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.

|  |
| --- |
| * 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.
 |

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

# Final check

|  |  |  |  |
| --- | --- | --- | --- |
|  | **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 / to specify] 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, vivo | HW&HiSi: ‘*to additionally modulate*’ is not clear to us. Original version is clearer, where the intension is whether the sequence used for waveform generation is specified or not. So we suggest to change back to ‘*a need to specify input signal*’. Also as a compromise, we can live with PAPR with FFS. |  |
| @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)HW&HiSi: the FFS on LP-WUR does not make sense. Suggest to remove it. |  |
| 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.***FL5-Higher-Proposal-24: Update the FSK agreement from RAN1#112*****Agreement**For M-bit MC-FSK generation study further the following options* Option FSK-1: N SCs of LP-WUS are separated to M pairs of segments with potential guard-bands in-between and around.
	+ segment comprises one sub-carrier or multiple contiguous SCs
	+ in a pair of segments one segment is modulated, other segment is zero power (from base-band point of view)
* Option FSK-2: N SCs of LP-WUS are separated to 2^M segments with potential guard-bands in-between and around.
	+ segment comprises one sub-carrier or multiple contiguous SCs
	+ one segment from 2^M segments is modulated, other segments of SCs are zero power (from base-band point of view)
* M >0
* N >1
* ~~Study how to generate segment in time domain, e.g. OOK-1 or OOK-4~~
* Study FSK with segment in time domain using OOK-4
* Other options are not precluded.

Note: N SCs of LP-WUS can be modulated to generate 2^M segments at BB of LP-WUR after self-mixing envelope detection. |  | 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.vivo: Regarding P2-P6, we agree with FL not to update the last RAN1#112 agreement on waveforms.HW&HiSi: For P3/P4, whether it is possible to move one step further to update the agreement as ‘Study FSK with segment in time domain using OOK-4’ |  |
| 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 | vivo: support by deleting last sub-bullet HW&HiSi: we don’t know why only existing NR reference signal is considered here. We can make it more general by the changes in red ‘Synchronization and RRM performance ~~with the existing NR reference signal for each combination of waveform schemes and receivers~~’ |  |
| 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,vivo | HW&HiSi: we don’t know clearly how to evaluate ‘capability to support the agreed use cases’, so suggest to remove it, and see what companies bring to the next meeting. |  |
| @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 |  | CATTWe need to define the waveform generation for OOK-4 before studying CP |
| 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 and may impact performance of legacy UE due to spectral leakage..
 | MTK, FW (there is a typo in Alt2, may followed by will),vivo | HW&HiSi: changes in red ‘additional guard bands, and may impact performance of legacy UE due to spectral leakage.’ |  |
| 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, CATT |  | 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 / sequence based on LP-WUS-waveform ] (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?)vivo: we don’t agree with different priorities on serving cell and neighbor cell in terms of relaxation of RRM measurements in MR, but fine to discuss it further. We suggest the modification below, hope it will address intel’s concern***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*HW&HiSi: ‘*~~LP-WUS-waveform based~~ sequence based on LP-WUS-waveform (LP-SS)*’ | CATT (more progress on LP-WUS design needed) There are different levels of LP-WUR receiver sensitivities. We need to agree whether the LP-WUR would have same coverage as those of NR channels/signals first before discussing RRM aspects.  |
| 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) and/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 | vivo: minor modification on the last bullet* *Detection rate of always ON periodic reference signal(s) and/or LP-WUS*
	+ *FFS how to calculate/define detection rate*

HW&HiSi: prefer to keep FFS to LP-SINR and Detection rate since they are not use in legacy RRM measurement in IDLE/INACTIVE mode. And a small change ‘*~~LP-WUS-waveform based~~ sequence based on LP-WUS-waveform (LP-SS)*’ | CATTThe RSSI, RSRP, RSRQ, and SINR measurements would be defined when the waveform and LP-WUS or other LP-SS transmission are defined. All measurements also require time domain filtering to ensure the confidence of the statistic measure. |
| @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: whether the support of receiving existing OFDMA-based NR signals can up to UE implementation~~

*Note: LP-WUR for* OFDMA-based LP-WUS may also receive LP-SS.  | Vivo, HW | 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 | CATTThe characteristic of the LP-WUS and LP-SS waveform needs to be agreed for different LP-WUR architecture. |
| @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,vivo,HW&HiSi (if proposal 11 can be agreed, we can compromise to this although we do not think that this FFS is in its rightful place since we are studying about LP-WUS information and we already have Alt 1) |  |  |
| @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 LP-WUS is 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.)vivo: how coverage extension can benefit from synchronization improvement is not clear to us, suggest to delete the newly added FFS.Some wording suggestion for the last sub-bullet:* *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 LP-WUS is ~~are~~ not sufficient, e.g. below threshold.*

HW&HiSi: not sure why we need to mention ‘*improve synchronization*’, suggest to remove it. | 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~~*

***FL2-Higher-Proposal-16b: (would this wording address HW concern?)**** *It is recommended to define LP-WUS transmission occasion(s) with a periodicity, where a LP-WUS can be transmitted by gNB only in a occasion window within each period.*
	+ *FFS: periodicity of configured occasion window*
	+ *FFS: granularity of starting location of occasion window, e.g. symbol/slot*
	+ *FFS: defining fix position of occasion(s) in occassion window or not*

 | MTK,vivo | HW&HiSi: We would not agree to this, since with the wording change, the meaning is totally different from intension ‘**put continuous and duty cycle to a side**’. Original wording is ‘*can only be transmitted from the starting location of a LP-WUS occasion*’, which is defining occasion/slot for LP-WUS. But current wording is just how to configure duty-cycle. First, we suggest to change the main bullet back (in red) ‘*a LP-WUS can ~~only~~ be transmitted by gNB only from the starting location of an ~~in those~~ occasion~~(s)~~*’Second, we suggest the following to allow continuous monitoring ‘*FFS: periodicity of configured occasion(s), where the length of periodicity can be equal to or larger than the length of configured occasion(s)*’  |  |
| 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~~*
 |  |  |  |