**3GPP TSG-RAN WG4 Meeting #107 R4-230xxxx**

**Incheon, KR, May 22nd – May 26th, 2023**

**Agenda item:** 8.21.4

**Source:** Moderator (vivo)

**Title:** Topic summary for [107][139] FS\_NR\_LPWUS

**Document for:** Information

# Introduction

This email summary covers the discussions in AI 8.21 for Rel-18 LP-WUS/WUR SI.

# Topic #1: LP-WUR architectures

## Companies’ contributions summary

|  |  |  |
| --- | --- | --- |
| **T-doc number** | **Company** | **Proposals / Observations** |
| [**R4-2307147**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2307147.zip) | Huawei, HiSilicon | ***Proposal 1: As long as the variant LP-WUR architectures belong to the architectures mentioned in RAN1 LS, they can be considered in RAN4 evaluation.***  ***Proposal 2: Given poor coverage performance and incapable of supporting of multi-band operation, it is proposed to rule out RF ED LP-WUS architecture for the following RAN4 evaluation.***  ***Proposal 3: The possible degradation of filter rejection for real implementation should be counted in evaluation of guard RBs for LP-WUS.***  ***Proposal 4: RAN4 evaluation for the issues identified so far should consider all possible LP-WUS waveforms.***  *Observation 1: For ACS, from the simulation results against waveform OOK-1, it is observed that 5th order Butterworth filter can provide better performance under same condition. To have similar performance without ACI, about 600kHz guard band (roughly 2 RBs for 30kHz SCS and 4 RBs for 15kHz SCS) is needed to protect LP-WUS from interference of the adjacent NR carrier.*  *Observation 2: There are other waveform candidates are under discussion in RAN1. If no soon convergence of the candidates, more simulation would be needed to have a good view on the possible guard RBs between LP-WUS and NR signals.*  ***Proposal 5: Guard RB evaluation should be based on RAN1 progress on the LP-WUS waveforms. The final conclusion in RAN4 on the required guard RBs should be applicable for all possible LP-WUS waveforms considered by RAN1.***  *Observation 3: For ICS, from the simulation results against waveform OOK-1, it is observed that at least 180kHz guard band is needed for protection of LP-WUS from interference of adjacent in-channel NR signals. To better counter the frequency offset effect, 360kHz GB would be preferred.*  *Observation 4: The required guard RBs are less for ICS compared to ACS.*  ***Proposal 6: Since RAN4 already agreed the GB size is RB based granularity, it would be better to use ICS instead of ASCS to unify the terminology used in RAN4 evaluation.***  *Observation 5: It was already agreed that SNR evaluation should be performed by RAN1 with consideration of RF impairments.*  ***Proposal 7: No need to have particular discussion of RF impairments unless it has direct impact on the evaluation of guard RBs between LP-WUS and NR signals.*** |
| [**R4-2307249**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2307249.zip) | Nokia, Nokia Shanghai Bell | [**Observation 1:** Frequency planning and allocation is country specific and should be considered when designing the WUS both in frequency span and frequency location/ flexibility.](#_Toc134888674)  [**Observation 2:** As the NR bands can be divided among operators, the location of the WUS needs to be flexible to accommodate different operators.](#_Toc134888675)  [**Observation 3:** Fixing WUS location has multiple negative consequences for the network.](#_Toc134888676)  [**Observation 4:** Frequency location of the WUS will be known to LR in advance.](#_Toc134888677)  [Proposal 1: WUS frequency location shall be flexible.](#_Toc134888678)  [**Observation 5:** WUS signals will encounter both in-channel, as well as adjacent channel interference.](#_Toc134888679)  [**Observation 6:** There is a trade-off between filter-order and number of guard RBs. A larger filter order will have sharper roll-off and may require a smaller guard RBs; but this comes at the cost of higher filter complexity and power consumption.](#_Toc134888680)  [**Observation 7:** In case of ±10 KHz CFO, at least two guard RBs on each side will be required if interference level lower than -25 dB is required.](#_Toc134888681)  [**Observation 8:** In case the WUS signal is at the edge of a carrier, ACS will come into picture.](#_Toc134888682)  [**Observation 9:** In case of mixed numerology of LP-WUS and NR signals, a guard band between LP-WUS and NR carriers is a must.](#_Toc134888683)  [**Observation 10:** The inter-carrier interference arising due to carrier frequency offset can be mitigated to a certain extent through guard RB selection.](#_Toc134888684)  [Proposal 2: Guard RBs should be determined considering the ASCS, ACS, SINR values for different WUS locations within UE BWP, filter order, and CFO.](#_Toc134888685) |
| [**R4-2307460**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2307460.zip) | Qualcomm Incorporated | **Observation 1: Based on the most recent LS RAN1 is looking also into RF architectures support FSK and OFDMA and not only analog envelope detection.**  **Observation 2: While IF-filter can provide good selectivity against adjacent channels and even in-channel subcarriers which are not immediately adjacent to WUS, the selectivity may suffer if WUS location is flexible.**  **Observation 3: IF-filter size and cost and their impact to practicality of the WUR design may be prohibitive aspects and need to be considered in IF envelope detection feasibility.**  **Observation 4: Analog envelope detection based receiver is unlikely perform acceptably if WUS is placed at channel edge.**  **Observation 5: When LO can be placed in the middle of WUS allocation, interferers are easier to reject. This can be enabled by fixed WUS frequency location or scheduling timeline which allows time for LO re-tuning.**  **Observation 6: If LO re-tuning is not possible and WUS can be scheduled at carrier edge, analog baseband filtering provides little help towards interferers and therefore possibilities for RF power savings are reduced**  **Observation 7: In the analysed scenarios providing a two RB guard band on either side of the WUS does not provide a meaningful difference in SINR after analog baseband filter.**  **Observation 8: Low power consumption needs to be balanced with negative impacts to performance.**  **Proposal 1: Inform RAN1 that analog envelope detection architectures will perform poorly or not work at all under adjacent channel interference if WUS is placed immediately adjacent to channel edge. To improve the likelihood of operation multiple MHz offset is needed, but exact value needs further study. For architectures using digital detection, placing WUS away from channel edge can enable use of simpler RF HW and power savings.**  **Proposal 2: Inform RAN1 that required NF can be concluded based on coverage target, which is expected to full coverage of the cell, and SNR where wake-up signal can be successfully detected. For reference, 9 dB NF and -1 dB SNR is used for typical NR UE in reference sensitivity test case, but typical NR UE also has 2 receivers. RAN1 should take into account in wake-up signal design that lower SNR will enable higher NF and therefore also lower power consumption. 9 dB noise figure would not be possible to reach at least with RF envelope detection.** |
| [**R4-2308179**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2308179.zip) | ZTE Corporation | ***Proposal 1.*** ***No need to restrict symmetric guard bands within the WUS channel bandwidth***  ***Proposal 2. For FR1, it is feasible to locate the LP-WUS within the carrier except the minimum guard-band.***  ***Proposal 3. De-prioritize/Remove the RF ED architecture for LP-WUR architecture.*** |
| [**R4-2308198**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2308198.zip) | CMCC | **Observation 1:** **RF requirement analysis may need to be categorized by different UE device with different power consumption assumption.**  **Proposal 1: it’s suggested to be emphasized into reply LS to RAN1 that final ACS is only based on LP-WUS performance analysis and only for RAN1 analysis purpose whereas there is no detailed verification of co-existence issue considering there is no conclusion of LP-WUS signal design.**  **Proposal 2: the methodology for guard RB is that at first conclude the relationship between guard RB and adjacent channel selectivity based on typical LP-WUS performance. And then down-select guard RB based on target ACS value although current it’s hard to be concluded from simulation.**  **Proposal 3: if we assume the same coverage as normal UE, target ACS is about 32dB for 9dB NF, 26dB for 15dB NF and 17dB for 24dB NF.**  **Proposal 4: the same value of ACS is also applicable for sub-carrier selectivity.**  **Proposal 5: it’s RAN4’s responsibility to decide whether to consider dedicated LP-WUS operation band. besides, final example band should be global operation band with commercial network proposed by operator or spectrum management organization.** |
| [**R4-2308260**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2308260.zip) | vivo | **Observation 1:** The detailed ASCS definition is still not clear in RAN4, which should be aligned first. In our simulation, for WUS=5MHz, the ASCS BWinterference is 5MHz.  **Proposal 1: RAN4 should further define and clarify a detailed definition for ASCS metric.**  **Observation 2:** Currently, the ASCS target is not clear in both RAN1 and RAN4.  **Proposal 2: RAN4 should decide a target ASCS value, for example 20dB. Then the corresponding number of guard RB is 0.5RB at each side using 5th order filtering.**  **Proposal 3: If no ASCS target can be concluded, several ASCS options with corresponding number of Guard RBs in Table 2 can be provided to RAN1.**  **Observation 3:** Given there is existing guard band for each NR channel, for 100MHz NR channel, if 5th order filter is used, no guard RB is needed for ACS. But for 20MHz, if ~30dB ACS should be achieved, then 1RB for guard RBs is needed.  **Proposal 4:** **For different NR CBW, RAN4 should defined different number of required guard RBs for LP-WUS ACS.**  **Proposal 5: RAN4 should decide a target ACS value, for example ~30dB. Then the corresponding number of required guard RB is 0RB for 100MHz CBW and 1RB for 20MHz CBW, using 5th order filtering.**  **Proposal 6: If no concluded ACS target in RAN4, the ACS results listed in Table4 can be captured in the reply LS to RAN1.**  **Proposal 7: The guard RBs at channel edge for LP-WUS ACS could also be used for NR downlink signal.**  **Proposal 8: RAN4 should decide whether worst case of ASCS and ACS has been covered by case 1 and case 2, and case 3 analysis is not needed.**  **Proposal 9: LP-WUS can be flexible located within NR carrier as long as the required guard RBs are configured.**  **Proposal 10: RAN4 recommend 3dB and 6dB power boosting for LP-WUS.** |
| [**R4-2308261**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2308261.zip) | vivo | Reply LS to RAN1 |
| [**R4-2308365**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2308365.zip) | MediaTek Inc. | **Observation 1: For the new WUR architecture variant with switch, information on when and how to assess the received signal level thus perform switching accordingly would be helpful for further discussion.**  **Proposal 1: For testing purpose, an LP-WUR should be able to be configured on the same raster point as main receiver, however, it can also be configured on a raster point other than main receiver.**  **Proposal 2: Guard RBs is part of a WUS channel bandwidth, and should not overlap with the guard band of NR carrier.**  **Proposal 3: RAN4 to focus on symmetric guard RBs in a WUS channel bandwidth.**  **Proposal 4: RAN4 to decide the number of guard RBs after RAN1 finalizes the WUS signal design.** |
| [**R4-2309033**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2309033.zip) | Sony | **Observation 1 The RF envelope-detection based architecture has the highest potential for power saving but has some implementation difficulties when it comes to channel filtering.**  **Proposal 1 For a fair evaluation of LP-WUS/LP-WUR, companies should provide a noise figure and power consumption for each proposed LP-WUR architecture.**  **Proposal 2 The complexity aspect should be considered for the design of LP-WUS/WUR scheme.** |
| [**R4-2309054**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2309054.zip) | Apple | **Proposal 1:** **For the case of WUS in-channel with the main receiver (MR), RAN4 should further develop the evaluation framework for ASCS and align on a set of coexistence system level simulation assumptions with the goal of identifying a range of ASCS targets as a function of WUS SNR (expected from RAN1), guard gap size, and the UE filtering characteristic.**  **Proposal 2:** **For the case of WUS in separate channel from MR, RAN4 should further develop the evaluation framework for ACS and align on a set of coexistence system level simulation assumptions with the goal of identifying a range of ACS targets as a function of WUS SNR (expected from RAN1), WUS & NR channel bandwidths, and the UE filtering characteristic.**  **Proposal 4:** **RAN4 shall continue to study the scenario of WUS in a separate band from MR.**  **Observation 1:** **Coexistence system level simulations can also be adopted to the separate band WUS scenario, where assumptions on out of band rejection can be taken in the stead of a ASCS/ACS.** |
| [**R4-2309203**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2309203.zip) | Ericsson | Reply LS to RAN1  Proposal-1:ACS requirement should be further discussed in the context of the guard band.  Proposal-2:Wait the RAN4 further study from guard RB evaluation framework  Proposal-3:Wait RAN1 response before concluding the noise figure question.  Proposal-4:Further investigation is needed on WUS signal generation using the OFDM transmitter. |
| [**R4-2309204**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2309204.zip) | Ericsson | **Observation 1 There could be further UE power saving benefit if the WUS coverage using a WUR could be same with the paging signal coverage of the main receiver.**  **Observation 2 The WUR noise figure has dependency to the main receiver noise figure if the WUR and MR coverage target the same.**  **Observation 3 REFSENS of WUR can be specified when WUS SNR target and coverage requirement is known.**  **Observation 4 Narrow band blocking requirement does not apply to WUR.**  **Observation 5 The ED operated within a limited dynamic range and REFSENS level of WUR should at least match its low end of ED dynamic range.**  **Observation 6 REFSENS of WUR can be specified when WUS SNR target and coverage requirement is known.**  **Observation 7 RF envelop detector architecture may have issue with ACS and inband blocking requirement for existing NR bands.**  **Observation 8 High Q IF BPF filter is needed in IF ED architecture**  **Observation 9 Not synchronized LO to BS pose a risk to degrade the IF ED performance**  **Observation 10 Coherent or non-coherent receiver is an import aspect of the receiver design**  **Proposal-1:****Consider the above phase noise profile table for RF impairment caused by phase noise.**  **Proposal-2: Use above equation to evaluate the phase noise impact.**  **Proposal-3: Consider the above CFO numbers for simulation.**  **Proposal-4: Model the ADC impairment as a AWGN, noise power level is up to further discussion. E. g SNR degradation allowance.**  **Proposal-5: Model the RF impairment of ED as a square-law operator.**  **Proposal-6:Further discuss the DC offset modeling.**  **Proposal-7:WUR ACS should be further discussed in the context of the guard band design and main receiver test requirement.**  **Proposal-8:Discuss the WUR ACS and inband blocking requirements in relation to the main receiver requirement**  **Proposal-9:Send LS to RAN1 about the power consumption benefit of the new variant of WUR architecture.** |

## Open issues summary

### Sub-topic 1-1 UE ACS evaluation

*Moderator: background information, agreements in WF for ACS and ASCS:*

***Issue: General evaluation framework for both ACS and ASCS***

*Agreement:*

* *The following aspects can be starting point for further discussions*
* *Framework in RAN4 that the ACS and ASCS value can be evaluated based on the following aspects:* 
  + *Typical filter characteristic, e.g. filter order, pass BW, cut-off frequency*
  + *Guard RB size within LP-WUS channel bandwidth*
  + *RF impairment can also be considered*
* *Averaged power attenuation at ACS or ASCS frequency range*
* *FFS whether SINR of the wanted signal at detector input is needed*
* *FFS whether use ICS to instead ASCS*
* *FFS Coexistence-simulation-based framework can also be considered*
  + *FFS on details of coexistence study (if needed) of LP-WUS*
  + *Coverage should be considered*

**Issue 1-1-1: Refinement of ACS evaluation framework for LP-WUR in RAN4**

* Proposals
  + Proposal 1: Guard RB evaluation should be based on RAN1 progress on the LP-WUS waveforms. The final conclusion in RAN4 on the required guard RBs should be applicable for all possible LP-WUS waveforms considered by RAN1. (Huawei)
  + Proposal 2: It’s suggested to be emphasized into reply LS to RAN1 that final ACS is only based on LP-WUS performance analysis and only for RAN1 analysis purpose whereas there is no detailed verification of co-existence issue considering there is no conclusion of LP-WUS signal design. (CMCC)
  + Proposal 3: WUS at edge of channel (case 2) is the worst case of ACS. (vivo)
  + Proposal 4: The complexity aspect should be considered for the design of LP-WUS/WUR scheme. (Sony)
  + Proposal 5: For the case of WUS in separate channel from MR, RAN4 should further develop the evaluation framework for ACS and align on a set of coexistence system level simulation assumptions with the goal of identifying a range of ACS targets as a function of WUS SNR (expected from RAN1), WUS & NR channel bandwidths, and the UE filtering characteristic. (Apple)
* Recommended WF
  + TBA

**Issue 1-1-2: Target ACS value for LP-WUR receiver**

* Proposals
  + Proposal 1: RAN4 should decide a target ACS value, for example ~30dB. Then the corresponding number of required guard RB is 0RB for 100MHz CBW and 1RB for 20MHz CBW, using 5th order filtering. (vivo)
  + Proposal 2: The methodology for guard RB is that at first conclude the relationship between guard RB and adjacent channel selectivity based on typical LP-WUS performance. And then down-select guard RB based on target ACS value although current it’s hard to be concluded from simulation. (CMCC)
  + Proposal 3: If we assume the same coverage as normal UE, target ACS is about 32dB for 9dB NF, 26dB for 15dB NF and 17dB for 24dB NF. (CMCC)
  + Proposal 4: WUR ACS should be further discussed in the context of the guard band design and main receiver test requirement. Discuss the WUR ACS and inband blocking requirements in relation to the main receiver requirement. (Ericsson)
  + Proposal 5: For ACS, from the simulation results against waveform OOK-1, it is observed that 5th order Butterworth filter can provide better performance under same condition. To have similar performance without ACI, about 600kHz guard band (roughly 2 RBs for 30kHz SCS and 4 RBs for 15kHz SCS) is needed to protect LP-WUS from interference of the adjacent NR carrier. (Huawei)
* Recommended WF
  + TBA

**Issue 1-1-3: Required number of guard RBs for LP-WUS ACS**

* Proposals
  + Proposal 1: For analog filter WUR, to improve the likelihood of operation multiple MHz offset is needed, but exact value needs further study. (Qualcomm)
  + Proposal 2: For different NR CBW, RAN4 should defined different number of required guard RBs for LP-WUS ACS. Guard RB is 0RB for 100MHz CBW and 1RB for 20MHz CBW, using 5th order filtering for ~30dB ACS. (vivo)
  + Proposal 3: If no concluded ACS target in RAN4, the ACS results listed in Table4 can be captured in the reply LS to RAN1. (vivo)
* **Table 4: 5MHz ACS results for case 2**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Filter order |  | ACS, BWinterference = 5MHz | | | | |
| Guard RB  NR CBW | 0RB | 0.5RB | 1RB | 2RB | 3RB |
| 5th | 20MHz, SCS = 15KHz | -28.20 | -29.51 | -30.37 | -32.43 | -34.40 |
| 100MHz, SCS = 30KHz | -34.51 | -36.33 | -38.07 | -41.33 | -44.33 |
| 4th | 20MHz, SCS = 15KHz | -23.71 | -24.70 | -25.35 | -26.92 | -28.42 |
| 100MHz, SCS = 30KHz | -28.35 | -29.76 | -31.11 | -33.64 | -35.97 |
| 3rd | 20MHz, SCS = 15KHz | -18.80 | -19.49 | -19.94 | -21.04 | -22.10 |
| 100MHz, SCS = 30KHz | -21.90 | -22.90 | -23.87 | -25.70 | -27.39 |
| 2nd | 20MHz, SCS = 15KHz | -13.43 | -13.84 | -14.11 | -14.77 | -15.41 |
| 100MHz, SCS = 30KHz | -15.18 | -15.80 | -16.40 | -17.54 | -18.62 |

* + Proposal 4: Guard RBs is part of a WUS channel bandwidth, and should not overlap with the guard band of NR carrier. RAN4 to decide the number of guard RBs after RAN1 finalizes the WUS signal design. (MTK)
* Recommended WF
  + TBA

**Issue 1-1-4: Whether guard RBs should be symmetric for ACS**

* Proposals
  + Proposal 1: No need to restrict symmetric guard bands within the WUS channel bandwidth. (ZTE, vivo)
  + Proposal 2: RAN4 to focus on symmetric guard RBs in a WUS channel bandwidth. (MTK)
* Recommended WF
  + TBA

**Issue 1-1-5: Whether ACS Guard RB at channel edge should be empty RB, or can also be used for NR signal**

* Proposals
  + Proposal 1: The guard RBs at channel edge for LP-WUS ACS could also be used for NR downlink signal. (vivo)
* Recommended WF
  + TBA

**Issue 1-1-6: Filter implementation**

* Proposals
  + Proposal 1: The possible degradation of filter rejection for real implementation should be counted in evaluation of guard RBs for LP-WUS. (Huawei)
* Recommended WF
  + TBA

**Issue 1-1-7: WUR RF impairments impacts**

* Proposals
  + Proposal 1: No need to have particular discussion of RF impairments unless it has direct impact on the evaluation of guard RBs between LP-WUS and NR signals. (Huawei)
  + Proposal 2: Consider the following RF impairment aspects: (Ericsson)
    - * Consider the phase noise profile in table 1 for RF impairment caused by phase noise:

Table 1: Phase noise profile of WUR with 5MHz BW

|  |  |  |  |
| --- | --- | --- | --- |
|  | Phase noise (dBc/Hz) | | |
| Offset | NF 9 dB | NF 12 dB | NF 15 dB |
| @5MHz | -99.4 | -99.4 | -99.4 |
| @10MHz | -108.1 | -105 | -102.1 |
| @15MHz | -120 | -117 | -114 |

* + - * Use the following equation to evaluate the phase noise impact:

P\_pn (dBm) = P\_interferer (dBm) + PN\_offset (dBc/Hz) + 10\*log10(BW)

* + - * Consider the following CFO numbers for simulation:

|  |  |
| --- | --- |
| Frequency Offset | - Initial acquisition  - TRP: uniform distribution +/- 0.05 ppm  - UE: uniform distribution +/- 5, 10, 20 ppm (each company to choose one)  - Non-initial acquisition  - TRP: uniform distribution +/- 0.05 ppm  - UE: uniform distribution +/- 0.1 ppm |

* + - * Model the ADC impairment as a AWGN, noise power level is up to further discussion. E. g SNR degradation allowance.
      * Model the RF impairment of ED as a square-law operator
      * Further discuss the DC offset modeling
* Recommended WF
  + TBA

### Sub-topic 1-2 UE ASCS evaluation

**Issue 1-2-1: ASCS evaluation**

* Proposals
  + Proposal 1: RAN4 should further define and clarify a detailed definition for ASCS metric, e.g. similar to ACS, for 5MHz WUS, the ACSC BWinterference is set as 5MHz. (vivo)
  + Proposal 2: Since RAN4 already agreed the GB size is RB based granularity, it would be better to use ICS instead of ASCS to unify the terminology used in RAN4 evaluation. (Huawei)
  + Proposal 3: WUS at center of channel (case 1) is the worst case of ASCS. (vivo)
  + Proposal 4: For the case of WUS in-channel with the main receiver (MR), RAN4 should further develop the evaluation framework for ASCS and align on a set of coexistence system level simulation assumptions with the goal of identifying a range of ASCS targets as a function of WUS SNR (expected from RAN1), guard gap size, and the UE filtering characteristic. (Apple)
* Recommended WF
  + TBA

**Issue 1-2-2: Target ASCS value for LP-WUR**

* Proposals
  + Proposal 1: The same value of ACS is also applicable for sub-carrier selectivity. (CMCC)
  + Proposal 2: RAN4 should decide a target ASCS value, for example 20dB. Then the corresponding number of guard RB is 0.5RB at each side using 5th order filtering. (vivo)
* Recommended WF
  + TBA

**Issue 1-2-3: Guard RBs for LP-WUS ASCS**

* Proposals
  + Proposal 1: Guard RBs should be determined considering the ASCS, ACS, SINR values for different WUS locations within UE BWP, filter order, and CFO. (Nokia)
  + Proposal 2: In case of ±10 KHz CFO, at least two guard RBs on each side will be required if interference level lower than -25 dB is required. (Nokia)
  + Proposal 3: For ASCS=20dB, the required number of guard RB is 0.5RB at each side using 5th order filtering If no ASCS target can be concluded, several ASCS options with corresponding number of Guard RBs in Table 2 can be provided to RAN1. (vivo)
  + Proposal 4: For ICS, from the simulation results against waveform OOK-1, it is observed that at least 180kHz guard band is needed for protection of LP-WUS from interference of adjacent in-channel NR signals. To better counter the frequency offset effect, 360kHz GB would be preferred. (Huawei)
  + Proposal 5: RAN4 to decide the number of guard RBs after RAN1 finalizes the WUS signal design. (MTK)
* Recommended WF
  + TBA

**Issue 1-2-4: WUS location within the carrier**

* Proposals
  + Proposal 1: WUS frequency location shall be flexible within the carrier except the minimum guard-band. (Nokia, vivo, ZTE)
  + Proposal 2: Inform RAN1 that analog envelope detection architectures will perform poorly or not work at all under adjacent channel interference if WUS is placed immediately adjacent to channel edge. To improve the likelihood of operation multiple MHz offset is needed, but exact value needs further study. For architectures using digital detection, placing WUS away from channel edge can enable use of simpler RF HW and power savings. (Qualcomm)
* Recommended WF
  + TBA

**Issue 1-2-5: Whether guard RBs should be symmetric for ASCS**

* Proposals
  + Option 1: No need to restrict symmetric guard bands within the WUS channel bandwidth for ASCS.
  + Option 2: Restrict symmetric guard bands within the WUS channel bandwidth for ASCS.
* Recommended WF
  + TBA

### Sub-topic 1-3 UE Noise figure

**Issue 1-3-1: General views on NF**

* Proposals
  + Proposal 1: For a fair evaluation of LP-WUS/LP-WUR, companies should provide a noise figure and power consumption for each proposed LP-WUR architecture. (Sony)
* Recommended WF
  + TBA

**Issue 1-3-2: Required Noise Figure**

* Proposals
  + Proposal 1: Inform RAN1 that required NF can be concluded based on coverage target, which is expected to full coverage of the cell, and SNR where wake-up signal can be successfully detected. For reference, 9 dB NF and -1 dB SNR is used for typical NR UE in reference sensitivity test case, but typical NR UE also has 2 receivers. RAN1 should take into account in wake-up signal design that lower SNR will enable higher NF and therefore also lower power consumption. 9 dB noise figure would not be possible to reach at least with RF envelope detection. (Qualcomm)
  + Proposal 2: Wait RAN1 response before concluding the noise figure question. (Ericsson)
* Recommended WF
  + TBA

### Sub-topic 1-4 WUS power boosting

**Issue 1-4-1: LP-WUS power boosting**

* Proposals
  + Proposal 1: Based on RAN1 LS, RAN4 recommend 3dB and 6dB power boosting for LP-WUS. (vivo)
* Recommended WF
  + TBA

### Sub-topic 1-5 Dedicated LP-WUS operation band

**Issue 1-5-1: Separated band for LP-WUS operation**

* Proposals
  + Proposal 1: it’s RAN4’s responsibility to decide whether to consider dedicated LP-WUS operation band. besides, final example band should be global operation band with commercial network proposed by operator or spectrum management organization. (CMCC)
  + Proposal 2: RAN4 shall continue to study the scenario of WUS in a separate band from MR. (Apple)
* Recommended WF
  + TBA

### Sub-topic 1-6 Variant of different LP-WUR architectures

**Issue 1-6-1: Variant of different LP-WUR architectures**

* Proposals
  + Proposal 1: As long as the variant LP-WUR architectures belong to the architectures mentioned in RAN1 LS, they can be considered in RAN4 evaluation. (Huawei)
  + Proposal 2: Send LS to RAN1 about the power consumption benefit of the new variant of WUR architecture. (Ericsson)
* Recommended WF
  + TBA

**Issue 1-6-2: LP-WUR architectures down selection**

* Proposals
  + Proposal 1: Given poor coverage performance and incapable of supporting of multi-band operation, it is proposed to rule out RF ED LP-WUS architecture for the following RAN4 evaluation. (Huawei)
  + Proposal 2: De-prioritize/Remove the RF ED architecture for LP-WUR architecture. (ZTE)
  + Proposal 3: The RF envelope-detection based architecture has the highest potential for power saving but has some implementation difficulties when it comes to channel filtering. (Sony)
* Recommended WF
  + TBA

**Issue 1-6-3: other requirements for LP-WUR**

* Proposals
  + Proposal 1: REFSENS of WUR can be specified when WUS SNR target and coverage requirement is known. (Ericsson)
  + Proposal 2: Narrow band blocking requirement does not apply to WUR. (Ericsson)
  + Proposal 3: RF requirement analysis may need to be categorized by different UE device with different power consumption assumption. (CMCC)
* Recommended WF
  + TBA

**Issue 1-6-4: testing aspects for LP-WUR**

* Proposals
  + Proposal 1: For testing purpose, an LP-WUR should be able to be configured on the same raster point as main receiver, however, it can also be configured on a raster point other than main receiver. (MTK)
  + Proposal 2: Narrow band blocking requirement does not apply to WUR. (Ericsson)
  + Proposal 3: RF requirement analysis may need to be categorized by different UE device with different power consumption assumption. (CMCC)
* Recommended WF
  + TBA

### Sub-topic 1-7 LP-WUS waveform assumptions

* Proposals
  + Proposal 1: RAN4 evaluation for the issues identified so far should consider all possible LP-WUS waveforms. (Huawei)
  + Proposal 2: OFDM based LR should be included in the studies. (Nokia)
  + Proposal 3: Further investigation is needed on WUS signal generation using the OFDM transmitter. (Ericsson)
* Recommended WF
  + TBA

# Topic #2: LP-WUS designs

## Companies’ contributions summary

|  |  |  |
| --- | --- | --- |
| **T-doc number** | **Company** | **Proposals / Observations** |
| R4-2307316 | Nokia, Nokia Shanghai Bell | 1. The LP-WUS modulation scheme selected should be easy to generate using the existing gNB architecture. OOK modulation schemes can be used via DFT spreading. 2. The LP-WUS modulation scheme selected should be resource efficient and should ensure efficient multiplexing with other NR signals. Compared to standard OFDMA, OOK is not resource efficient. However, it can be multiplexed with other NR signals. 3. The CP inclusion in the time domain waveform for every transmitted OFDM symbol has an impact on the LR reception. 4. OOK will suffer from ISI in a multi-path channel. 5. gNB should consider the impact of CP while designing the LP-WUS signal. 6. Evaluate if LR must discard padding symbols inserted by the gNB to overcome the CP impact. 7. OFDM based LR should be included in the studies. 8. Effect of LP-WUS signal on the network throughput and efficiency should be studied. |
| [**R4-2309203**](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_107/Docs/R4-2309203.zip) | Ericsson | Proposal-4:Further investigation is needed on WUS signal generation using the OFDM transmitter. |

## Open issues summary

### Sub-topic 2-1 WUS design

**Issue 2-1-1:** **CP impact on LP-WUS signal**

* Proposals
  + Proposal 1: gNB should consider the impact of CP while designing the LP-WUS signal.
  + Proposal 2: Evaluate if LR must discard padding symbols inserted by the gNB to overcome the CP impact.
* Recommended WF
  + TBA

**Issue 2-1-2: LP-WUS network throughput and efficiency**

* Proposals
  + Proposal 1: Effect of LP-WUS signal on the network throughput and efficiency should be studied.
* Recommended WF
  + TBA