# **Introduction**

This report provides a summary of the following post-meeting email discussion:

* [Post123][060][LPWUS] Low-power recevier in RRC Connected (Qualcomm)

 Scope: Collect comments for and if possible progress proposals in RAN2 scope (e.g. impact to / relation to DRX, other MAC impacts). Can also collect comments for and discuss proposals for which RAN2 impact is not clear yet (e.g. not clear if MAC impact etc), up to Rapporteur what to include.

 Intended outcome: Report with agreeable points, points for discussion, FFS points, pave the way for a first set of agreements etc for RRC Connected.

 Deadline: Long

The deadlines for this discussion are the following:

* **September 19th 18:00 UTC:** deadline forcompanies’ feedback;
* **September 20th 18:00** **UTC**: deadline for the rapporteur to provide a summary for review;
* **September 22nd 18:00 UTC**: hard deadline for companies’ feedback on the summary.

# **Contact information**

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# **Discussion**

Per instruction by the Chair, the objective of this email discussion is to discuss possible use cases of low-power receiver in RRC Connected. The discussion points are generated based on proposals in the submitted contributions ([1]~ [13]). If possible, we will try to produce a set of proposals for discussion and agreement at the next RAN2 meeting (RAN#123bis).

As this email discussion is for the SI, the rapporteur would like to suggest that we focus our discussion only on stage-2 issues. The discussion is organized into four areas, as follows:

* Whether and how LP-WUS may be used outside DRX active time (e.g. similar to legacy wakeup signaling for DRX on duration);
* Whether and how LP-WUS may be used inside DRX active time (e.g. associated with PDCCH monitoring adaptation);
* Whether and how LP-WUS may be used for RRM measurements in RRC Connected;
* Options for de-/activating LP-WUS monitoring.

Before starting the discussion, the rapporteur would like to cite the RAN1 agreements that are related to the use of LP-WUS in RRC Connected, since they are relevant to this email discussion:

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| * + In RRC CONNECTED mode, LP-WUS monitoring can be activated/deactivated by at least one or more of
		- by gNB RRC signaling, with or without UE assistance.
		- by gNB L1/L2 LP-WUS activation/deactivation signaling, with or without UE assistance.
		- based on pre-configured condition(s), such as timer.
		- LP-WUS monitoring by UE is known to gNB, study whether it could be transparent to gNB.
		- other options are not precluded.
* In RRC CONNECTED mode, study benefit of LP-WUS over existing Rel-15, R16, and R17 power saving techniques for following functionalities:
* LP-WUS with similar functionality as R16 DCP.
* LP-WUS activates/resumes PDCCH monitoring when LP-WUS is received.
	+ interaction with legacy power saving techniques, if any
* other functionalities are not precluded
* for evaluation
	+ companies to report
		- assumption on MR sleep state when LP-WUR is monitoring LP-WUS
		- deep sleep,
		- light sleep,
		- micro sleep
	+ how to activate/deactivate LP-WUS monitoring and deactivate/activate PDCCH monitoring
	+ LP-WUS waveform
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## LP-WUS outside DRX active time

Many contributions have proposed that LP-WUS can be used in conjunction with DRX, e.g. LP-WUS is monitored outside DRX active time and can be used to wake up MR to start procedures related to DRX on duration timer ([1][4][5][6][7][8][9][10][11][12][13]).

However, there are different views on how exactly LP-WUS may be used in this use case. More specifically, the proposals may be classified into the following three options:

* LP-WUS replaces DCP and these two types of wakeup signals are not configured/used simultaneously ([4][5][6][10][11][12]);
* Both LP-WUS and DCP can be configured for a UE. However, UE may use only one of them at any time, e.g. depend on network configuration or link quality, etc. ([1][4][6][9]);
* LP-WUS is used in conjunction with DCP, e.g. LP-WUS first wakes up MR, which then monitors DCP ([4][6][8] [10][12]).

Next, we first discuss whether the use of LP-WUS outside DRX active time should be studied. Then for

**Q1. Which one of the following options do you support on the use of LP-WUS outside DRX active time, in which case LP-WUS wakes up MR to start procedures related to DRX timer(s)?**

1. **There is no need to study the use of LP-WUS for waking up MR to start procedures related to DRX timer(s);**
2. **LP-WUS replaces DCP and these two types of wakeup signals are not configured/used simultaneously;**
3. **Both LP-WUS and DCP can be configured for a UE. However, UE may use only one of them at any time, e.g. depend on network configuration or link quality, etc.**
4. **LP-WUS is used in conjunction with DCP, e.g. LP-WUS first wakes up MR, which then monitors DCP.**
5. **LP-WUS is an independent feature from DCP and DRX, i.e., upon receiving the indication for MR ON, the UE follows the legacy procedure, e.g., DRX and DCP.**

 **(Note: This option is discussed in Q2).**You may select more than one option in your reply.

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| **Company** | **Option** | **Comments** |
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| Qualcomm | 3,4 | First, we think the use of LP-WUS for waking up DRX on duration timer can enable additional power savings than DCP.Second, we think it is good to have DCP configured when LP-WUS is configured. For example, depend on RAN1’s final design of LP-WUS, DCP may be used as a fallback when LP-WUS is out of coverage, or DCP may be used in junction with LP-WUS to reduce false wakeup if LP-WUS is a group-specific signal and has very limited payload.  |
| NEC | Option 2,3,4 | We are fine to research all cases related to DRX. |
| Nokia | 3, 4 | As DCP is already supported, simple replacement, i.e., option 2, would be of low priority. In option 3, as long as LP-WUS and DCP have different functions there seems to be no reason to use only one at a time, so our understanding is that it is also one option to use both of them. |
| OPPO | 2 | We are ok to discuss option 5 in Q2, but we understand Q1 is mainly discussing how LP-WUS interwork with DCP. As DCP only impact the start of onDurationTimer, we think option 1 should be more specific to refer to onDurationTimer. That is,**Updated option 1: There is no need to study the use of LP-WUS for waking up MR to start procedures related to onDurationTimer;** |
| Huawei, HiSilicon | See comments | We are fine to study the use of LP-WUS combined with C-DRX, e.g. impacts on DRX timer(s). However, purely to replace DCP is not beneficial for latency since it only impacts onduration timer. We think LP-WUS can wake up MR once it is received, e.g. to control the inactivity timer, which reduces the latency with the equal power saving gain. |
| LGE | Option 5 | We think that there is no reason to make an association between the LP-WUS and legacy procedure (DCP, DRX, etc.). This is because the power-saving gain would be enough if the MR is turned off when the LP-WUS is activated.For example, if the LP-WUS indicates the MR ON and the UE is configured with the DCP/DRX, the UE performs the DCP/DRX operation as configured. Otherwise, if the LR-WUS indicates the MR OFF, the UE turns off the MR and does not perform the DCP/DRX operation. |
| Apple | Option 3, 4, and Option X | We prefer to start the study the impact of LP-WUS on DRX in all possible options, e.g. integrating with DCP or not, acting like DCP or not. Besides Option 3,4, we can also consider Option X as below:**Option X:** LP-WUS is used to trigger UE enter the DRX active time and start DRX inactive timer.  |
| Futurewei | Option 2, 3, 4, 5 | We are open to all other options except option 1. |
| Lenovo | Option 2, 4 | We support options 2 & 4. For option 5, we think this might not be very different from option 4 so we are open to studying it.  |
| ZTE | Option 4 and 5  | For Option 2 and Option 3, we think they are similar. Since we assume NW can be aware of some conditions of the UE, e.g., the link quality, we see no benefit or necessity to let NW configure both functions but assume only one would be used. So at least we think Option 3 is not so needed.For Option 2 and Option 4, given that DCP is a legacy function, we prefer to keep it and so Option 4 may be better. For Option 4, we think it’s feasible and beneficial to jointly use LP-WUS and DCP, e.g., LP-WUS could indicate a group of UEs with the similar traffic whether to monitor DCP, and the corresponding DCP could indicate the UEs whether to monitor PDCCH for the next DRX cycle.Option 5 seems too general. It seems there may be no clear common understanding on the MR status in connected mode. But we are open to discuss. |
| Ericsson | Options 2 and 3 | We think RAN2 should aim for simplicity for evaluations considering the remaining time for the SI. The potential combinations of LP-WUS and DCP should be evaluated with respect to DCP as the baseline considering LP-WUS and DCP mainly as alternatives. This is especially the case if the intention is to wake up the MR from micro/light sleep using LP-WUS prior to *onDuration* time. |
| Samsung | Option 2 | RAN1 study is considering option 2 (use LP-WUS as replacement for DCP) for use of LP-WUS outside DRX active time so prefer to focus on that as baseline. |

## LP-WUS and PDCCH monitoring adaptation

There are proposals on using LP-WUS to enhance legacy PDCCH monitoring adaptation (e.g. PDCCH skipping, SSSG switching, etc):

* In [1] [9], it is proposed that LP-WUS can be used to resume/activate PDCCH monitoring during active time;
* In [2], it is proposed that LP-WUS can be used to control PDCCH monitoring at any time;
* In [6][13], it is proposed to study the relationship between LP-WUS and legacy UE power saving techniques, e.g. C-DRX, DCP, PDCCH skipping, SSSG switching.

In legacy, PDCCH monitoring adaption has been mostly in RAN1’s domain and transparent to upper layers, with certain exceptions (e.g. UL transmissions such as SR triggers termination of PDCCH skipping). Since RAN1 has already agreed that UE can activate/resume PDCCH monitoring when LP-WUS is received and interactions with legacy power saving techniques will be studied, the rapporteur would like to suggest that we discuss this topic from RAN2’s perspective, e.g. what RAN2 impacts should be studied.

**Q2. What should RAN2 study to support the use of LP-WUS in conjunction with legacy PDCCH monitoring adaptation features (e.g. use cases listed above)?**

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| **Company** | **Comments** (Please be specific, if possible) |
| OPPO | We think it would be more flexible to allow LP-WUS to be used at any time to wake up MR to monitor PDCCH. From RAN2’s perspective, we can study the spec impact on how does UE enter DRX active time upon receiving LP-WUS. This part might not be decided by RAN1. |
| Nokia | At least DRX interaction should be studied. RAN2 need to discuss not only how to start PDCCH monitoring, e.g., impact on various DRX timers, but also how to switch back to LP-WUS by considering DRX timers running. |
| Qualcomm | We think it is beneficial to use LP-WUS together with R16+ power saving features. For example, UE may monitor LP-WUS during power saving states (e.g. during PDCCH skipping) to reduce latency.However, in our understanding, most of such enhancements are expected to be more within RAN1’s scope. RAN2’s study on them are needed only if requested by RAN1. |
| NEC | From RAN2 perspective, PDCCH monitoring is generally operated during DRX active time, thus we need to clarify whether the PDCCH monitoring at any time after LP-WUS reception should also be related to any/new active timer or not. |
| Huawei, HiSilicon | We are not sure whether this question focuses on the case that LP-WUS is decouple with C-DRX. But generally, we agree that RAN2 needs to study the relationship between LP-WUS and legacy UE power saving techniques, e.g. PDCCH skipping, SSSG switching. And we also need to think about the modelling of the LP-WUS, whether it is impacts MAC (like DCP) or it is transparent to MAC (like PDCCH skpping). |
| LG | See our comments on Q1. |
| Apple | It’s good to support the use of LP-WUS in conjunction with legacy PDCCH monitoring adaptation. Since legacy PDCCH monitoring adaptation is applicable when UE is in CDRX active time or when CDRX is not configured, and there is no RAN2 spec impact, we assume same situation for the LP-WUS together with PDCCH monitoring adaptation, and RAN2 can make the following assumptions:1) It is only applicable when UE is in CDRX active time or when CDRX is not configured. 2) No RAN2 spec impact is expected for it.  |
| Futurewei | We should allow LP-WUS be used at any time for waking up MR to monitor PDCCH (i.e., decoupled from C-DRX). We should also allow LP-WUS be used in conjunction with the legacy UE power saving techniques, e.g., C-DRX, DCP. However, the NW should clearly configure the UE which behaviour to follow.  |
| ZTE | As mentioned in our comments for Q1, it needs more clarifications / discussion on whether LP-WUS can be used at any time for waking up MR in connected mode.Firstly, we can focus on the issues that are already on the table. We think it’s better to separately discuss the issue of LP-WUS and PDCCH skipping, e.g., to separate from the discussion for LP-WUS and DCP.For PDCCH skipping, we agree with Qualcomm that it is beneficial for UE to monitor LP-WUS during power saving states (e.g. during PDCCH skipping) and after reception of LP-WUS, UE can stop the PDCCH skipping in CDRX active time. |
| Ericsson | It could be beneficial to evaluate whether there are any significant gains from energy consumption standpoint if one uses LP-WUS to indicate that UE should resume PDCCH monitoring when in active mode by waking up the MR with respect to the legacy mechanisms. But such evaluation seems to be RAN1 scope so in RAN2 we can instead study how/when the UE should switch between MR and LPR and how such behaviour should interact with the legacy mechanisms, e.g., C-DRX. |
| Samsung | It is beneficial to study the impact to existing power saving features but this would be transparent to MAC so not sure how this will impact Layer 2. |

## Use of LP-WUS in RRM measurement

There are multiple contributions discussing the use of low-power radio/signaling in RRM measurements but with mixed views. For example,

* In [1][10], it is proposed that LP-WUR can be used for serving cell measurements or neighbor cell measurements to reduce the use of measurement gaps;
* In [2][7], it is argued that RRM measurement by MR is enough for RRC connected. Use of LP-WUR for RRM measurements is not well justified.
* In [5][8][9], it is proposed that the study for RRM measurements based on LP-WUS in RRC Connected can be postponed until its feasibility is confirmed by RAN1 and RAN4.

The rapporteur thinks that these three views cover most of the possible options and hence would like to invite your views on them. When you comment, please keep in mind that our discussion here is only from RAN2’s perspectives.

**Q3. Which of the following three views would you support?**

1. **In RRC Connected, LP-WUR can be used for serving cell measurements and/or neighbor cell measurements (additional options in Q5);**
2. **Use of LP-WUR for RRM measurements in RRC connected is not studied.**
3. **The study for use of LP-WUR for RRM measurements in RRC Connected can be postponed until its feasibility is confirmed by RAN1 and RAN4.**

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| **Company** | **Option** | **Comments** (Please provide reasons if possible) |
| OPPO | Option 3 | RRM measurements in RRC Connected was discussed in RAN1 with the following agreements made in RAN1#112bis-e.

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| Agreement* For RRC connected mode, the following is assumed for LP-WUS study in RAN1
	+ RLM/BFD/CSI are performed by UE Main Radio (MR)
	+ RRM measurements are performed by UE Main Radio (MR)
	+ Ultra-deep sleep state is not allowed for MR.

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

Since the feasibility of RRM measurements by LP-WUS in RRC Connected will need further study in RAN1, RAN2 can postpone the discussion on this topic. |
| Nokia | Option 3 | Although we see that RRC measurement in RRC\_CONNECTED is one area that RAN2 need to study, more time seems to be needed for RAN1. |
| Qualcomm | Option 1 | From RAN2’s perspective, we think use of LP-SS for serving cell measurement can be studied for some use cases, e.g. when non-RedCap UE’s dedicated BWP does not include CD-SSB. In this case, MR does not need to be in deep-sleep state. LP receiver is simply used as a second antenna of UE.Similarly, LP receiver can be used to perform inter-frequency measurement. That eliminates the need for measurement gaps for the main radio and hence can improve UE’s throughput (especially useful for XR). |
| NEC | Option 2,3 | Unlike RRC\_IDLE/INACTIVE, since ultra-deep-sleep of MR is not allowed in RRC\_CONNECTED, using MR to perform the RRM measurement is not a problem. |
| Huawei, HiSilicon | Option 3 |  |
| LGE | Option 3 |  |
| Apple | Option 3 | Lack of the feasibility shown in RAN1 and RAN4, it’s difficult for RAN2 to start the study in this aspect.  |
| Futurewei | Option 3 | Agree with OPPO. |
| Lenovo | Option 1 | Agree with QC, we think RRM Measurements in RRC\_Connected can be made by the LR for certain use cases which may also be beneficial in reducing the measurement gaps of MR, and can be studied from a RAN2 perspective.  |
| ZTE | Option 3 |  |
| Ericsson | Option 3 |  |
| Samsung | Option 3 |  |

**Q4. If you selected Option 1 in Q4, please indicate which one of the following options you support:**

1. **LP-WUR is used only for serving cell RRM measurements;**
2. **LP-WUR is used only for neighbor cell RRM measurements;**
3. **LP-WUR can be used for any type of RRM measurements.**

You may select more than one option. All options are for RRC Connected.

Again, our discussion here is only from RAN2’s perspective, if RAN1/4 can confirm their feasibility.

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| **Company** | **Option** | **Comments**  |
| Qualcomm | Option 3 | Please see our comment to Q3. |
| Lenovo | Option 1 | We think that study can be started with serving cell measurements as currently the coverage of LR is lower than MR, and neighbor cell measurements may be too complex. The study for neighbor cell measurements may be postponed till RAN1/ RAN4 feasibility is confirmed.  |
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## De-/activation of LP-WUS

There are a number of contributions discussing conditions for de-/activating LP-WUS monitoring ([1][4][5][6][13]). Since the proposals are rather diverse, the rapporteur summarize them as follows:

* Monitoring of LP-WUS is de-/activated based on NW indication;
* Network pre-configures UE with criteria for monitoring LP-WUR. UE then autonomously de-/activate its monitoring based on its evaluation whether the configured criteria is met.
* UL/DL transmissions by MR can be an additional criterion for UE to de-activate its monitoring.

These options are consistent with what RAN1 has agreed, except the one with UL transmission. Instead of repeating what RAN1 has agreed, the rapporteur thinks that we can discuss the delta, i.e. the proposal on UL transmission deactivating LP-WUS monitoring and if any additional options should be supported.

**Q5. In addition to the options agreed by RAN1 for de-/activating LP-WUS monitoring, do you think UL transmission by MR can also be a criterion for UE to de-activate its monitoring?**

**You may also propose in the Comments column any additional options that you think should be studied.**

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| **Company** | **Yes/No** | **Comments**  |
| OPPO | Yes | UL traffic arrival should be another condition for deactivation of LP-WUS monitoring, which is triggered at UE side.  |
| Nokia | Yes | Traffic can be one criterion to activate/deactivate the LP-WUS, and we should consider both UL and DL because PDCCH monitoring is for scheduling of either UL or DL. The question would be how the UE assumes that DL scheduling is less/more expected so that LP-WUS is activated/deactivated accordingly.  |
| Qualcomm | Yes | UL transmission triggers UE to start monitoring PDCCH using its main radio.  |
| NEC | Yes | Although it is noted there is no relationship between SR transmission on PUCCH and DRX Active Time, which means even though during DRX non-active time (i.e., DRX sleep mode), the UE still can do UL transmission. In other word, DRX mode is only to restrict PDCCH monitoring (considering power consumption from blind PDCCH monitoring) but not for PUCCH/PDSCH/PUSCH.However, just because the UE anyway will start active timer for UL Grant reception, which means the MR will be activated for PDCCH monitoring, in this sense, LR could be deactivated then. |
| Huawei, HiSilicon | Yes | We agree that DL transmissions will trigger UE to start PDCCH monitoring by MR, this is covered by the first bullet, i.e. triggered by the NW. For third bullet, this is mainly for condition triggered by UE itself, i.e. UL transmission. |
| LG | Yes | When there is a UL data to be transmitted, the UE turns on the MR and starts the legacy procedure. |
| Apple | Yes | From uplink latency requirement perspective, uplink data arrival in UE side should be able to wake up MR for PDCCH monitoring and uplink data transmission.  |
| Futurewei | Yes |  |
| Lenovo | Yes | As LR does not support any UL transmissions, MR must be woken up when there is any UL transmission.  |
| ZTE | Yes | Agree with some above comments. The condition that UL traffic arrives (not clear yet whether and how to specify this in MAC?) or BSR is triggered in UE side can wake up UE to monitor PDCCH. |
| Ericsson | Yes | Both UL and DL should be considered. |
| Samsung | Yes | UL transmission can be one criteria to deactivate use of LP-WUR but RAN2 should also study the LP-WUR activation after UL transmission like in case of CG based transmissions. |

## Other issues

Please comment in the table below if you think there are other issues that should be studied but have been missed in the questions above.

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| **Company** | **Issues** (Please be specific, if possible) |
| Nokia | Given that LP-WUS monitoring is deactivated/stopped for immediate scheduling via PDCCH, RAN2 would need to study how the UE can maintain its UL synchronization during LP-WUS monitoring. If the UE is not in UL synchronized state after switching back to PDCCH monitoring, the UE cannot perform immediate data transmission and would need to perform RA procedure. We think periodic CSI report during LP-WUS monitoring would be heavy because there is no scheduling while monitoring LP-WUS and more sporadic CSI report would be sufficient.**Proposal: RAN2 discuss how to maintain the UL synchronization while the UE monitors the LP-WUS.** |
| Nokia | We wonder what the RAN2 assumption would be for SPS and CG while the UE monitors LP-WUS and MR is in sleep, i.e., whether they are kept activated or assumed to be deactivated.**Proposal: RAN2 discuss the LP-WUS impact on SPS and CG.** |
| NEC | We may need to consider whether there is LP-WUS content difference between RRC\_CONNECTED and RRC\_IDLE/INACTIVE, whether it is same or not, or whether there is still false alarm issue or not for RRC\_CONNECTED UE. |
| LGE | We need to discuss common understanding first. In our understanding, * If LP-WUS is activated: The MR can dynamically turned on/off based on the LP-WUS indication.
* If LP-WUS is de-activated: The MR is always turned on.

We would like to ask RAN2 to confirm the above understanding to facilitate further discussion. |
| Apple | We need to confirm that the LP-WUS configuration and activation/deactivation in RRC\_CONNECTED state is UE specific.  |
| ZTE | We think it is essential or beneficial for UE to report kind of assistance information about LP-WUS to facilitate NW to apply LP-WUS for a specific UE, for example, whether UE desires a LP-WUS, or whether UE satisfies the condition of using LP-WUS. Different from the case of UE in idle or inactive mode, it’s feasible or easy for eNB to acquire some assistance information from a UE in connected mode. For the following proposal mentioned by Nokia:*Proposal: RAN2 discuss how to maintain the UL synchronization while the UE monitors the LP-WUS.*We understand it’s more in the scope of RAN1 discussion. Even from RAN2 perspective, we tend to understand it may be not an issue as it can rely on NW implementation, e.g., early provision of TAC.For the following suggestion mentioned by Apple:*We need to confirm that the LP-WUS configuration and activation/deactivation in RRC\_CONNECTED state is UE specific.*We think it cannot be confirmed but needs more discussion. At least in the possible case that LP-WUS is used in conjunction with DCP, we think the LP-WUS activation/deactivation may not be UE specific. |

# **Conclusions**

(To be added later)

# References

1. R2-2204523, Use of low-power receiver in RRC Connected, Qualcomm Incorporated.
2. R2-2307308, Discussion on LP-WUS/WUR in RRC\_Connected, vivo.
3. R2-2307260, Discussion on LP-WUR’s operation, OPPO.
4. R2-2307345, Discussing on LP-WUS monitoring for RRC\_Connected, Xiaomi Communications.
5. R2-2307424, Discussion on LP-WUS in RRC\_CONNECTED state, CATT.
6. R2-2307449, High layer procedures for LP-WUS in RRC\_CONNECTED state, Huawei, HiSilicon.
7. R2-2307462, Discussion on the considerations for LPWUS in RRC\_CONNECTED, NEC Corporation.
8. R2-2307592, RAN2 impacts of LP-WUS in connected mode ZTE Corporation, Sanechips.
9. R2-2307849, RAN2 impact of LP-WUS in RRC\_CONNECTED state, Apple.
10. R2-2308461, LP-WUS in RRC Connected Mode, Lenovo.
11. R2-2308532, Discussion on LP-WUS in RRC\_CONNECTED, Continental Automotive .
12. R2-2308810, LP-WUS/WUR for RRC Connected, Ericsson.
13. R2-2308748, On LP-WUS in RRC\_CONNECTED Nokia, Nokia Shanghai Bell