**3GPP TSG RAN WG1 #116 R1-24xxxxx**

**Athens, Greece, February 26th – March 1st, 2024**

**Agenda Item: 9.6.1**

**Source: Moderator (vivo)**

**Title:** **Summary of discussions on LP-WUS and LP-SS design**

**Document for:** **Discussion and Decision**

1. Introduction

In RAN#102 meeting, a new WI on LP-WUS was approved with the following objectives [1].

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| * To specify an LP-WUS design commonly applicable to both IDLE/INACTIVE and CONNECTED modes (RAN1, RAN4)   + Specify OOK (OOK-1 and/or OOK-4) based LP-WUS with overlaid OFDM sequence(s) over OOK symbol     - The LP-WUS design shall ensure that for IDLE/INACTIVE operation, the same information is delivered irrespective of LP-WUR type. The OFDM sequence can carry information.   + At least duty-cycled monitoring of LP-WUS is supported * For IDLE/INACTIVE modes   + Specify procedure and configuration of LP-WUS indicating paging monitoring triggered by LP-WUS, including at least configuration, sub-grouping and entry/exit condition for LP-WUS monitoring (RAN2, RAN1, RAN3, RAN4)   + Specify LP-SS with periodicity with Yms for LP-WUR, for synchronization and/or RRM for serving cell. (RAN1, RAN4)     - LP-SS is based on OOK-1 and/or OOK-4 waveform with or without overlaid OFDM sequences. Further down selection between with and without overlaid OFDM sequences is to be done within WI.     - Note: For LP-WUR that can receive existing PSS/SSS, existing PSS/SSS can be used for synchronization and RRM instead of LP-SS.     - Y will be decided within WI. 320ms is the start point.   + Specify further RRM relaxation of UE MR for both serving and neighbor cell measurements, and UE serving cell RRM measurement offloaded from MR to LP-WUR, including the necessary conditions (RAN4, RAN2) * For CONNECTED mode, specify procedures to allow UE MR PDCCH monitoring triggered by LP-WUS including activation and deactivation procedure of LP-WUS monitoring (RAN2, RAN1)   + Check in RAN#105 for potential TU adjustment in RAN2   + Note: In CONNECTED mode, UE MR ultra-deep sleep is not considered, and UE RRM/RLM/BFD/CSI measurements are performed by MR * Note: The target coverage of LP-WUS and LP-SS shall be the coverage of PUSCH for message3. * Note: The optimization of LP-WUS signal design for idle/inactive mode is prioritized over the optimization for connected mode. * Specify the necessary RAN4 core requirement(s) to support the feature (RAN4).   + This objective is to be further refined in RAN#103 |

This contribution summarizes the discussions on LP-WUS and LP-SS design in RAN1# 116.

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

Please provide your comments to Proposals and Questions tagged with [H][FL1] and [M][FL1] in this round.

1. Proposals for Online Sessions
   1. Proposals
2. LP-WUS design
   1. Waveform-selection of OOK-1 and/or OOK-4

The Rel-19 LP-WUR WI scope has included OOK-1 and OOK-4 as candidate solutions for the LP-WUS design ‘Specify OOK (OOK-1 and/or OOK-4) based LP-WUS with overlaid OFDM sequence(s) over OOK symbol’. RAN1 will decide whether both schemes or only one scheme is supported for LP-WUS.

Most companies [2][3][4][5][10][11][13][20][27][31] prefer to support both OOK-1 and OOK-4. Some companies show preference on one scheme over the other, e.g., [7] and [21] prefer to prioritize OOK-1 to simplify the design but can be open for OOK-4. [9], [19], and [23] prefer to prioritize OOK-4 by considering low generation complexity to support variable symbol rate, lower system overhead, latency, low-power consumption as well as better resource efficiency. Further, some company consider the choice to use OOK-1 and/or OOK-4 will not significantly change the ON power of the LP-WUR [33].

For OOK-1, some companies discuss mechanism to support higher symbol rate by using larger SCS, while several companies such as [2][4][7][8][9] prefer same SCS between LP-WUS and NR legacy signals to avoid additional complexity at gNB side.

One basic parameter for OOK-4 is M, i.e., the number of OOK symbols per OFDM symbol. Proponents of OOK-4 support at least M=2. In addition, several companies [2] [3] [4] [5] [10] [17] [27] propose M=1, e.g., OOK-1 can be supported as a specifical case of OOK-4 with M=1. Besides, some companies prefer M=4 for higher data rate while some company suggest further evaluation of M=4 on coverage with presence of timing error.

Considering waveform-selection of OOK-1 and/or OOK-4 is fundamental for LP-WUS design and most companies support both, proposal 3.1-1 is suggested as below.

#### *[H][FL1] Proposal 3.1-1: Support both OOK-1 and OOK-4 for LP-WUS.*

* *SCS of a CP-OFDM symbol used for LP-WUS generation is the same as SCS used for other NR transmissions in the same CP-OFDM symbol.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | N | An LP-WUS with OOK-1 has 4x the time-on-air as the same LP-WUS with OOK-4 M=4, therefore the energy-per-wakeup event is 4x higher with OOK-1. |
| Nokia/NSB | N | We should down select between OOK1 and OOK4. It must be clarified that for M=1, even though both OOK1 and OOK4 are same, DFT will be used for OOK4. Our preference is OOK4 because of its scalability. |
| DOCOMO |  | While we agree that OOK1 can be supported by OOK-4 with M=1, we are not sure whether such flexibility on M is necessary or not for now. This should be discussed together with required WUS bit rate and system overhead.  Also, whether same SCS is enough or different SCS is necessary depends on the required WUS bit rate and system overhead. |
| EURECOM | Y | In favor |
| Samsung |  | We would like to clarify the meaning of the same SCS used for other NR transmission. The intention is not to use different SCS between signals FDMed in the same CP-OFDM symbol when gNB transmit LP-WUS and other NR signal using the same IFFT module.  However, according to the current spec, the different SCS can be configured per BWP and it means that different SCS between signals FDMed can be supported from gNB side.  We support to have the same SCS between LP-WUS and other NR channel because our intention is not to increase the complexity of the gNB when OOK-1 is used. But we are wondering how it can be specified in the current spec. Do we specify the restriction that BWP for LP-WUS transmission and BWP for other NR channels should have the same SCS (SCS1)? In addition, if BWP for other NR channels in different time is configured with SCS2, LP-WUS SCS should be changed to SCS2? |

#### *[H][FL1] Question 3.1-1: For values of M for OOK-4 (M is the number of OOK symbols per OFDM symbol), do you support M=4 and any other values larger than 4?*

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| **Company** | **Comments** |
| Everactive | M=4 is a good compromise between OOK datarate (LP-WUS time-on-air) and the performance of the OOK symbols. |
| Nokia/NSB | Values M>4 requires strict time synchronization, which cannot be guaranteed with the LR architecture considered. Our preference is |
| DOCOMO | Similar to the above, we think required WUS bit rate and system overhead should be discussed together with M and SCS. |
| EURECOM | We support M=4. We also propose to consider M=8, with encoding 3 bits to the 8 OOK symbols, for improved spectral efficiency of the OOK transmission. |
| Samsung | From our understanding, the coverage of OOK-based LP-WUS is affected by SCS used for LP-WUS as well as M. For example, considering the results in TR38.869, M=4 can be acceptable for 15kHz SCS. However, for higher SCS such as 60kHz, M=4 seems not working. Therefore, SCS should be considered jointly. |

For OOK waveform generation, companies provide detailed discussion on several aspects, including bit extension, scrambling/overlaid OFDM sequence, DFT, Mapping frequency domain samples to existing constellation, FFT Shift, Pulse shaping, etc. These aspects can be discussed later based on progress on proposal 3.1-1.

* 1. Overlaid OFDM sequence for LP-WUS

Overlaid OFDM sequence is supported for LP-WUS as captured in WID ‘Specify OOK (OOK-1 and/or OOK-4) based LP-WUS with overlaid OFDM sequence(s) over OOK symbol. The LP-WUS design shall ensure that for IDLE/INACTIVE operation, the same information is delivered irrespective of LP-WUR type. The OFDM sequence can carry information.’

Companies [3][4][7][12][15] [20][21][26] discuss possibilities on the information delivered by OFDM sequence (s), there can be at least two options as listed below:

Assuming total information delivered by LP-WUS is a set of bits **X** = [x1, x2, … xL] irrespective of LP-WUR type. The LP-WUS occupies N OFDM symbols (M\*N OOK symbols, M is number of OOK symbols per OFDM symbol)

* Option 1: OFDM sequence(s) carry only part of **X**. Within first N1 OFDM symbols of the LP-WUS (N1<N)**,** M\*N1 OOK symbols carry a part of **X,** e.g., X1 (L1 bits), and remaining part of **X** (L-L1 bits) is carried by OFDM sequences within the first N1 OFDM symbols. OFDM-based LP-WUR can obtain total **X** by detection of OFDM sequences, and the location of OFDM sequences or detection of OOK symbols in the first N1 OFDM symbols.

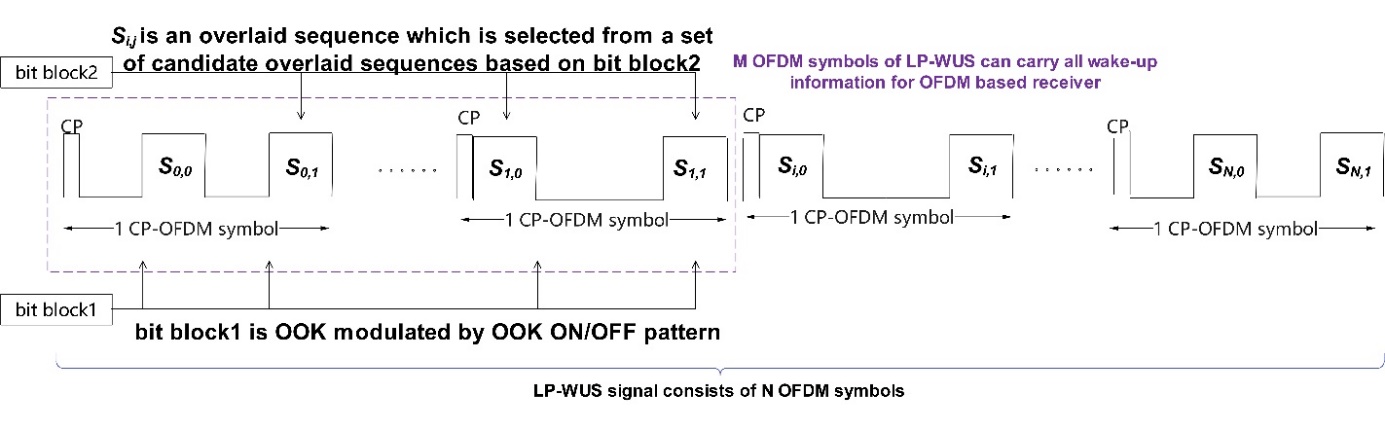


Figure 1 Option 1 from [4]

* Option 2: OFDM sequence(s) carry whole part of **X** . Within first N1 OFDM symbols of the LP-WUS (N1<N)**,** the whole **X** (L bits) is carried by OFDM sequence(s). OFDM-based LP-WUR can obtain total **X** by detection of OFDM sequences in the first N1 OFDM symbols.



Figure 2 Option 2 from [7]

It is suggested to discuss these two options as starting point and companies are encouraged to provide analysis on pros and cons for each option to help potential down-selection in future meeting.

#### *[M][FL1] Proposal 3.2-1: RAN1 to discuss how to carry information by OFDM sequence(s) based on two options as below.*

* Option 1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and location of the OFDM sequence(s)/OOK symbols.
* Option 2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s).

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| **Company** | **Y/N** | **Comments** |
| Everactive | Support both options | Ok with either option, provided it does not impact the quality of the OOK-4 modulated symbols. |
| Nokia/NSB. |  | We support Option 2 |
| EURECOM |  | Option 1 is preferred since it has better performance. Increasing the number of sequences will degrade the performance of the OFDM-based receiver. |
| Samsung |  | We are open to both options, but from our understanding, these options can be applicable only when Manchester coding is supported because OFDM sequence can be transmitted over ON pulses of OOK symbol. Therefore, it can be discussed after the decision on the proposal 3.6-1 |

As discussed above, OFDM based LP-WUR may obtain all information bits by reception of first N1 OFDM symbols of the LP-WUS. Early termination of reception of LP-WUS would be possible which saves power. Companies [12] [14] [20] also discuss whether/how to transmit overlaid OFDM sequence(s) in the remaining (N-N1) OFDM symbols of the LP-WUS to further improve OFDM detection performance, i.e., whether repetition of the information bits can be supported. Thus, FL suggested the proposal as below.

#### *[M][FL1] Proposal 3.2-2: RAN1 to discuss whether gNB can transmit information bits of LP-WUS repeatedly by overlaid OFDM sequence(s) in the OFDM symbols of the LP-WUS.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y | Ok with this proposal. |
| Nokia/NSB. |  | gNB can repeat the information bits of LP-WUS via the overlaid OFDM sequence |
| EURECOM | Y | If the target group consists of ED-WUR and OFDM-based WUR, the (N-N1) OFDM symbols should also use overlaid OFDM sequences to encode part of the payload, such that they can be combined with the correlation results from the N1 OFDM symbols for increased performance of the OFDM-based receiver. |
| Samsung |  | Information bits of LP-WUS can be repeatedly transmitted as one of options. Thus, whether to apply repetition is up to gNB configuration. And whether to receive all overlaid OFDM sequence repeatedly transmitted or not also can be up to UE implementation. |

For the overlaid OFDM sequence design itself, the properties of the sequences should be discussed first. The sequence should consider performance of both OOK detector and OFDM detector.

* For OFDM detector, the sequence with good correlation property is desirable, e.g., cross-correlation property. If sliding window-based detection is considered, auto-correlation property is also desirable.
* For OOK detector, the sequence should flatten the spectrum and the impact of timing error should be considered.

Also, the complexity at gNB/UE side as well as standard effort should be considered.

According to input from companies, existing OFDM sequences, including ZC sequence, m-sequence, Gold sequence, PN sequence are preferred by majority. Also, FFT/DFT sequence is proposed by one company [5].

#### *[M][FL1] Proposal 3.2-3: The following aspects should be considered for overlaid OFDM sequence design:*

* *The sequence should not compromise OOK detection performance.*
* *The sequence should have good cross-correlation property and/or auto-correlation property.*
* *The sequence based on existing NR OFDM sequence can be the starting point.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | N | Primary goal: the sequence should not compromise the OOK detection performance. In particular, for OOK-4 M=4, OFDM symbols are chosen to produce an OOK signal in the time domain. Existing NR OFDM sequences do not produce OOK sequences in the time domain, therefore these cannot be a starting point for OOK-4 M=4. |
| Nokia/NSB. |  | The sequence should also be robust against frequency offset. At this point, we don’t need to down-select from the list. |
| EURECOM | Y | Agree, note that the sequence should also not require a complex receive filter. |
| Samsung |  | For the first sub-bullet, does it mean that the performance of OOK-based LR should be prioritized over the performance of OFDM-based LR when designing overlaid OFDM sequence? From our understanding, performance of both receiver should be taken into account, but how to handle the trade-off relationship between performances of two receiver types is to be further discussed. |

Another aspect of the overlaid OFDM sequence is how the OFDM sequence(s) is overlaid [2] [8]. More specifically, whether the OFDM sequence is overlaid in time domain (before DFT), or the OFDM sequence is overlaid in frequency domain (after DFT and before IFFT).

#### *[M][FL1] Proposal 3.2-4: To specify overlaid OFDM sequences, considering the following two options:*

* *Option 1: Specify time domain OFDM sequence per OOK ON symbol.*
* *Option 2: Specify frequency domain OFDM sequence per OFDM symbol.*



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| **Company** | **Y/N** | **Comments** |
| Everactive | Support Option 1 | How do these options work with OOK-4? Option 1 seems to be the lowest risk of OFDM overlay degrading the quality of the OOK signal in the time-domain.  For low-power receivers with envelop-detectors in the signal path, the magnitude (amplitude) of the time-domain signal is most important. |
| Nokia/NSB. |  | We prefer Option 1 as long as the UE does not require any gNB specific information. |
| EURECOM |  | Option 1. An implementation can still be done in Option 2 by pre-computing and storing all possible frequency-domain signals. |
| Samsung |  | For Option 2, frequency domain OFDM sequence can be different based on SCS if the same BW of LP-WUS (e.g., 5MHz) is supported because the number of PRB within 5MHz is different. How to specify the OFDM sequences can be further discussed after other aspect is decided/discussed. |

Another important aspect for overlaid OFDM sequence is the understanding of ‘OFDM sequence can carry information’ in WID. There are three different interpretations,

1. Interpretation 1: OFDM sequence carries or not carry information per gNB configuration

* In case of OFDM sequence not carrying information,
  + gNB may not configure any overlaid OFDM sequence. It is up to gNB implementation to transmit an overlaid OFDM sequence.
  + gNB may configure a single overlaid OFDM sequence. With single known sequence (Ns=1), better detection performance can be achieved by OFDM-based LP-WUR.
* In case of OFDM sequence carrying information, the set of known sequence has Ns sequences, one of the Ns sequences can be transmitted to carry log2 (Ns) bits.

OFDM based LP-WUR may obtain all information bits by reception of first N1 OFDM symbols of the LP-WUS. Early termination of reception of LP-WUS would be beneficial for power saving.

1. Interpretation 2: OFDM sequence carries or not carry information per gNB configuration

* In case of OFDM sequence not carrying information, gNB configures a single overlaid sequence.

With single known sequence (Ns=1), better detection performance can be achieved by OFDM-based LP-WUR. OFDM-based LP-WUR has to receive all OFDM symbols of the LP-WUS.

* In case of OFDM sequence carrying information, the set of known sequence has Ns sequences, one of the Ns sequences can be transmitted to carry log2 (Ns) bits.

OFDM based LP-WUR may obtain all information bits by reception of first N1 OFDM symbols of the LP-WUS. Early termination of reception of LP-WUS would be beneficial for power saving.

1. Interpretation 3: OFDM sequence always carries information

The set of known sequence has Ns sequences, one of the Ns sequences can be transmitted to carry log2 (Ns) bits.

FL encourage companies to share views on above interpretations to align RAN1 understanding.

*For ‘OFDM sequence can carry information’ for the overlaid OFDM sequence in WID, there can be 3 different cases*

* Case 1: OFDM sequence does not carry information. It is up to gNB implementation to transmit an overlaid OFDM sequence.
* Case 2: OFDM sequence does not carry information. gNB configures single known sequence.
* Case 3: OFDM sequence carries information. gNB configures a set of Ns known sequences, one of the Ns sequences can be transmitted to carry log2 (Ns) bits.

#### *[M][FL1] Question 3.2-1: Do you think all or a subset of 3 cases above is covered by ‘OFDM sequence can carry information’ in WID?*

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| **Company** | **Comments** |
| Nokia/NSB. | In addition, we should also consider a case, where a single OFDM sequence may carry more than a bit of information in the ON duration. |
| EURECOM | The ON-sequence(s) (OFDM sequence(s)) must be specified and hence known to the receiver in order to carry out correlations. The Specification of the ON-sequence will also benefit ED implementation since the RX filters can be designed accordingly. Hence we do not support Case 1.  We support single and multiple OFDM sequences (Case 2 and Case 3). |
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* 1. Payload of LP-WUS

Companies discuss the contents carried by LP-WUS and corresponding payload range.

For RRC idle/inactive states, LP-WUS carries UE group/subgroup information for single or multiple POs. [2] [8] [10] [14] [20] [31] [32] consider Bitmap similar as Rel-17 PEI, while some companies consider codepoint similar as NB-IoT WUS [5][6] [10]. The number of subgroups can be 8 subgroups per PO [5][7][12][36][37][38] or 32 subgroups in case of a LP-WUS associated with multiple POs [5], or even larger if the number of groups is determined based on the total number of UEs in a tracking area [39][41], e.g., >= 100 or >=300. In addition, some company [3] considers cell-specific information such a SI change, ETWS/CMAS.

For RRC connected mode, some companies consider UE group/subgroup information [6] [7] [12] [44], and many companies consider UE specific information [2] [3][5] [10][12] [20], such as C-RNTI, gNB configured bit indication (as DCI format 2-6) or sequence for a UE, and the LP-WUS can carry UE-specific information for single or multiple UEs. In addition, one company [5] considers Scell dormancy and one company [12] considers SSS switching /BWP switching.

To support above information, companies provide preferred range of payload size. [8][11][31] support up to 8 bits. [12][14] support at least 8 bits. [5] supports 4~ 14 bits. [2][17][20] support up to 16 bits. [39] supports up to 20 bits. [38] supports payload range in {8,16,24} bits. [3][29] support up to 24 bits. [32] supports up to 64 bits. According to input from companies, the maximum information bits carried by LP-WUS is at least 8 bits.

One company [7] suggests to first discuss LP-WUS signal design aspects before determination of payload range.

#### *[H][FL1] Proposal 3.3-1: The maximum information bits (excluding CRC, if any) carried by LP-WUS is at least 8 bits. FFS larger payloads.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y |  |
| Nokia/NSB. | Y |  |
| DOCOMO | Y | This is good starting point for further discussion |
| EURECOM | Y | We support this proposal. |
| Samsung | Y | As the maximum information bits, we are fine with the proposal as a starting point.  From our understanding, it can be related to the number of subgrouping and the number of PO supported by one LP-WUS transmission. Furthermore, it should achieve the target coverage. Therefore, the larger payloads can be discussed based on 9.6.2/9.6.3 discussion as well as the results of evaluation for LP-WUS with larger payloads. |

* 1. How to carry information bits by LP-WUS

Payload of LP-WUS can be carried by one of [2] [5][6][7][8][9][10][14][20] [23][26][27] [28] [29][31],

* Option 1: Encoded bits
* Option 2: OOK sequence selection.

Furthermore, time/frequency domain resource may be used together with option 1/2 [10][34][40][41][42][43] [45].

Option 1 encodes each information bit carried by one or multiple OOK symbols (if Manchester coding or other coding scheme is used). Option 2 configures a set of OOK sequences with good correlation properties, and one sequence is assigned for a specific UE/UE group/UE subgroup. For easy understanding of (1) and (2), Figure 4 from [2] is copied as below.

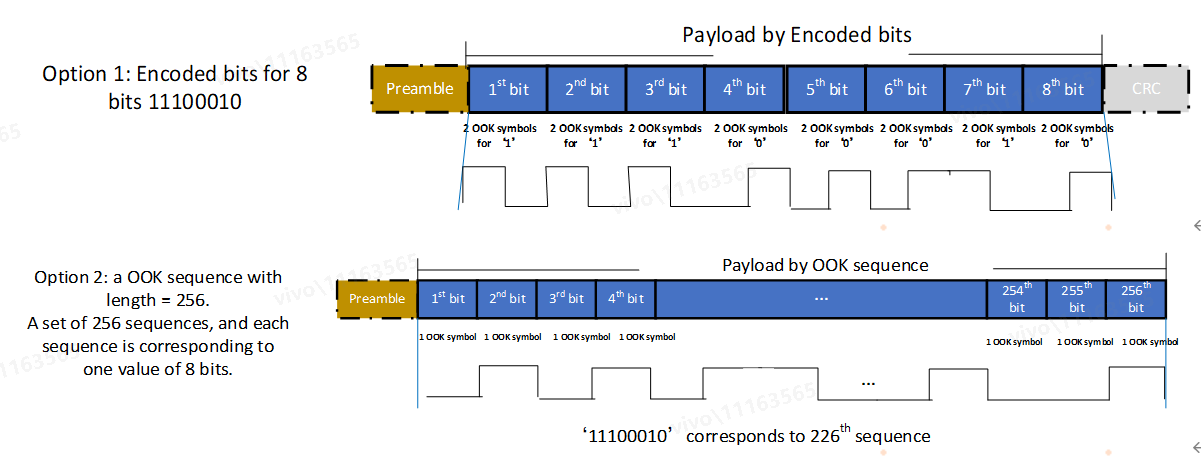


Figure 4 Time domain or frequency domain overlaid OFDM sequence

Different companies have different preference. [2][7][10][14][20][26][27][29][31] support option 1, [5][6][14][23] support option 2. [8] [9][28] are open for further discussion, considering the design highly depend on payload size of LP-WUS. To help better understanding of two options, benefit for each option provided by companies is summarized as below.

* Benefit for option 1
  + It has more flexibility in transmitting wake-up indications for single or multiple UE groups
  + It can easily support larger number of information bits, while it is challenge to find a large number of sequences with good correlation
  + It can also be complicated for the receiver to find the sequence with the highest correlation out of 256 sequences
  + It requires less standard effort, because of no sequence design.
* Benefit for option 2
  + the sequence-based LP-WUS enables more controllable performance/coverage by different number of candidate sequences and various sequence length
  + Lower overhead due to no CRC or FEC
  + Better synchronization
  + Common design for LP-WUS and LP-SS

#### *[M][FL1] Proposal 3.4-1: RAN1 further discuss how to carry information bits by LP-WUS, including following options*

* *Option 1: Encoded bits*
* *Option 2: OOK Sequence selection*
* *Time/frequency domain occasions can be combined with option above.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Support Option 1 - Manchester | This option also simplifies the processing and memory requirements on the LP-WUR, reducing power. |
| EURECOM |  | We support Option 1. Even with M=4, Option 2 will take a long time to transmit, i.e. device is ON much longer. How will overlaid OFDM sequences work in Option 2? Receiver of Option 2 seems also more complex than in Option 1. |

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| Samsung |  | What is the intention for the 3rd bullet? Both option1 and options 2 can be supported according to time/frequency domain occasion? |

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* 1. Necessity of preamble

The necessity of preamble is discussed by companies [2][3][5][6][8][11][12][14][16][20][26][31].

The necessity of preamble is determined by the tolerable timing error for LP-WUS detection and whether the maximum timing error between last LP-SS and the LP-WUS can be smaller than the tolerable error. According to timing/frequency error model in TR 38.869, timing error is derived by equation (1)

Te= ΔT+ Tr, (1)

where Tr is residual timing/frequency error Tr from calibration based on LP-SS and ΔT is additional timing drift after LP-SS. ΔT = Fr\*T ±0.5 \* F’ \*T2, if it is in transition region, or ΔT = Fe\*T, if it is linear region.

According to analysis from companies, different companies have different understanding on

1. Value of Fr.

It depends on whether LP-SS and/or MR can assist to correct frequency error. If frequency error can be corrected, then, the model of transition region is applied, otherwise, the model of linear region is applied, which lead to much larger ΔT than transition region case.

Some companies, e.g., [4] assume LP-SS can correct frequency error or MR can assist to correct frequency error, while [20] assume LP-SS does not correct frequency error and RTC clock is used for timing error.

(2) Value of T

Maximum value of T is maximum time distance between the last LP-SS and the LP-WUS. It depends on the decision of maximum LP-SS periodicity and LP-WUS periodicity.

Currently, the views are diverged, e.g., some companies prefer 320ms as upper bound of LP-SS periodicity while other companies prefer 320ms as lower bound of LP-SS periodicity.

(3) Value of Tr

The range of Tr depends on LP-SS sequence design.

Considering above 3 factors are still open, FL suggests to come back to preamble issue after progress of these factors.

#### *[M][FL1] Proposal 3.5-1: RAN1 to discuss the necessity of preamble preceding LP-WUS, considering following aspects*

* *Tolerable timing error for LP-WUS*
* *LP-SS periodicity*
* *Time/frequency error model, i.e. Fr and Tr.*

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| **Company** | **Y/N** | **Comments** |
| Everactive |  | Assume LP-SS is repeated at the same rate as the LP-WUS, e.g. every 320ms, then LP-SS can be used for timing synchronization and no preamble is required. |
| Nokia/NSB. | [Y] | If LR can use LP-SS to find the XO offset, which it should be, then the actual error while receiving LP-WUS is only the drift between LP-SS and LP-WUS. Thus, the preamble can be discussed under this framework. |
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#### *[M][FL1] Question 3.5-1: What is your view on whether LP-SS and/or MR can assist to correct frequency error?*

* *If LP-SS and/or MR can assist to correct frequency error,*
* *how to correct the frequency error?*
* *what is value of Fr?*

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| **Company** | **Y/N** | **Comments** |
| Everactive |  | LP-SS can correct the timing error – jitter accumulated due to higher ppm of the UE’s crystal oscillator. MR can assist to correct the frequency error – this is offset of the carrier frequency. |
| Nokia/NSB. | Y | LR should be able to correct frequency error to ensure reliable RRM measurements. |
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* 1. Coding

Coding is a typical tool to improve performance. Two types of coding are discussed by companies,

* Line code: Manchester coding can be decoded with simple algorithm and negligible power consumption, providing substantial gain in LP-WUS detection performance to achieve comparable coverage of Msg 3 PUSCH as studied in Rel-18.

Besides, Manchester encoding facilitates the threshold evaluation to determine the ON/OFF decision at each symbol. [3][4][7][8][9][12][17][22][29][31][33] support Manchester coding.

* FEC: simple channel coding is proposed by some companies. HW proposes hamming or RM code.

Based on majority view, FL suggests to first support Manchester coding.

#### *[H][FL1] Proposal 3.6-1: Support Manchester coding for LP-WUS.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y | Agree with supporting Manchester coding. |
| Nokia/NSB. | Y | It should be configurable, as the sequence type LP-WUS message may not need MC encoding, if the sequence is chosen to have certain property. |
| DOCOMO | Y |  |
| EURECOM | Y | Manchester coding is mandatory to support since, firstly, all of the SI analysis was done with MC and many of the results (impact of impairments) will not hold without that assumption. Second, the performance, especially in fading channels, is greatly improved because a threshold for decoding is not required. Thirdly, it facilitates overlaying OFDM sequences since the number of ON-pulses is known.  For M=4 (or similarly M>4) it is also suggested to support the simple extension of encoding 2 bits *jointly* into 4 OOK symbols instead of 1 bit to 2 OOK symbols separately. The power is concentrated into a single OOK symbol instead of 2 OOK symbols providing a significant SNR gain. |

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| Samsung | Y |  |

1. LP-SS design
   1. Waveform-selection of OOK-1 and/or OOK-4

Both OOK-1 and OOK-4 are supported by [2][8][10][16][27] for providing flexibility between resource overhead and detection performance. OOK-4 is supported/prioritized by [4][9][11][20] while OOK-1 is supported/prioritized by [21] [32]. And some companies prefer to use the same waveform as LP-WUS for LP-SS [14][25][29]. Further, similar as LP-WUS, several companies [2][4][7][8][9] also propose to support only the same SCS as NR signals is used for LP-SS generation if there is time overlapping between LP-SS and NR signals to avoid additional gNB complexity, i.e., additional IFFT modules.

#### *[H][FL1] Proposal 4.1-1: Support both OOK-1 and OOK-4 for LP-SS.*

* *S CS of a CP-OFDM symbol used for LP-SS generation is the same as SCS used for other NR transmissions in the same CP-OFDM symbol.*

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| **Company** | **Y/N** | **Comments** |
| Everactive | N | We suggest this is the same as the LP-WUS, since it will be the same hardware that is going to detect both the LP-SS and the LP-WUS. |
| Nokia/NSB. | N | Same as LP-WUS waveform, only OOK4 |
| DOCOMO |  | Unlike LP-WUS, LP-SS is used only for sync and RRM, and known sequence would be enough. We don’t see the necessity of having such flexibility, while we are open if majority want such flexibility |
| EURECOM | Y | Agree |

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| Samsung |  | Same comment with proposal 3.1-1. |

* 1. waveform-down selection between with and without overlaid OFDM sequences for LP-SS

Per WID, there is one task on down-selection between with and without specified overlaid OFDM sequences for LP-SS in WI. By going through contributions, moderator observes that the diverged part is whether to specify the overlaid OFDM sequence for OFDM-based LP-WUR, i.e., for sync and measurement purpose. Some companies consider there are no necessities for OFDM-based LP-WUR to detect LP-SS, as it can use the existing PSS/SSS for sync and RRM measurement [2] [7] [8][13][22]. Some other companies consider it’s beneficial for OFDM-based LP-WUR to detect LP-SS [4][9][10][16]. Further, some company mention that specifying overlaid OFDM sequence for OOK detection can help to provide better OOK performance when generated than left to gNB’s implementation [3].

* Reason for specifying OFDM sequence(s) from companies are summarized below:
* gives a possibility for LP-WUR with I/Q branches to be able to utilize LP-SS for time/frequency [4]
* synchronization and/or RRM measurement without RF retuning, if complete overlapping of LP-WUS/LP-SS and SSBs in the same BW within the gNB carrier BW is not guaranteed [4][9]
* Different SCS between SSB and LP-WUS may impose additional burden on LRs to adjust the reception strategy [9]
* The SSS sequence within SSB are based on m-sequence, which has very low processing gain (correlation gain) when the receiver is having a frequency offset comparable to 0.5× SCS. This may increase the initial synchronization of LRs unless there is an assistance from MR to synchronize the XO.[9]
* The performance of the sequence-based receiver using SSB for synchronization and measurement still needs to be verified. [10]
* There is essentially no additional specification work or complexity to specify the overlaid sequence for LP-SS, given that it is being specified for LP-WUS anyway.[10]
* specifying the sequence(s) does not make gNB implementation more complicated [4]
* does not require any addition resource overhead [4]
* OFDM sequence overlaid on an OOK bit can at least improve performance of coverage. [16]
* Reason for not specifying OFDM sequence(s) from companies are summarized below:
* Per WID, OFDM detector can perform RRM measurement and sync based on existing SSB in time domain without FFT.[2][7][8][13]
* OFDM detector can achieve required RRM accuracy and sync accuracy with shorter reception time based on SSB than LP-SS for better power consumption and shorter latency. [2][13]
* If LP-SS is transmitted far from the LP-WUS monitoring occasion, OFDM-based LP-WUR would require more power consumption since it needs to stay awake for a longer period to receive LP-SS. [7]
* Support of SSB and overlaid OFDM sequence for LP-SS increases work load for RAN4 on LP-WUR RRM measurement evaluation. [2] [7] [13]
* The potential drawback in overlaid LP-SS is that the overlaid signal may degrade synchronization performance of OOK receivers due to the overlaid structure which should consider both OFDM based receivers and OOK based receivers.[22]

Based on the reasons from two sides listed above, moderator observes that two sides have different views on the sync and RRM measurement performance by detecting SSS or LP-SS with overlaid OFDM sequence. For the proponents of overlaid OFDM sequences, some of them consider that the performance of detecting SSB for synchronization and measurement may be impacted by the sequence-based WUR and needs to be verified, while for the proponents of not specifying overlaid OFDM sequences, some of them consider that SSS can provide better performance than LP-SS in terms of low power consumption and low latency by considering shorter periodicity and shorter time duration of SSS than LP-SS. Further, it is also observed that work load for RAN4 will be increased if overlaid OFDM sequence is specified for sync and RRM measurement.

#### *[**H][FL1] Proposal 4.2-1: RAN1 to discuss the necessities of specifying overlaid OFDM sequence for LP-SS and down-select between with and without specified overlaid OFDM sequences for LP-SS in RAN1#116.*

Please provide inputs below on whether to support specifying overlaid OFDM sequence for LP-SS not

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y | The choice of overlaid OFDM sequence has a significant impact on the quality of the OOK signal in the time domain. Therefore it must be coupled to the generation of OOK-4 M=4 signals, and should be decided in RAN1. |
| Nokia/NSB. | N | We prefer to have LP-SS with overlay sequence, since LP-WUS carries overlay sequence and to ensure coherency between LP-WUS and LP-SS design. |

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| Samsung |  | We prefer to use LP-SS only for OOK-based LR. Therefore, it is no need to specify overlaid OFDM sequence for LP-SS. Although OFDM sequence can be used for LP-SS to flatten the spectrum, it can be designed for OOK-based LR rather than considering the performance of OFDM-based LR. If LP-SS is designed for both OOK-based and OFDM-based LR, the synchronization performance of both types of receivers should be taken into account to determine the overlaid OFDM sequence. |

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Considering the OOK waveform characteristics, designs with different pulse shaping and/or spectrum shaping lead to different performance, which shall be taken into account for OOK waveform design. This part can be jointly discussed with LP-WUS later.

* 1. LP-SS channel structure

There is a good support on sequence(s) only without encoded bits part needed for LP-SS channel structure [2] [3][4][7] [8][10][11][16][19][23][26][27][32], considering few information to be carried by LP-SS, e.g., multiple sequences could be used for distinguishing different cells.

#### *[**H][FL1] Proposal 4.4-1: Support LP-SS is based on OOK sequence*

*- FFS OOK sequence(s) details, including the sequence type, the number of sequences, and the sequence length*

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| **Company** | **Y/N** | **Comments** |
| Everactive | N | For consideration – repetitive bits are much more common for synchronization in other low-power standards such as Bluetooth and ZigBee. Therefore, instead of a sequence, the LP-SS could begin with a sequence of ‘11111111’ = which with Manchester translates to ‘0101010101010101’. This allows the LP-WUR hardware to train on timing of the OOK symbols, and also determine the optimal threshold to use for bit-slicing. |
| Nokia/NSB. | N | Other details such as frequency domain location should not be precluded at this stage. |
| DOCOMO | Y |  |

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| --- | --- | --- |
| Samsung | Y |  |

* 1. Periodicities of LP-SS

The periodicities of LP-SS depend on both sync requirement and RRM measurement accuracy requirement for OOK-based LP-WUR.

For sync requirement, it depends on the time error tolerance of the OOK detection, according to the evaluation in TR 38.869, up to 1 us is tolerable for OOK-4 with M=4 and up to 3 us is tolerable for OOK-4 M=2. Time error is mainly from the time drift as residual time error is marginal, and time drift mainly depends on the periodicity of LP-SS and the residual frequency error Fr. For example, assume Fr = 2.5ppm and T =320 ms, the time error is around 0.8us. If the residual frequency error is larger than 2.5 ppm, or the periodicity of LP-SS is larger than 320ms, the time error will increase accordingly, which may exceed the tolerable time error for OOK-4 with M=4. Therefore, the periodicities of LP-SS should be carefully selected.

For measurement requirement, from the evaluation in TR38.869, it is observed that multiple sources report 4 or 5 samples for a DRX cycle of 1.28 ms, which indicates the periodicities of LP-SS is no more than 320ms. [14]

Companies’ proposed value(s) are summarized as below:

* At least 320ms periodicity is supported. [2][12]
* The periodicities of LP-SS are not larger than 320ms [4][11]
* The periodicity of LP-SS is suggested to be 320ms [14] [33]
* Start with the following with higher values preferable: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms.[8]
* At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity [3]
* 320ms, 640ms, 960ms [32]
* The periodicity of LP-SS can use 320ms as baseline [34]
* The periodicity of LP-SS should be shorter than I-DRX cycles(1.28s) such as 320ms (start point at WID) [35]
* LP-SS periodicity should not exceed 160 ms. [36]

#### *[H][FL1] Proposal 4.5-1: Support at least 320ms as the periodicity of LP-SS*

* *FFS: other values, if needed*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y | Longer time shifts can be tolerated by turning on the LP-WUR “early” and monitoring for the LP-SS. The time between the LP-SS and the LP-WUS signals is more critical and should be minimized. |
| Nokia/NSB. |  | If LP-SS can be used to correct the frequency offset, then further relaxation should be considered. |
| DOCOMO | Y | OK as starting point |

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| Samsung | Y |  |

1. Time/frequency resource for LP-WUS and LP-SS

For time resource for LP-WUS, companies discuss the necessity of continuous monitoring [21][25], the reference point for LP-WUS time resource determination [17][24], e.g., using PO or SSB or LP-SS as reference point, multiple MOs per LP-WUS occasion [2][4][24][25], e.g., for LP-WUS repetition with or without beam sweeping or gNB transmission flexibility. For time resource for LP-SS, discussion of periodicity is captured under section 3.2.5. Within a period, LP-SS with beam sweeping is proposed by [2][12][16][27][30].

For frequency resource, candidate bandwidth and frequency location of LP-WUS and LP-SS are discussed by companies.

[2] [6] [14][17][28] prefer to support single bandwidth 5MHz for LP-WUS, because 5MHz provides bandwidth for sufficient LP-WUS energy and frequency diversity to meet coverage requirement with reasonable overhead as evaluated in SI phase, and single bandwidth can minimize LP-WUR complexity compared to support of multiple bandwidths. [2] [6] [17] prefer to support same bandwidth for LP-SS and LP-WUS to reduce LP-WUR complexity. [9][24][31] prefer configurable bandwidth to achieve different coverage.

#### *[H][FL1] Proposal 5-1: At least support a bandwidth of 5MHz including blanked guard RBs for LP-SS and LP-WUS.*

* *FFS other bandwidth sizes.*
* *Note: integer number of RBs*

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| **Company** | **Y/N** | **Comments** |
| Everactive | Y | Agree with the proposal. |
| Nokia/NSB. | [Y] | For the 5MHz BW, we assume gNB BW is at least 20MHz. |
| DOCOMO | Y in general | For clarification, is 5MHz BW applied to both idle/inactive and connected modes? Considering potential different payload size between idle/inactive and connected modes, it would be better to clarified the same BW is supported. |
| EURECOM | Y | We agree. |

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| Samsung |  | Based on the subcarrier spacing, the number of PRB can be different for 5MHz. Therefore, if we consider a single BW such as 5MHz, the number of PRB for LP-WUS is specified differently based on the subcarrier spacing. Otherwise, the different BW is supported and the BW of LP-WUS is configured as the fixed number of PRBs, only single number of PRBs can be used in the gNB side, but the complexity of LR can increase. Therefore, further discussion is necessary whether to support the fixed MHz or the fixed number of PRBs as the BW of LP-WUS. |

1. Target coverage for LP-WUS and LP-SS
   1. Assumptions alignment for target coverage

As given in WID, the target coverage of LP-WUS and LP-SS shall be the coverage of PUSCH for message 3. To meet the target coverage, it is observed that a broad range of resources for WUS and a broad range of spectral efficiency reported by companies in TR38.869. Such broad ranges mainly come from variations in the following:

* Target coverage, e.g., target SNR for LP-WUS and LP-SS
* NF assumptions for LP-WUR type
* Expected SE for WUS for different waveform types
* Receiver detection scheme

And thus, to better converge LP-WUS and LP-SS designs in WI, further alignment on such variations is required in WI phase.[2][7][8]

#### *[H][FL1] Proposal 6.1-1: Align the NF assumptions for LP-WUR by the following:*

* NF=12dB for OOK-based LP-WUR
* NF=9.5dB for OFDM-based LP-WUR without FFT

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| **Company** | **Y/N** | **Comments** |
| Everactive | Support NF=12dB for OOK LP-WUR | NF of 10-20dB is achievable for a heterodyne OOK receiver with envelop detection. The higher the required NF, the higher the power of the LP-WUR. |
| Nokia/NSB. | Y | Agree with proposal. |

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| Samsung |  | Could you provide how to obtain the values for NF in the proposal? Is it the average of values reported by companies during SI? |

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#### *[H][FL1] Proposal 6.1-2: Align the target SNR for LP-WUS and LP-SS to achieve the target coverage given in WID is required. Companies are encouraged to report the target SNR for LP-WUS and LP-SS for further alignment, together with the associated assumptions.*

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| --- | --- | --- | --- | --- |
|  | NF(dB) | # of Tx chains for LP-WUS/LP-SS transmission | MIL value of MSG3 | Target SNR (dB) |
| Companyname-01 |  |  |  |  |
| Companyname-02 |  |  |  |  |
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* 1. Coverage improvement schemes

Companies propose the following schemes to improve the coverage achieved by LP-WUS and LP-SS:

* Power boosting[4], which may not be always available for all gNBs
* Spatial diversity[4], which requires to be used with time domain repetition and precoder is transparent to OOK based receiver
* Frequency domain diversity and time domain diversity[4], where multiple repetitions are required
* Time domain spreading code[4]
* Multiple beam transmissions/beam sweeping [2][12][16][30][27]

#### *[M][FL1] Proposal 6.2-1: RAN 1 further discuss the coverage improvement, including:*

* *Time domain diversity*
* *Frequency domain diversity*
* *Transparent spatial diversity*
* *Power boosting*
* *Multiple beam transmissions/beam sweeping*

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| **Company** | **Y/N** | **Comments** |
| EURECOM | Y | Transmit diversity schemes should be transparent to the WUR. |
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1. References
2. RP-234056, New WID: Low-power wake-up signal and receiver for NR (LP-WUS/WUR).
3. R1-2400253, LP-WUS and LP-SS design, vivo
4. R1-2400495, Discussion on LP-WUS design, ZTE, Sanechips
5. R1-2400123, Signal Design of LP-WUS and LP-SS, Huawei, HiSilicon
6. R1- 2400444, Design of LP-WUS and LP-SS, CATT
7. R1-2401452, LP-WUS and LP-SS Design, Qualcomm Incorporated
8. R1-2400743, LP-WUS and LP-SS design, Samsung
9. R1-2401146, LP-WUS and LP-SS design, Ericsson
10. R1-2400962, LP-WUS and LP-SS design, Nokia, Nokia Shanghai Bell
11. R1-2401023, LP-WUS and LP-SS design, Apple
12. R1-2401317, On LP-WUS and LP-SS Design, MediaTek Inc.
13. R1-2400569, Discussion on LP-WUS and LP-SS design, Xiaomi
14. R1-2400670, Discussion on LP-WUS/LPSS design, China Telecom
15. R1-2400338, Discussion on LP-WUS and LP-SS design, CMCC
16. R1-2400811, Discussion on LP-WUS and LP-SS Design, EURECOM
17. R1-2400065, Discussion on LP-WUS and LP-SS design, Spreadtrum Communications
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19. R1-2400904, Discussion on the LP-WUS and LP-SS design, Panasonic
20. R1- 2401208, Discussion on LP-WUS and LP-SS design, Fujitsu
21. R1-2400093, Discussion on LP-WUS and LP-SS Design, Futurewei
22. R1-2400527, Discussion on LP-WUS and LP-SS design, Honor
23. R1-2400684, Discussion on LP-WUS and LP-SS design framework for Low power WUS, InterDigital, Inc.
24. R1-2400863, LP-WUS and LP-SS design, Sony
25. R1-2400272, LP-WUS and LP-SS Design, TCL
26. R1-2401150, Views on LP-WUS and LP-SS design, KT Corp.
27. R1-2401335, Discussion on LP-WUS and LP-SS design, LG Electronics
28. R1-2400473, Discussion on LP-WUS and LP-SS design, NEC
29. R1-2401126, Discussion on LP-WUS and LP-SS design, NTT DOCOMO, INC
30. R1-2400634, Discussion on LP-WUS and LP-SS design, Sharp
31. R1-2400211, Discussion on LP-WUS and LP-SS design, Transsion Holdings
32. R1-2401349, On LP-WUS and LP-SS design, Nordic Semiconductor ASA
33. R1-2400883, Discussion on LP-WUS and LP-SS design, Lenovo
34. R1-2400813, Discussion on LP-WUS and LP-SS design, Everactive
35. R1-2400591, Discussion on LP-WUS operation in RRC\_IDLEINACTIVE modes, OPPO
36. R1-2401127, Discussion on LP-WUS operation in IDLE/INACTIVE modes, NTT DOCOMO, INC
37. R1-2401318, On LP-WUS Operation in IDLE/INACTIVE Modes, MediaTek Inc.
38. R1-2400254, Discussion on LP-WUS operation in IDLE/INACTIVE modes, vivo
39. R1-2400963, LP-WUS operation in ILDE/Inactive mode, Nokia
40. R1-2400124, Procedures and functionalities of LP-WUS in IDLE/INACTIVE mode, Huawei, HiSilicon
41. R1-2400445, System design and procedure of LP-WUS operation for UE in IDLE/Inactive Modes, CATT
42. R1-2400496, Discussion on LP-WUS operation in IDLE/INACTIVE mode, ZTE
43. R1- 2400744, LP-WUS operation in IDLE/INACTIVE modes, Samsung
44. R1-2401336, Discussion on LP-WUS operation in IDLE/INACTIVE modes, LG Electronics
45. R1-2401319, On LP-WUS operation in CONNECTED modes, MediaTek Inc.
46. R1-2400340, Discussion on LP-WUS operation in CONNECTED mode, CMCC
47. Appendix : Proposals from contributions

**R1-2400253 vivo**

**Proposal 1: Do not support OOK-1 with different SCS than NR transmission in the same CP -OFDM symbol to avoid additional gNB implementation complexity.**

**Proposal 2: For both LP-WUS and LP-SS, support OOK-4 with variable M =1, 2 or 4, wherein OOK-1 can be supported by OOK-4 with M=1.**

**Proposal 3: The following aspects should be considered for overlaid OFDM sequence design:**

* **For single or multiple OFDM sequences, OOK detection performance should not be compromised due to OFDM sequence.**
* **For single or multiple OFDM sequences, the sequence should flatten the spectrum for frequency diversity and comply with existing RE power dynamic range in frequency domain.**
* **For multiple OFDM sequences, the sequence should have good cross-correlation.**

**Proposal 4: To specify overlaid OFDM sequences for OOK-4, considering the following two options:**

* **Option 1: Specify time domain OFDM sequence per OOK ON symbol, and specify each block of OOK-4 waveform generation. Existing sequence such as ZC sequence, m sequence and gold sequence can be the starting point.**
* **Option 2: Specify frequency domain OFDM sequence per OFDM symbol.**

**Proposal 5: Do not specify overlaid OFDM sequence for LP-SS for OFDM-based LP-WUR. LP-WUR with OFDM detector can use legacy PSS/SSS for RRM and sync.**

**Proposal 6: No less than 8 subgroups by LP-WUS should be supported for RRC idle/inactive state.**

**Proposal 7: Up to 16 information bits carried by LP-WUS should be supported for RRC connected state.**

**Proposal 8: The upper bound of number of information bits carried by LP-WUS (not including CRC) should be 16 bits. The number of information bits per LP-WUS within the upper bound can be flexibly configured by gNB.**

**Proposal 9: For common design for RRC idle/inactive and RRC connected mode, RAN1 further discusses pros and cons for OOK sequence selection and encoded bits for LP-WUS payload, with consideration of variable payload sizes up to 16 bits, variable use case (wake-up one and/or multiple UEs simultaneously), target performance, reasonable overhead, robustness to timing and frequency error, latency and standard effort.**

**Proposal 10: To decide the necessity of preamble, RAN1 first discusses the assumption on the frequency error correction by OOK-based LP-WUR using LP-SS and/or by the aid of MR.**

**Proposal 11: Support OOK sequence without payload for LP-SS.**

**Proposal 12: RAN1 discusses single OOK sequence or multiple OOK sequences is needed for LP-SS, with consideration of RRM and sync accuracy, robustness to inter-cell interference and standard effort.**

* **For single sequence, RAN1 specifies the single sequence, which is applicable to all cells.**
* **For multiple sequences, RAN1 specifies multiple sequences, and gNB configures one sequence for a cell**

**Proposal 13: Support periodic LP-SS transmission with beam sweeping within each period. At least 320ms periodicity is supported, FFS other values, if needed.**

**Proposal 14: For LP-WUS,**

* **Support LP-WUS with beam sweeping and multiple occasions per beam within each period for RRC idle/inactive state.**
* **Support LP-WUS with multiple occasions associated with a given beam within each period for RRC connected state.**

**Proposal 15: Support single 5MHz bandwidth for LP-WUS and LP-SS for all RRC states. Support flexible frequency location of LP-WUS/LP-SS, which can be independent from DL initial BWP as well as the carrier serving MR.**

**Proposal 16: Support Manchester coding for LP-WUS. Not support Manchester coding for LP-SS.**

**Proposal 17: Support RSRP and RSRQ as metrics for RRM measurement by LP-WUR**

* **For LP-WUR with OOK detector, RRM measurement is performed in time domain over the whole measurement bandwidth based on LP-SS.**
* **RSRP is linear average of received power of reference signal in OOK ON symbols of LP-SS.**
* **RSRQ = RSRP/RSSI, where RSSI is linear average of total received power over RSSI resources. The RSSI resource can be OOK OFF symbols of LP-SS, or all OOK symbols of LP-SS per gNB configuration.**
* **For LP-WUR with OFDM detector, RRM measurement is performed in time domain over the whole measurement bandwidth based on SSB.**

**Proposal 18: The required SNR value(s) should be determined for LP-WUS and LP-SS design to achieve the coverage target, e.g.,**

* **For OOK-based LP-WUR, further narrow down the required SNR value(s) within the range of [-0.58 7.06] dB for # of TX chains=1.**
* **For OFDM-based LP-WUR, further narrow down the required SNR value(s) within the range of [1.42 9.06] dB dB for # of TX chains=1.**

**Proposal 19: Use table 6 and table 7 in appendix 10.1 as evaluation assumptions for LP-WUS and LP-SS.**

**R1-2400495 ZTE, Sanechips**

***Proposal 1: OOK-4 waveform generation mechanism should be specified according to step1~step6.***

***Proposal 2: OOK-1 waveform should be generated by OOK-4 waveform generation mechanism.***

***Proposal 3: LP-SS and LP-WUS have the same CP length, and M value as starting point.***

***Proposal 4: The interference caused by NR signal/channel multiplexing could be further studied.***

***Proposal 5: For OOK-4, if OFDM sequences are used for carrying information, ZC sequence is preferred.***

***Proposal 6: Decide whether FFT block or time domain correlation is assumed for OFDM receiver.***

***Proposal 7: Adding CRC for LP-WUS payload is necessary for both OOK based and OFDM sequence based LP-WUS transmission.***

* ***8 or 10 bit length CRC is a starting point.***

***Proposal 8: For OOK based LP-WUS, Manchester code with code rate of at least 1/2 and 1/4 should be supported.***

***Proposal 9: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity.***

***Proposal 10: Cell specific information can be carried via LP-SS.***

***Proposal 11: If LP-SS carries cell specific information, the OFDM receiver is required to monitor LP-SS. If LP-SS does not carry any information, it could be up to UE implementation to decide whether to receive SSS or LP-SS.***

***Proposal 12: If OFDM receiver uses LP-SS for measurement, discuss RAN4 impacts and whether RRM performance is satisfied.***

***Proposal 13: For LP-SS, overlaid sequence could be considered***

* ***FFS whether overlaid sequences carry information***

***Proposal 14: Consider multiple 0-1 sequences for LP-SS as starting point.***

***Proposal 15: Preamble part can be considered in front of LP-WUS for detection performance impacted by timing error.***

***Proposal 16: For LP-WUS in IDLE/INACTIVE mode, irrespective of LP-WUR type, the same information carried by overlaid OFDM sequences and OOK symbols can be a starting point.***

* ***LP-WUS payload size can be up to 24bits.***

***Proposal 17: Both cell specific and Group specific LP-WUS could be supported.***

***Proposal 18: For information carried by OFDM sequence based LP-WUS, the number of blind detection times for OOK symbol with “ON” state should be considered.***

***Proposal 19: LP-SS could be used as a part of LP-WUS to save NW resources.***

***Proposal 20: For LP-WUS, at least the design of structure, payload size and carried information should be considered separately for IDLE/INACTIVE and CONNECTED modes.***

**R1-2400123 Huawei, HiSilicon**

1. ***Both OOK1 and OOK4 with overlaid sequence(s) are supported, where OOK-1 is specified as a special case of OOK-4 with M=1.***
2. ***Only the same SCS between LP-WUS and legacy NR signals that UE MR processes is supported.***
3. ***Support the following design***

* ***All the bits carried by one LP-WUS are divided as bit block 1 and bit block 2,*** 
  + ***Bit block 1 is carried by/modulates the ON/OFF pattern of the first M OFDM symbols***
  + ***Bit block 2 is carried by/modulates the overlaid sequences in the first M OFDM symbols.***
    - ***According to bit block 2, one overlaid OFDM sequence selected from a set of candidate OFDM sequences is on each OOK ON symbol***
    - ***Bit block 2 can also modulate the ON/OFF pattern of the remaining N-M OFDM symbols.***
* ***One LP-WUS consists of N OFDM symbols***

1. ***Further discuss and adopt sequence(s) considering the following aspects:***
   1. ***Sequence with good auto-correlation property and cross-correlation property***
   2. ***How to control the interference from LP-WUS transmitted from neighboring cells***
2. ***ZC sequences are considered as a starting point for the design of overlaid sequence(s).***
3. ***Pulse shape and/or spectrum shape are also considered in the design/selection of overlaid sequence(s).***
4. ***Support overlaid sequence(s) with a number of zero value samples at the beginning and the end of the sequence to have a concentrated waveform for time domain pulse shaping of LP-WUS.***
5. ***The value of ACS/ASCS should be further converged in WI phasein RAN4, which may have impact on LP-WUS/LP-SS design in RAN1.***
6. ***Time domain repetition and transmit diversity by precoder cycling are considered to improve the performance of LP-WUS.***
7. ***Coverage recovery schemes that exploits time / frequency diversities are considered.***
8. ***Binary spreading sequences are considered to multiplex WUSs on the same time-frequency resource and to improve the BLER.***
9. ***As the starting point, the waveform of LP-SS can have similar design as LP-WUS, including at least the following aspects：***
10. ***pulse shaping methods, including the concentrated waveform and the spectrum adjustment***
11. ***overlaid sequence(s)***
12. ***Consider LP-SS specific design requirement, including at least larger guard band/subcarrier, and shorter OOK symbol length.***
13. ***The design of LP-SS should consider the CP impact and the length of binary-valued sequence to generate LP-SS.***
14. ***For the OOK sequence of LP-SS, consider at least the following design principles***
15. ***Binary sequence with good auto-correlation property***
16. ***Limited length of consecutive '0's***
17. ***'0's and '1's inside the binary sequence are balanced***
18. ***A set of candidate values for LP-SS periodicity can be defined, which are not larger than 320ms.***
19. ***For serving cell RRM measurement offloaded from MR to LP-WUR, LP-RSRP and LP-RSRQ are introduced and specified as LP-SS based metrics.***
20. ***Further discuss whether existing SS-RSRP definition is reused for RRM serving cell measurement by OFDM based LP-WUR or define new LP-RSRP2 and LP-RSRQ2 by using existing SSS for LP-WUR that can receive PSS and SSS.***

**R1- 2400444 CATT**

**Proposal 1: The same information set could be configured to have transmission time interval differently for OOK and OFDM receiver in the LP-WUS design.**

**Proposal 2: The payload size of LP-WUS to be considered is** **in the range of 4~14 bits within one slot.**

**Proposal 3: OOK-1 modulated by OFDM sequence can be considered as a special case of OOK-4 modulated by OFDM sequence with M = 1. The LP-WUS could consider OOK-4 waveform could be supported with configurable value of M in consideration of the tradeoff between the network overhead of LP-WUS resource and the UE power consumption.**

**Proposal 4: The OFDM sequence to be modulated on the OOK waveform for LP-WUS should consider existing NR OFDM sequence, such as FFT, M-sequence, and Zadoff-Chu, to minimize the implementation cost and complexity of OFDM receiver by reusing the NR receiver components.**

**Proposal 5: The sequence with interference mitigation property such as low cross-correlation is not the critical for the selection of the OFDM sequence overlaid on the OOK waveform since the inter-cell interference mitigation is not expected to be critical for LP-WUS signals with smaller coverage area.**

**Proposal 6: The LP-WUS is multiplexed with NR DL channel/signals after the FFT to minimize the LP-WUS detection performance degradation with timing and frequency error. The FFT sequence is the best candidate of the OFDM sequence overlaid on OOK waveform with the FFT size is the 2x sub-multiple of IFFT size of system bandwidth.**

**Proposal 7: The Manchester channel coding scheme should be the candidate as the LP-WUS channel coding scheme.**

**Proposal 8: It is recommended to support a LP-WUS structure with wake-up information preceded by a fixed preamble sequence for assisting synchronization.**

**Proposal 9: The LP-WUS should be designed based on the sequence with simple non-coherent detection. The sequence of the short LP-WUS bits can be further protected by a set of orthogonal sequence, e.g., Walsh code, with spreading gain and error detection capability.**

**Proposal 10: For RRC\_IDLE/INACTIVE modes, the sequence based LP-WUS with orthogonal sequence grouping should be sufficient in indicating the paging subgroup and bundling subgroups.**

**Proposal 11: For RRC\_CONNETDE mode, the LP-WUS could be configured for the indication of UE wakeup in DRX adaptation and SCell dormancy. The LP-WUS can be configured for one or more UEs within the constraints of the payload size.**

**Proposal 12: The LP-SS should be multiplexed with NR channels/signals after the FFT in order to retrieve LP-SS without needing the FFT processing at the receiver. If the LP-SS is designed with the OOK-1 waveform modulated by FFT sequence, it can mitigate the inter-channel interference to neighboring NR channel/signals to the NR UE when it performs FFT processing even though the timing and frequency offset estimation is more challenged when OOK-1 waveform modulated by OFDM sequence.**

**Proposal 13: For structure of LP-SS, a fixed known preamble sequence concatenated with truncated cell ID information module could be considered in the LP-SS sequence design.**

**R1-2401452 Qualcomm Incorporated**

***Proposal 1: LP-WUS and LP-SS are not received by the UE in UL symbols determined by tdd-UL-DL-ConfigCommon*. *For connected mode UE, LP-WUS and LP-SS are also not received in UL symbols determined by tdd-UL-DL-ConfigDedicated.***

***Proposal 2: LP-WUS and LP-SS are configured in the same 4.32MHz bandwidth which contains 12RBs for 30kHz SCS.***

***Proposal 3: UE is allowed to only support OOK based LP-WUS detection.***

***Proposal 4: Support sequence-based LP-WUS design with one sequence associated with one or multiple UE groups.***

***Proposal 5: Support hybrid LP-SS transmission with periodic LP-SS and preamble of the LP-WUS.***

***Proposal 6: OOK symbols of the LP-SS is a sequence that carries the cell ID information. The overlaid OFDM sequence is a known sequence configured for the cell.***

**R1-2400743 Samsung**

**Proposal 1: The following options can be down-selected to generate OOK waveform after the evaluation for overlaid OFDM sequences depending on how to generate/receive overlaid OFDM sequences over OOK symbol.**

* **Option 1: The number of ON/OFF pulse within OFDM symbol is 1 (OOK-1).**
  + **Only support of same numerology for LP-WUS as that for other channel multiplexed.**
* **Option 2: The number of ON/OFF pulses within OFDM symbol (M) is provided by gNB, and UE can determine the pulse duration of ON/OFF pulse based on the value of M.**
  + **FFS: Whether/how to specify the overlaid OFDM sequences received by OFDM-based LP-WUR commonly applicable regardless of M.**

**Proposal 2: Based on the evaluation in the study phase, suggest to limit the maximum pulse rate as X kpps.**

* **X = 56kpps as the starting point. (FFS: whether to support 112kpps).**
* **X can be used to decide the acceptable residual error range of LP-SS.**

**Proposal 3: Support Manchester coding, at least for LP-WUS.**

* **FFS: Whether Manchester coding can be applied for LP-SS.**

**Proposal 4: The overlaid OFDM sequences should be applied per OOK symbol duration.**

**Proposal 5: Support to specify multiple candidates of OFDM sequence to carry multi-bit information over On-pulse of OOK symbol, at least for reduction of LP-WUS monitoring time of OFDM-based LP-WUR.**

* **FFS: how many sequences to be specified considering the achievement of the target coverage, total payload size carried by LP-WUS, and LP-WUR detection complexity.**

**Proposal 6: The overlaid OFDM sequences shall be designed based on the type of sequence used in NR synchronization signal/reference signal/random access channel.**

* **Candidates for the sequences type: M-sequence, Gold sequence, Zadoff-Chu sequence.**
* **FFS: how to generate ON pulse of OOK symbol with the candidates for sequences type.**

**Proposal 7: The information carried by LP-WUS can be discussed separately for RRC IDLE/INACTIVE state and RRC connected state.**

* **For all RRC states, wake-up indication for UE group/UE subgroup shall be supported by LP-WUS.**
* **Other additional information that should be carried by LP-WUS can be discussed in 9.6.2 and 9.6.3.**

**Proposal 8: A message-based channel structure for LP-WUS received by OOK-based LP-WUR can be designed with the following potential options for indicating wake-up information:**

* **Option 1: Bit-field-based Indication**
* **Option 2: Vector-based Indication**
* **Note: CRC bits are also transmitted to reduce the false alarm rate of OOK-based LP-WUS reception.**
* **FFS: How to carry the same wake-up information for UE with OFDM-based LP-WUR over the message-based LP-WUS if multiple OFDM sequences are specified for a single OOK ON pulse.**

**Proposal 9: To decide the payload size of LP-WUS, the following aspects to be discussed in advance.**

* **Channel structure of LP-WUS (e.g., vector-based or bit-field indication).**
* **The number of (sub)group to be supported by the single LP-WUS transmission.**
* **The maximum amount of resource that can be allocated for the single LP-WUS transmission including payload and CRC.**
* **The required amount of resource to achieve the target coverage.**

**Proposal 10: LP-SS should be designed for synchronization and serving cell RRM measurement of UEs with OOK-based LP-WUR.**

* **UEs with OFDM-based LP-WUR should not use LP-SS for synchronization and serving cell RRM measurement.**
* **FFS: How to generate ON pulse for LP-SS and whether to specify the generation method.**

**Proposal 11: Sequence-based channel structure can be applied to LP-SS design.**

* **FFS: the sequence type and the number of sequences used for LP-SS. 3 can be considered as the starting point considering the number of sequences for PSS in NR system.**

**Proposal 12: Measurement metric for LP-SS should be defined considering the following potential candidates:**

* **RSRP/RSRQ measured by LP-SS.**

**Proposal 13: For a comparison between various LP-WUS/LP-SS design candidates, the following option 1 and/or option 2 can be considered.**

* **Option 1: Align the required SNR as the target SNR used to determine whether LP-WUS/LP-SS achieves the target coverage.**
* **Option 2: Align the evaluation assumptions as much as possible to reduce the divergence of the results.**

**Proposal 14: Consider the evaluation assumption for the overlaid OFDM sequence as follows:**

* **For overlaid OFDM sequences evaluation, N should be provided where N is the number of overlaid OFDM sequence(s) which can be transmitted over ON pulse of OOK symbol**
* **According to N, multiple information bits can be carried within 1 ON pulse of OOK symbol.**
* **The details on how to generate OOK-1 or OOK-4 waveform with the overlaid sequence should be provided by companies.**

**Proposal 15: At least for evaluation of the overlaid OFDM sequence, the definition of FAR should be aligned between companies considering the number of cases in which LP-WUS for the target UE group are not transmitted.**

**Proposal 16: For evaluation of LP-WUS/LP-SS, the residual error after the reception of designed LP-SS should be considered to evaluate LP-WUS performance.**

* **Companies should report the residual error value and how to achieve the reported error value.**

**R1-2401146 Ericsson**

[**Proposal 1** **Following principles should be considered for LP-WUS and LP-SS design**](#_Toc159213608)

[**a.** **It should be possible to generate LP-WUS/LP-SS transmissions using existing gNB hardware and not trigger any new emissions or compliance requirements.**](#_Toc159213609)

[**b.** **It should be possible to multiplex the LP-WUS/LP-SS with other NR transmissions in time or frequency domain without causing interference.**](#_Toc159213610)

[**c.** **It should be possible to reuse any unused LP-WUS time and frequency resources for other transmissions.**](#_Toc159213611)

[**Proposal 2** **Paging misdetection performance of the UE should not be impacted when LP-WUS is used by the UE for power savings.**](#_Toc159213612)

[**Proposal 3** **Same sub-carrier spacing (SCS) should be used for LP-WUS and other NR transmissions in the same CP-OFDMA symbol.**](#_Toc159213613)

[**Proposal 4** **SCS used for LP-SS and Idle mode LP-WUS transmission should be same as the SCS used for initial BWP.**](#_Toc159213614)

[**Proposal 5** **Including a preamble part before the data part of LP-WUS transmissions should be considered.**](#_Toc159213615)

[**Proposal 6** **Performance of sequence-based and payload-based LP-WUS structures should be studied further.**](#_Toc159213616)

[**Proposal 7** **WUS payload size should be at most 8 bits in Idle/Inactive. Similar payload size should be considered for Connected mode.**](#_Toc159213617)

[**Proposal 8** **OOK-1 should be supported for LP-WUS. If OOK-4 is also supported, it should be with small M (e.g., M ≤ 4).**](#_Toc159213618)

[**Proposal 9** **LP-WUS design should allow OFDM-based LP-WUR to detect the information sent using OFDM sequences using a smaller monitoring duration compared to that of OOK-based LP-WUR (which detects information sent via OOK).**](#_Toc159213619)

[**Proposal 10** **It should be possible for NW to flexibly configure the placement of LP-SS resources in frequency and time to minimize overhead and NW energy efficiency impact.**](#_Toc159213620)

[**Proposal 11** **Consider following values for configuring LP-SS periodicity: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms (higher values preferred).**](#_Toc159213621)

**R1-2400962 Nokia Shanghai Bell**

1. **Consider scalable design for LP-WUS/LP-SS to support multiple BW options depending on the deployment scenario. For initial evaluation, 5MHz LP-WUS BW can be used.**

**The position of LP-WUS/LP-SS within the carrier BW should be flexible and configurable by the NW.**

**OOK4 modulation scheme should be prioritized for the WI as it reduces the generation complexity significantly compared to OOK1 scheme.**

**The considered modulation order is limited to the values considered in the SI, i.e., . Further discuss whether the is fixed or configurable and adaptive.**

**The use of Manchester encoding for OOK scheme should be considered if there is no preamble field in LP-WUS frame structure.**

**Explore if there are more efficient alternatives to Manchester encoding. e.g., a preamble followed by b/b or in general bit encoding for rest of the signal.**

**Evaluate further the options of applying pulse shaping in the ON duration of OOK symbols accounting impact on the gNB transmission.**

**The time-frequency resources used for LP-WUS should be the same irrespective of the device type used as LR, i.e., LR type specific LP-WUS transmission should be avoided.**

**The number of overlay sequences used to provide more information in a single ON duration of OOK signal should consider the underlying modulation order, i.e., , used by OOK signal.**

**The correlation gain and cross-correlation between sequences diminish with the increase in used by the underlying OOK sequence, since increasing reduces the ON duration length, i.e., sequence length of embedded sequence itself.**

**Polyphase sequence like Zadoff-Chu, which also falls under CAZAC family, should be considered as an overlay sequence due to its robustness against frequency offset.**

**Embedding a constellation symbol on the overlay sequence, like chip sequence, provides more information bits per ON duration for SD receivers compared to OOK based ED receivers.**

**RAN1 should evaluate whether LP-WUS requires a preamble or not and if so, the design of it should be discussed.**

**RAN1 should evaluate whether LP-WUS requires a CRC field or not and if required, then the size and the polynomial used should be defined.**

**RAN1 should evaluate the content and the structure of LP-WUS payload.**

**As the performance of payload-based and sequence-based LP-WUS structure depends on the length of the message content, RAN1 should first decide the range of the information content of the LP-WUS message.**

**Unified waveform design between LP-SS and LP-WUS would be beneficial from LR implementation, thereby choosing OOK4 modulation type should be prioritized.**

**The modulation order used by LP-SS should be restricted to with Manchester encoding to ensure better coverage and to facilitate accurate measurements for RRM purposes.**

**As the LP-SS benefit all kind of LRs, i.e., SD only, ED only, and dual mode receivers, i.e., ED + SD, overlaying a sequence in the ON duration and aligning the waveform design to LP-WUS should be selected.**

**LP-SS should provide both time and frequency synchronization to LRs of all types with minimal real-time constraints on the reception.**

**R1-2401023 Apple**

**Proposal 1: Specify both OOK-1 and OOK-4, with OOK-1 being considered as a special case of OOK-4 with M=1.**

**Proposal 2: For the LP-WUS structure, further consider the following options:**

* **Option 1: preamble + payload [+ CRC]**
* **Option 2: payload [+ CRC]**

**Proposal 3: It should be investigated what assumption can be made regarding the frequency tracking capability of an OOK-based receiver.**

**Proposal 4: For idle/inactive UEs, subgroup-based wake-up indication is supported for LP-WUS. Consider the following options for the wake-up indication:**

* **Option 1: use a bitmap, with one bit per subgroup**
* **Option 2: indicate the subgroup index directly**

**Proposal 5: For connected UEs, UE-specific wake-up indication is supported for LP-WUS.**

**Proposal 6: Further consider carrying full or partial cell ID information in the LP-WUS.**

**Proposal 7: The additional information carried in LP-WUS should be avoided or minimized.**

**Proposal 9: Consider the design options (e.g. large number of bits per OOK symbol, different coding schemes for bits carried on the overlaid sequences, and/or different bit ordering) that can enable early detection of LP-WUS by a sequence-based receiver.**

**Proposal 10: LP-SS uses a bit sequence. The following should be considered for the bit sequence design:**

* **The bit sequence should have good auto-correlation property**
* **Different cells should be able to use different bit sequences for LP-SS, and these sequences should have good cross-correlation properties**

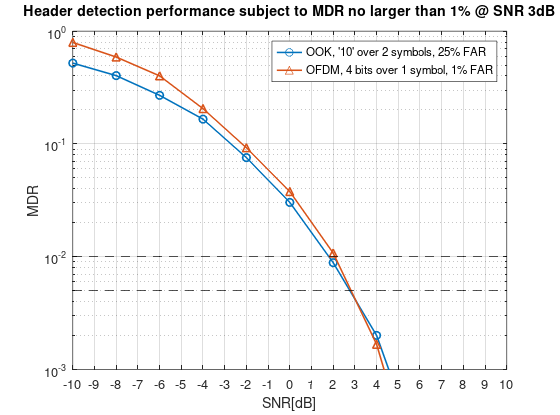
**Proposal 11: Specify overlaid sequences for LP-SS, similar to LP-WUS.**

**R1-2401317 MediaTek Inc**

**Proposal 1: Harmonized waveform design should aim for minimization of RF reception time for both OFDM and OOK WURs.**

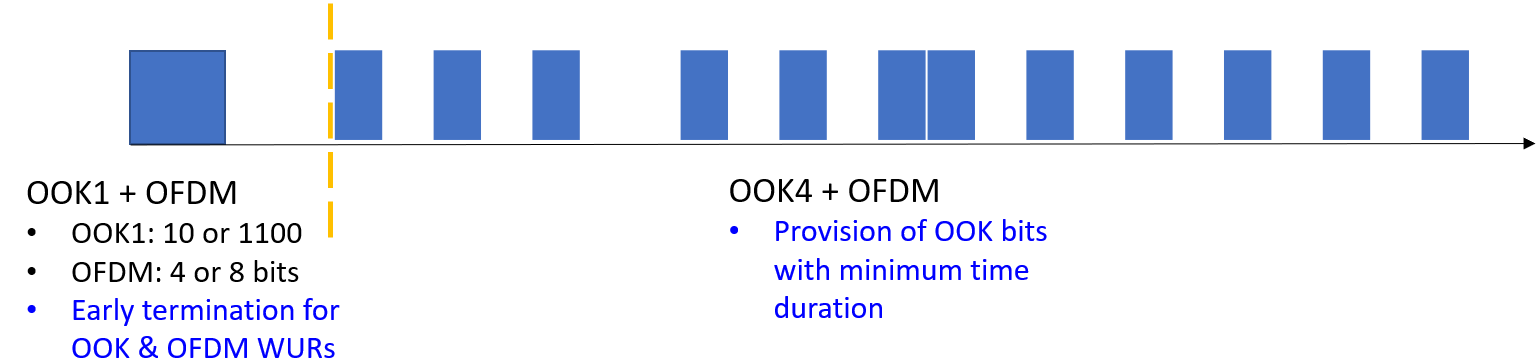
**Observation 4: With a dedicated OOK-1 + OFDM header design in LP-WUS,**

* **OOK WUR can skip 75% dummy LP-WUS monitoring**
* **OFDM WUR can confine LP-WUS RF reception time within 1- 2 symbols**



**Figure 2‑4: Feasibility of detecting the OOK-1 + OFDM header for early termination**

**Proposal 2: Introduce an OOK-1 + OFDM header for LP-WUS for reducing RF reception time for both OOK and OFDM WURs.**



**Figure 2‑3: LP-WUS structure with OOK-1 + OFDM header and OOK-4 + OFDM body.**

**Proposal 3: In addition to OOK-1 + OFDM header, the remaining part of LP-WUS applies OOK-4 + OFDM.**

* **OOK-4 design aims for minimum time duration for up to 8 bits of subgroup indication**
* **FFS: New OFDM sequence under OOK-4 on-duration for optimizing PAPR and/or OOK WUR detection performance**

**Observation 5: LP-SS is for serving cell measurement. To avoid confusion of measuring a neighbor cell LP-SS, LP-SS design should include multiple sequences for distinguishing serving cell from 2 or 3 neighbor cells.**

**Proposal 4: At least 3 or 4 LP-SS sequences are supported for Rel-19.**

**Proposal 5: LP-SS design targets 90%-percentile measurement accuracy with RSRP difference < 3dB at -6 dB SNR for one-shot measurement**.

**Proposal 6: LP-SS design targets 90%-percentile synchronization accuracy with residue timing error < 3 us at -6 dB SNR for one-shot synchronization**.

**Table 1: Tolerance to timing error by waveform (quoted from Secion 8.3.1 of TR 38.869 [2])**

|  |  |
| --- | --- |
| **Waveform** | **Tolerance up to timing error [us]** |
| OOK-1 30kHz SCS | 5 |
| OOK-4 M=2 | 3 |
| OOK-4 M=4 | 1 |
| OOK-4 M>4 | 1 |

**Proposal 7: OOK-4 + OFDM waveform design used for LP-WUS can be reused for LP-SS.**

**R1-2400569 Xiaomi**

***Proposal 1：If relatively small bitrate carried in LP-WUS, OOK-1 modulation should be discussed as the baseline for LP-WUS.***

***Proposal 2：Both OOK-1 and OOK-4 could be further discussed for LP-SS.***

***Proposal 3：Same and different SCS between LP-WUS/LP-SS and other NR channel/signals in an OFDM symbol could be both supported in RAN1.***

***Proposal 4：Preamble could be supported in LP WUS for better synchronization performance when longer periodicity of LP-SS is configured.***

***Proposal 5：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS***

***Proposal 6：The full discussion of option 1 in RAN1 is imperative, while the potential benefits of option 2 can be explored if sufficient time permits.***

***Proposal 7：LP-WUS information could be carried by overlaid OFDM sequence(s) over OOK symbol in LP WUS with shorter duration for shorter latency. Or overlaid sequences could be detected throughout the entire duration of LP-WUS to ensure reliability and coverage.***

***Proposal 8：***

* ***A fixed OOK pattern can be used for LP-SS for minimal impact for OOK based receivers.***
* ***At least cell ID can be indicated by LP-SS indicated by different time-frequency resource positions or explicitly by overlaid OFDM sequences***

***Proposal 9：In RRC idle/inactive state***

* ***At least UE sub-group ID is indicated in LP WUS, similar as PEI.***
* ***Maximum payload size for UE subgrouping in LP-WUS is at least [8].***
* ***Other information such as PWS can be further discussed if need.***

***Proposal 10：In RRC connected state***

* ***A LP WUS occasion can correspond to one or multiple UEs, with separate indication for each UE/UE subgroup.***
* ***SSSG switching/ BWP switching could also be considered in LP WUS.***

***Proposal 11：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.***

***Proposal 12：The duration of LP-SS can be 4 or 8 symbols, to facilitate the choice of OFDM symbols of LP-SS considering the existing time domain pattern of SSB.***

***Proposal 13： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.***

***Proposal 14:***

* ***The*** ***reference frequency of LP-SS should be further discussed.***
* ***The bandwidth of LP-SS is no more than 5MHz.***

***Proposal 15：Both options for LP WUS and NR channel multiplexing can be considered in RAN1. Collisions handling is needed to prevent potential collisions between LP-WUS/LP-SS and legacy NR channels.***

***Proposal 16：If coverage enhancement is needed，the following should be further discussed.***

* ***Robust coding, e.g., Manchester coding***
* ***Lower bit rate, e.g., 0.25, 0.5, 0.67***
* ***Time domain repetition***
* ***Power boosting, e.g. Power offset to SSB for LP-SS***

**R1-2400670 China Telecom**

***Proposal 1: A suitable OFDM sequence design shall be considered based on the following aspects:***

* ***Sequence types, such as ZC sequence, Gold sequence or some predefined sequence***
* ***Sequence generation parameters, such as u/v values in the ZC sequence generation procedure***
* ***Payload size carried on the corresponding sequence.***

***Proposal 2: LP-WUS generation description in the potential spec. may including the following section:***

* ***General***
* ***Sequence generation***
* ***LP-WUS format 0/1***

***Proposal 3: OOK-1 LP-WUS generation description in the potential spec. may include the following section:***

* ***Sequence modulation***
* ***Mapping to virtual resource blocks if necessary***
* ***Mapping to physical resource blocks***

***Proposal 4: OOK-4 LP-WUS generation description in the potential spec. may include the following section:***

* ***Rate match to generate signal blocks***
* ***Sequence spread or sequence modulation based on the target signal bandwidth***
* ***DFT precoder***
* ***Central part repetition***
* ***Mapping to virtual resource blocks if necessary***
* ***Mapping to physical resource blocks***

***Proposal 5: The scheme ‘central part repetition’ should be supported based on following steps:***

* ***Generate a DFT precoding input with bandwidth R***
* ***Generate multiple DFT precoding inputs based on different frequency start position***
* ***Cut off the side lobe***
* ***Sequential splicing***

***Proposal 6: Not considering overlaid OFDM sequence in the LP-SS design.***

***Proposal 7: Only duty-cycled monitoring is better to be utilized in the monitor mechanism.***

**R1-2400338 CMCC**

**Proposal 1: Consider mapping frequency domain samples to the existing constellation, e.g., QPSK, 16QAM, 64QAM.**

**Proposal 2: Preamble is necessary for LP-WUS to tolerate time error.**

**Proposal 3: The following options can be considered for LP-WUS structure design:**

* **Part 1: LP-WUS preamble signal.**
* **Part 2: LP-WUS information signal.**
  + **Option1: payload+CRC**
  + **Option2: sequence 1(wake-up or not)+sequence 2(additional information)**

**Proposal 4: The payload size is suggested to set at least 8 bits and the CRC size at least to be 10 bits in Option 1.**

**Proposal 5: Consider the following sequence design in Option 2 (sequence based) are investigated considering comparable coverage to the Msg3:**

* **For sequence 1 part:**
  + **Alt 1a: one 4 symbol length sequence for carrying 1-bit(e.g,,presence/absence) information;**
  + **Alt 1b: one 8 symbol length sequence for carrying 1-bit(e.g,,presence/absence) information.**
* **For sequence 2 part:**
  + **Alt 2a: 4 symbol length sequence,carrying 1-bit, and eight 1-bit sequences are concatenated carrying total 8-bit;**

**Alt 2b: 8 symbol length sequence carrying 2-bit, and four 2-bit sequences are concatenated carrying total 8-bit.**

**Proposal 6: Regarding LP-WUS resources occupation, at least 4 symbols per bit can be considered which is comparable to msg3 coverage with 3dB reservation.**

**Proposal 7: The following alternatives can be considered for overlaid OFDM sequence on LP-WUS:**

* **Alt 1: Overlaid sequences are carried on LP-WUS payload signal part**
  + **Alt 1-1: total information on every ‘ON’ duration , e.g., 8-bit information is repeated in every ‘ON’**
  + **Alt 1-2: total information on one ‘ON’ duration, e.g., 8-bit information is carried on the first or last ‘ON’**
  + **Alt 1-3: information are split and carried on multiple ‘ON’ duration , e.g., 4 ‘ON’ duration and each carries 2-bit information**
  + **Alt 2: Overlaid sequences can also be carried by LP-SS.**

**Proposal 8: The bandwidth of LP-WUS should at least be confined to 5MHz and is the same in RRC IDLE/INACTIVE and CONNECTED states.**

**Proposal 9: Support flexibility configuration of LP-WUS bandwidth location. Both inside and outside initial DL BWP can be considered.**

**Proposal 10: Support LP-WUS and signals/channels used by MR could be located in different bands/carriers.**

**Proposal 11: The periodicity of LP-SS is suggested to be 320ms.**

**Proposal 12: Support the same waveform design for LP-WUS and LP-SS to decrease the complexity of LP-WUR.**

**Proposal 13: Consider the following information to be carried in LP-SS:**

* **Cell ID related information;**
* **An indication for whether UE needs to read LP-WUS configuration from the current cell.**

**R1-2400811 EURECOM**

**Proposal 1: Consider jointly encoding more than one bit via Manchester Coding.**

**Proposal 2: For multiple ON-Sequences, jointly encode the payload with OOK and sequence encoding.**

**Proposal 3: Consider WUR-type dependent wake-up to reduce unnecessary wake-ups.**

**R1-2400065 Spreadtrum Communications**

**Proposal 1: Manchester coding can be a mandatory feature for LP-WUS design for OOK with overlaid OFDM sequence.**

**Proposal 2: OFDM sequence on overlaid OOK for connected UE shall be supported and whether the same information for all UE categories needs further discussion.**

**Proposal 3: LP-SS and LP-WUS should have the same waveform type in one cell.**

**Proposal 4: Support encoded bit-based message for OOK based LP-WUS.**

**Proposal 5: Some coverage enhancement with low complexity can be considered for LP-WUS.**

**Proposal 6: CSI-RS-Resource can be the reference for LP-WUS configuration.**

**R1-2400590 OPPO**

***Proposal 1: The content of LP-WUS should include the wake-up indication information, additional information (e.g., cell information, SI change and ETWS/CMAS information, tracking area information, RAN area information, etc.) is not necessary to be carried in LP-WUS.***

***Proposal 2: Per UE-group and / or per UE-subgroup indication for LP-WUS targets to 8-bits or 16-bits payload.***

***Proposal 3: Manchester coding/modulation is used for LP-WUS signal. CRC bits are adopted.***

***Proposal 4: Specify OOK-4 based LP-WUS with overlaid OFDM sequence(s) over OOK symbol.***

***Proposal 5: Further study how to overlay OFDM sequence over OOK symbols, whether it is per OFDM symbol or per OOK symbol.***

***Proposal 6: If OFDM sequence overlaid over OOK symbols could carry information, it should decide the content of information carried by OFDM sequence. The information may be same as the indication information of LP-WUS, or carry additional information while include the same indication information of LP-WUS, or different from indication information of LP-WUS.***

***Proposal 7: If OFDM sequence overlaid over OOK symbols could carry information, it should decide the mapping between OFDM sequence and information carried via OFDM sequences.***

* ***Option1: Entire information is mapped to one OFDM sequence.***
* ***Option2: Each segment of entire information is mapped to one independent OFDM sequence.***

***Proposal 8: The BW of LP-WUS for RRC IDLE/INACTIVE state could be same as that for RRC CONNECTED state.***

***Proposal 9: Allocated fixed number of PRBs for LP-WUS signal instead of a fixed BW size, such as 6PRBs or 12PRBs.***

***Proposal 10: LP-WUS and LP-SS could share the same BW and similar frequency location. The transmission of LP-WUS and LP-SS is TDM, without further guard bands in between two signals.***

***Proposal 11: The monitoring occasion of LP-WUS could be determined via the reference signal and the time offset. LP-SS signal or PO could be used as the reference signal to determine the monitoring occasion of LP-WUS.***

***Proposal 12: Introducing same type of sequences on top of LP-SS OOK symbols same as that for LP-WUS.***

* ***Consider a fixed sequence or sequences fully/partially associated with cell ID.***

***Proposal 13: LP-WUS and LP-SS share the same frequency location, SSB location should be associated with LP-WUS/LP-SS.***

* ***Consider shorter periodicity like 80ms or 160ms for LP-SS.***
* ***Multiple LP-SSs can be transmitted in a period. Each LP-SS can be associated with a beam/SSB.***

***Proposal 14: LP-SS introduce Gold or M sequences and Manchester coded/modulated into OOK symbols.***

**R1-2400904 Panasonic**

**Proposal 1: LP-WUS should be designed and commonly applied for both RRC CONNECTED and IDLE/INACTIVE mode UEs with fixed symbol rate, irrespective of the SCS used by NR waveform.**

**Proposal 2: Regardless which one or both waveforms would be supported for LP-WUS and LP-SS, LP-SS and LP-WUS should always follow the same waveform and numerology in the applicable configuration.**

**Observation 2: Both OOK-1 and OOK-4 become more sensitive to timing error with higher bitrate due to shorter symbol / time segment length.**

**Observation 3: In the case of higher bitrate such as 56 kbps, OOK-4 has slightly better performance than OOK-1 with wider SCS, as OOK-1 with shorter CP is more sensitive to inter-symbol interference.**

**Observation 4: With carrier frequency offset, there is no significant performance gap between OOK-1 and OOK-4 and both are robust to even large carrier frequency error. But the robustness also relies on the bandwidth of LP-WUS and GB.**

**Observation 5: BLER performances in both OOK-1 and OOK-4 get worse with larger number of OFDM symbols constituting a block.**

**Observation 6: In the case of 28 kbps with smaller payload size, i.e., lower number of OFDM symbols, OOK-1 has better performance than OOK-4 with timing error.**

**Observation 7: In the case of 56 kbps with larger payload size, i.e., higher number of OFDM symbols, OOK-4 is slightly better than OOK-1 with large number of OFDM symbol over 32, regardless of timing error or not.**

**Observation 8: For OOK-1, different SCSs such as 30kHz and 60kHz does not obviously impact symbol timing estimation performance in different SNR.**

**Observation 9: For OOK-4, different SCSs such as 15kHz and 30kHz, and different M such as M=1,2 does not obviously impact symbol timing estimation performance in different SNR.**

**Observation 10: Due to the shorter CP length that is less robust to delay in the fading channel, timing estimation performance of OOK-1 with higher SCS is slightly worse than that of OOK-4, especially in higher SNR.**

**R1-2401208 Fujitsu**

**Proposal 1: Either OOK-1 or OOK-4 should be chosen in Rel-19 as a single option**

**Proposal 2: OOK-4 should be supported to prioritize resource efficiency to carry multiple bits by LP-WUS over UE power consumption**

**Proposal 3: Discuss the following options for the target coverage of LP-WUS:**

* **Option 1:The coverage target of LP-WUS includes Msg.3 repetition**
  + **Option 1-1: Fixed coverage target corresponding to the maximum number of repetitions for Msg.3.(i.e. 8 repetitions)**
  + **Option 1-2: Configurable coverage target based on the available number of repetitions for Msg.3 (i.e. 2, 4, 8 repetitions)**
    - **LP-WUS-specific Coverage enhancement technology should be considered to satisfy repetition Msg.3 coverage. e.g. LP-WUS repetition, LP-WUS power boosting**
* **Option2: The coverage target does not include Msg.3 repetition**
  + **Further discuss how to address the coverage gap between Msg.3 repetition and WUS**

**Proposal 4: RAN1 to discuss the following aspects on LP-SS:**

* **Periodicity in milliseconds (Y ms)**
  + **Option 1: Fixed to a single value**
  + **Option 2: Support multiple values, allowing cell-specific configurability.**
* **Proposal 5: The sequence of LP-SS is determined based on cell-ID**

**R1-2400093 Futurewei**

LP-WUS Design (Structure)

***Proposal 1: Support at least the alternative to carry up to 16 bits of LP-WUS information using encoded bits with an 8-bit CRC.***

LP-WUS Design (Waveform)

***Proposal 2: A LP-WUR-enable UE supports both OOK-1 and OOK-4 based LP-WUS design with one or more values of M to provide network deployment flexibility.***

***Proposal 3: Reuse existing definition of low-PAPR sequence to generate the overlaid OFDM sequence(s) over OOK symbols.***

***Proposal 4: Support OOK-1 and OOK-4 based LP-WUS design with low frequency envelope channels to enable ED-based LP-WURs robustness against narrowband and inter-cell interference.***

LP-SS Design

***Proposal 5: Support low density sequences generated using waveform Option OOK-4 with M>1 for LP-SS design.***

***Proposal 6: Consider a preamble to precede the transmission of an LP-WUS if LP-SS periodicity is >= 320 ms and the time offset between LP-WUS and last LP-SS is, e.g., > 50 ms.***

**R1-2400527 Honor**

***Proposal 1: Prioritize OOK-1.***

***Proposal 2: Prioritize M sequence.***

***Proposal 3: Support both duty-cycled monitoring and continuous monitoring.***

***Proposal 4: Discuss the schemes for OOK and OFDM sequences to carry LP-WUS information: separate carrying, priority carrying and repeated carrying.***

**R1-2400684 InterDigital, Inc**

***Proposal 1.*** *Support LP-SS without overlaid OFDM sequences.*

***Proposal 2.*** *Support time domain repetition and Manchester coding for LP-WUS signal structure.*

***Proposal 3.*** *Support up to 10 repetitions of LP-WUS with Manchester coding to achieve comparable performance with PUSCH for Msg 3.*

**R1-2400863 Sony**

***Proposal 1 – Support LP-WUS structure with two fields, a preamble field for synchronization and cell identification purposes and a data field for indication of subsequent actions and/or wake-up group identity, depending on state of the operation.***

***Proposal 1 – Support LP-WUS structure with two fields, a preamble field for synchronization and cell identification purposes and a data field for indication of subsequent actions and/or wake-up group identity, depending on state of the operation.***

***Proposal 3 – Support to transmit both an OFDM-based and an OOK-based LP-WUS at the same time for UEs to choose which to detect in accordance with their capabilities.***

***Proposal 4 – Support LP-SS structure with two fields using OOK-4 transmission structure and sequences from m-sequence family with good auto- and cross correlation properties.***

**R1-2400272 TCL**

**Proposal 1: The structure of LP-SS can contains a sequence for synchronization and a message with encoded bits for activation or de-activation of LP-WUS monitoring.**

**Proposal 2: Consider, a configurable BW size within the range of 5MHz and 20MHz for LP-WUS and LP-SS in both idle/inactive and connected state.**

**Proposal 3: Study a dedicated BWP for the placement of LP-WUS and LP-SS, with the maximum bandwidth within the range of 5MHz to 20MHz.**

**Proposal 4: The configurable BW of LP-WUS and LP-SS and its associated dedicated BWP can be configured to the UE during initial access.**

**Proposal 5: To locate LP-WUS in the time domain, a reference point and an offset from the reference point be used:**

* **For idle/inactive UEs, the incoming PO or SSB can be used as a reference point**
* **For connected UEs, SSB or periodic LP-SS can be used as reference point.**

**Proposal 6: Study the configuration of time and frequency resources for LP-WUS and LP-SS to the UE.**

**Proposal 7: Study the following indication method for LP-WUS successful detection;**

* **Implicit derivation of LP-WUS detection from the first ACK message received from the MR, which is sent by the UE for receiving the data/signaling.**
* **Explicit derivation of LP-WUS detection, where the MR sent ACK message before receiving the signaling/data.**

**R1-2401150 KT Corp**

**Proposal 1: Operating bands for LR is specified as limited sets for the hardware simplification, consequently, not necessarily same with the capability of MR.**

**Proposal 2: BSs can configure both the same and different operating bands with MR for the LP-WUS.**

**Proposal 3: Discuss further to decide whether to support the operation of LP-WUS/WUR on the shared spectrum.**

**Proposal 4: Multiple occasions in time can be configured during one duty-cycled monitoring period of LP-WUS, i.e., monitoring time is configured.**

**Proposal 5: The monitoring period for the duty-cycled LP-WUS can be configured to zero or same with the monitoring time. That is, the contiguous monitoring is supported.**

**Proposal 6: The followings are specified as capability information elements of UEs.**

* **Capability on LP-WUS**
* **Operatable bands for the LP-WUS**
* **Operatable signal type of LP-WUS, e.g., decodability of harmonized OFDM sequence.**

**R1-2401335 LG Electronics**

**Proposal #1: Specify the LP-WUS structure including preamble part, message part and CRC**

* **Preamble part: Configurations on message part can be included**
* **Message part: UE ID or sub-group ID can be included**
* **CRC part: It can be optionally attached according to the length of message part**

**Proposal #2: Discuss on which type of information is delivered by overlaid OFDM sequence**

**Proposal #3: Discuss on the sequence length (and detailed mapping to OFDM symbol) of overlaid OFDM sequence considering LP-WUR sampling rate**

**Proposal #4: Discuss on the separate transmissions for preamble part and message part of LP-WUS**

**Proposal #5: Discuss on the bandwidth and frequency location of LP-WUS with consideration of NW flexibility and LP-WUR complexity**

**Proposal #6: Study on whether LP-WUS is transmitted in CP duration of MR OFDM symbol for NR signal/channel**

**Proposal #7: Study on how to define/construct OOK symbols within OFDM symbol for OOK-4**

**Proposal #8: Specify the sequence-based signal with consecutive OOK symbols for LP-SS**

**Proposal #9: Discuss on the required LP-SS periodicity for synchronization and RRM measurement purpose separately**

**Proposal #10: Consider LP-SS without overlaid OFDM sequence as starting point. The necessity of overlaid OFDM sequence on LP-SS can be discussed with consideration of its performance benefit**

**Proposal #11: Discuss how to configure the LP-SS transmission/monitoring occasions (together with LP-WUS monitoring occasions) considering synchronization and RRM measurement**

**Proposal #12: Discuss on the bandwidth and frequency location of LP-SS with consideration of NW flexibility and LP-WUR complexity**

**Proposal #13: Consider the inter-cell interference mitigation technique for LP-SS design**

**R1-2400473 NEC**

***Proposal 1: support both OOK-1 and OOK-4 for LP-WUS and LP-SS generation.***

***Proposal 2: RAN1 to confirm whether an LP-WUR (at least for LP-WUR with RF/IF envelop detection) has the capability of CP removal.***

***Proposal 3: study the inter-symbol-interference (ISI) issue and the CP-to-OOK interference issue due to the sync error, consider utilizing zero-CP or partial zero-CP to avoid the interference.***

***Proposal 4: support flexibly configuring frequency locations of one or more LP-WUS bands within a carrier, UE can select an LP-WUS band based on its UE ID or a PF/PO it is intended to monitor.***

***Proposal 5: support message based LP-WUS structure with a preamble and a CRC.***

***Proposal 6: support repetition of LP-WUS to improve the coverage.***

***Proposal 7: support sequence based LP-SS, the existing sequence generation method in NR, e.g., m-sequence, gold sequence, can be a start point.***

***Proposal 8: support beam based transmission of LP-SS in order to achieve similar beamforming gain as SSB.***

***Proposal 9: support QCL relationship between an LP-SS and an SSB.***

***Proposal 10: support FDM multiplexing of an LP-SS and its QCLed SSB.***

***Proposal 11: support repetition of an LP-SS in an LP-SS periodicity.***

**R1-2401126 NTT DOCOMO, INC**

**Proposal 1:**

* **For down selection between OOK-1 and OOK-4 for LP-WUS, study how many bits need to be transmitted on LP-WUS for each RRC state**
  + **Note: This needs to be discussed together with the corresponding L1 procedures in AIs 9.6.2 and 9.6.3**
* **For down selection between OOK-1 and OOK-4 for LP-SS, study how many sequences are needed for LP-SS**
  + **Note: This needs to be discussed together with the corresponding L1 procedures in AI 9.6.2**

**Proposal 2:**

* **Study whether it is feasible that OFDM-based LP-WUR is assumed to be able to receive existing PSS/SSS**

**Proposal 3:**

* **For RRC idle/inactive/connected states, strive for a unified LP-WUS BW-size whose location is configurable within a NR carrier**
  + **FFS: BW-size considering LP-WUS payload size and coverage in each RRC state**

**R1-2400634 Sharp**

**Proposal 1: Manchester coding can be a mandatory feature for LP-WUS design for OOK with overlaid OFDM sequence.**

**Proposal 2: OFDM sequence on overlaid OOK for connected UE shall be supported and whether the same information for all UE categories needs further discussion.**

**Proposal 3: LP-SS and LP-WUS should have the same waveform type in one cell.**

**Proposal 4: Support encoded bit-based message for OOK based LP-WUS.**

**Proposal 5: Some coverage enhancement with low complexity can be considered for LP-WUS.**

**Proposal 6: CSI-RS-Resource can be the reference for LP-WUS configuration.**

**R1-2400211 Transsion Holdings**

**Proposal 1 It is recommended that the location of LP-WUS in the bandwidth part should be studied.**

**Proposal 2 It is recommended that LP-WUS could support subgroup indication as well as R17 PEIs.**

**Proposal 3 It is recommended that entry and exit monitoring conditions of LP-WUS should be studied.**

**Proposal 4 It is recommended that the LP-SS should support multiple beams.**

**R1-2401349 Nordic Semiconductor ASA**

***Proposal-1:*** *Support OOK-4, M=1 and M=2 waveforms.*

***Observation-1:*** *OOK-4 modulation order M increases the PAPR, however, differences in PAPR are not large. Difference grows with reduced channel BW of a carrier.*

***Proposal-2:*** *15 and 30kHz SCS is supported for LP-WUS. SCS can be explicitly configured for the LP-WUS.*

***Proposal-3:*** *Consider shortening of the ON-duration pulse. ZC sequences are used as the overlaid sequence.*

***Proposal-4:*** *Maximum number of payload bits of LP-WUS is 8. Overlaid sequence could carry information related to SI update or PWS/ETWS.*

***Proposal-5:*** *LPWUS information is delivered as a payload with CRC. A simple block-code can be considered on top of Manchester coding.*

***Proposal-6:*** *LP-WUS BW is 12/24RB for 30/15kHz SCS. Support 6/12RB LP-WUS can be considered.*

***Proposal-7:*** *Support the 320ms LP-SS periodicity, consider optimization of the time-location of LP-SS occasions and LP-WUS MOs. Alternatively, consider transmitting additional preamble before each LP-WUS.*

**R1-2400883 Lenovo**

***Proposal 1: Consider OOK-1 as the LP-SS waveform with overlaid sequence for the baseline LP-SS design.***

***Proposal 2: Consider 640ms, 960ms as candidate periodicity for LP-SS***

***Proposal 3: RAN1 consider the feasibility of generating multiple binary pattern modulated using OOK waveform for LP-SS***

***Proposal 4: RAN1 consider association of binary pattern of LP-SS to that of NR SSB to detect the cell id.***

***Proposal 5: RAN1 consider LP-PSS and LP-SSS similar to NR-PSS and NR-SSS to convey the cell id information.***

***Proposal 6: Consider achieving byte level synchronization by using a SYNC word.***

***Proposal 7: Consider synchronization mechanism in LPWUR using***

* ***Coarse synchronization using LP-SS***
* ***Fine synchronization using preamble transmission in every slot***
* ***Byte level synchronization using SYNC word***

***Proposal 8: Specification allows same UE to switch between envelope-based detector and correlator based detector to improve power saving and coverage improvements.***

***Proposal 9: Usage of DFT-s-OFDM or OFDM based OOK using single bit OOK per OFDM symbol at the transmitter side can be left to the BS implementation.***

***Proposal 10: Consider both OOK-1 and OOK-4 as the LP-WUS waveform depending on the payload size with overlaid sequence for the baseline LPWUS design.***

**R1-2400813 Everactive**

Proposal 1: UE assumes Homodyne/zero-IF or Heterodyne with IF envelope detection architecture for OOK-based LP-WUR implementation.

Proposal 2: LP-WUS OOK-1 and/or OOK-4 signal must include Manchester encoding.