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Discussion of R19 Work on LP-WUS/LP-WUR

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Outline

- LP-WUS SI Conclusion
- Details and views on SI outcomes
  - Receiver Architectures
  - KPIs Evaluation & LP-WUS Design
  - RRM Measurements by LP-WUR
  - Procedures and Higher Layer Protocol
- Proposed Rel-19 LP-WUS WI Scope

LP-WUS SI Conclusion

Based on RAN1 completed study, the following SI objectives are addressed.

- **Objective 1**: use cases are identified, evaluation methodologies are developed, and KPIs are defined
  - Power sensitive devices including IoT, wearable and eMBB use cases for both RRC Idle/Inactive and Connected.
  - UE KPIs including power consumption, coverage, latency and UPT.
  - System KPIs including overhead, system capacity for XR traffic, and network energy consumption.
- **Objective 2**: LP-WUR architectures are identified and analyzed.
- **Objective 3**: LP-WUS waveforms are evaluated, and subset of the options (OOK-1/4,FSK-2, OFDMA) are recommended for further down-selection, if any.
- **Objective 4**: baseline L1 procedures are identified, and higher layer protocol changes are discussed/evaluated.
  - Activation/deactivation of LP-WUS monitoring, fallback to legacy, and LP-WUS functionality
  - RRM measurement relaxation for MR and/or offloading to LP-WUR
- **Objective 5**: LP-WUS KPIs are evaluated
  - Power saving gain: significant with sufficient relaxation to MR RRM measurements in RRC Idle/Inactive, and moderate/significant for XR, FTP, or IM traffic in RRC Connected.
  - Paging latency: moderate increase, with MR ramp up from ultra-deep sleep, but potential latency reduction techniques are proposed and evaluated.
  - Coverage: NR PUSCH Msg3 MIL performance is achievable but NR PDCCH AL8/AL16 MIL is challenging
  - Network overhead:
    - Resource: can be marginal for OOK/FSK-2 based LP-WUS carrying up to 24 bits with NR PUSCH Msg3 comparable coverage.
    - Power consumption: marginal especially when LP-SS is transmitted FDM with NR SSB/SIB-1

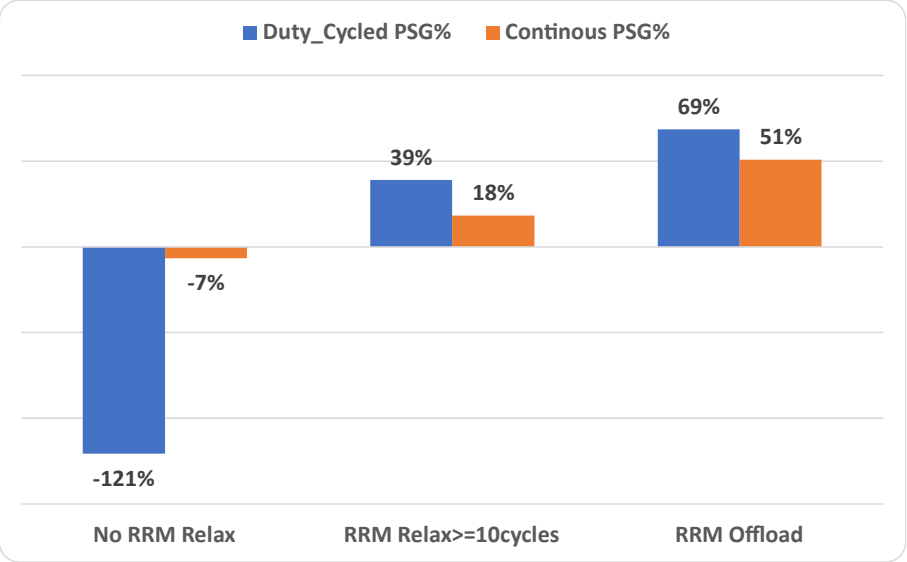
Proposal 1: Sufficient study has been completed addressing SI objectives, feasibility is concluded, and therefore normative work on LP-WUS can commence.

Receiver Architectures

- LP-WUR architectures are identified/analyzed to facilitate the design and evaluation of LP-WUS without mandating any specific implementation.
  - Envelope detection (ED)-based architectures (single/parallel)
    - Architectures with RF ED:
      - provide lowest power consumption at expense of limited support of multi-band operation.
    - Heterodyne/homodyne architecture with IF/BB ED:
      - provide better selectivity and multi-band operation support at slightly higher power consumption.
  - Architectures for OFDMA-based signals
    - Provide better detection performance than ED-based architectures at higher power consumption
    - Reduction in power consumption compared to main radio (MR) can be achieved using:
      - Lower performance LNA/amplifier
      - Relaxed requirements on Oscillator/PLL/ADC
      - Reduced BB processing, e.g., time domain sequence correlation without FFT
- In addition to LP-WUS detection, LP-WUR may support synchronization signal processing and RRM measurements (at least for serving cell).

KPIs Evaluation: Power Saving and Latency

- It is agreed in LP-WUS SI to consider IoT/wearables and eMBB use cases in both RRC Idle/Inactive and Connected states
- Power Saving Gain (PSG) [1]
  - Duty-Cycled Monitoring
    - LP-WUR "ON" power <= 10 units:
    - PSG>= 39% with RRM measurement relaxation
  - Continuous Monitoring
    - LP-WUR "ON" power <= 1 unit:
    - PSG>= 18% with RRM measurement relaxation
  - RRM measurement offloading to LP-WUR can result in average PSG of 69% and 51% for duty-cycled and continuous monitoring



- LP-WUS with dynamic PO configuration can reduce latency compared to legacy iDRX/eDRX while providing power saving gain.

Observation 1: with sufficient MR RRM measurement relaxation, significant PSG can be achieved even with continuous monitoring but requires LP-WUR's ON power consumption <= 1 unit.

LP-WUS/LP-SS Design: Waveforms

- Waveform options agreed for LP-WUS are based on
  - MC-ASK and MC-FSK waveforms which can be generated using the OFDM generator with no/limited impact on gNB complexity and received by very low power WURs.
  - OFDMA-based signals, e.g., PSS/SSS, which can improve coverage and spectral efficiency but require higher complexity and/or power WURs.
- A new synchronization signal (LP-SS) based on MC-ASK/MC-FSK can assist in time/frequency synchronization and measurement offloading to LP-WURs.

<table>
<tr><th colspan="2">MC-ASK</th><th colspan="2">MC-FSK</th><th>OFDMA-based</th></tr>
<tr><td>OOK-1</td><td>Single OOK bit/pulse per OFDM symbol, data rate support constrained by SCS</td><td>FSK-2</td><td>2^M frequency segments carry M FSK modulated bits, generation complexity comparable to OOK-1, requires parallel receiver but enables frequency error estimation, symbol length independent of data rate tolerating high timing errors</td><td rowspan="2">Sequence based signal design/detection limiting payload size and forward compatibility, requires I/Q receiver and frequency error compensation impacting power consumption.</td></tr>
<tr><td>OOK-4</td><td>M OOK bit/pulse per OFDM symbol (flexible rate support), requires DFT (memory storage possible), shorter symbol length at higher data rate impacts tolerance to timing error</td><td>Note</td><td>Envelope intermediate frequencies (IFs) design can generate the 2^M segments of FSK-2 in the envelope of the LP-WUR's received signal (no need for parallel receiver)</td></tr>
</table>

Proposal 2: Consider OOK-4 for flexible data rate adjustment, FSK-2 for robustness against timing error and frequency error estimation capability, and overlayed OFDM sequences for better coverage when needed to limit impact on power saving gain.

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LP-WUS/LP-SS Design: Structure and Content

- Two alternative structures for carrying LP-WUS information
  - Sequence, however, the increase in payload size can increase LP-WUR complexity
  - Encoded bits which can be accompanied by a frame check sequence (FCS), e.g., CRC.
- The following information are agreed for LP-WUS content
  - Information on targeted user(s) in RRC Idle/Inactive/connected state
  - Indication to wake-up for PDCCH monitoring in RRC connected
- Other information on cell ID, system information change, and ETWS/CMAS can be included in LP-SS/LP-WUS.

[1] R1-2306428, Evaluation of LP-WUS and Performance Results

KPIs Evaluation: Coverage and Overhead

- Design targets for LP-WUS/LP-SS coverage can be
  - Option 1: PUSCH Msg3
  - Option 2: PDCCH for paging
- LP-WUS/LP-SS can achieve better coverage than PUSCH Msg3 [1]
  - LP-WUS: 16 information + 8 CRC bits using OOK-4 (M=2) over 5 MHz and 24 OFDM symbols.
  - LP-SS: 32-bit sequence using OOK-4 (M=8) over 5 MHz and 4 OFDM symbols.
- Coverage enhancement techniques can be used to match PDCCH coverage using, e.g.,
  - Payload reduction, power boosting, transmit diversity (cyclic precoding), time domain repetition, and frequency hopping.
- LP-WUS/LP-SS can be supported for IoT use cases in urban deployments with coverage exceeding that of PUSCH Msg3 at a resource overhead <1.9% [1]

System Bandwidth	20 MHz		100 MHz	
Number of Beams	4	8	4	8
LP-SS Periodicity				
320 ms	0.0450%	0.0900%	0.0090%	0.0180%
640 ms	0.0225%	0.0450%	0.0045%	0.0090%
1280 ms	0.0113%	0.0225%	0.0023%	0.0045%
2560 ms	0.0056%	0.0113%	0.0011%	0.0023%
5120 ms	0.0028%	0.0056%	0.0006%	0.0011%
10240 ms	0.0014%	0.0028%	0.0003%	0.0006%

Resource overhead for LP-SS [1]

System Bandwidth		20 MHz		100 MHz	
Number of Beams		4	8	4	8
Waveform	Traffic Model				
LP-WUS-1	Model-1	0.8660%	1.7321%	0.1732%	0.3464%
	Model-2	0.0722%	0.1443%	0.0144%	0.0289%
LP-WUS-2	Model-1	0.4330%	0.8660%	0.0866%	0.1732%
	Model-2	0.0361%	0.0722%	0.0072%	0.0144%
	Model-1: 1 message/2 hours/device **Model-2:** 1 message/day/device **LP-WUS-1**: Waveform Option OOK-4 with M=2 **LP-WUS-2**: Waveform Option FSK-2 with M=2				

Resource overhead for LP-WUS considering 10^6 devices/km2 connection density [1]

Proposal 3: NR PUSCH Msg3 is the LP-WUS coverage target without enhancements.

RRM Measurement by LP-WUR

- LP-WUS power saving can only be achieved with MR's RRM measurement relaxation
  - LP-WUR can be used to assist in RRM measurements
- LP-WUS can provide high power saving gains if RRM measurements are offloaded to LP-WURs, at least for the serving cell.
- The following measurement metrics are agreed for LP-WUR:
  - LP-RSSI
  - LP-RSRP
  - LP-SINR
  - LP-RSRQ
- An OOK-based LP-SS (4 OFDM symbols) can achieve an LP-RSRP measurement accuracy of ± 2.5 dB at 90th-percentile and -3dB SNR.[1]

Proposal 4: Support relaxation of MR RRM measurements and/or RRM measurement offloading to LP-WUR, at least for serving cell.

Procedures and Higher Layer Protocol

- UE can perform any of the following procedures upon LP-WUS detection
  - In RRC Idle/Inactive
    - Legacy PO monitoring: LP-WUS monitoring can be transparent but can increase paging latency
    - Dynamic PO monitoring: Paging latency can be reduced but LP-WUS monitoring is non-transparent
    - RACH procedure initiation: Paging latency can be reduced but may require large LP-WUS payload
  - In RRC Connected
    - PDCCH monitoring
- LP-WUS monitoring activation/deactivation can be
  - Based on UE implementation or preconfigured criteria if gNB transmits both legacy paging indication and LP-WUS
  - Based on signaling if gNB **does not** transmit legacy paging indication with LP-WUS
- UE may fall back to legacy operation in case LP-WUS channel condition is not sufficient.

Proposal 5: Support at least legacy/dynamic PO monitoring in RRC Idle/Inactive and PDCCH monitoring in RRC connected as functionality upon LP-WUS detection.

Proposed Rel-19 LP-WUS WI Scope

- Specify a design for LP-WUS/LP-SS (RAN1)
  - Structure and waveform based on at least MC-OOK (e.g., OOK-4) and/or FSK-2 which may be overlayed by OFDM-based signals
  - Coverage at least matches PUSCH msg3 without enhancements
  - Limited to no impact on gNB implementation complexity
- Specify LP-WUS related procedures in RRC Idle/Inactive and Connected (RAN1,RAN2)
  - LP-WUS monitoring activation and deactivation, and fallback to legacy operation
  - UE procedures upon detection of LP-WUS
    - At least legacy and/or dynamic PO monitoring in RRC Idle/Inactive
    - At least PDCCH monitoring in RRC Connected
- Specify RRM measurement relaxation and/or offloading to LP-WUR, based on LP-SS and/or PSS/SSS, at least for serving cell (RAN4,RAN2)
- UE RF core and RRM performance requirements (RAN4)

Thank You.

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