

China Academy of Telecommunication Technology ■

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大唐电信集团 RP-233016

Views on Low-Power wakeup receiver

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Study of LP-WUR/WUS

- Study of low-power wakeup receiver (LP-WUR) and wakeup signals (LP-WUS) has been completed with results and observations captured in TR38.869
 - Evaluation methodologies
 - LP-WUR power model
 - MR ultra-deep sleep power model
 - Evaluation results
 - UE power saving
 - User perceived throughput (UPT)/Latency
 - Coverage
 - Network Overhead
 - Network Energy consumption
- Study of low-power wakeup receiver architectures
 - RF envelop detector
 - Heterodyne architecture with IF envelope detection
 - Homodyne/zero-IF architecture with baseband envelope detection
 - OFDM receiver
- L1 signal/channel design for LP-WUR
 - OOK, FSK, and OFDM waveform
 - Synchronization signals and mechanisms for LP-WUR
 - LP-WUS design and related procedures
 - UE behavior in monitoring LP-WUS
 - RRM measurements

Observations from LP-WUR Evaluations

- UE Power saving
 - RRC_IDLE/Inactive UEs
 - UE power saving gain up to more than 90% compared to the baseline I-DRX operation by using LP-WUS/WUR to trigger UE MR paging monitoring
 - Paging latency reduction and moderate UE power saving gain compared with eDRX
 - RRC_CONNECTED UEs
 - UE power saving gain up to more than 10% for XR
 - UE power saving gain more than 60% and UPT improvement more than 10% using LP-WUS for DRX adaptation for FTP and IM traffic
 - UE power saving gain more than 40% and similar UPT performance for always-ON PDCCH monitoring
- Coverage - LP-WUS can achieve comparable MIL performance with that of NR PUSCH MSG3
- Overhead –
 - For OFDM based LP-WUS carrying information of up to 24bits, the overhead up to 0.16% for 20MHz or 100MHz system BW
 - For OOK/FSK-2 based LP-WUS carrying information up to 24bit, the overhead is up to 4.4% for 20MHz
- Network Energy Consumptions
 - The increase of the network energy consumption caused by the addition of the LP-SS signal transmission with 320ms periodicity, 4 or 8 beams and no more than 14 symbols is (0.06%~3.9%), (0.07%~2.716%), (0.388%~1.076%) for zero load, low load and medium load respectively

LP-WUR architecture

- For OOK waveform,
 - For RF envelope detection,
 - Relative Power consumption for ON duration: 0.01 - 0.2
 - Noise figure: 12 - 22 dB
 - For heterodyne architecture,
 - Relative power consumption for ON state: 0.1 – 4.0
 - Noise figure: 9 - 15 dB.
 - For homodyne/zero-IF architecture,
 - Relative power consumption for ON state: 0.05 – 4.0
 - Noise figure: 10 - 16 dB.
- For FSK waveform- The LP-WUR architectures is based on parallel OOK receivers
 - For parallel heterodyne architecture,
 - Relative power consumption for ON state: 0.1 – 1.0
 - Noise figure: 9 - 15 dB.
 - For parallel homodyne/zero-IF architecture,
 - Relative power consumption for ON state: 0.1 – 1.0
 - Noise figure : 10~16 dB.
- For OFDMA-based signals,
 - For time-domain correlation,
 - Relative power consumption for ON state: 0.15~10/30
 - Noise figure: 7-25 dB
 - For frequency-domain correlation,
 - Relative power consumption for ON state: 1 - 30
 - Noise figure: 7 - 12 dB

LLS performance

- OFDM waveform
 - Coverage for LP-WUS with lower resource overhead.
 - Capable of reusing PSS/SSS as the RS for RRM measurement and
 - Robustness to Timing errors
 - can be further improved using sliding window at the receiver.
- OOK-1/OOK-4
 - High spectral efficiencies
 - Robustness to frequency error and timing error decreased
 - Can be improved to mitigate the effect of timing error by the sliding window or by pulse shaping filter in time domain. .
- FSK-2
 - spectral efficiencies varying with M
 - Robustness to frequency error and moderate timing error.
 - Can be further improved using frequency error correction (i.e., utilizing 2^M parallel receiver structure or frequency domain sliding window), larger guard band between segments at expense of less frequency diversity, and/or single frequency segment FSK2-envelope IF.
 - Timing error robustness can be further improved using sliding window or by pulse shaping in time domain.
 - Uniform distribution of frequency spectrum density can be achieved using single frequency segment FSK2-envelope IF which can provide robustness against frequency fading.
 - Sequences to generate ON duration in OFDMA transmitter, if specified, can help receiver (with I/Q branches) performance.

Discussion of Rel-19 LP-WUS Objectives

- Rel-19 LP-WUS work item objectives was discussed offline in RAN#101.
 - The main focus of the discussions are the waveform of LP-WUS and associated the LP-WUR
- Waveform Candidates of LP-WUS
 - OOK-1/OOK-4
 - OOK-1/OOK-4 modulated by OFDM as harmonized solution
 - Standalone OFDM
 - FSK modulated by OFDM
- In addition, the need of additional synchronization signals, e.g., LP-SS were discussed along with all LP-WUS waveform candidate.
 - SSB could be used by the standalone OFDM waveform of LP-WUS
 - The overhead of synchronization signals (LP-SS) needs to be minimized since they are periodic signals.
 - The periodicity of LP-SS needs to be limited to long duty cycle, e.g., 320 ms and larger, in minimizing the overhead

Summary of Rel-19 Objectives Discussion in RAN#101 in RP-232616

Only Q1 and Q2 are discussed, 4 directions are identified. And also the number of supporting companies are listed. In order to facilitate scoping the WI, moderator suggests to choose one of the direction for further discussion.

- Direction 1 (Number of supporting companies:13):
 - Waveform-option-1: OOK-1 and/or OOK-4, as described in section 7.2.1.1 (A)(D) in TR38.869.
 - Waveform-option-3: Harmonized design that accommodates OOK-1/OOK-4 and OFDM waveform, i.e., specified overlaid OFDM sequences over OOK symbol
 - For RRC IDLE/INACTIVE, in addition to existing PSS/SSS, LP-SS (, i.e., OOK-1 and/or OOK-4 waveform with/without overlaid OFDM sequences with potential further down selection in WI phase) for LP-WUR that cannot receive existing PSS/SSS, is supported for synchronization and/or RRM for serving cell.
- Direction 2 (Number of supporting companies:13):
 - Waveform-option-3: Harmonized design that accommodates OOK-1/OOK-4 and OFDM waveform, i.e., specified overlaid OFDM sequences over OOK symbol
 - For RRC IDLE/INACTIVE, in addition to existing PSS/SSS, LP-SS (, i.e., OOK-1 and/or OOK-4 waveform with/without overlaid OFDM sequences with potential further down selection in WI phase) for LP-WUR that cannot receive existing PSS/SSS, is supported for synchronization and/or RRM for serving cell.
- Direction 3(Number of supporting companies:2)
 - Waveform-option-3: Harmonized design that accommodates OOK-1/OOK-4 and OFDM waveform, i.e., specified overlaid OFDM sequences over OOK symbol
 - Waveform-option-2: standalone OFDM-based sequences,
 - For RRC IDLE/INACTIVE, in addition to existing PSS/SSS, LP-SS (, i.e., OOK-1 and/or OOK-4 waveform with/without overlaid OFDM sequences with potential further down selection in WI phase) for LP-WUR that cannot receive existing PSS/SSS, is supported for synchronization and/or RRM for serving cell.
- Direction 4(Number of supporting companies:2)
 - Waveform-option-5: Harmonized design that accommodates FSK-2 and OFDM waveform
 - For RRC IDLE/INACTIVE, in addition to existing PSS/SSS, LP-SS (, i.e., OOK-1 and/or OOK-4 waveform with/without overlaid OFDM sequences with potential further down selection in WI phase) for LP-WUR that cannot receive existing PSS/SSS, is supported for synchronization and/or RRM for serving cell.

LP-WUS/WUR WI by RAN Chair in RP-232645

- References: [RWS-230488](#), [RP-231540](#), [RP-232616](#)
- Potential objectives:
 - Waveform & LP-SS support
 - Waveform-option-1 + waveform-point-3, or waveform-point-3 only → **Further downselection**
 - Waveform-option-1: OOK-1 and/or OOK-4, as described in section 7.2.1.1 (A)(D) in TR38.869.
 - Waveform-option-3: Harmonized design that accommodates OOK-1/OOK-4 and OFDM waveform, i.e., specified overlaid OFDM sequences over OOK symbol
 - For RRC IDLE/INACTIVE, in addition to existing PSS/SSS, LP-SS (, i.e., OOK-1 and/or OOK-4 waveform with/without overlaid OFDM sequences with potential further down selection in WI phase) for LP-WUR that cannot receive existing PSS/SSS, is supported for synchronization and/or RRM for serving cell.
- For IDLE/INACTIVE operation, specify
 - UE serving cell RRM measurement offloaded from MR to LR
 - Further time domain relaxation (at least X times) of UE MR RRM measurement for both serving and neighbor cell measurement
 - X to be determined in the WI phase
- Note: For CONNECTED mode, UE RRM/RLM/BFD/CSI measurements are performed by MR
- To specify an LP-WUS design commonly applicable to both IDLE/INACTIVE and CONNECTED modes
- For IDLE/INACTIVE mode, to specify procedures to allow UE MR paging monitoring triggered by LP-WUS
- For CONNECTED mode, to specify procedures to allow UE MR PDCCH monitoring triggered by LP-WUS
- At least duty-cycled monitoring for LP-WUS is supported
- Note: LP-WUS shall be able to reach at least the coverage of PUSCH for message3

Proposals for Rel-19 LP-WUR WI Objectives

- **Specify the signals and waveforms for the UE low-power wakeup receiver (LP-WUR) in achieving further UE power saving for CONNECTED and IDLE/Inactive UEs (RAN1)**
 - Specify the OOK-1/OOK-4 waveform modulated by OFDM of the low-power wakeup signals (LP-WUS)
 - Specify the information carried by LP-WUS
 - The physical layer procedure of UE monitoring of LP-WUS
 - Specify the OOK-1 waveform without overlaid OFDM sequences with for LP-SS.
- **Specify the LP-WUS signals/procedure for UE LP-WUR of IDLE/Inactive and CONNECD mode UEs in achieving UE power saving (RAN1, RAN2)**
 - Specify the LP-WUS as the early paging indication for IDLE/Inactive mode UEs
 - Specify the LP-WUS as wakeup indication for PDCCH monitoring with/without C-DRX configuration for CONNECTED mode UEs
 - Study and specify whether LP-WUS is used for UE mobility management
- **Architecture and Higher Layer Procedure enhancement for LP-WUR [RAN2, RAN3]**
 - Configuration and procedure of LP-WUS signals
 - MAC procedure in supporting wakeup indication by LP-WUS
 - UE behavior of receiving LP-WUS
- **Performance of low-power wakeup receiver [RAN4]**
 - Specify the minimum performance of LP-WUR
 - Specify the ACL of LP-WUS while it is transmitted with NR signals/channel in the same carrier

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