3GPP TSG RAN WG1#112bis-e R1-230XXXX

**e-Meeting, April 17th – April 26th, 2023**

Source: Moderator (vivo)

Title: FL Summary #1 of evaluation results on LP-WUS/WUR

Agenda Item: 9.11.1

Document for: Discussion and Decision

# Introduction

This document summarizes the evaluation results [1 - 19] for AI 9.11.1 and email discussions.

The issues in this document are tagged and color coded with [H] or [M].

# Template for evaluation results

Many companies submitted their simulation results according to the assumptions made in RAN1#111. Moderator recommends to work on a template to collect the results during this meeting. Including

* Collecting results for power, latency, overhead, capacity and etc.
* Collecting results for link budget for LP-WUS and NR channel (for comparison purpose)

<https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_112/Inbox/drafts/9.13(FS_NR_LPWUS)/9.13.1/results%20collecting>

# Evaluation Results

## Plans

FL recommends the following plans for consolidating the results for each company.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Provide comments to the structure of consolidation** | **provide comments to companies' results** | **Update simulation results if needed** |
| **Week 1 (April 25-29)** | 1st round | 1st round | Y |
| **Week2 (May 2-6)** | 1st round | 1st round | Y |
| **Week3 (May 9 -13)** |  |  | Y |
| **Week4 (May 16 - 20)** | 2nd round | 2nd round | Y |
| **RAN1 WG Meeting (May 23 - 27)** | Discussion on observations | | |

## Consolidation of the power and latency evaluation

***<Editors’ Note: The following figures are draft version, it may be updated according to companies’ input. Some of the results may not be presented in the figure which may be due to, e.g., difficulties to calculate/consolidate the values or wrong placement of the results. It may be added later.>***

[Q]: For section 3.2, do you have any general comments regarding the **structure of the consolidation** of the results, e.g., adding or removing any sub-section/figures, how to filtering and categorizing the results

|  |  |
| --- | --- |
| ***Companies*** | ***Comments*** |
| MTK1 | * To point out a need for RRM offloading and RRM relaxation, the results of RRM measurement performed by MR should be provided. * To point out a need for LP-SS, the resluts of duty cycle given larger power consumption values such as 1/2/4/10/30 should be provided. |
| Company A |  |
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### RRC IDLE/INACTIVE mode

#### Duty cycled LP-WUS

Comparing Duty cycled LP-WUS and I-DRX as baseline

##### Collection of the results

FAR=1%, LP-WUR on state power <=20unit, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

**Figure 1-1. XXX**

**Figure 1-2. XXX**

*Note1: XX company assumes latency is not paging latency... latency is calculate to the end of sync/resync.*

*Note2: XXXXX*

*Note3: XXXXX*

*<Editor Note: Do we need to capture the results for FAR > wake-up arrival rate?>*

FAR=0.1%, LP-WUR on state power <=20unit, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

*Note1: Nokia provides results assuming FAR is 0.001%*

*Note2: XXX*

*Note3: XXX*

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
|  |  |  |  |
|  |  |  |  |

##### Observations

###### General Observations

The following observations are made,

* Compared with i-DRX with and without PEI, LP-WUS provide power saving gain (XX%-XX%)
* Compared with i-DRX with and without PEI paging latency (YY-YY) second, LP-WUS will result in paging latency (ZZ-ZZ) second

#### Continuous monitoring LP-WUS

Continuous monitoring LP-WUS comparing with I-DRX as baseline

##### Collection of the results

FAR=1%, LP-WUR on state power <=0.1unit , no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

FAR=1%, LP-WUR on state power >0.1unit, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

FAR=0.1%, LP-WUR on state power <=0.1unit, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

*Note1: Nokia provides results assuming FAR is 0.001%*

FAR=0.1%, LP-WUR on state power >0.1unit, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

FAR=0%, LP-WUR on state power <=0.1unit, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

FAR=0%, LP-WUR on state power >0.1unit, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company X** |  |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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|  |  |  |  |

##### Observations

###### General Observations

The following observations are made,

With WUR power setting less than 0.1,

* Compared with i-DRX with and without PEI, LP-WUS provide power saving gain (XX%-XX%)
* Compared with i-DRX with and without PEI paging latency (YY-YY) second, LP-WUS will result in paging latency (ZZ-ZZ) second

With WUR power setting no less than 0.1,

* Compared with i-DRX with and without PEI, LP-WUS provide power saving gain (XX%-XX%)
* Compared with i-DRX with and without PEI paging latency (YY-YY) second, LP-WUS will result in paging latency (ZZ-ZZ) second

#### Various LP-WUR “ON” state relative power

Comparing various relative power of LP-WUR “ON” state and I-DRX as baseline

##### Collection of the results

0.1%<wake-up arrival rate <=1% , FAR=1%, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

wake-up arrival rate <=0.1% , FAR=0.1%, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company X** |  |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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|  |  |  |  |

##### Observations

###### General Observations

When 0.1%<wake-up arrival rate <=1% (FAR=1%),

* The power saving gain according to different WUR ON power setting is as follows,
  + (?, 1] unit, power saving gain (XX-XX%)
  + (1, 4] unit, power saving gain (XX-XX%)
  + (4, ?] unit, power saving gain (XX-XX%)

When wake-up arrival rate <=0.1% (FAR=0.1%),

* The power saving gain according to different WUR ON power setting is as follows,
  + (?, 1] unit, power saving gain (XX-XX%)
  + (1, 4] unit, power saving gain (XX-XX%)
  + (4, ?] unit, power saving gain (XX-XX%)

#### eDRX

Comparing Duty cycled LP-WUS and eDRX as baseline

##### Collection of the results

FAR=1%, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

FAR=0%, LP-WUR duty cycle ratio <=1%, no RRM measurement performed by MR or MR RRM relaxed at least 8 times of I-DRX cycle, MR in ultra-deep sleep

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company X** |  |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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|  |  |  |  |

##### Observations

###### General Observations

* LP-WUS provide power saving gain (XX%-XX%) compared with e-DRX.
* LP-WUS can reduce the paging latency by (XX-XX) second compared with e-DRX.

#### RRM

**Measurement performed by MR only and MR RRM relaxed X times and RRM offload to LR**

##### Collection of the results

0.1%<wake-up arrival rate <=1% , LP-WUR duty cycle ratio <=2%, MR in ultra-deep sleep, LP-WUR on state power <=4unit, baseline: I-DRX

wake-up arrival rate <=0.1% , LP-WUR duty cycle ratio <=2%, MR in ultra-deep sleep, LP-WUR on state power <=4unit, baseline: I-DRX

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company X** |  |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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##### Observations

###### General Observations

Compared with i-DRX, LP-WUS operation with

* MR RRM relaxation for X1 times can provide power saving gain (XX-XX%)
* MR RRM relaxation for X2 times can provide power saving gain (XX-XX%)
* MR RRM offload to LR can provide power saving gain (XX-XX%)

### RRC CONNECTED mode

*<Note: will provide after consolidating the excel sheet results>*

#### XR traffic model

Description of the schemes are as follows,

* Always on: i.e., UE is always available for gNB scheduling
* R17 Scheme i.e., R17 PDCCH skipping and/or R17 SSSG switching
* LP-WUS with MR enters micro/light/deep sleep: i.e., LP-WUS trigger MR to wake up from micro/light/deep sleep.

##### Collection of the results

*Note: the assumed WUR ON power is no more than 1 unit by all the companies.*

*Note: the figures show the average values.*

*Note: the figures show the average values.*

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
|  |  |  |  |
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##### Observations

###### General Observations

For low load XR traffic,

* R17 scheme compared with baseline (Always on) provide power saving gain (XX-XX%) and capacity (YY-YY%)
* LP-WUS compared with baseline (Always on) provide
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up

For high load XR traffic,

* R17 scheme compared with baseline (Always on) provide power saving gain (XX-XX%) and capacity (YY-YY%)
* LP-WUS compared with baseline (Always on) provide
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and capacity (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up

###### Details

*<Editor’s Note: Rapporteur will summarize it according to the results collected >*

See Annex 2

#### FTP 3 model

Description of the schemes are as follows,

* Always on: i.e., UE is always available for gNB scheduling
* R16 Scheme i.e., C-DRX + DCI2\_6
* R17 Scheme i.e., C+DRX + DCI2\_6 + R17 PDCCH monitoring adaptation
* LP-WUS with MR enters micro/light/deep sleep: i.e., LP-WUS trigger MR to wake up from micro/light/deep sleep.

##### Collection of the results

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

|  |  |
| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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|  |  |  |  |

##### Observations

###### General Observations

When WUR ON power setting is **NO** more than 1 unit,

* LP-WUS compared with R17 scheme provide
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up
* LP-WUS compared with R16 scheme provide
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up

When WUR ON power setting is more than 1 unit,

* LP-WUS compared with R17 scheme provide
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up
* LP-WUS compared with R16 scheme provide
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from micro-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from light-sleep when WUS indicate to wake-up
  + power saving gain (XX-XX%) and UPT gain (YY-YY%) when MR is assumed from deep-sleep when WUS indicate to wake-up

###### Details

*<Editor’s Note: Rapporteur will summarize it according to the results collected >*

*See Annex 3*

## Consolidation of coverage evaluation

*<Note: will provide after consolidating the excel sheet results>*

### Collection of the results

*<Editor’s Note: Waiting for more input for the excel sheet and provide figures>*

*<Placeholder: Figures >*

|  |  |
| --- | --- |
| Sources | Link Budget Results |
| Huawei | In Table 1, we provide the MIL results for some scenarios based on the link results in our companion paper [4], where no FEC, no power boosting, no special handling to obtain larger time/frequency/space domain diversity is assumed. In these simulations, the following are considered if not extra mentioned.   * The data rate is the fixed to be 56 kbps, i.e. 2-bit per OFDM symbol for 30 kHz SCS. * The total time/frequency resources are the same, where the BW is 4 RBs, and the transmission time for a LP-WUS is 24 OFDM symbols. * The total energy across the total time/frequency resources are the same. * There are some mis-alignment of FAR target per trial. This is because OOK and FSK performance is based on Manchester encoding, which has a very low FAR value (<10-15). For other simulations, the FAR target per attempt or accumulated within a DRX are directly set to determine the corresponding threshold.   **Table 1 MIL of LP-WUS for different modulation and different condition**   |  |  |  |  | | --- | --- | --- | --- | | **Modulation type** | **Condition** | **MIL** | **Note** | | OOK-2 | Te=0us, Fe=0ppm | 130.68 | FAR for one trial: <10-15, BW = 4RB | | Te=2us, Fe=0ppm | 130.18 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=10ppm | 130.08 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=0ppm | 137.68 | FAR for one trial: <10-15, BW = 12RB | | OOK-4 | Te=0us, Fe=0ppm | 135.48 | FAR for one trial: <10-15, BW = 4RB | | Te=2us, Fe=0ppm | 130.68 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=10ppm | 135.48 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=0ppm | 141.58 | FAR for one trial: <10-15, BW = 12RB | | Te=0us, Fe=0ppm | 135.98 | FAR for one trial: <10-15, concentrated waveform, BW = 4RB | | Te=2us, Fe=0ppm | 133.82 | FAR for one trial: <10-15, concentrated waveform, BW = 4RB | | FSK-1 | Te=0us, Fe=0ppm | 130.48 | FAR for one trial: <10-15, BW = 4RB | | Te=2us, Fe=0ppm | 129.68 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=10ppm | 130.28 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=0ppm | 137.58 | FAR for one trial: <10-15, BW = 12RB | | FSK-2 | Te=0us, Fe=0ppm | 133.28 | FAR for one trial: <10-15, BW = 4RB | | Te=2us, Fe=0ppm | 132.78 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=10ppm | 132.98 | FAR for one trial: <10-15, BW = 4RB | | Te=0us, Fe=0ppm | 140.38 | FAR for one trial: <10-15, BW = 12RB | | Sequence detection of LP-WUS | Te=0us, Fe=0ppm | 145.43 | FAR for one trial: ~10-3，which can correspond to duty-mode monitoring, BW = 4RB | | Te=1us, Fe=0ppm | 143.40 | FAR for one trial: ~10-3，which can correspond to duty-mode monitoring, BW = 4RB | | Te=0us, Fe=10ppm | 144.48 | FAR for one trial: ~10-3，which can correspond to duty-mode monitoring, BW = 4RB | | Te=0us, Fe=0ppm | 143.57 | FAR for one trial: ~10-7 which corresponds to an accumulated FAR of 10-3 for continiously monintoring per each 1.28s DRX cycle, BW = 4RB | | Te=0us, Fe=0ppm | 148.63 | FAR for one trial: ~10-3，which can correspond to duty-mode monitoring, BW = 10RB | | Te=0us, Fe=0ppm | 147.22 | FAR for one trial: ~10-7 which corresponds to an accumulated FAR of 10-3 for continiously monintoring per each 1.28s DRX cycle, BW = 10RB |  1. **LP-WUS can reach the same coverage level as legacy PUSCH with certain configurations, e.g. LP-WUS bandwidth.** 2. **If further enhancements are used, such as power boosting, FEC, and time/frequency/space diversity, the coverage performance of LP-WUS can be further improved.** |
| OPPO | **Table 8: Simulation assumptions for LP-WUS**   |  |  | | --- | --- | | **Attributes** | **Assumptions** | | Carrier Frequency | 2.6GHz/700MHz | | Waveform | OOK-1: Single-bit in 1 OFDM symbol, SCs of LP-WUS are   * OOK=1 means all SCs are modulated * OOK=0 means all SCs are zero power (from base-band point of view) | | Channel structure | Payload(32bits)+CRC(8bits) | | SCS of OFDM generator for NR signal | 15KHz | | Configuration for  LP-WUS signal | For OOK waveform   * Option 1a: M=1 and SCSs = 15kHz (same as NR signal) | | WUS duration | Number of OFDM symbols: 1\*40\*2 = 80 | | Code scheme | Manchester code and the code rate (e.g., 1/2) | | gNB Channel BW | 20MHz | | LP-WUS BW | * 5MHz including subcarriers for guard band * 4.32MHz (i.e.,24 RBs) for LP-WUS transmission for 15kHz SCS   GB is symmetrically placed on each side of LP-WUS | | Adjacent subcarrier interference | * PDSCH mapped on resources other than that for WUS and guard band;   EPRE of LP-WUS / EPRE of PDSCH =ρ, where ρ=0 dB | | ADC bit width | 1-bit |   **Table 9: Coverage performance for LP-WUS and legacy NR signals**   |  |  |  |  | | --- | --- | --- | --- | |  | PDCCH AL8 | PUSCH | LP-WUS | | Urban (2.6GHz) | 151.33 dB | 137.38 dB | 137.40 | | Rural 700MHz | 150.42 dB | 141.67 dB | 139.10 |   ***Observation 9:*** *The coverage performance of LP-WUS of OOK-1 is worse than PDCCH and could be comparable to PUSCH.* |
| Intel | **Table 5: Simulation assumptions**   |  |  | | --- | --- | | **Attributes** | **Assumptions** | | Carrier frequency | 2.6GHz | | Channel structure | Preamble + message | | Coding scheme | Manchester coding 1/2,1/4, 1/8 | | Waveform | OOK-4 | | Payload size | 4 information bits (no CRC) | | WUS waveform | OOK-1, OOK-4 | | SCS | OOK-1: 160/20/240kHz  OOK-4: 15/30kHz | | gNB Channel BW | 20MHz | | WUS Bandwidth | 12/10/8/4 PRBs with SCS 30kHz  24 PRB for SCS 15kHz  3/6/12 PRBs for SCS 60/120/240kHz | | Guard band | 1 PRB on each side of LP-WUS BW | | Adjacent subcarrier interference | Signal to interference power ratio 0/3/6 dB | | Filter | 5th order Butterworth LP filter | | Sampling Rate | Down-sampling factor 8, i.e., 3.84MHz | | Frequency error/drifts | 0/20/100/200 ppm | | ADC | 1/2/4, ideal | | Channel Model | TDL-C 300ns | | Number of Rx for LP-WUS | 1 Rx | | UE speed | 3 km/h |   **Table 3: Link budget MIL**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | **System configuration** | **Common PDCCH** | | **PUSCH (1Mbps)** | **LP-WUS** | | Carrier frequency (GHz) | 2.6 | | | | | Pathloss model | TDL-C, 300ns | | | | | UE speed (km/h) | 3 | | | | | Number of transmit chains | 4 | 4 | 1 | 4 | | Number of receive antennas | 2 | 1 | 4 | 1 | | PSD | 33 | 33 |  | 33 | | Occupied BW (PRB) | 48 | 48 | 10 | 12 | | Transmit power for occupied BW | 45.38 | 45.38 | 23 | 39.35 | | Data channel EIRP | 62.86 | 62.86 | 22 | 56.84 | | Receiver noise figure (dB) | 7.00 | 7.00 | 5.00 | 15.00 | | Required SNR (dB) | -8.3 | -4.50 | -5.25 | -3.5 – 6 | | Receiver sensitivity | -97.12 | -93.32 | -99.61 | -93.95 | | Link budget (MIL) | 162.78 | 158.98 | 140.35 | 149.98 - 140.48 |   From the above calculation, MIL for LP-WUS can be better than PUSCH. However, there is a big gap between the MIL for LP-WUS and common PDCCH with one or two Rx. Note: the MIL of unicast PUSCH largely depends on the assumed data rate for the UL traffic in coverage or RedCap study.  **Observation 4:**   * A preliminary calculation shows that the MIL for LP-WUS can be better than PUSCH but is much worse than common PDCCH. |
| Nokia | **Table 11. Summary of MIL for different scenarios and channels**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Scenario | Physical channel | MIL [dB] for different receiver assumptions | | | | 1RX (RedCap) device | 2RX (RedCap) device | 4RX device | | Rural, 700MHz | PDCCH- AL16 | 149,5 | 151,7 | -1 | | PDCCH- AL8 | 145,5 | 149,7 | -1 | | PDSCH | 148,15 | 150,7 | *-*1 | | PUSCH | 134,6 | | 138,97 | | Urban, 2.6GHz | PDCCH AL-16 | 156,6 | 159,9 | 166,27 | | PDCCH AL-8 | 153,2 | 157,7 | 164,28 | | PDSCH | 151,0 | 154,4 | 161,0 | | PUSCH | 134,6 | | 137,6 | | Urban, 4GHz | PDCCH- AL16 | 156,6 | 159,9 | 165,74 | | PDCCH- AL8 | 153,2 | 157,8 | 163,63 | | PDSCH | 149,0 | 152,8 | 159,5 | | PUSCH | 132,5 | | 135,2 | | Note 1: 2RX baseline assumed for 700MHz. MIL would be 3dB (antenna gain) better than for RedCap. | | | | |   In below Table 11 we have summarized results based on earlier evaluations under Coverage enhancement and RedCap study, for selected channels. Note that in 1RX and 2RX RedCap UE the 20MHz BW limitation is applied as well as the -3dB antenna gain (in RX and TX). Considering the possible difference in noise figure, the detection performance of LP-WUS (to acceptable missed detection rate) needs to be several dBs better than that of e.g. 1RX RedCap to reach similar coverage DL coverage. |
| Qualcomm | Thus, according to the agreement, we need to study the coverage of LP-WUS in terms of MIL margin. In Table 4‑3, we have initial coverage analysis results based on example WUS design and assumptions given in [4].   * OOK-based WUS design is based on sequence of OOK symbols. The duration of each OOK symbol and OOK sequence length, number of OOK sequences determines the data rate of the OOK-based LP-WUS, i.e., data rate (bps) = log2(# of OOK sequences) (bits) / OOK sequence tx duration (sec). * OFDM-based WUS design is based on # of sequences and tx duration; i.e., data rate (bps) = log2(# of OFDM sequences) (bits) / sequence tx duration (sec). * For this analysis of OOK based WUS, we assume length 128 OOK sequence carrying 6 information bits (i.e., #sequences used = 32) during 8 OFDM symbols giving 21bkps in columns (d) of Table 4‑3. * For the analysis of OFDM based WUS, we assume 6 information bits of transmission during 2 OFDM symbols giving 84kbps in column (f) of Table 4‑3. * Additional NF of 8dB is assumed for LP-WUR giving NF=15dB.   **Comparison with PDCCH**  **Table 8** shows the MIL margin results of following channels.   1. RedCap 1Rx PDCCH CSS (AL 16) [38.875] 2. RedCap 1Rx PUSCH 1Rx [38.875] 3. eRedCap PUSCH [38.865] 4. Example Rel-18 OOK based WUS design of 21kbps w/ NF=15dB 5. Example Rel-18 OOK based WUS design of ~1kbps w/ NF=15dB 6. Example Rel-18 OFDM based WUS design of 84kbps w/ NF= 12 dB 7. Example Rel-18 OFDM based WUS design of 10.5kbps w/ NF= 12 dB   The (d) OOK-based WUS (21kbps) has the similar required SNR of -3dB as (a) PDCCH CSS AL16 (first column) but has higher NF (15dB) than Redcap. Thus, the resulting MIL values is 9dB less than that of (a) PDCCH. To recover this loss, we can lower the data rate of WUS (to ~1kbps), which is (e).  **Observation 10: Based on initial evaluation, OOK based LP-WUS with NF=15dB and data rate of ~1kbps could provide similar coverage as RedCap 1Rx PDCCH CSS AL16 in Urban and Rural scenarios. (Note that the NF and data rate may depend on receiver architecture and details of WUS designs.)**  The (d) OFDM-WUS (84kbps) has the similar required SNR of -3dB as (a) PDCCH CSS AL16 (first column) but has higher NF (12dB) than Redcap. Thus, the resulting MIL values is 6dB less than that of (a) PDCCH. To recover this loss, we can lower the data rate of WUS (to 10.5kbps), which is (g).  **Observation 11: OFDM based LP-WUS with NF= 12 dB and data rate of 10.5 kbps could provide similar coverage as RedCap 1Rx PDCCH CSS AL16 in Urban and Rural scenarios. (Note that the NF and data rate may depend on receiver architecture and details of WUS designs.)**  **Comparison with PUSCH**  One can also compare the WUS coverage with that of PUSCH. In this case, WUS of 21bkps could provide better coverage in all scenarios except Urban 4GHz, 1Rx, 24dBm/MHz. Here, we see that one difficulty of using PUSCH as bottleneck reference channel is that PUSCH has almost the same MIL margin of -3dB irrespective of scenarios, whereas WUS has large variation in MIL across different scenarios. This is fundamental issue in comparing the MIL of a downlink (DL) channel with that of an uplink (UL) channel; DL channel MIL depends on DL PSD, signal BW, but UL may not depend on that.  **Observation 12: Based on initial evaluation, OOK based LP-WUS with NF=15dB and data rate 7kbps has better MIL than PUSCH in all scenarios except Urban 4GHz, 1Rx, 24dBm/MHz. (Note that PUSCH data rate used in this comparison is originally coming from eMBB requirements. If RAN1 wants to use PUSCH as a reference target, then, a new PUSCH data rate for IoT application needs to be defined.)**  **Observation 13: Based on initial evaluation, OFDM based LP-WUS with NF=12dB and data rate 56 kbps has better MIL than PUSCH in all scenarios except Urban 4GHz, 1Rx, 24dBm/MHz.**  **Observation 14: The PUSCH coverage (MIL margin) is mostly independent of scenarios, whereas the DL LP-WUS MIL values have large variation depending on scenarios.**  **Table 4‑3 MIL margin for (A) RedCap 1Rx PDCCH CSS (AL 16) and PUSCH [38.875] w/ reference NF=7dB, for (B) 1Rx eRedCap PUSCH [38.865], and (C) Example Rel-18 OOK-based WUS design with NF=15(=7+8)dB (including additional NF=8dB) and (D) Example Rel-18 OFDM-based WUS design with NF=12dB (including additional NF=5dB).**   |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **MIL margin (in dB)** | **(A)  RedCap 1Rx,**  **(UE NF=7dB, gNB NF=5dB)** | | | **(B)  eRedCap 1Rx** | **(C) Example Rel-18 OOK based WUS[3]**  **(NF=15dB)** | | **(D) Example Rel-18 OFDM based WUS[3]**  **(NF=12 )** | |  |  | | (a) | (b) |  | (c) | (d) | (e) | (f) | (g) |  |  | | PDCCH CSS, AL16 | PUSCH  1Mbps(Urban)  100kbps(Rural) | MIL margin  Difference  = (a)-(b) | PUSCH  0.25Mbps  (11PRBs, Urban)  25kbps  (25PRBs, Rural) | OOK based  WUS  (21 kbps) | OOK based  WUS  (~1 kbps[2]) | OFDM based  WUS  (84 kbps) | OFDM based  WUS  (10.5 kbps[5]) |  |  | | ReqSNR =  -4dB | ReqSNR =  -5dB |  |  | ReqSNR=  -3dB | ReqSNR=  -12dB | ReqSNR =  -3dB | ReqSNR =  -9dB |  |  | | Urban 2.6GHz, 1Rx, 33dBm/MHz DL PSD | 11.4 | -3 | 14.4 | 1.76 | 3.4[1] | 11.4[2] | 6.4[4] | 11.4[5] |  |  | | Rural, 0.7GHz, 1Rx, 36dBm/MHz DL PSD | 7.1 | -2.8 | 9.9 | 0.34 | -0.9[1] | 7.1[2] | 2.1[4] | 7.1[5] |  |  | | Urban 4.0GHz, 1Rx, 33dBm/MHz DL PSD | 14.5 | -3 | 17.5 | 1.98 | 6.5[1] | 14.5[2] | 9.5[4] | 14.5[5] |  |  | | Urban 4.0GHz, 1Rx, 24dBm/MHz DL PSD | -0.8 | -3 | 2.2 | 2.45 | -7.2[1] | -0.8[2] | -5.6[4] | -0.8[5] |  |  | | Note [1]: The additional NF of 8dB and required SNR of -3dB gives 9dB lower MIL margin compared to that of RedCap 1Rx, PDCCH CSS AL16.  Note [2]: The reduced required SNR of WUS (by reduced data rate) recovers the loss in MIL margin from additional NF of 8dB. It was assumed that doubling WUS duration reduces required SNR by ~ 2dB.  Note [3]: Example Rel-18 WUS design is given in our companion paper on WUS design and L1 procedure.  Note [4]: The additional NF of 5dB gives 5dB lower MIL margin compared to that of RedCap 1Rx, PDCCH CSS AL16.  Note [5]: The reduced required SNR of WUS (by reduced data rate) recovers the loss in MIL margin from additional NF of 5dB. It was assumed that doubling WUS duration reduces required SNR by ~ 2dB. | | | | | | | | |  |  | |
| ZTE | The assumptions for LLS are shown in Table 4.  Table 4. The assumptions for LLS   |  |  | | --- | --- | | **Attributes** | **Assumptions** | | Carrier Frequency | 2.6GHz for OOK | | Waveform | OOK | | Channel structure | For OOK, the following two Options are considered in LLS   * Option 2: Sequence only, * Option 3: Payload+CRC, | | Payload size | 24bits data + 8 bits CRC | | Sequence | 32-length sequence by the repetition of [0 1 0 1 0 1 0 1] | | Coder scheme | Manchester coding 1/2 | | SCS of OFDM generator for NR signal | 30kHz | | Configuration for LP-WUS signal | For OOK waveform,   * Option 2b: M =4 for SCS = 30 kHz (same as NR signal) | | WUS duration | Based on payload size and coding scheme or the length of preamble sequence | | MDR/FAR assumption | * The miss-detection rate (MDR) of LP-WUS 1%, * The false-alarm rate (FAR) of LP-WUS:0.1% | | gNB Channel BW | 20MHz and with Normal CP=2.344us。 | | LP-WUS BW | Option 1:   * 5MHz including subcarriers for guard band * 4.32MHz (i.e.,12 RBs) for LP-WUS transmission for 30kHz SCS * 11 subcarriers with 30KHz SCSs are used for guardband on each side of LP-WUS | | Filter | 3rd order Butterworth LPF   * Filter bandwidth =4.32 MHz, * Cutoff frequency = 4.98/2 MHz | | Adjacent subcarrier interference | PDSCH with randomly modulated QPSK mapped on resources other than that for WUS and guard band;  EPRE of LP-WUS / EPRE of PDSCH =0 dB | | Sampling Rate | 7.68 MHz | | ADC bit width | Ideal ADC | | Channel Model | TDL-C 300ns | | Number of Rx for LP-WUS | 1 Rx | | UE speed | 3 km/h | | Inter-cell interference | No | | Phase noise modeling | No | | Oscillator max frequency error | No | | Oscillator max time error | No |   The initial results are given in Figure 15.  Figure 15. Initial coverage comparison between OOK signal and PUSCH  ***Proposal 12: The target coverage of LP WUS should be better than PUSCH.*** |
| MTK | **Table 3: Link Budget (MIL) Analysis**   |  |  |  | | --- | --- | --- | | **Scenarios** | **Urban 2.6GHz** | | | Description of LP WUS | OOK Sequence | NR SSS | | **System configuration** | | | | Carrier frequency (GHz) | 2.60 | | | Pathloss model | NLOS TDL-C | | | Target error rate (BLER/MDR etc.) | 1% initial BLER (no retransmission) | | | **Company reporting Assumptions for LP-WUS/WUR** | | | | False alarm rate (FAR) | 1% | | | Channel Structure | 4-chip sequences | 127-chip sequences | | Number of information bits delivered | 1 | 1 | | Waveform | OOK | OFDMA | | Coding Scheme | None | | | Frequency Domain Allocation (MHz) | 4.32 | 3.81MHz | | Guard band (MHz) | 0.72 | N/A | | Time Domain Allocation (Y ms) | 0.5 | | | Efficiency(bit/s/Hz) | 0.000396825 | | | Receiver structure | zero-IF | OFDMA | | Frequency error/drifts | 0 ppm | | | ADC bit-width | 4 | Ideal | | Sampling rate (MHz) | 3.84 | 20 | | Parameters for BB BPF/LPF | 5th-Order Butterworth with 4.32MHz | Ideal | | **Other assumptions if not listed above** | | | | 1. Non-coherent: Both receivers apply non-coherent detection 2. Timing: Perfect Timing 3. Channel: TDL-C with a mobile speed of 3km per hour and RMS delay spread of 300ns (long) | | | | **Transmitter** | | | | (3a) System bandwidth for downlink, or occupied bandwidth for uplink (Hz) | 100000000 | | | (3c) bandwidth used for the evaluated channel (Hz) | 4320000 | 3810000 | | **Receiver** | | | | (10) Number of receiving antenna elements | 1 | | | (13) Receiver noise figure (dB) | 15 | | | (19) Required SNR (dB) | -3 | -1.5 | | (22) Receiver sensitivity | -93.26 | -92.30 | | (22bis) MCL | 150.67 | 149.17 | | (23) Hardware link budget, MIL | 152.02 | 150.52 | | **Calculation of available path loss** | | | | (30) Maximum range (based on (29) and according to the system configuration section of the link budget) (m) | 292.12 | 267.42 |   **Observation:** When using non-coherent detection with the same amount of time and frequency resources and information bits, both OOK-based signalling and SSS-based signalling show comparable performance in terms of MIL and MDR. In other words, there is no significant difference in the performance of these two signalling methods when non-coherent detection is used under these conditions. |
| Nordic | Methodology for coverage enhancements has been agreed, what remains open is the coverage target. From Table 1 and Table 2 (considering WUS Required SNR to be 0), it may become obvious that LP-WUS may have hard time to match the coverage of PDCCH. Even if Noise figure would be the best possible (in the range of agreed values) the required SNR would need to be pushed down from 0dB to -7dB to match PDCCH coverage. This resulting in very low data rates. Therefore, to give room for worse noise figure, LP-WUS should be designed to target coverage not worse than that of PUSCH.  **Table 1 MIL RedCap 1Rx 700MHz**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | 700MHz (15kHz SCS) |  |  |  |  | |  | **NR CSS PDCCH** | **NR PUSCH** | **LP-WUS** | **LP-WUS** | | Carrier BW (MHz) | 20,00 | 20,00 | 4,00 | 4,00 | | PSD (dBm/MHz) | 36,00 | - | 36,00 | 36,00 | | Occupied BW (PRBs) | 48,00 | 4,00 | 11,00 | 11,00 | | **Occupied BW (MHz)** | **8,64** | **0,72** | **1,98** | **1,98** | | Tx Power in occupied BW(dBm) | 45,37 | 23,00 | 38,97 | 38,97 | | Tx Array gain | 0,00 |  | 0,00 | 0,00 | | Tx Antenna Gain (dB) | 8,00 | 0,00 | 8,00 | 8,00 | | Tx EIRP (dBm) | 53,37 | 23,00 | 46,97 | 46,97 | | Rx Antenna gain (dB) | 0,00 | 8,00 | 0,00 | 0,00 | | Beamforming Rx gain (dB) | 3,00 | 9,00 | 0,00 | 0,00 | | Thermal noise density (dBm/Hz) | -174,00 | -174,00 | -174,00 | -174,00 | | Rx interference density (dBm/Hz)   [37.910] | -169,30 | -165,70 | -169,30 | -169,30 | | **Rx Noise figure (dB)** | **7,00** | **5,00** | **9,00** | **24,00** | | Total Rx Noise + int density (dBm/Hz) | -164,99 | -164,03 | -163,63 | -149,95 | | Effective noise power (dBm) | -95,62 | -105,46 | -100,66 | -86,98 | | **Required SNR\* (dB) from [1]** | **-3,10** | **-2,40** | **0,00** | **0,00** | | Rx sensitivity (dBm) | -98,72 | -107,86 | -100,66 | -86,98 | | **Link budget (MIL) (dB)** | **155,09** | **147,86** | **147,63** | **133,95** |   **Table 2 MIL RedCap 1Rx 2.6GHz**   |  |  |  |  |  | | --- | --- | --- | --- | --- | | 2,6GHz (30kHz SCS) |  |  |  |  | |  | **NR CSS PDCCH** | **NR PUSCH** | **LP-WUS** | **LP-WUS** | | Carrier BW (MHz) | 20,00 | 20,00 | 4,00 | 4,00 | | PSD (dBm/MHz) | 33,00 | - | 33,00 | 33,00 | | Occupied BW (PRBs) | 48,00 | 30,00 | 11,00 | 11,00 | | **Occupied BW (MHz)** | **17,28** | **10,80** | **3,96** | **3,96** | | Tx Power in occupied BW(dBm) | 45,38 | 23,00 | 38,98 | 38,98 | | Tx Array gain | 0,00 |  | 0,00 | 0,00 | | Tx Antenna Gain (dB) | 8,00 | 0,00 | 8,00 | 8,00 | | Tx EIRP (dBm) | 53,38 | 23,00 | 46,98 | 46,98 | | Rx Antenna gain (dB) | 0,00 | 8,00 | 0,00 | 0,00 | | Beamforming Rx gain (dB) | 3,00 | 9,00 | 0,00 | 0,00 | | Thermal noise density (dBm/Hz) | -174,00 | -174,00 | -174,00 | -174,00 | | Rx interference density (dBm/Hz)   [37.910] | -169,30 | -165,70 | -169,30 | -169,30 | | **Rx Noise figure (dB)** | **7,00** | **5,00** | **9,00** | **24,00** | | Total Rx Noise + int density (dBm/Hz) | -164,99 | -164,03 | -163,63 | -149,95 | | Effective noise power (dBm) | -92,61 | -93,70 | -97,65 | -83,97 | | **Required SNR\* (dB) from [1]** | **-3,00** | **-10,50** | **0,00** | **0,00** | | Rx sensitivity (dBm) | -95,61 | -104,20 | -97,65 | -83,97 | | **Link budget (MIL) (dB)** | **151,99** | **144,20** | **144,63** | **130,95** | |
| Ericsson | Below we provide initial link budget comparison between two candidate OOK structures whose performance is evaluated in [6]   * WUS1: sequence-based OOK WUS (1 slot WUS), WUR noise figure 6 dB worse than main receiver * WUS2: SSS-based signal detection based WUR capable of processing I/Q samples in time-domain (4 OFDM symbols WUS), WUR noise figure 3 dB worse than main receiver   **Table 4.2-1: Link-budget comparison for WUS.**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **System configuration** | **PDCCH (4 Rx, AL16)** | **PDCCH (2 Rx, AL16)** | **PDCCH (1 Rx, AL16 for Redcap)** | **WUS1 (1bit in 1slot)** | **WUS2  (1bit in 4sym)** | | Carrier frequency (GHz) | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | | Target packet error rate for the required SNR | 1% | 1% | 1% | 1% | 1% | | Number of transmit chains | 4 | 4 | 4 | 4 | 4 | | Downlink Power Spectrum Density (dBm/MHz) | 33 | 33 | 33 | 33 | 33 | | Number of receive chains | 4 | 2 | 1 | 1 | 1 | | Receiver noise figure (dB) | 7 | 7 | 7 | 13 | 10 | | Thermal noise density (dBm/Hz) | -174 | -174 | -174 | -174 | -174 | | **Occupied channel bandwidth (MHz)** | 17.3 | 17.3 | 17.3 | 5 | 5 | | **Required SNR (dB)** | -9.2 | -6 | -3 | -2.5 | -4.5 | | Receiver implementation margin (dB) | 2 | 2 | 2 | 2 | 2 | | Receiver sensitivity (dBm) | -101.8 | -98.6 | -95.6 | -94.5 | -99.5 | | **Link-budget [MIL] in dB** | 161.9 | 158.7 | 155.7 | 149.2 | 154.2 | |
| vivo | In the section, we provide our preliminary evaluation results. Detailed simulation assumptions are provided in Appendix C and several configurations definition are listed as followed:  - Config-1: 4.32MHz/8.64MHz BW, preamble length-16 chips, payload-12bits, CRC-8bits  - Config-2: 4.32MHz/8.64MHz BW, sequence length 28 chips  - Config-3: 4.32MHz/8.64MHz BW, sequence length 8 chips  The modulation of the above three configurations is OOK-4 and the chip rate is 56kbps, which means there are two segments for on/off states within one OFDM symbol. For better coverage performance, we show both 4.32MHz/8.32MHz BW, and more simulation parameters can be found in Appendix C.  In the following figures, we provide the coverage comparison between LP-WUS and legacy NR signals for both normal UE and Redcap UE. As shown in following figures,the LP-WUS configs can achieve higher MIL than PUSCH. In the three configurations above, LP-WUS Config-2 with length 28, can achieve the best performance. The MIL of LP-WUS configs cannot achieve comparable MIL as PDCCH AL16-2Rx for normal UE. And the MIL of LP-WUS Config-2 can achieve comparable MIL as PDCCH AL8. For R18 Redcap UE with 1Rx, the MIL of LP-WUS can be comparable with PDCCH AL16, and the MIL of LP-WUS Config-2 is 1dB higher than the MIL of PDCCH AL16 in Rural scenario.   |  |  |  |  | | --- | --- | --- | --- | | **Attributes** | **Assumptions** | | | | Carrier Frequency | 2.6GHz | | | | Case name | **LP-WUS Config1** | **LP-WUS Config2** | **LP-WUS Config3** | | Channel structure | sync: 16 chips  data: 12bits(24 chips)  CRC: 8 bits (16 chips) | Sequence only: 28 chips | Sequence only: 8 chips | | Chip rate | 56kbps | 56kbps | 56kbps | | WUS duration | 2 slots | 1 slot | 4 symbols | | Performance metric | FAR <0.1%  MDR 1% | FAR < 1%  MDR 1% | FAR < 1%  MDR 1% | | Waveform | OOK -4 | | | | Coding | 1/2 rate Manchester coding (For information bits and CRC bits) | | | | Impairment | {200 ppm,0.1ppm/s}, in saturated region | | | | Beacon periodicity | 1.28 sec  Note: beacon periodicity is used to calculate the time drift for WUS monitoring | | | | SCS | 30kHz | | | | gNB Channel BW | 20MHz (50 RB) | | | | WUS BW | 4.32MHz/8.64MHz | | | | Guard band | 1RB on each side of LP-WUS bandwidth | | | | Filter | 5th Order Butterworth with 4.32MHz bandwidth | | | | ASCI | PDSCH mapped on RBs not used for LP-WUS and guard band;  EPRE of LP-WUS vs EPRE of PDSCH = 1:1. | | | | Sampling Rate | 3.84 MHz | | | | ADC bit width | 4 bits ADC | | | | Channel Model | TDL-C 300 | | |   **Figure 14. MIL comparison between PUSCH/PDCCH and LP-WUS (Urban 2.6GHz normal UE)**    **Figure 15. MIL comparison between PUSCH/PDCCH and LP-WUS (Rural 700MHz normal UE)**  **Figure 16. MIL comparison between PUSCH/PDCCH and LP-WUS (Urban 2.6GHz Redcap UE)**  **Figure 17. MIL comparison between PUSCH/PDCCH and LP-WUS (Rural 700MHz Redcap UE)** |

***Moderator: Companies please provide your comments to the evaluation results.***

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

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| --- | --- |
|  | **Comment** |
| **Company X** |  |
| **Company Y** |  |
| **Company Z** |  |

Comments to each companies’ results

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|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
| **Company X** |  |  |  |
| **Company Y** |  |  |  |
| **Company Z** |  |  |  |
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### Observations

*<Editor’s Note: will provide later>*

## Resource overhead

### Collection of the results

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| Ericsson | Table 4.3-1 Resource overhead of different LP-WUS candidates   |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Signal | Overhead (%) | | | | | | | | | | 100 ms interarrival time | | | 1 s interarrival time | | | 60 s interarrival time | | | |  | Per UE | For 10 UEs | For 20 UEs | Per UE | For 10 UEs | For 20 UEs | Per UE | For 10 UEs | For 20 UEs | | 1-bit OOK WUS | 5.09 | 50.86 | >100 | 0.51 | 5.09 | 10.17 | 0.01 | 0.08 | 0.17 | | 48-bit OOK WUS | >100 | >100 | >100 | 15.09 | >100 | >100 | 0.25 | 2.51 | 5.03 | | 1-bit SSS-based WUS | 0.13 | 1.30 | 2.59 | 0.01 | 0.13 | 0.26 | 2.16e-4 | 2.16e-3 | 4.32e-3 | | PDCCH AL16, 2 OFDM symbols | 0.08 | 0.84 | 1.68 | 0.01 | 0.08 | 0.17 | 1.40e-4 | 1.40e-3 | 2.80e-3 |   **Observation 10 Overhead of LP-WUS/WUR operation depends on the amount of resources used for WUS including any guard bands and WUR synchronization resources (LP-SS).**  **Observation 11 For overhead comparison, consider LP-WUS resources required to match paging PDCCH performance in terms of link budget.**  **Observation 12 For the same number of packets, the total overhead becomes larger with shorter inter-arrival time. For inter-arrival time of 100 ms, the overhead of LP-WUS based on OOK can be significant when there are multiple WUS transmissions required for many UEs.** |
| ZTE | Based on above, we calculate the system overhead percentage based on the following formula    If each LP-WUS transmission has the same resource occupation, it can be written as  P=M\*NLP-WUS\*SLP-WUS\*12/(Nband\*T\*12)  Where   * Nband means the total RBs for a band or carrier in a cell * NLP-WUS, i means the number of RBs for ith LP-WUS transmission including the guardband bandwidth and signal bandwidth * SLP-WUS,i means the number of symbols for ith LP-WUS transmission including guard time if any * Assuming that LP-WUS is transmitted M times in duration T, FFS how to determine M   As for the times of LP-WUS transmission in idle/inactive mode, there are two methods.  Method 1: UEs number in a cell, paging rate for a UE is assumed. Based on UEs number and paging rate, the number of LP-WUS transmission in idle/inactive mode can be obtained.  Method 2: based on PF, PO configuration, obtain the number of LP-WUS in idle/inactive mode |
| vivo | **Observation 27: For IDLE/INACTIVE mode, the upper bound of resource overhead used for LP-WUS is less than 1% for 100MHz system BW even in worst UE Connection density for both IoT and eMBB cases. For CONNECTED mode, the resource overhead of LP-WUS is less than 0.5% even in high load cases such as 10 XR UEs per cell.**   |  |  |  |  | | --- | --- | --- | --- | | **Resource overhead ratio,** *R* | **RRC Idle/inactive mode** | **RRC Connected mode** | | | **XR traffic** | **eMBB traffic** | | **20MHz, 30KHz SCS** | 0.07% ~ 3.93% | - | - | | **100MHz, 30KHz SCS** | 0.01% ~ 0.79 % | 0.43% | 0.036% | |
| Spreadtrum | **Table 5: Resource overhead for R17 PEI and the LP-WUS**   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | **R17 PEI** | | **The LP-WUS** | | | Information bits | 12 bits | 41 bits | 12 bits: a small part of 48-bit for ng-5G-S-TMSI. The main radio should monitor PO after wake-up | 41 bits: the main part of 48-bit for ng-5G-S-TMSI). The main radio may not monitor PO after wake-up, if the remaining bits for ng-5G-S-TMSI is carried by location of the LP-WUS occasion, like PO location which carries some bits of UE ID | | Occupying REs | 288 (576 may be also feasible since R17 PEI has lower MDR than paging PDCCH) | 576 | 288\*y  (11-x) dB => y times of REs compared to R17 PEI | 576\*y  (11-x) dB => y times of REs compared to R17 PEI |   It can be observed that the resource overhead of the LP-WUS is much larger than that of R17 PEI. For example, when y=5 (i.e. 5dB coverage shrinkage compared to R17 PEI), the LP-WUS may need 288\*4 or 576\*4 REs for 12 or 41 bits respectively.  ***Observation 7: System overhead of the LP-WUS is much larger than that of R17 PEI.*** |

***Moderator: Companies please provide your comments to the evaluation results.***

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

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|  | **Comment** |
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Comments to each companies’ results

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|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
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### Observations

*<Editor’s Note: will provide later>*

## Network power consumption

### Collection of the results

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| vivo | **Table 11. Assumption on baseline and LP-SS configuration**   |  |  | | --- | --- | | **Scheme** | **Assumption** | | Baseline:  SSB and SIB1 transmitted in FDM manner;  RACH monitoring | * Periodicity of SSB/SIB1 transmission, RACH monitoring: 20ms * SSB: 4 slots with 2 SSBs in each slot, where 1 SSB occupies 4 OFDM symbols and 20 PRBs * SIB 1: occupies 4 slots and 48 PRBs * RACH: occupies 1 slot | | LP-SS | * Periodicity of LP-SS: P=200,400,800ms * 1 LP-SS occupies 4 slots (enabling beam-sweeping) and 11PRBs |   **Table 12. The additional network energy power consumption for periodic LP-SS transmittion under different network loads based on NES power model CAT 1 &CAT2**   1. **Zero load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Zero load | FDM with SSB/SIB 1 | P=200 | 0.12% | 0.09% | | P=400 | 0.06% | 0.05% | | P=800 | 0.03% | 0.03% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 2.69% | 1.62% | | P=400 | 1.40% | 0.84% | | P=800 | 0.75% | 0.45% |  1. **Low load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Low load | FDM with SSB/SIB 1 | P=200 | 0.09% | 0.08% | | P=400 | 0.05% | 0.04% | | P=800 | 0.02% | 0.02% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 2.01% | 1.34% | | P=400 | 1.04% | 0.69% | | P=800 | 0.55% | 0.37% |  1. **Light load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Light load | FDM with SSB/SIB 1 | P=200 | 0.05% | 0.05% | | P=400 | 0.03% | 0.03% | | P=800 | 0.02% | 0.01% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 1.70% | 0.87% | | P=400 | 1.14% | 0.46% | | P=800 | 0.92% | 0.25% |  1. **Medium load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Medium load | FDM with SSB/SIB 1 | P=200 | 0.03% | 0.03% | | P=400 | 0.02% | 0.02% | | P=800 | 0.01% | 0.01% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 0.56% | 0.54% | | P=400 | 0.28% | 0.28% | | P=800 | 0.17% | 0.16% |   **Observation 28: The additional network energy consumption for periodic LP-SS transmission is low, especially when LP-SS is transmitted with SSB/SIB 1 in FDM manner.**   |  |  |  | | --- | --- | --- | |  | The additional network energy consumption forperiodic LP-SS transmission with a periodicity of 800ms to 200ms | | | NES power model CAT 1  (across different network loads) | NES power model CAT 2  (across different network loads) | | FDM with SSB/SIB 1 | 0.01%~0.12% | 0.01%~0.09% | | TDM with SSB/SIB 1 | 0.17%~2.69% | 0.16%~1.62% | |
| ZTE | Then the percentage for increased BS power consumption by introducing LP-WUS can be evaluated based on the following formula:    Where *r* is the percentage for increased BS power consumption by introducing LP-WUS, P2 is the total BS power consumption after introducing LP-WUS, P1 is the total BS power consumption for baseline scheme without introducing LP-WUS.  More specifically, the following scenarios are considered for NWES.   |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | For evaluation purpose,   * a load (L) % of a cell is a percentage of resources used for UE specific PDSCH / PUSCH * The following load scenarios are considered  |  |  | | --- | --- | | Load scenario | Characteristics | | Idle/empty load | * Include cell-specific signals and channels, and * L = 0 | | low load | * Include cell-specific signals and channels, and * 0 < L≤15 | | Light load | * Include cell-specific signals and channels, and * 15 < L≤ 30 | | Medium load | * Include cell-specific signals and channels, and * 30 < L≤ 50 | | For CA, the companies report whether the load is defined per CC or across all CCs. | | | |

[Q]: Comments

General comments to add or remove any sub-section/figures, and how to filter or categorize the results

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Comments to each companies’ results

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|  | **Result Company A** | **Result Company B** | **Result Company C** |
| **Company X** | Question1: XXXXX  Answer1: XXXXX…  Question2: …  Answer2: … |  |  |
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### Observations

*<Editor’s Note: will provide later>*

## Link level simulation results

***Moderator: to be handled in AI9.11.3***

# void

# Reference

**The following contributions are submitted in RAN1#112-bis in AI 9.11.1,**

1. R1-2302331 Evaluation of LP-WUS and Performance Results FUTUREWEI
2. R1-2302339 Evaluations for LP-WUS Huawei, HiSilicon
3. R1-2302506 Evaluation methodologies for R18 LP-WUS/WUR vivo
4. R1-2302570 Evaluation for lower power wake-up signal OPPO
5. R1-2302621 Discussion on evaluation on low power WUS Spreadtrum Communications
6. R1-2302687 Remaining issues of Deployment scenarios and evaluation methodologies and preliminary performance results of LP-WUR CATT
7. R1-2302815 Evaluations on LP-WUS Intel Corporation
8. R1-2302827 Discussion on evaluation on LP-WUS InterDigital, Inc.
9. R1-2302861 Evaluation of low power WUS Sony
10. R1-2302890 Low power WUS Evaluation Methodology Nokia, Nokia Shanghai Bell
11. R1-2302948 Evaluation on LP-WUS ZTE, Sanechips
12. R1-2302968 Evaluation on low power WUS xiaomi
13. R1-2303150 Evaluation on LP-WUS/WUR Samsung
14. R1-2303332 Evaluation on low power WUS MediaTek Inc.
15. R1-2303429 Discussion on evaluation for LP-WUS LG Electronics
16. R1-2303505 On performance evaluation for low power wake-up signal Apple
17. R1-2303537 On LP-WUS evaluation Nordic Semiconductor ASA
18. R1-2303612 Evaluation methodology for LP-WUS Qualcomm Incorporated
19. R1-2303759 Low power WUS evaluations Ericsson

# Annex (observation from contributions for information)

## Power and Latency

### RRC IDLE/INACTIVE mode

#### General comparison between I-DRX paging with/ without PEI or e-DRX and LP-WUS schemes

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| --- | --- |
| CATT | **Observation 1: Comparing to i-DRX with DCI format 2\_7 as the PEI triggering the paging DCI monitoring, LP-WUR/WUS used as the PEI can achieve 96.4%, 99.1% and 99.4% power saving gain, with the assumption that LP-WUR having the same receiver sensitivity as that of NR receiver under 1%, 0.1%, 0.001% paging rate, respectively.** |
| Nokia | **Observation 7:** The overall service/paging latency including sub-systems boot-up, calibration, and re synchronization, incurs the average delay of approximately 1200ms, which is bit more than DRX latency of 640ms. |
| Qualcomm | **Observation 2**:   * **Compared with PEI and PO, for both DS and ULPS, the PSGs when using LP-WUR is significant. For example, in Figure 7, for case of sec and RRM offloading to LP-WUR, at paging cycle of 1.28 sec, the total power consumption at the UE is 0.4 power units under ULPS while the power consumption using PEI/PO under DS (since it achieves more power saving for UE under PEI/PO) is approximately 1.3-1.4 power units. Hence, the PSG of LP-WUR relative to PEI/PO is around 70%** * **RRM offloading and/or relaxation can significantly reduce power consumption. This is because the MR can stay in ULPS for long time, which will allow for significant power saving as shown in Figure 7.** * **At low latency regime, DS achieves the lowest power consumption for a UE, due to the cost of transition time and energy of entering an ULPS. On the other hand, at 1.28 seconds to high latency requirements (or paging cycle durations), UE can enter ULPS and achieve the most power saving. In general, the optimal sleep state depends on latency requirement.** |
| Ericsson | 1. In general, WUR provides higher power saving for use cases with smaller latency bound relative to mean inter-arrival time of traffic bursts. |
| vivo | **Observation 4: Compared with I-DRX paging, LP-WUR/WUS scheme with continuously monitoring configuration can achieve around 50%~98% power saving gain when the relative power of LP-WUR “ON” state is no more than 1 unit, with marginal latency increase.**  **Observation 5: Compared with eDRX, LP-WUR/WUS scheme with continuously monitoring configuration can largely reduce the paging latency (23x), with comparable UE power consumption.**  **Observation 6: LP-WUR/WUS scheme provides a much better trade-off between latency and power consumption when relative power of LP-WUR “ON” state is no more than 1unit, compared with I-DRX paging and eDRX scheme.**  **Observation 7: Battery life is inversely proportional to relative power of LP-WUR “ON” especially when the traffic is extremely sparse e.g., paging rate is 0.001%.** |
| Sony | **without RRM measurement:**  ***Observation 1 – Introducing a LP-WUS/WUR in DRX results in 6-10 times power saving for paging rate of 10% and in 36-43 times power saving when paging rate is reduced to 0.1%. In eDRX, using LP-WUS/WUR we can reach as high as 27 times power saving for 10% paging rate and this increases to up to 85 times for a 0.1% paging rate.***  ***Observation 2 – Introducing an LP-WUS/WUR allows a large reduction in cycle length at a fixed power consumption. For example, at a power consumption of 0.1 units, the cycle length can be reduced by 290 times, leading to correspondingly reduced wake-up delays.*** |

#### Relative power of LP-WUR “ON” state

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| Futurewei | ***Observation 11: A measurement relaxation factor , at FAR (Alt 2) , is sufficient to result in LP-WUS power saving gain of using LP-WUR with ‘always-on’ monitoring for PON and of using LP-WUR with ‘duty-cycled’ monitoring for PON .***  ***Observation 12: LP-WUS assistance for MR re-synchronization can ease the requirement on measurement relaxation factor as , at FAR (Alt 2) , being sufficient to result in LP-WUS power saving gain of using LP-WUR with ‘always-on’ monitoring for PON and of using LP-WUR with ‘duty-cycled’ monitoring for PON .*** |
| ZTE | ***Observation 1: Compared with DRX with/without PEI, the LP-WUS for one UE or multiple UEs can achieve lower power consumption when PWUR on=0.01, PWUR\_on=0.5 and PWUR on=1.***  ***Observation 2: For Case 1, compared with eDRX with/without PEI, the LP-WUS brings more UE power consumption when PWUR on=0.5, 1, or 20.***  ***Observation 3: For Case 2, compared with eDRX with/without PEI, the LP-WUS brings more UE power consumption when PWUR on=1 or 20.*** |
| Samsung | **Observation 1:**   * **For i-DRX cycle, regardless of , should be limited to small value.** * **For e-DRX cycle, regardless of , discontinuous monitoring significantly reduces power consumption compared to continuous monitoring.** * **When in both e-DRX cycles, it can be seen that the average power consumption of Rel-18 UE is lower than that of Rel-17 UE at or less.** |
| vivo | **Observation 8: Continuously LP-WUS monitoring is not a feasible configuration when the relative power of LP-WUR “ON” is higher than 1unit.**  **Observation 9: Duty cycled LP-WUS monitoring can significantly reduce UE power consumption of LP-WUS scheme except for the case with the relative power of LP-WUS “ON” to be 20 or 40units, but latency will increase accordingly.**  **Observation 10: Up to 45% power saving gain will be lost if UE main radio goes into deep sleep rather than ultra-deep sleep during LP-WUS monitoring.** |
| OPPO | ***Observation 1:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per UE= 1% and per UE paging, when relative power for ‘LP-WUR on state’ is 0.01/0.05/0.1/0.5/1, LP-WUR monitor LP-WUS under “continuously monitoring” manner can have 34.54%~88.40% power saving gain under Low SINR case, while have 35.03%~88.99% power saving gain under Medium SINR case, and have 35.47%~89.58% power saving gain under High SINR case compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).*  ***Observation 3:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per UE= 1% and per UE paging, when relative power for ‘LP-WUR on state’ is 0.01/0.05/0.1/0.5/1/2, LP-WUR monitor LP-WUS under “discontinuously monitoring” manner can have 30.26%~88.62% power saving gain under Low SINR case, while have 30.74%~89.21% power saving gain under Medium SINR case, and have 31.17%~89.80% power saving gain under High SINR case compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).*  ***Observation 5:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per Group= 9.56% and per UE Group paging, when relative power for ‘LP-WUR on state’ is 0.01/0.05/0.1, LP-WUR monitor LP-WUS under “continuously monitoring” manner can have 8.83%~13.28% power saving gain under Low SINR case, while have 12.46%~16.99% power saving gain under Medium SINR case, and have 15.81%~20.43% power saving gain under High SINR case compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).*  ***Observation 7:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per Group= 9.56% and per UE Group paging, when relative power for ‘LP-WUR on state’ is 0.01/0.05/0.1/0.5, LP-WUR monitor LP-WUS under “discontinuously monitoring” manner can have 0.43%~13.48% power saving gain under Low SINR case, while have 3.92%~17.19% power saving gain under Medium SINR case, and have 7.07%~20.64% power saving gain under High SINR case compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).* |
| spreadtrum | ***Observation 3: For RRC IDLE or INACTIVE state, the power value of LP-WUR ‘on’ can be small, e.g. 0.01, for low-complexity LP-WUR architecture. For RRC CONNECTED state, the power value of LP-WUR ‘on’ can be large, e.g. 1, for high-complexity LP-WUR architecture.*** |
| Intel | **Observation 1:** For idle/inactive mode, without consideration on RRM by main radio   * For power consumption of LP-WUS operation compared with IDRX and eDRX   + Significant benefit on power saving in LP-WUS operation are observed for both IDRX and eDRX, except when LP-WUS is always ON with ON power of e.g., 4 units.   **Observation 2:** For the power consumption of LP-WUS operation in idle/inactive mode   * For (15000, 400ms) and RRM by MR in every 20 paging cycles   + large power saving gain is observed except when LP-WUS is always on with on power of 2 or 4 units. However, the gain is reduced compared to the case without RRM by MR. |
| Apple | **Observation 2: For idle/inactive UEs, the power saving gain of LP WUS/WUR is not very sensitive to the power consumption of LP WUR, as long as the power consumption of LP WUR is sufficiently lower (e.g. one order of magnitude lower) than the MR and the ON duration is relatively short.** |

#### Traffic arrival rate, including FAR, per UE or group paging rate

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| Futurewei | ***Observation 9: At target latency (~2s), increasing FAR (Alt 2) from 0.1% to 1% results in only ~5% drop in LP-WUS power saving gain, but increasing it to 10% can result in a significant drop in power saving gain.***  ***Observation 13: The number of UEs per paging group (N) has minimal impact on LP-WUS power saving gain and support of can result only in a drop of compared to the maximum power saving gain.*** |
| Huawei | **Observation 2: Reducing the number of MR transitions by reducing how often a UE is woken up by LP-WUS can increase the power saving gain, which can be achieved by:**  **a) Minimizing the use of UE grouping but maintaining a good trade off with the supported data rate; and/or**  **b) Minimizing the FAR value but maintaining a good trade off with the coverage performance.**  **Observation 3: For the case without RRM measurement and per-UE indication, ~87% power saving gain can be achieved.**  **Observation 4: If LP-WUS carries per-group indication, the latency is larger than R17 baseline since the MR needs to wait for the legacy PO to receive paging. If UE can receive paging in the nearest PO, the latency is comparable to per-UE indication.** |
| CATT | **Observation 2:** **The lower paging rate is, the more power saving gain would be obtained by LP-WUR.** |
| Nokia | **Observation 1:** For always-on or frequent LP-WUS monitoring, FAR needs to be kept very low or the MR transition energy needs be reduced to ensure good power saving gain.  **Observation 2:** If non-zero FAR is assumed, assuming constrained time occasions for LP-WUS monitoring can offer better power saving performance.  **Observation 6:** Reducing paging probability via LP-WUS design would need to account the impact to overhead, feasibility of multiplexing (LP-WUS) and latency of transmitting LP-WUS.  **Proposal 9: Evaluate further the need and ways to limit the paging probability impact to power saving gain, while considering the other implications.** |
| ZTE | ***Observation 11: For Case 1/Case 2, compared with DRX without PEI, the LP-WUS has power saving gain when the probability of extra MR power on caused by FAR is lower than 10% /5%.*** |
| Qualcomm | **Observation 3: PSG of LP-WUR is limited when paging rate is high.**  **Observation 4: If PFA increases from 1% to 10%, this will result in around 70% PSG loss.** |
| Ericsson | Observation 5 Increasing false paging or false alarm reduces the WUR power saving gain. False paging is dominant for larger N (~40% power saving reduction for N=10). |
| vivo | **Observation 18: As FAR for LP-WUS increases, UE power consumption goes up.**  **Observation 19: As the paging rate and the number of UE in group increase, power consumption of LP-WUS scheme will increase.** |
| Intel | * For power consumption of LP-WUS operation compared with IDRX and eDRX   + Reduced power consumption is observed with reduced FAR or reduced paging arrival rate R\_E. |
| Nordic | ***Observation-2:***   * *When group paging rate is high, WUR is not bringing benefit compared to eDRX. However, max latency is decreased from 20 to 1 second.* * *When latency of MR and MR+WUR is comparable, WUR reduces the power consumption from 65% to 10% depending on group paging rate.* |

#### LP-WUS monitoring: discontinuous/duty-cycled

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| Futurewei | ***Observation 10: At target latency (~2s), LP-WUR with ‘always-on’ monitoring can provide two digit power saving gain for PON and FAR (Alt 2) .***  ***Observation 14: At higher target latency (~15s) with a configured long LP-WUR duty cycle, a higher FAR can be accommodated at the drop in LP-WUS power saving gain.*** |
| Nokia | **Observation 3:** Power saving benefit of duty cycled operation can be maintained to 320ms monitoring periodicity.  **Proposal 7: Consider LP-WUS operation assuming defined monitoring occasions i.e. duty cycled operation.**  **Observation 4:** Assuming that decision whether to monitor LP-WUS or normal PO, is left for UE implementation, the paging configuration used in the deployment would need to reflect the targeted latency. |
| ZTE | ***Observation 4: Compared with LP-WUS with always on monitoring, the extra power consumption caused by LP-WUS with on-off duty cycled monitoring is small when the WUR-on power is 0.01, 0.5 and 1.***  ***Observation 5: For Mode 1, compared with DRX with PEI, the OFDM*** ***sequence-based LP-WUS (Alt 4) with on-off duty cycled has power saving gain only when duty cycle rate is < =5% for Case 1 and 6% for Case 2 and duty cycle is 1.28s.***  ***Observation 6: For Mode 2, compared with DRX with PEI, the OFDM*** ***sequence-based LP-WUS (Alt 4) with on-off duty cycled has power saving gain when on duration=1ms with duty cycle >90ms, on duration=2ms with duty cycle >110ms, on duration =4ms with duty cycle>130ms for Case 1 and on duration=1ms with duty cycle >80ms, on duration=2ms with duty cycle >100ms, on duration =4ms with duty cycle>120ms for Case 2.***  ***Observation 7: For Mode 1, compared with DRX with PEI, the OFDM sequence-based LP-WUS (Alt 5) with on-off duty cycled has power saving gain only when duty cycle rate is < =2% for case 1 and duty cycle is 1.28s.***  ***Observation 8: For Mode 2, compared with DRX with PEI, the OFDM sequence-based LP-WUS (Alt 5) with on-off duty cycled has power saving gain when on duration=1ms with duty cycle >300ms, on duration=2/4ms with duty cycle >350ms for Case 1.***  ***Observation 15: The latency for duty cycle monitoring mechanism would be larger than that for always on monitoring and the different duty cycle monitoring schemes have different impacts on the latency.*** |
| Qualcomm | **Observation 5: Monitoring power consumption and WUR monitoring duration are two key aspects to determine UE’s average power consumption.**  **Observation 6: Duty cycling could reduce average LP-WUR power consumption significantly.**  **Observation 7: Average power consumption is insensitive to instantaneous LP-WUR monitoring power at low and moderate paging cycle durations (low to moderate latency requirements).**  **Observation 8: For low paging cycle durations (e.g., 1.28 sec), power consumption is insensitive for LP-WUR monitoring power.** |
| Ericsson | 1. For duty-cycled WUR operation, results for the evaluated cases indicate that significant power savings are possible when assuming WUR active power PWUR = 0.5, 4, 10 units.   Observation 6 For duty-cycled WUR operation, results indicate that when assuming WUR Off-power (0.001, 0.01, 0.05 units) and WUR ramp-up time (10ms, 20ms), the power savings gains are not significantly impacted and large power savings gains are still possible. |
| vivo | **Observation 11: With fixed duty cycle ratio and relative power of LP-WUR “ON” state, different LP-WUR duty cycle lengths have no or less impact on UE power consumption of LP-WUS scheme, and the difference is due to the number of LP-WUR ON-OFF transition.**  **Observation 12**错误!未指定顺序。**: For LP-WUS scheme, latency will be reduced with the increase of duty cycle ratio of LP-WUS monitoring, while UE power consumption will increase accordingly.**  **Observation 13: The power consumption of LP-WUS scheme with 20 or 40units LP-WUR “ON” power is ten or hundred times larger than that with less than 1unit LP-WUR “ON” power. So does the corresponding battery life.**  **Observation 14**错误!未指定顺序。**: Only when duty cycle ratio is extremely low e.g., 0.1%, substantial power saving gain (e.g., up to 50%) can be achieved in the case of high relative power of LP-WUS “ON” i.e., 20 or 40units.** |
| OPPO | ***Observation 2:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per UE= 1% and per UE paging, when relative power for ‘LP-WUR on state’ is 2/4, LP-WUR monitor LP-WUS under “continuously monitoring” manner have not power saving gain compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).*  ***Observation 4:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per UE= 1% and per UE paging, when relative power for ‘LP-WUR on state’ is 4, LP-WUR monitor LP-WUS under “discontinuously monitoring” manner have not power saving gain compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms)*  ***Observation 6:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per Group= 9.56% and per UE Group paging, when relative power for ‘LP-WUR on state’ is 0.5/1/2/4, LP-WUR monitor LP-WUS under “continuously monitoring” manner have not power saving gain compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).*  ***Observation 8:*** *For I-DRX cycle length of 1.28s, with FAR = 0.1%, Paging Rate Per Group= 9.56% and per UE Group paging, when relative power for ‘LP-WUR on state’ is 1/2/4, LP-WUR monitor LP-WUS under “discontinuously monitoring” manner have not power saving gain compared to I-DRX with PEI (Additional transition energy**from ultra-deep sleep is 15000, and ramp-up time is 400ms).* |
| Intel | **Observation 1:** For idle/inactive mode, without consideration on RRM by main radio   * For power consumption of LP-WUS operation compared with IDRX and eDRX   + The duty-cycle based operation can save much more power than always on operation. |
| Sony | ***Observation 4 – The operation of LP-WUR based on duty-cycling is necessary to reduce the total power consumption. The long transition time to wake-up the main radio from ultra-sleep time together with sleep time of the duty-cycle can prevent some UEs from meeting the delay requirement.*** |

#### RRM relax/offload

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| Futurewei | ***Observation 15: LP-WUS assistance for MR re-synchronization can result in more than 10% of additional LP-WUS power saving gain at a fixed FAR (Alt 2).*** |
| Huawei | **Observation 7: when the power consumption of LP-WUR is as high as relative power unit of 4, power saving gain can be only observed with duty cycle based LP-WUS, which has difficulty to support latency sensitive traffics, e.g. voice traffic.**  **Proposal 5: At least support continuous monitoring for LP-WUS.** |
| CATT | **Observation 5:** For eDRX based operation the power saving benefits can be maintained with relaxed MR based measurements.  **Proposal 8: Evaluate further possible ways to relax MR mobility measurement activity to maintain power saving benefits.** |
| ZTE | ***Observation 9: For Case 1, when N is relaxed to 16, LP-WUS has power saving gain compared with DRX with PEI when R\_E=1% and PWUR on=0.5.***  ***Observation 10: For Case2, when N is relaxed to 30, LP-WUS has power saving gain compared with DRX with PEI when R\_E=1% and PWUR on=0.5.*** |
| MTK | Observation 4 OOK-based LPWUR has low PSG without RRM relaxation, but RRM relaxation requires periodic LP-SS with increased overhead, while OFDMA-based LPWUR can support RRM relaxation, but a duty cycle increases latency and cannot be used in RRC CONNECTED.  Proposal 6 RAN1 should use a combination of two different receiver approaches - one based on OOK and the other based on OFDMA. The OOK-based approach would be used to monitor a wake-up signal, while the OFDMA-based approach would use a longer duty cycle to perform synchronization and RRM measurement. |
| Qualcomm | **Observation 2**:   * **Compared with PEI and PO, for both DS and ULPS, the PSGs when using LP-WUR is significant. For example, in Figure 7, for case of sec and RRM offloading to LP-WUR, at paging cycle of 1.28 sec, the total power consumption at the UE is 0.4 power units under ULPS while the power consumption using PEI/PO under DS (since it achieves more power saving for UE under PEI/PO) is approximately 1.3-1.4 power units. Hence, the PSG of LP-WUR relative to PEI/PO is around 70%** * **RRM offloading and/or relaxation can significantly reduce power consumption. This is because the MR can stay in ULPS for long time, which will allow for significant power saving as shown in Figure 7.** * **At low latency regime, DS achieves the lowest power consumption for a UE, due to the cost of transition time and energy of entering an ULPS. On the other hand, at 1.28 seconds to high latency requirements (or paging cycle durations), UE can enter ULPS and achieve the most power saving. In general, the optimal sleep state depends on latency requirement.** |
| Ericsson | **Observation 8 WUR power saving gain is reduced if MR wakes up frequently to perform RRM measurement.**  **Observation 9 When MR performs RRM measurements, legacy deep sleep provides more WUR power saving gain when measurements are performed frequently while ultra-deep sleep suits better when the measurements are more relaxed.** |
| vivo | **Observation 15: Even if RRM measurement is performed by main radio at a relaxed level, the total UE power consumption of LP-WUS scheme increases distinctly.**  **Observation 16: No power saving gain can be obtained by duty cycled LP-WUS monitoring (with 2% duty cycle ratio) scheme, even for the case MR RRM periodicity is relaxed, when the relative power of LP-WUR “ON” is 20 or 40units.**  **Observation 17: RRM measurement completely performed by WUR will greatly help reduce UE power consumption of LP-WUS scheme.** |
| sony | ***Observation 3 – Power saving gain is limited if the main receiver needs to wake up to perform measurements.*** |
| Nordic | ***Observation-2:***   * *When RRM measurements are offloaded to WUR and assuming comparable latency between MR and MR+WUR, it is possible to reduce consumption of MR+WUR down to 5% of MR.* * *When measurements are offloaded, FAR is reduced from 1%->0.1%, and with comparable latency, it is possible to reduce consumption of MR+WUR down to <1% of MR.* |

#### MR transition energy and time from ultra-deep sleep

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| Huawei | **Observation 5: If large power saving gain and small latency is expected, good implementation of MR is necessary to reduce the transition energy and ramp-up time.**  **Observation 6: Reducing the number of MR transitions by reducing the RRM measurement by MR can increase the power saving gain, which can be achieved by:**  **a) Relaxing the RRM measurements requirements; and/or**  **b) Offloading partially or completely the RRM measurements from MR to be done by LP-WUR.**  **Observation 8: With shorter required time on sync/re-sync, larger power saving gain and smaller latency can be obtained.** |
| Ericsson | **Observation 7 The additional sync/re-sync time for MR has a larger impact on cases with a higher paging rate. The overall power saving gain is less sensitive to MR sync/re-sync time for small paging rates (e.g., 1%).**  **Observation 13 LP-WUS/WUR operation in RRC\_INACTIVE/RRC\_IDLE incurs additional latency in terms of paging delay compared to DRX-based operation if the main-radio waking-up/ramp up time is large.** |
| spreadtrum | * For Alt 1, i.e. transition energy 15000, when the LP-WUS indicates to monitor PO, the power consumption is about 21670. Therefore, when per group paging probability is 10%, the total power consumption is about 1.7\*0.9+21670\*0.1 ≈ 2169. Therefore, the power saving gain is (2516-2169)/2516 ≈ 14%. * For Alt 2, i.e. transition energy 40000, when the LP-WUS indicates to monitor PO, the power consumption is about 46270. Therefore, when per group paging probability is 10%, the total power consumption is about 1.7\*0.9+46270\*0.1 ≈ 4629. Therefore, the power saving gain is (2516-4629)/2516 ≈ -84%.   ***Observation 9: When transition energy is not huge, there is positive power saving gain for normal DRX length (e.g. 1.28s) for the LP-WUS.*** |
| Apple | **Observation 1: For idle/inactive UEs, the power saving gain of LP WUS/WUR highly depends on MR transition energy and the probability of MR waking up.** |

#### Other perspectives

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| ZTE | Dynamic PO to reduce latency  ***Observation 12: Compared with DRX/eDRX, the latency reduction of LP-WUS based on legacy PO is -115%/94.7%.***  ***Observation 13: Compared with DRX/eDRX, the latency reduction of LP-WUS based on dynamic PO is 29.6%/98.2%.***  ***Observation 14: Compared with legacy PO, the latency reduction of LP-WUS based on dynamic PO is 67.3%.***  ***Proposal 10: Dynamic PO should be considered for LP-WUS.***  ***Observation 16: The latency impact caused by miss detection is small if dynamic PO is used.*** |
| Samsung | **Observation 2:**   * **In the i-DRX cycle, the average latency of the Rel-18 UE is very high compared to that of the Rel-17 UE because of the ramp-up time (400ms).** * **As the e-DRX cycle increases, the time between PTWs increases significantly, resulting in a significant increase in average latency for both Rel-17 and Rel-18 UE.**   **Proposal 7: Study how to reduce the average latency when LP-WUS is introduced.** |
| Qualcomm | **Observation 2**:   * **Compared with PEI and PO, for both DS and ULPS, the PSGs when using LP-WUR is significant. For example, in Figure 7, for case of sec and RRM offloading to LP-WUR, at paging cycle of 1.28 sec, the total power consumption at the UE is 0.4 power units under ULPS while the power consumption using PEI/PO under DS (since it achieves more power saving for UE under PEI/PO) is approximately 1.3-1.4 power units. Hence, the PSG of LP-WUR relative to PEI/PO is around 70%** * **RRM offloading and/or relaxation can significantly reduce power consumption. This is because the MR can stay in ULPS for long time, which will allow for significant power saving as shown in Figure 7.** * **At low latency regime, DS achieves the lowest power consumption for a UE, due to the cost of transition time and energy of entering an ULPS. On the other hand, at 1.28 seconds to high latency requirements (or paging cycle durations), UE can enter ULPS and achieve the most power saving. In general, the optimal sleep state depends on latency requirement.** |
| Ericsson | **Observation 14 For duty-cycled WUR, value of the offset between WUS monitoring occasion and paging occasion can be adjusted such that the latency is minimized.** |
| Spreadtrum | ***Observation 1: If the LP-WUR supports mobility (continuous coverage) and if the LP-WUS is deployed in the same frequency as SSB in the cell, the cell frequency search is not necessary at the LP-WUR after wake-up.***  ***Observation 2: If the LP-WUR does not support mobility, the cell frequency search is not necessary at the LP-WUR after wake-up, which has been done in cell re-selection at the LP-WUR.***  For simplicity, we can assume cell frequency search is not included in sync/re-sync.   * For Alt 2, i.e. transition energy 40000, when the LP-WUS indicates to monitor PO, the power consumption is about 50110. Therefore, when per group paging probability is 10%, the total power consumption is about 5.6\*0.9+50110\*0.1 ≈ 5016. Therefore, the power saving gain is (6327-5016)/ 6327≈ 21%.   ***Observation 10: When transition energy is huge, there is positive power saving gain for long DRX length (e.g. 5.12s) for the LP-WUS.*** |

### RRC CONNECTED mode

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| CATT | Figure 5: The average PSG of LP-WUS scheme  **Observation 3: With the shorter DRX cycle, the more PSG would be achieved by LP-WUS.**  **Observation 4:** **For a given DRX configuration, large FTP3 inter-arrival time can provide high power saving gain since MR can stay longer time in deep sleep.**     1. LP-WUR sensitivity =-80dBm (b) LP-WUR sensitivity =-85dBm     (c) LP-WUR sensitivity =-90dBm  Figure 6: The average system PSG for LP-WUS scheme for different LP-WUR sensitivity  **Observation 3: With the shorter DRX cycle, the more PSG would be achieved by LP-WUS.**  **Observation 4:** **For a given DRX configuration, large FTP3 inter-arrival time can provide high power saving gain since MR can stay longer time in deep sleep.**  **Observation 5: The power saving gain increases as the increase of the number of devices with LP-WUR in the coverage area. The increase of the number of devices with LP-WUR would require the increase of the receiver sensitivity of LP-WUR.** |
| Nokia | **Observation 12:** Overhead analysis should be considered for different LP-WUS designs and LP-WUR architectures, accounting any guard needed.  **Observation 13:** The possible latency impact of LP-WUS should be accounted in system level modelling when e.g. XR traffic is analysed.  **Observation 14:** Planned Rel-18 enhancements, such as support of non-integer DRX periods aligned with XR frame rates, should also be accounted in the system level evaluations. |
| ZTE | Table 5 DL only, 30Mbps, 60fps, jitter range = [-4,4]ms, InH   |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **Power saving scheme** | **CDRX cycle (ms)** | **ODT (ms)** | **IAT (ms)** | **#UE /cell** | **floor (Capacity)** | **Percentage of satisfied UE** | **Mean PSG of all UEs (%)** | **UPT(Mbps)** | | Baseline | - | - | - | 11 | 11 | 93.9% | - | 324 | | LP WUS | / | 5 | 4 | 11 | 11 | 93.9% | 26% | 242 | | Skipping+switching | 10 | 8 | 4 | 11 | 11 | 90.3% | 17% | 235 |   Table 6 DL only, 30Mbps, 60fps, jitter range = [-8,8]ms, InH   |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | | **Power saving scheme** | **CDRX cycle (ms)** | **ODT (ms)** | **IAT (ms)** | **#UE /cell** | **floor (Capacity)** | **Percentage of satisfied UE** | **Mean PSG of all UEs (%)** | **UPT(Mbps)** | | Baseline | - | - | - | 11 | 11 | 93.9% | - | 325 | | LP WUS | / | 5 | 4 | 11 | 11 | 90.18% | 26% | 238 | | Skipping+switching | 10 | 8 | 4 | 11 | 11 | 90.9% | 16% | 246 |   ***Observation 18: LP-WUS can provide 26% PSG for XR traffic with 30Mbps in InH. PDCCH skipping and SSSG switching can provide 16%-17% PSG for XR traffic with 30Mbps in InH.***  Table 7 evaluation results for FTP 3 traffic   |  |  |  |  | | --- | --- | --- | --- | | Scheme | relative power of LP-WUR “ON” | PSG (Compared to Baseline) | UPT loss (compared to Baseline) | | Baseline-AlwaysOn | - | - | - | | CDRX (160-8-100) ms | - | 72.7% | 70.9% | | PDCCH skipping-switching- DCI 2-6 | - | 83.4% | 77.9% | | LPWUS (wake-up delay 3ms) | 1 | 72.6% | 39% | | 10 | 64.9% | | LPWUS (wake-up delay 10ms) | 1 | 94% | 67.7% | | 10 | 86.4% | | Genie |  | 95.2% | - |   ***Observation 19: LP-WUS can provide 72.6%-94% PSG with 39%-67.7% UPT loss for FTP 3 traffic. PDCCH skipping and switching and DCI 2-6 scheme can provide 83.4% PSG with 77.9% UPT loss for FTP 3 traffic. CDRX can provide 72.7% PSG with 70.9% UPT loss for FTP 3 traffic.*** |
| vivo | **Figure 9. Power saving gain and system capacity results for R17 PDCCH monitoring adaption and LP-WUS/WUR schemes**  **Figure 10. Power saving gain and system capacity results for R17 PDCCH monitoring adaption and LP-WUS/WUR schemes**  **Observation 22:** **Compared to the existing R15/16/17 power saving schemes, LP-WUS monitoring combined with main receiver micro sleep can bring {6%~15%} additional UE power saving gain with no capacity loss in both low load and high load cases.**  **Observation 23: Compared to the existing R15/16/17 power saving schemes, LP-WUS monitoring combined with main receiver light sleep can bring {10%~22%} additional UE power saving gain, with acceptable capacity loss at least in low load case.**  **Figure 11. UPT and power consumption of evaluation schemes**  **Observation 24: UPT of LP-WUR scheme (wake-up latency 0ms case) is the same as always-on scheme which means it can effectively reduce power consumption without affecting network scheduling.**  **Observation 25: When the relative power of WUR “ON” state is no more than 1unit, LP-WUS monitoring with PDCCH skipping scheme can achieve the best trade-off performance in both UPT and power saving, compared with the existing UE power saving schemes.**  **Observation 26: When the relative power of WUR “ON” state is larger than 1unit i.e., 20 or 40 units,** **LP- WUS monitoring with PDCCH skipping scheme has no power saving gain advantage, compared with the existing power saving schemes.** |
| Ericsson | Figure 4.4-1: Capacity and power consumption performance for one flow traffic    Figure 4.4-2: Capacity and power consumption performance for three flow traffic  **Observation 15 For CONNECTED mode, WUS may provide power saving gain when in light traffic scenario at the cost of capacity loss due to extra resource allocation in connected mode. The power saving gain are lower when the traffic is intense.** |
| Xiaomi | |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | PDCCH without PDSCH | PDCCH with PDSCH | Deep sleep | Deep sleep TransitionEnergy | Light sleep Energy | Light sleep TransitionEnergy | Micro sleep Energy | WUS MonitorEnergy | Total Energy | PSG | Delay  (ms) | % of satisfied UEs | | Baseline | 95.36 | 13.93 | 0 | 0 | 0 | 0 | 0 | 0 | 109.29 | N/A | 1.27 | 100% | | CDRX | 67.38 | 17.39 | 0 | 0 | 0 | 0 | 12.07 | 0 | 96.84 | 8.13% | 2.18 | 98.41% | | LP WUS+ CDRX | 55.68 | 17.39 | 0 | 0 | 0 | 0 | 17.33 | 0.1170 | 90.52 | 17.17% | 2.18 | 98.41% |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | PDCCH without PDSCH | PDCCH with PDSCH | Deep sleep | Deep sleep transition | Light sleep | Light sleep transition | Micro sleep | WUS Monitor | Total | PSG | Delay  (ms) | | Baseline | 91.72 | 24.84 | 0 | 0 | 0 | 0 | 0 | N/A | 116.56 | N/A | 2.46 | | genie | 0 | 24.84 | 0.0535 | 1.38 | 13.37 | 5.65 | 1.71 | N/A | 47.00 | 59.67% | N/A | | PDCCH skipping | 32.77 | 24.84 | 0 | 0 | 2.84 | 7.46 | 0 | N/A | 67.91 | 41.74% | 2.70 | | Scheme 1 | 4.31 | 24.84 | 0 | 0 | 2.84 | 7.46 | 12.81 | 0.2846 | 52.54 | 54.92% | 2.70 |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  | PDCCH monitoring Energy | PDSCH+PDCCH  Energy | DEEP SLEEP  Energy | DEEP SLEEP  Transition  Energy | LIGHT SLEEP  Energy | LIGHT SLEEP  Transition  Energy | MICROSLEEP  Energy | WUS  Monitor  Energy | Total  Energy | PSG | Delay  (ms) | | Baseline | 99.75 | 0.7662 | 0 | 0 | 0 | 0 | 0 | 0 | 100.5162 | N/A | 0.25 | | CDRX | 33.50 | 0.7662 | 0.5505 | 2.4878 | 0.0132 | 0.01025 | 0.000614 | 0 | 37.32374 | 62.87% | 46.77 | | Case 4-1 | 0.36322 | 0.75608 | 0 | 0 | 0 | 0 | 44.72314 | 0.99385 | 46.83629 | 53.40% | 0.75 | | Case 4-2 | 0.35347 | 0.75608 | 0 | 0 | 19.28908 | 0.49140 | 0 | 0.99395 | 21.88429 | 78.23% | 3.78 | | Case 4-3 | 0.33285 | 0.75623 | 0.89910 | 2.13840 | 0 | 0 | 0 | 0.99415 | 5.12119 | 94.91% | 10.69 | |

## Coverage

**Huawei:** LP-WUS can reach the same coverage level as legacy PUSCH with certain configurations, e.g. LP-WUS bandwidth.

**Vivo:** For Normal UE, LP-WUS with proper configurations can achieve close MIL as PDCCH AL8. While for Redcap UE, LP-WUS with proper configurations can achieve close MIL as PDCCH AL16.

**OPPO:** The coverage performance of LP-WUS of OOK-1 is worse than PDCCH and could be comparable to PUSCH.

**Intel:** A preliminary calculation shows that the MIL for LP-WUS can be better than PUSCH but is much worse than common PDCCH.

**Nokia:** observes that use lower date rate may facilitate to achieve target coverage and multiplexing with other NR transmission.

**Qualcomm** observes that

* OOK-based WUS uses at least 4 times more resources than OFDM-based WUS to achieve the same misdetection and false alarm performance.
* OOK based LP-WUS with NF=15dB and data rate of ~1kbps could provide similar coverage as RedCap 1Rx PDCCH CSS AL16 in Urban and Rural scenarios
* OFDM based LP-WUS with NF= 12 dB and data rate of 10.5 kbps could provide similar coverage as RedCap 1Rx PDCCH CSS AL16 in Urban and Rural scenarios.
* OOK based LP-WUS with NF=15dB and data rate 7kbps has better MIL than PUSCH. (except Urban 4GHz, 1Rx, 24dBm/MHz)
* OFDM based LP-WUS with NF=12dB and data rate 56 kbps has better MIL than PUSCH. (except Urban 4GHz, 1Rx, 24dBm/MHz)
* RAN1 strives to design LP-WUS to have a similar coverage as NR [PDCCH] channel.

## Resource overhead

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| Ericsson | Table 4.3-1 Resource overhead of different LP-WUS candidates   |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | Signal | Overhead (%) | | | | | | | | | | 100 ms interarrival time | | | 1 s interarrival time | | | 60 s interarrival time | | | |  | Per UE | For 10 UEs | For 20 UEs | Per UE | For 10 UEs | For 20 UEs | Per UE | For 10 UEs | For 20 UEs | | 1-bit OOK WUS | 5.09 | 50.86 | >100 | 0.51 | 5.09 | 10.17 | 0.01 | 0.08 | 0.17 | | 48-bit OOK WUS | >100 | >100 | >100 | 15.09 | >100 | >100 | 0.25 | 2.51 | 5.03 | | 1-bit SSS-based WUS | 0.13 | 1.30 | 2.59 | 0.01 | 0.13 | 0.26 | 2.16e-4 | 2.16e-3 | 4.32e-3 | | PDCCH AL16, 2 OFDM symbols | 0.08 | 0.84 | 1.68 | 0.01 | 0.08 | 0.17 | 1.40e-4 | 1.40e-3 | 2.80e-3 |   **Observation 10 Overhead of LP-WUS/WUR operation depends on the amount of resources used for WUS including any guard bands and WUR synchronization resources (LP-SS).**  **Observation 11 For overhead comparison, consider LP-WUS resources required to match paging PDCCH performance in terms of link budget.**  **Observation 12 For the same number of packets, the total overhead becomes larger with shorter inter-arrival time. For inter-arrival time of 100 ms, the overhead of LP-WUS based on OOK can be significant when there are multiple WUS transmissions required for many UEs.** |
| ZTE | Based on above, we calculate the system overhead percentage based on the following formula    If each LP-WUS transmission has the same resource occupation, it can be written as  P=M\*NLP-WUS\*SLP-WUS\*12/(Nband\*T\*12)  Where   * Nband means the total RBs for a band or carrier in a cell * NLP-WUS, i means the number of RBs for ith LP-WUS transmission including the guardband bandwidth and signal bandwidth * SLP-WUS,i means the number of symbols for ith LP-WUS transmission including guard time if any * Assuming that LP-WUS is transmitted M times in duration T, FFS how to determine M   As for the times of LP-WUS transmission in idle/inactive mode, there are two methods.  Method 1: UEs number in a cell, paging rate for a UE is assumed. Based on UEs number and paging rate, the number of LP-WUS transmission in idle/inactive mode can be obtained.  Method 2: based on PF, PO configuration, obtain the number of LP-WUS in idle/inactive mode |
| vivo | **Observation 27: For IDLE/INACTIVE mode, the upper bound of resource overhead used for LP-WUS is less than 1% for 100MHz system BW even in worst UE Connection density for both IoT and eMBB cases. For CONNECTED mode, the resource overhead of LP-WUS is less than 0.5% even in high load cases such as 10 XR UEs per cell.**   |  |  |  |  | | --- | --- | --- | --- | | **Resource overhead ratio,** *R* | **RRC Idle/inactive mode** | **RRC Connected mode** | | | **XR traffic** | **eMBB traffic** | | **20MHz, 30KHz SCS** | 0.07% ~ 3.93% | - | - | | **100MHz, 30KHz SCS** | 0.01% ~ 0.79 % | 0.43% | 0.036% | |
| Spreadtrum | **Table 5: Resource overhead for R17 PEI and the LP-WUS**   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | **R17 PEI** | | **The LP-WUS** | | | Information bits | 12 bits | 41 bits | 12 bits: a small part of 48-bit for ng-5G-S-TMSI. The main radio should monitor PO after wake-up | 41 bits: the main part of 48-bit for ng-5G-S-TMSI). The main radio may not monitor PO after wake-up, if the remaining bits for ng-5G-S-TMSI is carried by location of the LP-WUS occasion, like PO location which carries some bits of UE ID | | Occupying REs | 288 (576 may be also feasible since R17 PEI has lower MDR than paging PDCCH) | 576 | 288\*y  (11-x) dB => y times of REs compared to R17 PEI | 576\*y  (11-x) dB => y times of REs compared to R17 PEI |   It can be observed that the resource overhead of the LP-WUS is much larger than that of R17 PEI. For example, when y=5 (i.e. 5dB coverage shrinkage compared to R17 PEI), the LP-WUS may need 288\*4 or 576\*4 REs for 12 or 41 bits respectively.  ***Observation 7: System overhead of the LP-WUS is much larger than that of R17 PEI.*** |
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## Network power consumption

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| vivo | **Table 11. Assumption on baseline and LP-SS configuration**   |  |  | | --- | --- | | **Scheme** | **Assumption** | | Baseline:  SSB and SIB1 transmitted in FDM manner;  RACH monitoring | * Periodicity of SSB/SIB1 transmission, RACH monitoring: 20ms * SSB: 4 slots with 2 SSBs in each slot, where 1 SSB occupies 4 OFDM symbols and 20 PRBs * SIB 1: occupies 4 slots and 48 PRBs * RACH: occupies 1 slot | | LP-SS | * Periodicity of LP-SS: P=200,400,800ms * 1 LP-SS occupies 4 slots (enabling beam-sweeping) and 11PRBs |   **Table 12. The additional network energy power consumption for periodic LP-SS transmittion under different network loads based on NES power model CAT 1 &CAT2**   1. **Zero load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Zero load | FDM with SSB/SIB 1 | P=200 | 0.12% | 0.09% | | P=400 | 0.06% | 0.05% | | P=800 | 0.03% | 0.03% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 2.69% | 1.62% | | P=400 | 1.40% | 0.84% | | P=800 | 0.75% | 0.45% |  1. **Low load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Low load | FDM with SSB/SIB 1 | P=200 | 0.09% | 0.08% | | P=400 | 0.05% | 0.04% | | P=800 | 0.02% | 0.02% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 2.01% | 1.34% | | P=400 | 1.04% | 0.69% | | P=800 | 0.55% | 0.37% |  1. **Light load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Light load | FDM with SSB/SIB 1 | P=200 | 0.05% | 0.05% | | P=400 | 0.03% | 0.03% | | P=800 | 0.02% | 0.01% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 1.70% | 0.87% | | P=400 | 1.14% | 0.46% | | P=800 | 0.92% | 0.25% |  1. **Medium load case**  |  |  |  |  |  | | --- | --- | --- | --- | --- | | **Load type** | **Transmission occasion of LP-SS** | **LP-SS transmission with periodicity P (unit: ms)** | **Additional network power consumption vs. baseline: CAT 1** | **Additional network power consumption vs. baseline: CAT 2** | | Medium load | FDM with SSB/SIB 1 | P=200 | 0.03% | 0.03% | | P=400 | 0.02% | 0.02% | | P=800 | 0.01% | 0.01% | | TDM with SSB/SIB 1  (adjacent slots) | P=200 | 0.56% | 0.54% | | P=400 | 0.28% | 0.28% | | P=800 | 0.17% | 0.16% |   **Observation 28: The additional network energy consumption for periodic LP-SS transmission is low, especially when LP-SS is transmitted with SSB/SIB 1 in FDM manner.**   |  |  |  | | --- | --- | --- | |  | The additional network energy consumption forperiodic LP-SS transmission with a periodicity of 800ms to 200ms | | | NES power model CAT 1  (across different network loads) | NES power model CAT 2  (across different network loads) | | FDM with SSB/SIB 1 | 0.01%~0.12% | 0.01%~0.09% | | TDM with SSB/SIB 1 | 0.17%~2.69% | 0.16%~1.62% | |
| ZTE | Then the percentage for increased BS power consumption by introducing LP-WUS can be evaluated based on the following formula:    Where *r* is the percentage for increased BS power consumption by introducing LP-WUS, P2 is the total BS power consumption after introducing LP-WUS, P1 is the total BS power consumption for baseline scheme without introducing LP-WUS.  More specifically, the following scenarios are considered for NWES.   |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | For evaluation purpose,   * a load (L) % of a cell is a percentage of resources used for UE specific PDSCH / PUSCH * The following load scenarios are considered  |  |  | | --- | --- | | Load scenario | Characteristics | | Idle/empty load | * Include cell-specific signals and channels, and * L = 0 | | low load | * Include cell-specific signals and channels, and * 0 < L≤15 | | Light load | * Include cell-specific signals and channels, and * 15 < L≤ 30 | | Medium load | * Include cell-specific signals and channels, and * 30 < L≤ 50 | | For CA, the companies report whether the load is defined per CC or across all CCs. | | | |

## Link level simulation results

***Moderator: to be handled in AI9.11.3***

|  |  |
| --- | --- |
| **intel** | * A BW of 12PRB for LP-WUS achieves a good balance of link performance and resource efficiency * On the impact of the number of OOK symbols per OFDM symbol and the Manchester spreading factor   + with equal total duration of an information bit, a larger OOK symbol duration (smaller M) is better   + a larger duration for an information bit (smaller M or larger SF) may lose some power gain due to non-coherent detection. * ADC of 3 bits or more achieves ideal performance. * The performance of LP-WUS is not sensitive to frequency error. * The timing error has significant impact on OOK based LP-WUS transmission if the time error is not corrected. * the LP-WUS performance for SCS 15 or 30kHz are almost equal assuming the same total duration per information bit. |
| **Samsung** | * + Multi-bit ADC operation provides better performance compared to 1-bit ADC operation for detection MC-OOK based LP-WUS.   + The finer sliding granularity of LP-WUS detection is necessary for sequence-only MC-OOK based LP-WUS to support the following conditions: * Lower OOK pulse duration for high bit-rate. e.g., over 60kbps * Lager drifted timing/frequency error. e.g., the average time from previous synchronization > 10s   + For sequence-only LP-WUS design, how to constitute the candidates of sequences that share the same frequency/time resource for LP-WUS monitoring can affect the detection performance.   + There are trade-off between the detection performance and the followings. * Reducing bit rate of LP-WUS. * The relaxation of FAR requirement. |
| **Xiaomi** | observes that frequency/time domain configuration and channel structure leading to different LP-WUS performance. |
| **MTK** | There is no significant difference in the performance of OFDM and OOK-based signaling methods when non-coherent detection is used under same resource overhead. |

# Annex2

## Low load case

### jitter range {-4ms, +4ms}

#### Compared with alwayson

MR enters micro sleep during LP-WUS monitoring, LP-WUS scheme can achieve:

Source vivo:

* + Power saving gain is 29.71% with no capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 34.1% with {0.6%~10.6%} capacity loss.

#### Compared with Rel-17 baseline scheme

MR enters micro sleep during LP-WUS monitoring, LP-WUS scheme can achieve:

Source vivo

* + Power saving gain is 8.29% whit no capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 8.29% with {0.6%~10.6%} capacity loss.

### jitter range {-8ms, +8ms}

#### Compared with alwayson baseline

MR enters micro sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 27.84% with no capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 36.6% with {0.6%~10.6%} capacity loss.

#### Compared with Rel-17 baseline scheme

MR enters micro sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 15.46% whit no capacity loss.

Source vivo:

* + Power saving gain is 25.73% with {0.6%~12.4%} capacity loss.

## High load case

### jitter range {-4ms, +4ms}

#### Compared with alwayson baseline

MR enters micro sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 25.1% with 0.3% capacity loss.

Source ZTE:

* + Power saving gain is 26% with no capacity loss.

Source xiaomi:

Power saving gain is 17.17%~54.92% (note: capacity impact not provide).

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 29.22% with {9.72% ~38.33%} capacity loss.

#### Compared with Rel-17 baseline scheme

MR enters micro sleep during LP-WUS monitoring,

Source vivo

* + Power saving gain is 7.21% whit no capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 12.31% with {9.42%~38.13%} capacity loss.

### jitter range {-8ms, +8ms}

#### Compared with alwayson baseline

MR enters micro sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 24.11% with no capacity loss.

Source ZTE:

* + Power saving gain is 26% with 3.7% capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 32.34% with {9.94%~37.38%} capacity loss.

#### Compared with Rel-17 baseline scheme

MR enters micro sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 14.745% whit no capacity loss.

MR enters light sleep during LP-WUS monitoring,

Source vivo:

* + Power saving gain is 23.99% with {8.54%~36%} capacity loss.

# Annex 3

## Compared to alwayson baseline

### MR enter micro sleep

***When assuming MR enters micro sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 42.95%~44%*

*Xiaomi: 53.4%*

***UPT loss:***

*Vivo: no loss*

*Xiaomi: null*

***When assuming MR enters micro sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: 1.65%~22.83% (WUR on power is assumed as 20/30/40units)*

***UPT loss:***

*Vivo: no loss*

### MR enter light sleep

***When assuming MR enters light sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 67.95%~69%*

*ZTE: 72.6%*

*Xiaomi: 78.23%*

***UPT loss:***

*Vivo: 26%*

*ZTE: 39%*

*Xiaomi: null*

***When assuming MR enters light sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: 26.65%~47.83% (WUR on power is assumed as 20/30/40units)*

*ZTE: 64.90% (WUR on power is assumed as 10units)*

***UPT loss:***

*Vivo: 26%*

*ZTE: 39%*

### MR enter deep sleep

***When assuming MR enters deep sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 85.68%~86.73%*

*ZTE: 94%*

*Xiaomi: 94.91%*

***UPT loss:***

*Vivo: 57%*

*ZTE: 67.7%*

*Xiaomi: null*

***When assuming MR enters deep sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: 44.39%~65.56%*

*ZTE: 86.4%*

***UPT loss:***

*Vivo: 57%*

*ZTE:* 67.7%

## Compared to Rel-16 DRX+DCI 2\_6 baseline

### MR enter micro sleep

***When assuming MR enters micro sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: -112.79%~ -66.96%*

***UPT gain:***

*Vivo: 175.77%*

### MR enter light sleep

***When assuming MR enters light sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 30.66%~32.93%*

***UPT gain:***

*Vivo: 104.12%*

***When assuming MR enters light sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: -58.70% ~ -12.87%*

***UPT gain:***

*Vivo: 104.12%*

### MR enter deep sleep

***When assuming MR enters deep sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 69.02%~71.29%*

*CATT: 7.74%~88.10%*

***UPT gain:***

*Vivo: 18.04%*

*CATT: null*

***When assuming MR enters deep sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

*Power saving gain:*

*Vivo: -20.32%~2.60%*

*UPT loss:*

*Vivo: 18.04%*

## Compared to Rel-16 DRX+DCI 2\_6 + Rel-17 PDCCH scheme

### MR enter micro sleep

***When assuming MR enters micro sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo:* *-334.22%~-240.71%*

***UPT gain:***

*Vivo: 653.52%*

### MR enter light sleep

***When assuming MR enters light sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

***Power saving gain:***

*Vivo: -223.84%~-130.33%*

***UPT gain:***

*Vivo: 457.75%*

### MR enter deep slee

***When assuming MR enters deep sleep state and WUR on power is no more than 1unit***

***Power saving gain:***

*Vivo: 36.78%~41.41%*

***UPT gain:***

*Vivo: 222.53%*

***When assuming MR enters deep sleep state and WUR on power is larger than 1unit e.g., 10 20 30 40units***

*Power saving gain:*

*Vivo: -145.52%~-52.05%*

*UPT loss:*

*Vivo: 222.53%*

***Moderator: Companies please provide your comments to the evaluation results.***

|  |  |
| --- | --- |
| ***To*** | ***Comments*** |
| Company A | [Company B]Comments…  [Company A]Response…  [Company C]Further clarification/comments |
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