3GPP TSG RAN WG1 #112b-e R1-230xxxx

e-Meeting, Apr 17 - Apr 26, 2023

Agenda Item: 9.11.3

Source: Moderator (Nordic Semiconductor ASA)

Title: Summary #4 of discussions on L1 signal design and procedure for low power WUS

Document for: Discussion/Decision

# Introduction

In Rel-18, a study item was approved for low-power wake-up signal and receiver for NR (WID in RP-222644 [1]), and it includes the following objectives.

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| * 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.
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This contribution summarizes the remaining proposals in RAN1#112b-e. Provide feedback directly to the Table

# Final check

|  |  |  |  |
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|  | **Support** |  **Support with wording update**  | **Not support because**  |
| FL@Samsung, Intel: proposal applies to all schemes, please note “*and to modulate input signal of N SCs for other MC-ASK/FSK schemes*” in main bulletFL@ALL: PAPR is controversial, I keep it FFS ***FL5-Higher-Proposal-1a:*** *Study further methods to modulate input signal of the DFT/Least-Square block for OOK-4, and methods to modulate input signal of N SCs for other MC-ASK/FSK schemes** *study whether there is a need to additionally modulate input signal or it can be left up to gNB implementation*
* *study methods with respect to*
	+ *improving frequency diversity by flattening the spectrum, frequency repetition and frequency hopping*
	+ *impact to dynamic range in frequency domain*
	+ *FFS: impact to PAPR of generated time domain modulated MC-ASK/FSK symbol*
	+ *improving robustness to timing error*
	+ *necessary spectrum adjustment for compatibility with CP-OFDM generation*
 | MTK, FW |  |  |
| @Samsung I am not so sure it would be the same, OOK-3 may be more complex to receive that OOK-1.***FL5-Lower-Proposal-1b*****Observation**For all studied waveform schemes, if different waveforms can be pre-generated and stored in thememory, the computational complexity at gNB to generate different waveforms (FFS: or at LP-WUR to decode different waveforms) is expected to be the same. | HW, ZTE, VIVO, FW, Apple, Intel, MTK | FW (not sure how pre-generating and storing waveforms at LP-WUR can help with decoding complexity of OOK waveforms) |  |
| FL: Regarding “new schemes/clarifications”, there is quite an opposition to update the last RAN1#112 agreement on waveforms. P2: It was understood that 2 additional segments can be a known signal, i.e. synch signal modulated with FSK. P3/4: It needs more study on how much information combination of OOK-4 and FSK-1/2 actually carry. We can continue in RAN1#113 where it will be easier to discuss F2F. For now we have agreement to study * Study how to generate segment in time domain, e.g. OOK-1 or OOK-4

P5: It has been understood that information is generated by using sequences of different length within LP-WUS BW. It has been understood that it can be received with already agreed receiver architecture. M baseband filters are needed as in FSK-2 to receive M bits.Based on above companies should have enough understanding if they want to simulate this scheme. However, it would be hard to explicitly agree on the proposal. P6: FSK1 could be updated so that pairs of segments are replaced with sets of segments which are FSK-2 this creating parallel FSK-2 modulations. It is understood that scheme is not precluded, but it may be hard to make explicit agreement. |  | FW: (1) For P2, we agree with a note indicating the 2 additional segments carrying a known signal. (2) For P5, we are OK not to have an explicit separate agreement with details, but suggest amending the following note to FSK-2 scheme:Note: N SCs of LP-WUS can be modulated to generate 2^M segments at BB of LP-WUR after self-mixing envelope detection. |  |
| FL has same understanding with Sony,sub-bullet 5 and 6 are for different type of GB, outer resp. inner GB.FL: added MTK bullet which can be controversialFL@Ericsson: I tried to clarify that Manchester is not the only coding that can be considered.If we cannot agree on this it may serve as FL guidance for RAN1#113 meeting.***FL4-Lower-Proposal-2b:*** To focus simulation effort further, focus on answering at least the following: * For each combination of waveform schemes and receiver architectures, the impact of timing and frequency error
* For waveforms using segments, for different segment sizes in time/frequency, impact of frequency-selectivity, inter symbol interference and ~~[~~power boosting~~]~~
* What are sampling rate requirements and ADC dynamic range requirements for each waveform scheme.
* Performance with and without Manchester coding or other coding
* As function of in-band/out-of-band ACI and phase-noise, what size of guard-band (outside of LP-WUS).
* In terms of frequency error, what guard-gap (between segments) is needed
* Impact of BW choice
* ~~(From MTK)~~Synchronization and RRM performance with the existing NR reference signal for each combination of waveform schemes and receivers
 | MTK: It is important to check how to benefit the always-on signal in the cellular network |  |  |
| FL: I removed controversial FFS bullets, if this not flying FL suggests dropping this proposal in RAN1#112b-e@Apple: Proposal to me sounds stronger than what was agreed so far“Agreement RAN1#112: *When comparing waveforms of LP-WUS, consider the impact to gNB for each of the waveform generation schemes. Consider whether there is impact to PAPR and a need for additional hardware for WUS.*”@Sony: If feasibility to reuse existing hardware is too strong, we could re-word with “possibility”?**FL5-Higher-Proposal-22** Consider the following qualitative aspects in addition to agreed KPI in selection of waveform(s). For example* [~~feasibility~~/possibility] to generate waveform at gNB using existing hardware.
* ~~FFS: capability to be received with one or more the agreed receiver architectures e.g. energy detection and time domain correlation.~~
* FFS: capability to support flexible bitrate per within fixed TF resource.
* ~~FFS: complexity of reception of waveform.~~
* ~~FFS: complexity of generation of waveform~~.
* ~~FFS: feasibility to receive waveform using existing hardware (or at least part of the existing hardware).~~
* FFS: capability to support the agreed use cases, e.g., IoT, wearable, and eMBB in IDLE/INACTIVE and RRC CONNECTED.
* ~~FFS: Capability to coexist with NR common signals such as SSB in NR bands of 5MHz.~~
* Other aspects can be further discussed.
 | MTK |  |  |
| @MTK, I prefer not to add FFSes at this point, this can trigger more FFS at this point.***FL5-Lower-Proposal-3:*** *Study how the CP is handled for OOK-4 atthe transmitter and at the receiver.**Note: There is no intention to change CP-OFDMA generation at the transmitter.*  | HW, ZTE, VIVO, HW, IDC, Apple, MTK, FW |  |  |
| FL@Xiaomi: support of mixed SCS has not been much seen in field so far, and the reason is the complexity. 😊FL@ALL: It seems that some companies have issue with O4, while other would not except proposal without O4.FL@Sony: Clarified “guard-band (with NR signals)”Let’s try to go with Alt2. ***FL5-Higher-Proposal-4*** For a case of LP-WUS SCS is different to SCS used for other NR transmissions in CP-OFDM symbol overlapping in time with LP-WUS transmission agree on the following observations.* **O1:** If higher data rate is expected to be supported, SCS of LP-WUS should be higher than SCS of NR transmissions in FR1.
* **O2:** NR specification supports FDM and TDM multiplexing of signals/channels generated with different SCS. It may be feasible from specification point of view to support the case.
* ~~Alt1: HW, ZTE, VIVO, FW, Samsung, Oppo, ///, Apple, [Sony]~~
	+ **~~O3:~~** ~~The case may require additional guard-bands (with NR signals) due to spectral leakage. Spectral leakage can be alleviated partially by pulse shaping performed at gNB. Larger guard-band (with NR signals) will negatively impact spectral efficiency. Spectral leakage will negatively impact performance of legacy UEs.~~
	+ **~~O4:~~** ~~complexity at gNB may increases and gNB may require new hardware.~~
* **Alt2:** ZTE, VIVO, FW, HW (2nd preference), Samsung, Intel, ///, Nokia, Apple, [Sony]
	+ the case may will increase complexity at gNB and may require new hardware, pulse shaping, or additional guard bands.
 | MTK, FW (there is a typo in Alt2, may followed by will) |  |  |
| FL: improved FFS wording based on Samsung input***FL5-Higher-Proposal-6****At least for IDLE/Inactive mode* * *at least one BW-size <=5MHz is recommended to be supported for FR1*
	+ *if additional BW-size(s) are recommended to be supported, BW-size can be up to 20MHz*
	+ *FFS: LP-WUS size (including guard-bands) is an integer number of PRBs*
 | HW, ZTE, VIVO, Samsung, Apple, Intel, MTK, FW |  | Ericsson wants to leave this to WID |
| FL: Leaving feasibility FFS for offloading neighbor cell measurements matches to what was contributed to RAN1#112b-eAt least Intel is not OK to put neighbor-cell RRM relaxation on the same bar as serving cellApple would not be OK with precluding study of neighbor cell RRM measurements offloading to LP-WUR***FL5-Higher-Proposal-9:****For Idle/Inactive mode, study offloading of RRM measurements of serving cell to LP-WUR and relaxation of RRM measurements of serving cell (neighbor cell with second priority) in MR considering** *periodic reference signal(s) is/are used for measurements.*
	+ *FFS: reference signal(s) to measure, e.g. PSS/SSS/PBCH DMRS, LP-WUS-waveform based sequence (LP-SS)*
	+ *FFS: periodicity, content, e.g. cell ID in case SSB is not used*
* *FFS: periodic reference signal(s) is/are cell dependent.*
* *MR performs serving cell and (neighbor cell with second priority) measurements*
	+ *Alt1: with relaxed periodicity if RRM measurement in MR is relaxed.*
	+ *~~Alt2a: only when reference signal(s) based measurements~~*
		- *~~are below a threshold if RRM measurement is offloaded to LP-WUR. FFS threshold based on LP-WUS metric.~~*
	+ *Alt2b: only when reference signal(s) based measurements by LP-WUR satisfy certain condition(s), e.g. are below threshold.*
		- *FFS threshold.*
		- *Note: the case where serving cell measurements are always performed by LP-WUR even if MR is ON, e.g. WUR and MR coverage is equal case, is not precluded.*
	+ *Other alternatives are not precluded*

*~~Opt1: Note: RRM measurements of neighbor cells by LP-WUR is not precluded by this agreement and can be further studied.~~**Opt2: FFS: Feasibility of RRM measurements of neighbor cells by LP-WUR*  | MTK, IDCC | Intel ([FFS: neighbor]) FW (what is the difference between “• *FFS: periodic reference signal(s) is/are cell dependent*.” and having “cell ID” under the first bullet?) | CATT (more progress on LP-WUS design needed) |
| FL does not see reason why LP-SINR or Detection rate could not be further studied. N is controversial, we need to see how the resource is defined first, may not necessarily reuse legacy definition. It is left FFS, including the case N=1.If proposal is not agreed, companies can focus next meeting on how to define resource for LP-RSSI, LP-RSRP, etc…***FL5-Higher-Proposal-10:****For at least RRM serving cell measurement performed by LP-WUR based on reference signals(s), RAN1 identified at least the following metrics for further study and evaluation* * *LP-RSSI or Energy detection: linear average of received power over a RSSI resource.*
	+ *FFS RSSI resource.*
* *LP-RSRP: linear average of received power of resource of reference signal(s) or signal(s) parts.*
	+ *FFS resource of reference signal(s) or signal(s) parts*
* *~~FFS:~~ LP-SINR = LP-RSRP/(power of interference and noise)*
	+ *FFS how to define “power of interference and noise”*
* *LP-RSRQ= [N x] LP-RSRP/LP-RSSI*
	+ *~~Alt1: N = size of resource of reference signal(s) or signal(s) parts / size of RSSI resource and~~*
	+ *Alt2: FFS: N, if any*
* *~~FFS:~~ Detection rate of always ON periodic reference signal(s) or LP-WUS*
	+ *FFS how to calculate/define detection rate*

*FFS: Feasibility of different receiver architectures to support the above metrics. e.g. need for ADC, AGC, with different reference signal(s).**Note: Reference signal for performing measurements can be e.g. SSB (PSS/SSS/PBCH DMRS), LP-WUS-waveform sequence (LP-SS)* | MTK, FW |  | CATT |
| @Xiaomi, indeed occasions could be for different beams, like we have for paging, nothing precluded at this point.@MTK, I captured your input a bit differently, OK?“FFS: LP-SS transmission pattern …” seems to be too much detail at this stage, more of WID aspect, FL would suggest to remove***FL5-Higher-Proposal-11:****At least for LP-WUR architectures that cannot receive existing OFDMA-based NR signals for synchronization, at least periodic synchronization signal used by LP-WUR (LP-SS) is required. Study further** *required periodicity of LP-SS.*
* *waveform used for LP-SS, and whether it should be the same or can be different as used for LP-WUS, assuming that LP-WUR can receive both.*
* *structure of LP-SS*
	+ *Alt1: sequence based only*
	+ *Alt2: sequence + message with encoded bits*
	+ *FFS: sequence*
* *supporting additionally aperiodic synch signal for fine synchronisation*
* *feasibility of time/frequency estimation/correction for different waveforms/receivers architectures*
* *~~[FFS: LP-SS transmission pattern, e.g. multiple transmissions of LP-SS within each period, e.g. DRX window, beam sweeping window]~~*
* *FFS: whether can be used as reference signal(s) for RRM measurements as well and vice versa.*
* FFS: which architectures are not able to receive existing OFDMA-based NR signals.

*Note: LP-WUR for* OFDMA-based LP-WUS may also receive LP-SS.  |  | MTK: We still have concerns on using “architectures”. Most of the agreed architectures can support receiving existing OFDMA-based NR signals by UE implementations (e.g., pre-stored to memory for cross-correlation). We suggest removing architectures to make it general.***FL5-Higher-Proposal-11:****At least for LP-WUR ~~architectures~~ that cannot receive existing OFDMA-based NR signals for synchronization, at least periodic synchronization signal used by LP-WUR (LP-SS) is required. Study further*FFS: whether the support of receiving existing OFDMA-based NR signals can up to UE implementation | CATT |
| @HW, and chance you can except FFSes? Seems majority is fine to keep the last FFS@Intel: clarified that FFS is on type of encoding scheme.***FL5-Higher-Proposal-13:*** *Study further following alternatives to carry the LP-WUS information using:** *Alt 1: by sequence(s) selection*
	+ *FFS sequence type*
* *Alt 2: by encoded bits*
	+ *FFS: what type of encoding scheme*
	+ *FFS: with or without CRC/FCS*
* *FFS: LP-WUS need to be preceded by known one or more sequence(s).*
 | MTK, FW |  |  |
| @Below FFS from MTK, for FL OK to keep, but already not clear to Ericsson**FL5-Higher-Proposal-21a:*** *Study techniques/mechanisms to enhance coverage performance of LP-WUS, in case enhancement is deemed needed, focus at least on*
	+ *reducing payload size of LP-WUS*
	+ *power boosting*
	+ *time domain solutions: repetition in time, interleaving in time*
	+ *frequency domain solutions: repetition in frequency, frequency-hopping*
	+ *channel coding*
	+ *code domain solutions: CDM between LP-WUSs*
	+ *FFS: increased number of receive antennas*
	+ *FFS: improve synchronization by reusing the existing NR reference signal*
* *For above, study potential gains available as well as drawback(s) of the technique(s)/mechanisms(s), e.g. system overhead, increased complexity network energy consumption etc…*
* *Study potential issues and corresponding solutions for the case when LP-WUS is insufficient ~~would be designed with coverage smaller than the coverage of NR~~*
	+ *Study fallback mechanisms where the Main Radio switches to legacy operation in case the channel condition of are not sufficient, e.g. below threshold.*
 | MTK: For LPWUR only uses LPSS for synchronization, it is possible to further enhance by using the existing NR RS additionally.  | FW (- we do not see the relationship between synchronization improvement and coverage enhancement, - we understand that interleaving in time might be relevant only if channel coding is considered.) | CATT (coverage target defined first?) |
| FL: prefer not to discuss new added FFS in SID, moreover, we did not yet agree on LP-SS.***FL2-Higher-Proposal-16:*** * *It is recommended to define LP-WUS transmission occasion(s) with a periodicity, where a LP-WUS can ~~only~~ be transmitted by gNB only in those occasion(s) within each period.*
	+ *FFS: periodicity of configured occasion(s)*
	+ *FFS: granularity of starting location, e.g. symbol/slot*
	+ *~~FFS: monitoring conflict to periodic LPSS or SSB (PSS/SSS/PBCH)~~*
	+ *~~FFS: there is one or more corresponding transmission occasion within a periodicity for a UE~~*
 | MTK |  |  |
| FL: seems we need to progress more with other aspects first, proposal is dropped in RAN1#112b-e. We can use this as starting point in future. ***~~FL5-Lower-Proposal-17:~~*** * *~~Regarding procedures for MR, upon wake-up from ultra-deep-sleep~~****~~,~~*** *~~for~~**~~“Option 1: perform PO monitoring, and afterwards follow legacy procedures”, study whether a support of dynamic PO, i.e. PO outside of regular paging frame could reduce latency.~~*
* *~~FFS: Study whether the case where LP-WUS monitoring is configured together with PEI monitoring is beneficial to be supported.~~*
 |  |  |  |
| FL: I would drop this one in RAN1#112b-e. Next meeting companies could focus on whether any of these aspects should be still discussed in Study phase.***~~FL5-Lower-Proposal-18:~~*** *~~From RAN1 point of view, LP-WUS monitoring can be activated semi-statically and/or dynamically through MR.~~* * *~~FFS broadcast or UE-specific signalling~~*
* *~~FFS need for UE confirmation of gNB activation~~*
* *~~FFS activation by gNB based on UE request~~*
* *~~FFS: UE being able to autonomously decide whether to monitor PO or LP-WUS~~*
	+ *~~FFS: need for informing gNB about change of monitoring~~*
* *~~FFS: UE following criteria to determine whether PO or LP-WUS is monitored.~~*
* *~~FFS: need for informing gNB about change of monitoring~~*
 |  |  |  |