**3GPP TSG RAN WG1 #118 R1-24xxxxx**

**Maastricht, NL, August 19th - 23rd, 2024**

**Source: Moderator (vivo)**

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

**Agenda Item:** **9.6.1**

**Document for: Discussion and Decision**

1. Introduction

This contribution summarizes the discussions on LP-WUS and LP-SS design in RAN1# 118.

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

 Please at least provide your comments to proposals and questions tagged with [H][FL1] in this round.

1. Proposals for Online Sessions
	1. Proposals for Tuesday online session
	2. Proposals for Wednesday online session
	3. Proposals for Thursday online session
	4. Proposals for Friday online session
2. LP-WUS design
	1. OOK-1/OOK-4 waveform

###  M values for OOK-4

In RAN1 116bis meeting, RAN1 made following agreement.

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| **Agreement**For OOK-4 with M >1, support M=2 & M=4 (working assumption) for LP-WUS. * FFS whether value of M depends on SCS
* FFS M=1 for OOK-4
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For working assumption of M for OOK-4, companies [18][2][4][8][5][3][16][27][15][12][26][23] [19][21][22] proposed to support M=4, to reduce LP-WUS overhead/increase data rate. [18][2][4][8][3] [16][27][15][12][19][22] propose to support M=4 for both 15& 30KHz SCS. [27][15] consider candidate M values for RRC idle/inactive and RRC connected mode separately. [23] confirms M=4 at least for 15kHz SCS. [7][11][23][17] do not support M=4 for 30kHz SCS with concern on tolerable timing error. [11] analyzes timing accuracy of LP-SS with M=4 which is larger than tolerable timing error 2us for LP-WUS with M=4 for 30kHz SCS. But according to other companies’ evaluation for LP-SS with M=4, e.g., [4][8], timing error is less than 2us. [7] analyzes achievable SNR for LP-WUS with M=4 is higher than target SNR values. But based on evaluation results from other companies, e.g., [4], target SNR can be achieved with repetition. Besides, according to FL’s understanding, for scenarios with higher SNR, e.g., for RRC connected mode, M=4 may not need repetition thus higher data rate can be achieved. Furthermore, with larger M value can enable earlier termination for OFDM-based LP-WUR because of larger number of OOK ON symbols in an OFDM symbol.

Considering no company has concern on M=4 for 15kHz SCS, FL suggests to first agree on this case, while keep 30khZ as working assumption.

**[H][FL1] Proposal 3.1-1**: Confirm the Working Assumption that OOK-4 with M=4 for 15KHz SCS is supported for LP-WUS.

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| **Agreement**For OOK-4 with M >1, support M=2 & M=4 for LP-WUS. * M=4 for 15KHz SCS
* M=4 for 30KHz SCS (working assumption)
* FFS M=1 for OOK-4
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| **Company** | **Y/N** | **Comments** |
| vivo |  | We prefer M=4 for both 15kHz 30kHZ SCS. In our evaluation, LP-WUS with M=4 for 30kHz SCS can also achieve desirable performance at required SNR for Msg 3 PUSCH coverage with presence of timing error. Moreover, for RRC connected mode, UE typically works at higher SNR, which further motivates M=4 for 30kHz SCS. Having said that, we can live with the proposal to first agree on M=4 for 15kHz SCS while keep 30khZ as working assumption. |
| Qualcomm | Y |  |
| InterDigital | Y | Fine for confirming the working assumption. One comment from our side would be that we should define applicable Ms for other SCSs for FR2 as we are allowing LP-WUS operation in FR2 by defining QCL relationship and multi-beam operation. |
|  Nordic |  | If we specify M=4 for 15kHz, same design may apply to 30kHz, but in our opinion, not all combinations of M and SCS should be part of baseline feature. We can agree to the proposal, if it is common understanding that combinations of M and SCS are subject of feature discussions.  |

### SCS configuration for LP-WUS

Companies discuss whether LP-WUS/LP-SS SCS can be different from NR signal in same OFDM symbol and how to derive LP-WUS/LP-SS SCS [8][9][16][12][23][22]. Regarding how the UE derives the SCS, it can be either determined according to configuration by gNB [9][3][16][12][22] or pre-defined rule [5][3][12][23], such as according to initial DL BWP SCS, or SSB SCS, or active BWP.

**[M][FL1] Proposal 3.1-2:** Single SCS for LP-WUS is used by LP-WUR, further discuss following options

- The single SCS is configured by gNB

- The single SCS is determined by pre-defined rule

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| **Company** | **Y/N** | **Comments** |
| vivo | Y | We support single SCS configured by gNB for simplicity and flexibility.  |
| Qualcomm | Y | We support gNB configuration of the SCS. |
| InterDigital | Y | Fine, but we prefer supporting single SCS configuration.  |
| Nordic | Y | Fine with proposal. We think both sub-bullets should be supported. |

* 1. Overlaid OFDM sequence for LP-WUS

### Time or frequency domain sequence

 In RAN1 117 meeting, RAN1 agreed to down-select from following options.

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| **Agreement**For overlaid OFDM sequence(s) for LP-WUS in time or frequency domain, down-selection from the following:* Option 1-1: overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing
	+ The length of overlaid sequence(s) depends on the number of REs used for LP-WUS and the value of M
* Option 1-2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before DFT/LS processing
	+ The length of overlaid sequence(s) depends on the number of REs used for LP-WUS
* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing
	+ The length of overlaid sequence(s) depends on the number of REs used for LP-WUS
* Option 3: overlaid sequence(s) are the sequence(s) of an OOK on symbol in time domain after IFFT processing
	+ The length of overlaid sequence(s) depends on IFFT size and the value of M

FFS: same or different options are applied for OOK-1 and OOK-4 M>1.  |

Company view on these options are summarized as below:

* Option 1: time domain sequence before DFT/LS (signal S1)
	+ Option 1-1:

 [2][3][4][8][9][10][13][14][15][18][23][24][27]

* For OOK-4 only: [8][15][18][21][23]
* For both OOK-1 & OOK-4: [2][3][4][9][10][13][18][24][27]
	+ Option 1-2: [11][12][16][17][19]
* For OOK-4 only: [12][18]
* For both OOK-1 & OOK-4: [16]
* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing (signal S2): [18][8][11][12][15][23][19]
* For OOK-1 only: [8][12][15][18][19][23][21]
* For both OOK-1 & OOK-4: [8][19]
* Option 3: overlaid sequence(s) are the sequence(s) of an OOK on symbol in time domain after IFFT processing (signal S3): [5] for both OOK-1 and OOK-4
	+ Under option 3, [5] proposes separate IFFT for LP-WUS and NR signal for LP-WUS and NR signal multiplexing after IFFT to reduce ICI.



Figure 1: 3 options for overlaid sequence for LP-WUS

**Table 1 Pros/cons for 4 options provided by companies**

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| --- | --- | --- |
|  | Pros provided by companies  | Cons provided by companies |
| Option 1-1 | 1. Smaller number of sequences to be specified than option 2/3.
2. Existing NR sequence can be directly reused
 | 1. restriction on gNB implementation, because of specified DFT
2. Performance slightly degrades than option 2, for OOK-1 with gold seq, but no degradation for OOK-1 with ZC seq.
3. The overlaid sequence length depends on M value

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| Option 1-2 | 1. The sequence length does not vary with M
 | 1. restriction on gNB implementation, because of specified DFT
2. Correlation property cannot be guaranteed due to OFF chips in the OFDM symbol.
3. Correlation property may be different in different OOK ON chips.
4. UE complexity is increased due to additional detection combination of multiple OOK symbols.
5. It requires more sequences to be defined than option 1-1.
 |
| Option 2 | 1. More flexible for gNB implementation than option 1
2. For OOK-1, existing gNB implementation can be reused
3. The sequence length does not vary with M
 | 1. For OOK-4 M>1, larger number of sequences to be specified than option 1-1
2. For OOK-4 M>1, existing NR sequence cannot be directly reused, hard coded for each element may be needed.
3. For OOK-4 M>1, it is unclear how to generate more than one OOK ON in one OFDM symbol
 |
| Option 3 | 1. More flexible for gNB implementation than option 1
2. Better detection performance than option 2 due to smaller ICI by separate IFFT for LP-WUS and NR signal.
 | 1. Performance degrades at least compared with option 1-1.
2. Standard is complex to specify OFDM sequences
3. gNB complexity is increased for generation certain OFDM sequences after IFFT, especially if IFFT size for LP-WUS and other NR signal is different
4. The length of overlaid sequence depends on IFFT size, but IFFT size is never specified.
 |

Regarding Cons (1) for option 1 and Pros (1) for option 2/3, as explained by several proponent companies of option 1, DFT block does not require gNB to perform on-the-fly DFT computations. gNB can store the frequency domain symbols without any need for additional on-the-fly computations, which is similar as option 2/3. Therefore option 1 does NO restriction on gNB implementation.

Good support for option 1-1 for OOK-4 M>1 is observed, while views on OOK-1 is still a bit split. Thus, FL suggests following proposals.

**[H][FL1] Proposal 3.2-1**: For overlaid OFDM sequences for LP-WUS in time or frequency domain, support option 1-1 for OOK-4 M>1.

* Option 1-1: overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing

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| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y |  |
| InterDigital | Y |  |
| Nordic  | Y |  |

**[H][FL1] Proposal 3.2-2:** For overlaid OFDM sequences for LP-WUS in time or frequency domain, further down-selection between following two options for OOK-1

* Option 1-1: overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing for OOK-4 with M=1
* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing for OOK-1

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| **Company** | **Which option do you support**  | **Which option you can NOT live with**  | **Comments** |
| vivo | Option 1-1 |  | Unified design for M=1 & M>1 is desirable. |
| Qualcomm | Option 1-1 |  | We slightly prefer the unified design of option 1-1. But if the overlaid sequence is ZC, option1-1 and option 2 are equivalent. |
| InterDigital | Option 1-1 |  | Unified design is preferred. |
| Nordic  | Option 1-1 |  | We would be also OK with Option 2, if ZC sequence is selected for overlaid. |

### Sequence type

In RAN1 117 meeting, RAN1 agreed to down-select sequence based on existing NR sequence type

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| **Agreement**Support overlaid OFDM sequence based on existing NR sequence type for LP-WUS* Down select among gold sequence, m sequence and ZC sequence
	+ FFS the overlaid OFDM sequence is time or frequency domain sequence.
	+ FFS how to reuse the existing sequences
	+ Note: Strive to minimize the impact on OOK detection performance
* If overlaid OFDM sequence is supported for LP-SS, the same sequence type is used for both LP-SS and LP-WUS
 |

Based on input from companies, the preference on each sequence type is captured as below.

* ZC sequence: [2][4][9][3][13][16][14][27][18][12][17][29]. [8] for sequence before IFFT for OOK-4.
* M sequence: [3][11][19][21].
* Gold sequence: [3][11][21]. [8] for sequence before DFT for OOK-4, and sequence before IFFT for OOK-1

Besides, [19][3] discuss whether directly use existing NR sequence type or use existing NR sequence type for random phase. [3] shows better performance of random phase with gold sequence than directly using ZC sequence for OOK detector. [19] shows almost identical performance of random phase with m sequence and directly using m sequence.

**Table 2 Pros/cons for 3 sequence types provided by companies**

|  |  |  |
| --- | --- | --- |
|  | Pros provided by companies  | Cons provided by companies |
| ZC sequence  | 1. Good spectral properties, i.e., flat spectrum.
2. Low PAPR in time domain.
3. Good auto and cross-correlation property, and robust to synchronization error.
4. Larger sequence pool than m sequence, especially with presence of larger synchronization error.
5. Higher conversion gain of the envelope detector for the OOK-based LP-WUR than m and gold sequence.
 | 1. Increased complexity because ZC is not used for NR downlink channels, compared with m and gold.
2. Complex multiplication by UE side is more complicated than m and gold sequence.
3. ZC sequence with certain root is sensitive to CFO larger than 5ppm.
 |
| M sequence | 1. Easy to handle for sequence generation
2. Better performance than ZC
 | 1. Can not generate ON/OFF pattern in time domain, if the sequence is specified in frequency domain
2. Increase back-off power at transmitter side and requiring high cut off performance filter at the receiver side， due to non-constant amplitude in time and frequency domain
 |
| Gold sequence | 1. Easy to handle for sequence generation
2. Already used for DL, which minimizes additional complexity and implementation efforts for both gNB and UE
3. Better cross-correlation than m sequence
4. Better performance for OOK detector than ZC sequence
 | 1. Can not generate ON/OFF pattern in time domain, if the sequence is specified in frequency domain
2. Increase back-off power at transmitter side and requiring high cut off performance filter at the receiver side， due to non-constant amplitude in time and frequency domain
3. Worse performance when larger sync error is present
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To determine the selection type, companies propose following design principles

* Flat in frequency and time domain [2] [4] [6][15][27]

[2][6][25][18] provide evaluation result showing different sequences do not affect OOK detection performance.

* Good Correlation property to ensure OFDM detector performance: [2][4][7]
	+ Good cross-correlation to avoid false alarm: [2][4][7][10]
	+ Good correlation to be robust to synchronization error: [4][10], FFS [2][7]
* Inter-cell interference/confusion: [2][4][7][3]
* Reception complexity for complex multiplications: [2][10]

**[H][FL1] Proposal 3.2-3:** Support ZC sequence for overlaid sequence for OOK-4 M>1. FFS overlaid sequence for OOK-1.

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| **Company** | **Y/N** | **Comments (if you don’t support ZC sequence, please provide the sequence type you support and reason)** |
| vivo | Y  | We support ZC sequence as overlaid sequence for OOK-4 M=1 and M>1.  |
| Qualcomm | Y | As a complex sequence without the restriction of being a binary sequence, ZC can have more sequences with good correlation properties with the same sequence length. |
| InterDigital | Y | InterDigital |
| Nordic | Y |  |

Companies also discuss number of sequences per OOK ON chip or per OFDM symbol carrying information bits, with range of 4 to 16 for OOK-4 [2][16][11] and up to 256 sequences for OOK-1 [8]. Besides, if we also consider inter-cell interference [4][3], the number of sequences to be specified may be even larger. The number of candidate sequences would affect sequence type selection. Therefore, FL encourages more input for the number of sequences.

**[H][FL1] Question 3.2-1:** Regarding the number of overlaid sequences,

Q1: what is your preferred number of overlaid sequences to carry LP-WUS information bits per OOK ON chip/OFDM symbol?

Q2: Do you consider inter-cell interference randomization/reduction for overlaid OFDM sequence? If yes, how many set of sequences you prefer?

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| **Company** | **Comments**  |
| vivo | Q1: we think 4~8 overlaid sequences per OOK ON chip would be reasonable, considering tradeoff between performance (good correlation), complexity and power saving (early termination for OFDM receiver). Besides, proper number of sequences may vary with M, because longer sequence may be easier to support larger number of sequences with good cross-correlation property. e.g., 8 for M=1&2, 4 for M=4. Q2: for OOK- detector, different overlaid sequences in different cell can not reduce inter-cell interference. In that sense, it is more proper to rely on different time and frequency resource rather than sequence to reduce inter-cell interference. But if we consider a scenario without OOK-detector, i.e., only OFDM-detector receiving a LP-WUS, inter-cell interference randomization by sequence may be beneficial. Up to 3 or 4 sets would be sufficient.  |
| Qualcomm | Q1: We support upto 4 candidate overlaid sequences per OOK ON chip to carry upto 2 bits of information. A higher number of sequences leads to false alarm error.Q2: We think multiple overlaid sequences can randomize interference from LP-WUS to other channels/signals such as existing NR channels/signals. We support upto 4 overlaid sequences used in the sequence hopping pattern if the overlaid sequence does not carry information. If overlaid sequences carry information, there is already randomization due to the random content of the LP-WUS, and no further randomization of the sequences is needed.  |
| InterDigital | Q1. We believe that number of overlaid sequences can be discussed after deciding details of the information which needs to be delivered. Q2. Open to discuss.  |
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### How to carry information by OFDM sequences

In RAN1 116bis meeting, RAN1 agreed to consider 4 options.

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| **Agreement**Regarding the overlaid OFDM sequence(s) of LP-WUS, consider the following options:* Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol or OFDM symbol duration. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence.
* Option 1-2: The overlaid OFDM sequence is pre-determined from multiple sequences. This sequence carries NO information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the OOK ON/OFF pattern.
* Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol or OFDM symbol duration, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Consider the following two sub-options.
* Option 2-1: 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 2-2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the overlaid OFDM sequence(s)
* Option 3: One sequence is selected from multiple candidates overlaid OFDM sequences on one or more OOK ‘ON’ symbols, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s).
* Option 4: Use of modulated overlay sequence with constellation point: overlay sequence acting as a spreading sequence and constellation point carrying information for OFDM-based LP-WUR.

Other options are not precluded. |

There are two cases:

Case #1: overlaid OFDM sequence does not carry information, i.e., option 1 & option 1-2. UEs with OFDM-based LP-WUR can obtain information bits of LP-WUS by the presence of the overlaid OFDM sequence

Case #2: OFDM sequence carries information, i.e., option 2,3,4. UEs with OFDM-based LP-WUR can obtain information bits based on which sequence/constellation is detected.

For case #1, [2][13][14] support option 1, [4][3] support option 1-2. For above options, FL observes different companies have different understanding on

1. Whether the overlaid sequence can be different for different cells for option 1 and option 1-2.

Some companies think option 1 means only single overlaid OFDM sequence is specified, while other companies explain option 1 also supports multiple specified overlaid OFDM sequence though gNB only configure one sequence for the LP-WUS.

1. Within a cell, whether the overlaid sequence can be different in different OOK ON chips/OFDM symbols of LP-WUS for option 1-2.
2. Whether OFDM detector obtains information bits by the OOK ON/OFF pattern and/or the presence of the overlaid sequence, by both options.

Based on companies’ discussion, the motivation of using different sequences for different cells, irrespective of same or different sequences in different OOK ON chips/OFDM symbols within a cell, is to randomize inter-cell interference or differentiate overlaid sequence from other cells [2][3]. Using different sequences in different OOK ON chips/OFDM symbols within a cell is to further increase randomization [4][3], or combat fast channel fading [3], or reduce spectral lines [18]. [14] questions the benefit of inter-cell interference randomization, considering anyway OOK detector can not take advantage of interference randomization by different sequences. Then it is more reasonable to coordinate LP-WUS resources to avoid overlapping rather than using different sequences. [2] shows no performance gain by different sequences in different OOK ON chips/OFDM symbols, while larger standard effort is expected for option 1-2, i.e., specify how to rotate overlaid sequences in different OOK ON chip/OFDM symbols.

To resolve above confusion for each option, FL adds some notes for clarification of option 1 and option 1-2.

**[M][FL1] Proposal 3.2-4:** In case of overlaid OFDM sequence not carrying information, down-select between following two options:

Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol or OFDM symbol duration. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence.

Option 1-2: The overlaid OFDM sequence is pre-determined from multiple sequences. This sequence carries NO information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the OOK ON/OFF pattern.

Note 1: for both options, multiple overlaid OFDM sequences is specified.

Note 2: for both options, gNB can configure different overlaid OFDM sequence(s) for different cells.

Note 3: for both options, OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence or the OOK ON/OFF pattern.

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| **Company** | **Preferred Option**  | **Comments** |
| vivo | Option 1 | For inter-cell interference randomization, since option 1 also support different overlaid sequence for different cells in note 2, we think option 1 is sufficient. Option 1 is simpler than option 1-2 and we observe similar performance for option 1 and option 1-2 as shown in our tdoc.  |
| Qualcomm | Option 1-2 | We support the sequence hopping function with upto 4 sequences for randomizing interferences from LP-WUS to existing NR channels/signals.  |
| InterDigital |  | We are not clear that whether we need to define the case of overlaid OFDM sequence not carrying information. In our view, overlaid OFDM sequence carrying information should be enough.  |
| Nordic | Option 1 | we also think that cell level coordination may be sufficient. In addition, for LP-WUS there will be also random data randomization.  |

For case #2, [2][4] [3][13][14][12][10][17][24], support option 2, [8][16] support option 3. [9] supports option 4.

For option 3, [8] and [16] have different understanding.

* Understanding 1 by [8]: The information may not be carried on all OOK ON symbols, e.g., full information is carried in first N1 symbols, while remaining symbols can be up to gNB implementation to transmit or not transmit information by the specified overlaid OFDM sequence.
* Understanding 2 by [16]: The overlaid OFDM sequence mapped from OOK bits within the OFDM symbol could be transmitted with repetition.

Based on FL’s understanding, understanding 2 is already covered by option 2, because current wording of option 2 has no restriction on same or different overlaid sequences on each OOK ON symbol in an OFDM. Understanding 1 can also be covered by option 2 as mentioned by some companies. To make it clearer, FL suggests to replace ‘each’ OOK ON symbol to ‘an’ OOK ON symbol as suggested by [2].

For option 4, as analyzed in [9], the performance of constellation scheme is significantly inferior to other schemes under TDL-C 300ns channel. The performance can be improved by rake receiver or FFT operation, but it is undesirable to limit overlaid sequence for certain receiver type [3].

Based on majority view, FL suggests to go with option 2 with minor modification as below.

**[H][FL1] Proposal 3.2-5:** In case of overlaid OFDM sequence carrying information, support option 2:

* Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on ~~each~~ an OOK ‘ON’ symbol or OFDM symbol duration, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Consider the following two sub-options.
* Option 2-1: 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 2-2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the overlaid OFDM sequence(s)

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| **Company** | **Y/N** | **Comments** |
| vivo | Y | We are supportive of modified option 2. Whether/how to enable repetition of information bits carried by overlaid OFDM sequences in a LP-WUS can be further discussed.  |
| Qualcomm | Y |  |
| InterDigital | Y |  |
| Nordic  | Y |  |

### Other aspects for overlaid OFDM sequence design

1. Discussion on concentrated OOK waveform to improve robustness to timing error and reduce spectral leakage [18][4][9][14] or reduce impact of CP [9].

Whether the concentrated OOK waveform is needed, e.g., considering presence of preamble [14], and whether up to gNB implementation [14] or reflected by sequence design [4][9] can be further discussed.

1. Discussion on cyclic shifting for DFT [4] [9] [3][14].

The impact of DFT shift on OOK-based and OFDM-based LP-WUR can be further discussed. If performance degradation is observed, mechanism to compensate the cyclic shift, e.g., pre-compensation by using an alternating “1” and “-1” as a cover code of overlaid OFDM sequence [3][4][9] or compensation at LR as legacy operation [14] can be further discussed.

1. Discussion on mapping frequency samples to existing NR QAM or sequence constellation [9][14][15][13].

[15][13][13] thinks it is beneficial to support mapping frequency samples to existing NR QAM or sequence constellation to reuse existing gNB hardware [15][13]. [9][14] do not support. [9] analysis quantizing LP-WUS frequency domain signal using QAM constellation impairs the time domain signal significantly as the OOK modulation order $M$ increases, and the impact is different for different overlaid sequence types. [14][15] think unnecessary to quantize to QAM constellation, considering arbitrary values are allowed in frequency domain by existing NR, e.g. consider precoded signals for MU-MIMO which surely are different from QAM constellation or existing sequences [14], or DMRS for PUSCH in NR [15].

* 1. What information bits to be carried by LP-WUS and how to carry by LP-WUS

### RRC idle

In RAN1 117 meeting, RAN1 agreed to down-select among bitmap and codepoint schemes for RRC idle/inactive state.

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| **Agreement**For RRC idle/inactive state, down-select among the following options for at least indicating subgroup information using LP-WUS:* Option 1: A LP-WUS indicates a bitmap with each bit corresponding to one subgroup of N subgroups for part of, one or more PO(s), e.g., N is 8~16, 24
	+ Number of information bits for a LP-WUS is at least N, single LP-WUS to wake up one or more subgroups
* Option 2: A LP-WUS indicates a codepoint value corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least ceil (log2(X1)), where X1 is the number of codepoints indicating one or more subgroups. X1 is reported by companies, X1 could be smaller, equal to or larger than N.
* Option 3: A LP-WUS indicates multiple codepoint values with each corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least K\*ceil (log2(X2)), where X2 is the number of codepoints indicating one or more subgroups. X2 is reported by companies, X2 could be smaller, equal to or larger than N.
	+ K is the number of multiple codepoint values in a LP-WUS where K is larger than 1
* How to satisfy FAR is reported by companies, e.g., FEC/CRC
* Note: multiple TDMed LP-WUSs can be used to support more subgroups for each option.
* Note: Y% effective paging rate per PO is reported by companies
* The followings are considered when down-select among options:
	+ The number of supported UE subgroups per PO: M
	+ Average network overhead to indicate the number of UE subgroups M per PO
	+ False wake up rate due to subgroup-based indication, which will impact the power saving gain
	+ Paging latency
* Note: Coverage target shall be met under 1%BLER, 1% FAR (for false alarm from noise)
 |

Based on input from companies, Company views are summarized as below.

* Option 1: [2][7][16][14][27][15][12][26][19][18][30], [9] if per subgroup paging rate is > 1%.
* Option 2: [4][11][3][6] [13][21][20][22][18], [9] if per subgroup paging rate is ≤ 1%
* Option 3: [4][5][3][17][22], [9] if per subgroup paging rate is ≤ 1%

[8][9][10] are open for further study. Some companies [2][9][6][10] suggest RAN1 should first decide the maximum number of subgroups or maximum payload, because the performance of options depends on corresponding assumption.

**Table 3: Benefit of each option provided by proponent companies**

|  |  |  |
| --- | --- | --- |
|  | Benefit of the option provided by proponent companies  | Drawback of the option provided by proponent companies |
| Option 1:  | * Useful when paging rate is high, with lower overhead [8][7], or lower false wake up rate [9].
* Better flexibility and the possibility of simultaneously addressing multiple subgroups [2][8][7][6].
* Shorter latency [2][8][7][6][15]
* Smaller number of MOs to be monitored by UE [2][8]
* Simpler network management for smaller number of MOs [2][7]
* Smaller configuration signaling overhead [2]
* Lower false wake-up rate because of independent bit for each subgroup [2]
* Similar to existing PEI [2][6]
 | * Incapable of supporting >16 subgroups per LP-WUS
* Larger overhead when paging rate is low [4][6][5]
* Worse detection performance [4][6][5]
* Higher reception complexity with multiple hypothesis [4]
 |
| Option 2: | * Lower overhead when paging rate is low [4][6].
* Capable of supporting larger number of subgroups, e.g., up to 256 subgroups per PO and more than 256 subgroups per LO [4]
* Early termination of detection [4]
* No impact of information bits for other UEs, thus better detection performance than option 1 [4][6].
* Similar to NB-IoT group WUS [6]
 | * Larger overhead when paging rate is high [8][7]
* Lower power saving gain, due to higher false wake up rate and multiple MOs to be monitored [2][8][9][7]
* Longer latency [2][8] [7][6]
* More difficult for network management for larger number of MOs [2][7]
* Large RRC signaling overhead for codepoint configuration [2][10]
 |
| Option 3:  | Similar as option 2. In addition, * Lower overhead than option 2, with 2-stage sequences [5]
 | * Option 3 can be realized by concentration of multiple option 2 LP-WUS on different LP-WUS MOs [6], but payload is larger due to fixed number of blocks [2].
* More standard effort to determine association between subgroup and each block [13]
 |

Both option 2 and option 3 are codepoint options. Option 3 can be realized by concatenation of multiple option 2 LP-WUS on different LP-WUS MOs [6][2], therefore, it is sufficient to only support one of two options. [2] thinks option 3 is less flexible, because K blocks is always transmitted even if none of UEs associated with some blocks are not paged, assuming a constant payload for LP-WUS. Though LP-WUS with variable payload can be achieved by adding a header [9], there is additional overhead for header and it is more complicated for UE reception.

**[H][FL1] Proposal 3.3-1:** For RRC idle/inactive state, down-select between option 1 and one of option 2/option 3.

* Option 1: A LP-WUS indicates a bitmap with each bit corresponding to one subgroup of N subgroups for part of, one or more PO(s), e.g., N is 8~16, 24
	+ Number of information bits for a LP-WUS is at least N, single LP-WUS to wake up one or more subgroups
* Option 2: A LP-WUS indicates a codepoint value corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least ceil (log2(X1)), where X1 is the number of codepoints indicating one or more subgroups. X1 is reported by companies, X1 could be smaller, equal to or larger than N.
* Option 3: A LP-WUS indicates multiple codepoint values with each corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least K\*ceil (log2(X2)), where X2 is the number of codepoints indicating one or more subgroups. X2 is reported by companies, X2 could be smaller, equal to or larger than N.
	+ K is the number of multiple codepoint values in a LP-WUS where K is larger than 1

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | We support option 1, assuming up to 16 subgroups is sufficient. We don’t support option 2/3, but regarding one of option 2 and option 3, we think option 2 is better than option 3. Option 3 is less flexible and has larger overhead than option 2, because option 3 has to always transmits K blocks even if only one of K blocks needs to be waken-up.  |
| Qualcomm | Y | For idle and inactive mode, our analysis (R1-2407040, section 2.3.1) of the required number of information bits showed that codepoint value based design should be the solution to adopt. Our paging delay analysis showed that codepoint value introduces negligible paging delay. Based on this, we support option 2. Option 3 can be additionally considered. |
| InterDigital | Y | Fine and we support Option 2.  |
| Nordic  | Y | After reading companies contributions, our proposal would be to take Option 2, however the Sigen’s LO parameter K should be max 2.  |

### RRC connected mode

In RAN1 116bis meeting, RAN1 agreed to consider bitmap and codepoint for RRC connected mode.

|  |
| --- |
| **Agreement**Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, at least consider the following：* Option 1: A bitmap with each bit corresponding to [one or more] UEs
* Option 2: A codepoint value corresponding to one or part of UE identity, e.g., C-RNTI
* Option 3: A codepoint value corresponding to [one or more] UEs
* Option 4: Multiple codepoint values with each corresponding to [one or more] UE(s)
* Option 5: Multiple bit blocks with each corresponding to [one or more] UE(s)
* Combination of above options are not precluded.
* FFS how to carry LP-WUS information, e.g, by encoded bits (with/without CRC) and/or by OOK sequence selection for ‘ON-OFF’ pattern for OOK symbols of LP-WUS.
* FFS how to carry LP-WUS information by overlaid OFDM sequences.
	+ It doesn’t preclude considering the configuration where a single candidate overlaid OFDM sequence is used
* FFS details of LP-WUS information to trigger PDCCH monitoring (e.g. whether above is applicable to one or more serving cells)
 |

Based on input from companies, Company views are summarized as below.

* Option 1: [2][7][16][13][14][12][10][26][19][25]
* Option 2: [4][20][22]
* Option 3: [4][20] [19][21][22]
* Option 4: [5][4][22][25]
* Option 5: [26][17]
* Combinations of option 1 and one of option 2/3/4: [2]
* Further discuss after mechanism of LP-WUS for connected UEs is determined: [15]

For option 1, supporting companies think bitmap is beneficial when probability for UE to wake-up is large. [2] provides overhead analysis for option 1 vs option 2 in table 5 as copied below. [6] analyzes, for connected mode, depending on the traffic characteristics, it is possible that probability for UE to wake up is large, e.g., around 50%, where bitmap-based LP-WUS is better. [8] also analyzes overhead under different paging rate, showing bitmap with smaller overhead than codepoint when per PO paging rate ≥ 60% (per subgroup paging rate = 10%). The observation can be applicable to RRC connected mode.

For option 2/3/4, supporting companies think benefit of codepoint in RRC idle/inactive is also applicable to RRC connected mode.

For option 5, supporting companies think group-cast LP-WUS is beneficial to wake-up multiple UEs using different bit block in a LP-WUS.

Companies also discuss desirable option for different LP-WUS operation methods. [2][13][15][10] prefer option 1 if LP-WUS is to replace DCP. If LP-WUS is not before the beginning of *onDurationTimer*, e.g. anytime, [15][2] consider codepoint option or codepoint + bitmap option is desirable.

Considering good support for option 1, FL makes following proposal.

**[H][FL1] Proposal 3.3-2:** Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, support option 1.

* Option 1: A bitmap with each bit corresponding to [one or more] UEs

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | Bitmap can wake-up multiple users simultaneously by one LP-WUS, which is very efficient for RRC connected mode when wake-up probability is quite high for multiple UEs. It is beneficial especially when LP-WUS replacing DCP.  |
| Qualcomm | N | We prefer a unified design with idle/inactive mode. Hence, we support codepoint based design options 2, 3 and 4. |
| Nordic  | Y | we do not think unified design is possible, the UE ID/subgroup will be likely different. |





* 1. Preamble

The necessity of preamble is discussed by companies. [18][8][6][5][3][13][15][12][11][10][23] support preamble for timing acquisition, or AGC stabilization, or channel/interference estimation. [4][9][16][14] think preamble is unnecessary. [4] observes preamble results in increased overhead. [9] analyzes the use of preamble can be ignored as the additional performance gains for having it is marginal, if Manchester encoding is used.

Since the necessity of preamble highly depends on the residual frequency error after frequency error correction of LP-SS discussed under section 4 and LP-SS periodicity discussed under section 3. FL suggests to discuss preamble issue after progress in these sections.

* 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. Furthermore, Manchester coding is also useful for overlaid OFDM sequence as it can provide a significant ‘on’ pulse.

[18][4][8][7][5][6][3][13][14][15][25][29] support Manchester coding. [9] supports Manchester coding at least when there is no preamble in LP-WUS. [14] thinks even with presence of preamble, Manchester coding is useful considering optimal threshold would vary during WUS duration and threshold estimation by preamble would consume additional power.

* FEC: simple channel coding is proposed by some companies [4][8][9], e.g., hamming or RM code. FEC can further improve performance, however, this may increase the complexity of LR.

Among proponent companies, no company questions the benefit of Manchester coding for encoded bits. For LP-SS, [4][9][6] think it is beneficial to use Manchester coding for LP-SS, e.g., for sequences with balanced 0&1 [4], helpful for mismatched correlation [4] and for proper threshold determination [9]. while the necessity of Manchester coding for LP-SS is questioned by [2][7][8]. [7] analyzes the demodulation of Manchester coding should be performed every hypothesis before conducting correlation if Manchester coding is applied for LP-SS which increases complexity. [2][7] think Manchester coding consumes twice resources, while performance is not as good as a binary sequence with double length. [2] provides simulation results which show no gain provided by Manchester coding for LP-SS even when the binary sequence length is not doubled. [8] thinks the number of sequences is decreased due to Manchester coding. [23] is open for further study, considering potential power imbalance issue if without Manchester coding and correlation property degradation if with Manchester coding.

**[H][FL1] Proposal 3.5-1:** Regarding Manchester coding for LP-WUS/LP-SS:

- Support Manchester coding for LP-WUS

- Not support Manchester coding for LP-SS

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y |  |
| Nordic  | Y |  |

1. LP-SS
	1. Binary sequence design for LP-SS

### The number of binary LP-SS sequences for the ‘ON-OFF’ pattern

|  |
| --- |
| **Agreement**Further down-select the number of binary LP-SS sequences for the ‘ON-OFF’ pattern:* 3
* 4
* 8
* 16
 |

Regarding the number of binary LP-SS sequences for the ‘ON-OFF’ pattern, companies support the following values based on reasons as listed below:

* 3： [2][7][11][8][12][6][13][30][25][5]
	+ Sufficient for frequency reuse factor=3 consider MSG 3 coverage comparable
	+ Additional coordination among cells can be considered if more interference cells observed.
* 4： [2] [8] [6] [27] [13][5]
* 8： [9][4] [13]
	+ Theoretical hexagonal grid may not work well in practical deployments with different sizes.
* 16： [4][17]

Considering non-ideal grid in the practical deployments, FL suggests the following:

**[H][FL1] Proposal 4.1-1:** The number of binary LP-SS sequences is 8.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo |  | We agree that UE may see more than 3 or 4 neighboring cells in practical non-ideal grid deployments, but we still think 3 or 4 sequences would be sufficient, because there can be coordination among neighboring cells not only for sequence resource but also for time and frequency resources, e.g., 3 different sequences together with 3 or 4 different time and frequency resources to support more than 8 neighboring cells. Having said that, we can be open for 8, if companies really foresee difficulty for time/frequency coordination, but we have strong concern on 16, with unnecessary complexity, standard effort and increased overhead, because the sequence length would be much longer to support such large number of sequences.  |
| Qualcomm | N | We think more concrete information (e.g., from field) is needed to show why 3 or 4 binary sequences for LP-SS does not work in the field. |
| Nordic  | N | 4 is sufficient. This should be sufficient for OOK LR for which coverage at cell-edge is not expected.  |

### The LP-SS sequence type

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| --- |
| **Agreement**For the binary LP-SS sequence type for the ‘ON-OFF’ pattern in a LP-SS, further down-selection from the following:* Gold sequence
* M sequence
* Computer searched sequence
* FFS: the length of LP-SS sequence
 |

Regarding the down-selection among the three sequence types as shown above, companies propose the following design principles and metrics for comparison:

* Balanced 0 & 1 within the sequence and within each OFDM symbol of the sequence[2][3][4][9][7][6]
	+ Both the OOK sequence itself and the envelope of the modulated LP-SS signal are centred around their mean value to improve detection performance
	+ Ensure the same power of OOK symbols across different OFDM symbols
	+ Facilitate the RSRP estimation
* Good auto-correlation for better timing estimation [4][2] [7][3] [6]
	+ Mainlobe width [4][2]
	+ First valley value [4]
	+ Side lobe value [4]
	+ 1st peak cor/2nd largest peak cor [2]
* Good cross-correlation for mitigating inter-cell interference [4][2] [7][3] [6]
	+ 1st peak auto-cor/1st peak cross-cor [2]
* Limited length of consecutive '0's to avoid losing AGC [4][3]

One company [18] has different views on the balanced 0 & 1 within the sequence by considering lower number of OOK ON symbols per OFDM getting more benefit from power pooling within one OFDM symbol, and thus, propose to have lower density of OOK ON symbols than OOK OFF symbols.

Further, considering there would be time error and frequency error when detecting LP-SS, the above design principles shall be considered under time and frequency error instead of ideal assumption. Also the length of sliding window for performing timing estimation hypothesis shall be determined based on the time error anticipated by LP-SS to guarantee that the peak location is not missed.

**[H][FL1] Proposal 4.1-2:** The binary LP-SS sequence type down-selection is based on the following:

* Balanced 0 & 1 within the sequence and within each OFDM symbol of the sequence
* Good auto-correlation within sliding window under time and frequency error, e.g., mainlobe width, 1st peak cor/2nd largest peak cor
* Good cross-correlation within sliding window under time and frequency error, e.g., 1st peak auto-cor/1st peak cross-cor

Note 1: the time and frequency error are determined based on the residual frequency error assumed for LP-SS design.

Note 2: the sliding window length is determined by the time error anticipated by LP-SS.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | Support design principles above to select LP-SS sequence. For Note 1 and Note 2, we think it is beneficial to align the assumption of residual error and maximum sliding window length, because different assumptions would lead to different results.  |
| Qualcomm | Y | For short binary sequences, we think certain computer is needed not matter which type of sequences is selected. |
| Nordic  | Y | no need to limit design to particular sequence type, if sequence is 16 or 32 bits log. |

### The length of LP-SS sequences

Besides the number of LP-SS sequences and the LP-SS sequence type, the length of LP-SS shall be also determined to achieve both sync accuracy and RRM measurement accuracy.

In general, the sequence length, M value and the occupied OFDM symbols by LP-SS are related to each other. With sequence length fixed, fewer OFDM symbols are used for larger M, while with the number of OFDM symbols fixed, longer sequence is used for larger M. Companies [2] [6] provide evaluation results showing how sequence length, M value and the occupied OFDM symbols affect both sync accuracy and RRM measurement accuracy.

For sync accuracy, as observed in [6] for M=2, 4, with the same number of OFDM symbols, the larger M provides higher sync accuracy. With the same M value, more OFDM symbols provide higher sync accuracy.

For RRM accuracy, as observed in [6] for M=2, 4 and [2] for M=2, 4, 8, with the same number of OFDM symbols, different M values don’t affect RSRP accuracy. With the same M value, more OFDM symbols provide higher RSRP accuracy.

Therefore, there would be two alternatives for determining LP-SS length for different M values:

* Alt.1: The same length of LP-SS sequence is assumed for different M values
	+ Easy for sequence design
	+ But different OFDM symbols will be used for different M values, results in a variable LP-SS time resource depending on M
* Alt.2: The same number of OFDM symbols is assumed for different M values
	+ LP-SS time resource keeps constant regardless of M values, and thus, the RSRP accuracy is same across different M values
	+ Different lengths of LP-SS sequence need to be designed for different M values, but the complexity can be reduced by support only few M values, e.g., one M value for OOK-1 and one M value for OOK-4

[H][FL1] Question4.1-1: Do you assume alt.1 the same length of LP-SS sequence applied for both OOK-1 and OOK-4 with different M values? or do you assume alt.2 the same number of OFDM symbols used by LP-SS sequence for both OOK-1 and OOK-4 with different M values?

|  |  |  |
| --- | --- | --- |
| **Company** | **Alt.1 or alt.2?** | **Comments** |
| vivo  | Alt 2  | Currently, we consider Alt 2, and we agree with FL that the design targeting only few M values can be sufficient for performance while reduce standard effort, e.g., M=1 and M=4. If we go with Alt 1, it would unnecessarily increase LP-SS overhead especially for M=1 case.  |
| Qualcomm |  | We wonder whether Alt. 1 and Alt. 2 restrictions are needed at all. |
| Nordic  | Alt1 | Design could scale like SSB. |

Further, [4] and [6] proposes to use timing estimation performance to determine the length of binary LP-SS sequence, e.g., achieve a timing estimation error greater than T us for P % of the time at the operating point of the required SNR. Specifically, [4] assumes T=1, P=1 and [6] assumes T=1, P=10. Considering LP-SS mainly provides sync for LP-WUS detection, the required SNR value for LP-WUS can be reused, e.g., -3dB. Besides, as agreed in #116, the RRM measurement performance could be checked by the RRM measurement accuracy based on X LP-SS samples within a period comparable to Y=the length of I-DRX cycle that is larger or equal to 1.28s. Regarding the SNR for RRM measurement, [11] proposes to consider SNR=-6dB as the operating SNR for LP-SS to provide some measurement margin for ensuring LP-WUS works well at SNR=-3dB.

Notably, considering LP-WUS with OOK-1 is more tolerable to timing error, the accuracy requirement is less stringent in this case compared to OOK-4 with M>1, and thus, it’s better to separate the sync accuracy requirement for OOK-1 and OOK-4 with M>1.

Based on above, FL suggests the following:

**[H][FL1] Proposal 4.1-3:** For determining the length of LP-SS sequence, the evaluation assumes the following:

* Sync accuracy: timing estimation error greater than T us for P= [10] % of the time for at least SNR= [-3] dB, T= [3]us for OOK-1, T= [1] us for OOK-4 with M>1.
* RRM measurement accuracy: X LP-SS samples within a period comparable to Y=the length of I-DRX cycle that is larger or equal to 1.28s for at least SNR=[-6]dB, X and Y is up to company report.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm |  | We are generally fine with the proposal except for whether -6dB RRM measurement margin requirement is really needed. |

### Determination of binary LP-SS sequence used in a cell

|  |
| --- |
| **Agreement**For the LP-SS sequence used in a cell,* Option 1: the information necessary for determining the sequence is explicitly configured
* FFS: Additional support of determining the sequence by predefined rule without configuration
 |

[7][20] proposeadditional support of sequence determination by predefined rule is not needed with the following reason:

* With up to 16 binary sequences, only indicating which binary sequence is used for a cell may not cause the overhead taking into account the total information size of SIB related to LP-WUS/LP-SS.
* With explicit configuration, it gives more flexibility to gNB to control the sequences in different cells

[23] supports cyclic shift using physical cell ID for pre-defined rule when LP-SS sequence configuration is absent

**[M][FL1] Proposal 4.1-4**: For the LP-SS sequence used in a cell, determining the sequence by predefined rule without configuration is not supported.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y | The signaling of overhead of the network configuration is quite small. Hence, network can always explicitly configure the sequence.  |
| Nordic  |  | We can go with majority view. But we prefer cell-id based approach, which can be used for the case when LP-WUS is deployed in the same cell where MR camps.  |

* 1. LP-SS with or without overlaid OFDM sequences

As agreed in RAN1#116 meeting, the following three options are considered for further down-selection:

* Option 1: Do not specify the overlaid OFDM sequences(s)
* Option 2: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation without targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Option 3: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Companies support option 1 [2][7][18][21] with the following reasons:
	+ Per WID, OFDM detector can perform RRM measurement and sync based on existing SSB in time domain without FFT.
	+ Reuse existing transmissions (e.g., parts of SSB, TRS etc.) as ON symbols of LP-SS whenever possible
	+ 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.
	+ 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.
	+ Support of SSB and overlaid OFDM sequence for LP-SS increases work load for RAN4 on LP-WUR RRM measurement evaluation.
	+ It is not sure that the overlaid OFDM sequence for synchronization and measurement can be carried well within the shorter ON pulse of LP-SS with larger M values such as 4, 8.
	+ LP-SS should be designed considering the performance for both receiver types. And it becomes difficult to optimize the design of LP-SS for the specific receiver type.
	+ 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.
* Companies support option 2 [6][9][3][24][19][23] with the following reasons:
	+ Provide good OOK detection performance.
	+ If the overlaid OFDM sequence for the LP-SS does not carry information, network can configure fixed known sequence(s).
	+ It is up to UE implementation for whether and how to use the overlaid sequence of LP-SS for RRM measurement and synchronization.
* Companies support option 3 [4][16] [13][15][20] [23] with the following reasons:
	+ gives a possibility for LP-WUR with I/Q branches to be able to utilize LP-SS for time/frequency
	+ 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
	+ Different SCS between SSB and LP-WUS may impose additional burden on LRs to adjust the reception strategy
	+ 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.
	+ The performance of the sequence-based receiver using SSB for synchronization and measurement still needs to be verified.
	+ 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.
	+ specifying the sequence(s) does not make gNB implementation more complicated
	+ does not require any addition resource overhead
	+ OFDM sequence overlaid on an OOK bit can at least improve performance of coverage.
	+ The overlaid OFDM sequence can carry the same partial cell ID information as OOK symbols for the LP-SS
	+ In addition, we also need to discuss the MR RRM relaxation and MR RRM offloading to LP-WUR, the overlaid LP-SS design can facilitate the common design for RRM regardless LP-WUR type.

Further, [4] proposes when the overlaid sequence for LP-WUS is reused for LP-SS overlaid sequence， option 3 in the above agreement can be naturally achieved.

Based on pros and cons provided companies, FL suggests the following compromised proposal.

**[H][FL1] Proposal 4.2-1:** Support overlaid OFDM sequence(s) for LP-SS

* LP-SS reuse the overlaid OFDM sequence(s) specified for LP-WUS.
* It’s up to UE implementation to use the overlaid OFDM sequence(s) for sync and RRM measurement.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo |  | We still prefer option 1. But we can live with the proposal for progress, with assumption of UE implementation to use the overlaid OFDM sequence(s) for sync and RRM measurement, and no additional RAN4 requirement for the overlaid OFDM sequence(s). |
| Qualcomm | Y | A more important question seems whether RRM measurement and sync requirements need to be separately defined for OFDM based LP-WUR using the LP-SS overlaid sequences. |
| InterDigital |  | We prefer option 3. Not clear how UE can handle the measurement by UE implementation.  |
| Nordic  | Y, but | additional randomization of sequences could be introduced on top of LP-WUS design  |

* 1. Waveform-selection of OOK-1 and/or OOK-4

|  |
| --- |
| **Working Assumption**Support the following options for LP-SS* Option 1: OOK-1
* Option 2: OOK-4 with M=2,4, FFS:1,8,16
	+ FFS whether value of M depends on SCS
* The SCS of a CP-OFDM symbol used for LP-SS generation is the same as that used for LP-WUS generation

FFS how OOK-1 and OOK-4 are specified |

In last meeting, OOK-1 and OOK-4 with supported values of M has been discussed and the working assumption above has been agreed.

Regarding the sync performance of OOK-1, [8] provides evaluation results showing that 3us residual time error can be achieved by 4 symbol length LP-SS for OOK-1 at SNR=-3dB, which is sufficient timing synchronization for OOK-1 detection and thus, proposes to confirm the working assumption. [15][20][19][23] also proposes to confirm the working assumption.

Regarding the M value for OOK-4, [4][6][2] provide evaluation results showing that better time accuracy, i.e., less residual time error could be achieved by larger M attributing to narrower auto-correlation main lobe by shorter OOK symbol duration, i.e., M=8 can achieve finer time accuracy than M=4.

On the other hand, [8] provides results indicating that OOK-4 with M=8 does not necessarily outperform OOK-4 with M=2 or 4. Also, a larger value of M results in a higher complexity for gNB and UE. Hence, M>4 should not be supported for LP-SS.[9] also provides evaluation results showing that the estimated timing offset can be restricted within $\pm 1μsec$ by using $M=8$, and the estimated timing offset error is limited within $\pm 2μsec$ by using M=4, which is more than sufficient to ensure reliable detection of LP-WUS with $M\leq 4.$[9] discusses the sync performance by using edge detection and states that if the unpredictable timing drift between two LP-SS occasions is much smaller than the maximum tolerable timing error, the cross-occasion timing filtering is feasible to track the main part of the timing error and as a result there is no much benefit in using a higher M value. [9][21] also propose that network configures the same OOK modulation scheme (i.e., OOK-1 or OOK-4) and same M for OOK-4 for LP-SS and LP-WUS transmissions in the cell.

**[H][FL1] Proposal 4.3-1:** Confirm the working assumption with the following updates:

**Working Assumption**

Support the following options for LP-SS

* Option 1: OOK-1
* Option 2: OOK-4 with M=2,4 FFS:1~~,8,16~~
	+ FFS whether value of M depends on SCS
* The SCS of a CP-OFDM symbol used for LP-SS generation is the same as that used for LP-WUS generation

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | Just clarification, for OOK-1 or OOK-4 with M=1, we only expect to support one of them, which is aligned with LP-WUS discussion. |
| Qualcomm | Y |  |
| InterDigital | Y |  |
| Nordic  | Y | Option 2, where LP-SS M and SCS matches that of LP-WUS |

* 1. Periodicities of LP-SS

The periodicities of LP-SS depend on both sync requirement and RRM measurement accuracy requirement for LP-WUR. For RRM measurement accuracy, companies provide evaluation results to show the required number of samples to achieve measurement accuracy, summarized below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Measurement accuracy requirement for RSRP or RSRQ | # of required samples | SNR (dB) | Length of LP-SS (symbols) |
| [4] | RSRP: +3dB | 4 | -3 | 8  |
| [9] | RSRP: +3dB | >=4 | Irrespective of the operating SNR | 4 |
| [2] | RSRP: +4dB | 2 | -3 | 2  |
| [2] | RSRQ: +2dB | 3 | -3 | 2  |
| [18] | RSRP: +2.5dB | Not reported | Not reported | 4  |
| [8] | RSRP: +3dB | Not reported | -6, -9 | 2~6  |
| [11] | RSRP: +2dB | 1 | -4 | 8 |
| [6] | RSRP: +2dB | 1 | -3 | 4/8 |
| Panasonic | RSRP: +3B | 2 | 0 | 14 |
| ZTE | RSRP: +3dB | 1 | -3 | 4 |

Based on companies’ evaluation, it is observed that up to 4 samples are required to achieve the RSRP measurement accuracy and up to 3 samples are required to achieve the RSRQ measurement accuracy. Considering measurement accuracy achieved within a period which is comparable to Y=the length of I-DRX cycle that is larger or equal to 1.28s, at least a periodicity value of 320ms should be considered.

Further, [4] thinks it is essential for latency and paging reliability to support the mechanism that UE fallbacks to MR when LP-WUS coverage is not good enough, and thus, the LP-SS cannot be too sparse to ensure UE knows the coverage status in time. Therefore, ‘periodicity + ramp up time’ should be no longer than an I-DRX cycle. Considering the ramp up time can be 800ms and the I-DRX cycle length is 1.28s, the periodicity of LP-SS should be no longer than 480ms, which means that 640ms is insufficient but 320ms can be a good choice.

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

* At least 320ms periodicity is supported. [2]
* The periodicities of LP-SS are not larger than 320ms [4]
* The periodicity of LP-SS is suggested to be 320ms [12] [13]
* 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]
* 640ms, 960ms [28]
* 160ms, 320ms [16]

Based on above, FL suggests the following:

**[H][FL1] Proposal 4.4-1:** For LP-SS periodicity, support at least:

* 320ms
* 640ms
* FFS 160ms, 1280ms, 2560ms, 5120ms, 10240ms

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y | There is condition for the at least 320ms periodicity that the LP-WUR frequency error can be corrected. |
| Nordic  | Y, but | for 640ms with understanding that preamble (e.g. LP-SS sequence) is transmitted before LO  |

1. The time error and frequency error correction by OOK-based and OFDM-based LP-WUR

|  |
| --- |
| **Agreement**For timing error evaluation purpose, the following two options for residual frequency error are considered:* Option 1: The maximum frequency error (Fe) of RTC/oscillator is assumed, companies report Fe value and the applied LP-WUR type.
* Option 2: The residual frequency error (Fr) after frequency error correction/clock calibration by LR or after assistance from MR is assumed, companies report Fr value, how to achieve it and the applied LP-WUR type.

**Agreement**For frequency error evaluation purpose, the following two options for residual frequency error are considered:* Option 1: The maximum frequency error (Fe) of oscillator is assumed, companies report Fe value and the applied LP-WUR type.
* Option 2: The residual frequency error (Fr) after frequency error correction by LR or after assistance from MR is assumed, companies report Fr value, how to achieve it and the applied LP-WUR type.

**Agreement**The LP-WUS and LP-SS design assumes the residual frequency error after frequency error correction without considering impact of drift, is up to X ppm for OOK-based LP-WUR. * FFS X which is no larger than 20ppm
* Initial frequency error assumption: up to company report

For the overlaid OFDM sequence design of LP-WUS, it is assumed that the residual frequency error for OFDM-based LP-WUR after frequency error correction without considering impact of drift is not larger than Y.* FFS Y which is no larger than 20ppm and lower than X
* Initial frequency error assumption: up to company report
 |

For LP-WUS and LP-SS detection, both the suffered frequency error and time error depend on the residual frequency error after frequency error correction if supported.

For OOK-based LP-WUR, the candidate approaches proposed by companies for frequency error correction are listed as below:

* MR assists to correct the frequency error of LP-WUR [4].

It depends on how frequent MR is waked up, e.g, if MR performs relaxed RRM measurement with 8 times, the maximum residual frequency error Fr for LR accumulated after 8 I-DRX cycles can be reduced to 1.02ppm. Based on analysis in [4], the residual frequency error (Fr) can be <= 5ppm for both timing and frequency error evaluation purpose.

* Frequency error correction by LR through clock counting [2][6][18]

In this approach, the frequency error/time error is corrected by counting the clock cycles within a known period, e.g., the interval between two LP-SS, and then the frequency error can be corrected through adding or subtracting clock cycles by comparing the counted number of clock cycles to the ideal ones within the same interval. Specifically, assuming there is ideally a total of $N$ clock cycles within the interval between two adjacent LP-SS, but the actually counted number of clocks by LR is $N’$ , and thus, a frequency error $Δf\_{e}=floor(\frac{N’-N}{N}) $can be identified and corrected. The frequency error is positive if $N’>N$ and negative otherwise. The frequency correction precision depends on the reference frequency of the clock, higher reference frequency can achieve higher correction precision. In [2], up to 5 ppm residual frequency error can be achieved by divide a low reference frequency, e.g.,32.765kHz to 3.84MHz. In [18], an average of 6.5 ppm residual frequency error can be achieved by reference frequency of 3.84MHz.

The clock counting approach is more suitable to correct the frequency error for a low frequency crystal to save power, i.e., RTC, and for a high frequency crystal, i.e., RF LO, one possible way is relying on the calibrated low frequency crystal for correction. Another possible way is relying on MR for frequency error correction.



* Edge detection for timing estimation [9]

In this approach, the detection is performed over both transitions, namely, positive edge and negative edge of the ON duration pulse. [9]shows that the residual timing offset can be restricted to ±2μsec while using M=4 OOK signal by detecting the edge transitions.

* Timing and frequency domain sliding window algorithm [5]

The timing and frequency domain sliding window algorithm is a simple algorithm based on comparison of correlation peaks of samples with the sliding window in time from the reference time or with the sliding window in center frequency from the reference sub-band frequency.

For OFDM-based LP-WUR, the legacy frequency error correction approach for MR can be referred through detecting SSB or overlaid sequence of LP-SS if supported. It can also rely on MR for initial frequency error correction [4].

Companies’ inputs on the values of residual frequency error are summarized below:

For time error, residual frequency error after frequency error correction for OOK-based LP-WUR is

* Assume frequency error correction is supported [6] [9] [11], [2], [4], [17][5]
	+ Up to 5ppm: [11], [2], [4], [17]
	+ Up to 6.5ppm: [18]
	+ 19.5ppm and 28.7ppm for M-sequence, 21.1ppm and 32.4ppm for GOLD-sequence based LP-SS with M =4 and M=2 [5]
* Assume frequency error correction is not supported, the maximum frequency error of RTC is assumed
	+ Up to 20ppm: [10], [2], [3]

For frequency error, residual frequency error after frequency error correction for OOK-based LP-WUR is

* Assume frequency error correction is supported
	+ Up to 5ppm: [11], [2], [4] [17]
	+ Up to 20ppm: [2]
* Assume frequency error correction is not supported, the maximum frequency error of RF LO is assumed
	+ 50ppm: [2][13]
	+ 200ppm: [2][13]

Further, RAN4 RF has agreed that up to 20ppm frequency error for OOK-based LR is assumed for LLS simulation.

For time error and frequency error, residual frequency error after frequency error correction for OFDM-based LP-WUR is

* Assume frequency error correction is supported [11], [4], [2], [3]
	+ Up to 2ppm: [11]
	+ Up to 5ppm: [4], [2]
	+ 0.1ppm or 0.5ppm or 1ppm or 5ppm for OFDM based LP-WUR with FFT: [3]
* Assume frequency error correction is not supported
	+ 5ppm or 10ppm: [2]
	+ 20ppm for OFDM based LP-WUR with FFT: [3]

Based above, FL suggests the following:

**[H][FL1] Proposal 5-1:** For both time error and frequency error, the LP-WUS and LP-SS design assumes the residual frequency error after frequency error correction without considering impact of drift, is 5 ppm for OOK-based LP-WUR.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y |  |
| Nordic  | Y |  |

**[H][FL1] Proposal 5-2:** For both time error and frequency error, the overlaid OFDM sequence design of LP-WUS assumes that the residual frequency error for OFDM-based LP-WUR after frequency error correction without considering impact of drift is no larger than 5ppm.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y |  |
| Qualcomm | Y |  |
| Nordic  | Y |  |

1. Frequency resource for LP-WUS and LP-SS

In RAN1 117 meeting, RAN1 agreement on number of PRBs for LP-WUS and LP-SS with SCS 30kHz is shown below.

|  |
| --- |
| **Agreement**Update agreement in last meeting as below: From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz* X ~~to be down-selected between~~ = 11 ~~and 12~~ PRBs
* FFS if other number of PRBs needed, for LP-SS and LP-WUS with a channel bandwidth equal or less than 5MHz

FFS: Whether the above is applicable to FR2 |

In this meeting, companies continue discussion for 15kHz SCS. Companies view on X values for 15kHz SCS is summarized as below.

* X=1: [31]
* X=11: [8][4][9][27][26]
* X=20: [2]
* X=22: [2][11][6][5][3][16][26][17][23][22][29]
* X=27: [31]
* Further discussion of X=11 or X=22: [7][25]

**Table 5: Benefit of each candidate value for X provided by proponent companies**

|  |  |
| --- | --- |
|  | Benefit |
| X=1 | For IoT application |
| X=11 (Same number of PRBs as 30kHz SCS) | 1. Unified signal design, e.g., length of overlaid OFDM sequence is independent of the bandwidth
2. Smaller BW, which is easier to accommodate in small BW, e.g., 3MHz or 5 MHz
3. Applicable for all supported channel bandwidth, similar as PSS/SSS for below 5MHz channel bandwidth
 |
| X=20  | 1. Fit in 5MHz BW with more guard PRBs while minor performance degradation compared with 30kHz SCS case.
 |
| X=22 (Same bandwidth as 30kHz SCS) | 1. Comparable performance for 30kHz SCS
2. Easier LP-WUR implementation for filter design, i.e.., same bandwidth independent of SCS.
 |
| X=27  | 1. Fit in 5MHz BW assuming full BW can be used.
 |

Since most companies focus on X=11 and X=22 PRBs, FL suggests to focus on these two values for further down-selection. Considering X=11 PRBs is less than maximum transmission bandwidth configuration of 3MHz (15 PRBs) and X=22 PRBs is less than maximum transmission bandwidth configuration of 5MHz (25 PRBs), these two values can be considered for a channel bandwidth equal or larger than Y=3 and 5 MHz respectively. The value of Y depends on RAN4 discussion on ASCS and ACS. Currently, zero or one PRB for ASCS are proposed by companies. Size of ACS is more controversial, with range of zero to 4 PRBs, depending on whether ACS can be relaxed.

 **[H][FL1] Proposal 6-1**: From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than Y MHz

* X to be down-selected between 11 and 22 PRBs.
* FFS value of Y

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | We prefer 22 PRBs for performance and same filter bandwidth for 15&30kHz SCS.  |
| Qualcomm | Y |  |
| Nordic  | Y | there are pros and cons, but it is clear that for OOK LR 22 PRB is better choice  |

In addition, [6] also discusses bandwidth for FR2, considering 11 PRBs for SCS=120kHz and 22 PRBs for 60kHz. [25] thinks one of the PRBs supported for FR1 can be reused for FR2 without additional spec impact. [22] considers larger bandwidth, e.g., ≥20MHz for FR2.

**[M][FL1] Proposal 6-2**: X value for 15kHz and 30kHz SCS is applicable to FR2, if supported.

* FFS: which X value(s) for FR2, if the X value for 15kHz and 30kHz is different.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo | Y | OK to reuse FR1 X value(s) for FR2 to minimize standard effort.  |
| Qualcomm | Y | With this proposal, supporting FR2 does not required additional spec efforts.  |
| InterDigital | Y | Fine to reuse the value(s). However, we don’t agree that FR2 does not require additional spec efforts. For example, QCL relationship should be considered.  |

1. Coverage improvement schemes

Companies propose the following schemes to improve the coverage achieved by LP-WUS and LP-SS [4][3][12][25][26][20][24][17][26]:

* Power boosting, which may not be always available for all gNBs
* Time domain repetition
* Spatial diversity with time domain repetition, which requires to be used with time domain repetition and precoder is transparent to OOK based receiver
* Frequency domain diversity with time domain repetition
* Time domain spreading code
* Multiple beam repetition/sweeping

According to FL’s understanding, power boosting is up to RAN4 decision which is currently under RAN4 discussion.

To meet performance requirement at target SNR agreed in RAN1 117 meeting, time domain repetition would be needed. Details, e.g., number of repetitions, repetition pattern, can be further discussed, after progress of basic design of LP-WUS, e.g., encoded bits or sequence for LP-WUS, coding scheme.

For spatial diversity scheme, if it can be transparent to both OOK and OFDM detector, we may not need to discuss details of the scheme, but if it is non-transparent, further discussion is needed.

For frequency domain diversity scheme, it requires frequency hopping beyond a LP-WUS bandwidth, e.g., hop from a 5MHz bandwidth to another 5MHz bandwidth, which impacts reception complexity.

For time domain spreading code, considering limited interest, FL suggests not further consider this scheme. Multiple beam repetition/sweeping is already agreed 9.6.2, further discussion on details of beam repetition/sweeping is to be discussed in 9.6.2., thus is no further considered in this agenda item. FL encourage companies

**[M][FL1] Question 7-1**: For spatial diversity provided by [4], do you think it is transparent to both OOK based receiver and OFDM receiver?

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Qualcomm |  | Spatial diversity is transparent if there is no repetition. With repetition, it may not be always transparent. |
| InterDigital |  | Agree that it may not be transparent in some cases. |
| Nordic  |  | Right, if spatial diversity is applied within a repetition, i.e. not in-between repetitions |

**[M][FL1] Question 7-2:** For frequency domain diversity provided by [4], how do you consider frequency hopping is beyond LP-WUS bandwidth?

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| vivo |  | We don’t support frequency hopping beyond LP-WUS bandwidth. It increases complexity with retuning.  |
| Qualcomm |  | Frequency hopping of LP-WUS is challenging to LP-WUR implementation and hence not preferred in comparison to repetition and spatial diversity. |
| InterDigital |  | Do not support frequency hopping.  |
| Nordic |  | Hopping should not be considered for LP-WUS |

References

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4. R1-2405867, Signal Design of LP-WUS and LP-SS, Huawei, HiSilicon
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27. R1-2407136, On LP-WUS and LP-SS design, Nordic Semiconductor ASA
28. R1-2406814, Discussion on LP-WUS and LP-SS design, Lenovo
29. R1-2406504, Discussion on LP-WUS and LP-SS design, Everactive
30. R1-2406597, Discussion on LP-WUS and LP-SS design, RUijie networks
31. R1-2405966, Preliminary Assessment on Low-Power Wake-Up Receiver, Tejas Networks Ltd.

Appendix : Proposals from contributions

**R1-2406193 vivo**

Proposal 1: For candidate M values,

* + Support M=4 & M=1 for OOK-4 for LP-WUS in addition to agreed M=2.
	+ Support M=1, 2 and 4 for LP-SS.

Proposal 2: RAN1 further discusses following two cases for carrying information by OFDM sequence(s) with consideration of detection performance, LP-WUR complexity and power consumption,

* + Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence.
		- The single overlaid sequence can be same or different for different cells up to network management/configuration.
	+ Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on ~~each~~ an OOK ‘ON’ symbol ~~or OFDM symbol duration~~, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Down-select between the following two sub-options.
		- Option 2-1: 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 2-2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the overlaid OFDM sequence(s)

Proposal 3: Information bits repetition by overlaid OFDM sequence(s) in OFDM symbols of the LP-WUS without additional overhead can be considered.

Proposal 4: Support overlaid OFDM sequence(s) of an OOK ON symbol before DFT/LS processing.

Proposal 5: Support ZC sequence for overlaid OFDM sequence. FFS how to generate multiple sequences based on ZC sequence, e.g., different root and/or cyclic shift.

Proposal 6: Up to 4 or 8 candidates overlaid OFDM sequences per OOK ON symbol for information conveying can be supported. FFS different number of candidates overlaid OFDM sequences for different M.

Proposal 7: Do not specify overlaid OFDM sequence for LP-SS.

Proposal 8: Support up to 8 or 16 subgroups per LP-WUS.

Proposal 9: Support bitmap for RRC idle/inactive state, where each bit is corresponding to one subgroup. Proposal 10: Support a flexible frame work for bitmap and codepoint for RRC connected state. A LP-WUS can include X bits for codepoint plus Y bits for bitmap, where X and Y is configurable.

* + If X=0, LP-WUS information is indicated by UE-group specific bitmap.
	+ If Y=0, LP-WUS information is indicated by a UE specific or UE-group specific codepoint.
	+ If X ≠0 and Y≠0, LP-WUS information is indicated by sub-group codepoint and bitmap for UEs within the subgroup.

Proposal 11: Support encoded bits for LP-WUS.

Proposal 12: Select 3 or 4 sequences with length at least 16 among Gold, m and computer searched sequences based on following metrics:

* + Balanced 0 & 1 within the sequence and within each OFDM symbol of the sequence.
	+ Good aperiodic correlation
		- Low auto-correlation and low cross-correlation within a detection window.
		- Cross correlation metric = 1st peak auto-cor/1st peak cross-cor.
		- FFS metric for auto-correlation, e.g., main lobe, 1st peak cor/2nd largest peak cor
		- FFS: detection window length based on maximum timing error

Proposal 13: Support at least 320ms periodicity for LP-SS. FFS other values, if needed.

Proposal 14: Support 20 or 22 PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.

Proposal 15: Support Manchester coding for LP-WUS, if payload is carried by encoded bits. Not support Manchester coding for LP-SS, or LP-WUS if payload is carried by OOK sequence selection.

**R1-2406412 ZTE, Sanechips**

*Proposal 1: Time domain based OOK-4 waveform generation mechanism should be specified according to at least step1~step6.*

*Proposal 2: Unified time domain waveform generation for OOK-1 and OOK-4 should be supported.*

*Proposal 3: For SCS of LP-WUS, it could be configurable and*

* *If LP-WUS resource allocation is associated with DL BWP, the SCS of LP-WUS is the same as that of the DL BWP*
* *If LP-WUS resource allocation is NOT associated with DL BWP, a separate SCS can be configured for LP-WUS*

*Proposal 4: Support 22 PRBs for LP-WUS and LP-SS with SCS of 15kHz (PRBs for guardband are not included) for bandwidth equals or larger than 5MHz*

*Proposal 5: Bandwidth far smaller than 5MHz for LP-WUS and LP-SS needs further evaluation.*

*Proposal 6: For OOK based LP-WUS, Manchester code with code rate of at least 1/2 and 1/4 should be supported.*

*Proposal 7: For OFDM based LP-WUR without FFT or OOK based LP-WUR, the residual frequency error could be assumed as the maximum frequency error (Fe) of RTC, e.g., 20ppm.*

*Proposal 8: For OFDM based LP-WUR with FFT, the residual frequency error (Fr) can be assumed as 0.1ppm or 0.5ppm or 1ppm or 5ppm.*

*Proposal 9: LP-SS detection with sliding window should be used as baseline for LP-SS based TO estimation and LP-RSRP calculation.*

*Proposal 10: Confirm the working assumption from RAN1 #116bis with following updates:*

* *Support Option 2: OOK-4 with M=2,4,8 at least*
* *For OOK1 and OOK4 M=1 based LP-SS, further check whether the sync performance is allowed.*
* *Proposal 11: For binary sequence carried by LP-SS, at least the following design principles should be considered:*
* *Configure equal number of OOK-ON symbols (carrying bit “1”) and OOK-OFF symbols (carrying bit “0”) within M OOK symbols of one OFDM symbol*
* *Good auto-correlation*
* *Lower cross-correlation with shifted binary sequences, wherein the shift value at least includes time delay or time advance*

*Proposal 12: For the binary LP-SS sequence type for the ‘ON-OFF’ pattern in a LP-SS, Computer searched sequence and M sequence can be supported.*

*Proposal 13: At least OOK-4 with M =8 should be supported for LP-SS for SCS of 30kHz.*

*Proposal 14: For the overlaid OFDM sequence(s) for LP-SS, Option 2 is supported.*

*Proposal 15: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity.*

*Proposal 16: LP-Preamble is supported to be configurable and can be added before LP-WUS for further time error correction.*

*Proposal 17: For OOK based LP-WUS, OOK-4 with M=4 should be supported.*

*Proposal 18: For OOK-1/OOK-4, Gap can be inserted in the beginning and ending of each OOK symbol to solve the problem of LP-WUS detection performance loss caused by larger UE time error.*

*Proposal 19: Update option 1 and option 1-2 as follows:*

* *Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol or OFDM symbol duration. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence or OOK ON/OFF pattern.*
* *Option 1-2: The overlaid OFDM sequence is pre-determined from multiple sequences. This sequence carry NO information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence or the OOK ON/OFF pattern.*

*Proposal 20: Regarding the overlaid OFDM sequence(s) of LP-WUS,*

* *When OFDM sequence needs to carry information bits, option 2-2 is prioritized.*
* *When OFDM sequence does not need to carry information bits, option 1-2 is prioritized.*

*Proposal 21: For overlaid OFDM sequence(s) for LP-WUS in time or frequency domain,*

* *Option 1-1 is support.*
* *Option 2 can be used as gNB implementation*
* *Option 1-2 and Option 3 are not supported*

*Proposal 22: Regarding the LP-WUS information for idle/inactive UEs, Option 2 and Option 3 are prioritized to be further studied.*

*Proposal 23: Adding CRC for LP-WUS payload is necessary for both OOK based and OFDM sequence based LP-WUS transmission.*

* *8-Length CRC is a starting point, for example,* $g\_{CRC8}(D)=[D^{8}+D^{7}+D^{4}+D^{3}+D+1]$ *for a CRC length of L=8*

*Proposal 24: When OFDM sequences are used for carrying information, ZC sequence and M sequence are preferred.*

* *Four OFDM sequences carrying 2 bits information is a starting point*

*Proposal 25: For overlaid OFDM sequence design, study with existing Gold sequence, M-sequence and ZC sequence as starting point.*

* *Further clarify the definition for other candidates OFDM sequences if needed.*

*Proposal 26: Phase randomized Gold sequence should be supported for LP-WUS and LP-SS if the OFDM sequence is used to improve the OOK based LP-WUR detection performance.*

*Proposal 27: For OOK based LP-WUS, at least the following coverage improvement schemes should be further studied to achieve the coverage of PUSCH Msg3:*

* *Detection with sliding window*
* *Bit level repetition is prioritized*
* *Frequency hopping*

*Proposal 28: LP-SS could be used as a part of LP-WUS to save NW resources.*

*Proposal 29: For LP-WUS, at least the design of structure, payload size and carried information should be considered separately for IDLE/INACTIVE and CONNECTED modes.*

**R1-2405867 Huawei, HiSilicon**

1. *For OOK-4, confirm the working assumption of M=4 is confirmed for both 15kHz SCS and 30kHz SCS.*
2. *OOK-1 is specified as a special case of OOK-4 with M=1.*
3. *For LP-WUS, UEs are configured to monitor one or multiple LP-WUS occasions and each occasion can convey a block of information bits.*
* *The bit length of the block of information is configurable or determined only from RRC configurations.*
* *One LP-WUS occasion comprises of one or multiple OFDM symbols.*
	+ *Note: The OFDM symbol refers to the symbols after the processing “iFFT+CP” in S7.2.1.1 of TR 38.869*
* *FFS details of the pre-DFT sequences that refers to the input to the DFT/LS processing block in S7.2.1.1 of TR 38.869*
	+ *The size of pre-DFT sequence set*
	+ *Sequence generation/selection*
* *FFS the mapping from a block of information bits to pre-DFT sequences and OFDM symbols*
	+ *FFS: whether the series of pre-DFT sequences to wake up a UE only depends on UE-specific predetermined information*
1. *It is preferred to specify the overlaid sequence OOK-1 and OOK-4 in time domain.*
2. *With respect to the definition of overlaid sequence, adopt Option 1-1, i.e., overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing.*
3. *Regarding the overlaid OFDM sequence(s) of LP-WUS, if overlaid OFDM sequence does not carry information, option 1-2 is supported for potential inter-cell interference mitigation.*
4. *Regarding the overlaid OFDM sequence(s) of LP-WUS, both Option 2-1 and Option 2-2 are supported.*
	* *In order to reduce resource overhead, transmission duration of a LP-WUS targeting to wake up OFDM based receiver can be shorter than the transmission duration required for ED based receiver.*
5. *Further discuss and adopt sequence(s) considering the following aspects:*
	* *Sequence with good auto-correlation property and cross-correlation property*
	* *How to control the interference from LP-WUS transmitted from neighboring cells*
6. *Pulse shape and/or spectrum shape are also considered in the design/selection of overlaid sequence(s).*
7. *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.*
8. *For 15kHz SCS, support 11 PRBs for LP-WUS and LP-SS BW.*
9. *Time domain repetition and* *transmit diversity by precoder cycling are considered to improve the performance of LP-WUS.*
10. *Coverage recovery schemes that exploits time / frequency diversities are considered.*
11. *Binary spreading sequences are considered to multiplex WUSs on the same time-frequency resource to improve the BLER.*
12. *Regarding the LP-WUS information for idle/inactive UEs, support the codepoint mapping method, i.e. option 2 and/or option 3.*
* *It is supported that the same LO resources can be monitored by UEs from different PO’s.*
* *Note: multiple paging signals for respective UEs can be conveyed by multiple MO’s.*
1. *Regarding the LP-WUS information for connected UEs, support the codepoint mapping method, i.e. option 2, option 3 and/or option 4.*
2. *Overlaid sequence for LP-SS is specified.*
3. *LP-SS has similar design as LP-WUS, including at least the following aspects：*
	* *pulse shaping methods, including the concentrated waveform and the spectrum adjustment*
4. *The design of LP-SS should consider the CP impact and the length of binary-valued sequence to generate LP-SS.*
5. *The number of binary sequences for LP-SS can be 8 or 16.*
6. *Before determine the specific LP-SS sequence type, the LP-SS resources should be determined first, i.e.,*
	* *The number of OFDM symbols occupied by LP-SS*
	* *The length of binary LP-SS sequence*
	* *The number of LP-SS sequences*
	* *Timing estimation performance can be used as metric*
7. *In order to determine the specific LP-SS sequence, it is necessary to first define the metric for comparison, e.g., correlation characteristics, the main lobe width, the first valley value, and/or the side lobe value*
8. *For both timing and frequency error evaluation purpose, the residual frequency error (Fr) can be <= 5ppm after assistance from MR.*
9. *A set of candidate values for LP-SS periodicity can be defined, which are not larger than 320ms.*
10. *Preamble of LP-WUS is not supported.*

**R1-2406379 CATT**

Proposal 1: The same information set could be configured with different transmission time interval for OOK-based and OFDM-based LP-WUR in the LP-WUS design.

Proposal 2: The payload size of LP-WUS to be considered is in the range of 4~8bits within one slot duration.

Proposal 3: OOK-4 with M=1 can be supported and confirming OOK-4 with M=4.

Proposal 4: OOK-4 waveform of LP-WUS can be specified by a configurable M value.

Proposal 5: It is reasonable for the SCS of LP-WUS is same as that of the initial BWP (configured for CORESET#0) for RRC\_IDLE/INACTIVE mode and the active BWP for RRC\_CONNECTED mode.

Proposal 6: Option 2: The single SCS is determined by pre-defined rule, is preferred for simple and no spec impact to RRC configuration signaling.

Proposal 7: The LP-WUS is multiplexed with NR DL channel after IFFT to minimize the LP-WUS detection performance degradation by timing and frequency error.

Proposal 8: Support Option 3 with time domain Walsh sequence. The length of overlaid OFDM sequence is same with that of time domain sequence of an OOK symbol used for OOK-based LP-WUR.

Proposal 9: Either Gold-sequence or M-sequence can be supported for overlaid OFDM sequence of LP-WUS.

Proposal 10: The overlaid OFDM sequence should carry all information bits of LP-WUS in the design principle of the information carried by OFDM sequence and depending on the performance of the detection performance of the OOK-based LP-WUR whether the LP-WUS and NR signals/channels are multiplexed before or after IFFT.

Proposal 11: The Manchester coding should be the candidate as the LP-WUS channel coding method.

Proposal 12: It is recommended to support a LP-WUS structure with wake-up information preceded by a fixed preamble sequence for assisting synchronization.

Proposal 13: Support Option 3: A LP-WUS indicates multiple codepoint values.

Proposal 14: For RRC\_IDLE/INACTIVE mode, the sequence based LP-WUS with multiple orthogonal sequence should be sufficient for indicating the paging subgroup or bundling group of paging subgroups.

Proposal 15: 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 16: Same configuration of M for LP-SS and LP-WUS can be supported for low standardization complexity.

Proposal 17: Both Option 1: OOK-1 and Option 2: OOK -4 with M=1/2/4 can be supported for LP-SS waveform.

Proposal 18: The LP-SS should be multiplexed with NR channels/signals after the IFFT 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 IFFT sequence, it can mitigate the inter-channel interference to neighboring NR channel/signals to the NR UE when it performs IFFT processing even though the timing and frequency offset estimation is more challenged when OOK-1 waveform modulated by OFDM sequence.

Proposal 19: Either Gold-sequence or M-sequence can be supported for binary LP-SS sequence design.

Proposal 20: The number of binary LP-SS sequences can be 3 or 4.

Proposal 21: The preamble of LP-WUS is needed at least for the periodicity of LP-SS is larger than 205ms.

Proposal 22: The number of PRB should be scaled proportionally for different SCS (i.e., 22 PRBs for SCS=15 kHz)) within a fixed bandwidth, which would not degrade the coverage of LP-WUS and LP-SS for narrow bandwidth under larger SCS.

**R1-2407040 Qualcomm Incorporated**

*Proposal 1: Support time domain signal generation with the overlaid sequence transmitted in each OOK ON symbol (i.e., option 1-1) for LP-WUS with OOK-4.*

*Proposal 2: Support codepoint value based LP-WUS design with one codepoint value associated with one or multiple UE subgroups*

* *At most one LP-WUS carrying one codepoint value is transmitted in each LP-WUS MO within the LO*
* *A codepoint value can be associated with one UE subgroup, a subset of UE subgroups or all UE subgroups associated with the LP-WUS MO*
* *Multiple LP-WUS MOs can be configured in each beam in the LO, different LP-WUSs can be transmitted in these MOs to wake up different UE subgroups.*

*Proposal 3: Support preamble in the LP-WUS.*

*Proposal 4: Manchester coding is adopted for the codepoint value based LP-WUS with each codepoint value mapped to a sequence.*

*Proposal 5: support 3 or 4 LP-SS binary sequences.*

*Proposal 6: Support 22 PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.*

*Proposal 7: For FR2, support 11 PRBs for LP-WUS and LP-SS with SCS 120kHz (blanked guard RBs are not included).*

*Proposal 8: Do not specify the overlaid OFDM sequence for channel bandwidth less than 5MHz.*

**R1-2406661 Samsung**

Proposal 1: Regarding the overlaid OFDM sequence(s) of LP-WUS, discuss and down-select the following option first before considering the detailed options.

* Option 1-1: Specify multiple overlaid OFDM sequence candidates carrying information.

- multiple overlaid OFDM sequences corresponding to bit information are provided.

* Option 1-2: Specify multiple overlaid OFDM sequence candidates not carrying information.

- multiple overlaid OFDM sequences are used to reduce the interference of LP-WUS from different cell.

- single overlaid OFDM sequence is selected from the candidates for a LP-WUS.

* Option 2: Specify only single overlaid OFDM sequence for a LP-WUS not carrying information.

Proposal 2: The overlaid OFDM sequence should be designed to be transmitted over a single ON symbol of the OOK symbol.

* Do not support the cases that the overlaid OFDM sequence is transmitted on a OFDM symbol (for OOK-4 with M>1) or multiple OOK symbols.

Proposal 3: Support to specify multiple overlaid OFDM sequence candidates carrying information on one ON symbol (option 1-1 in proposal 1), 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 number of information bits carried by LP-WUS, and LP-WUR detection complexity.
* FFS: how to configure and generate the multiple candidates of OFDM sequence corresponding to information bits for UEs.
* FFS: whether to consider the position of ON pulse as the information at the OFDM-based LP-WUR.

Proposal 4: To design the overlaid OFDM sequence for LP-WUS, at least the following aspect should be considered:

* Larger coverage than that for OOK-based LP-WUS (target coverage: MSG3 PUSCH).
* Possible number of sequence having good cross correlation property.
* Good auto correlation property for an overlaid OFDM sequence.

Proposal 5: Support to have a common waveform generation for both OOK-1 and OOK-4 in the specification.

Proposal 6: For the supported M value of OOK-4 with M>1, do not support M = 4 at least for 30kHz SCS and higher SCS.

Proposal 7: Support 1/2 Manchester coding for LP-WUS.

Proposal 8: The LP-WUS information should be carried by encoded bits for OOK-based LP-WUR

* Support CRC attachment following the encoded bits to satisfy the target FAR.

Proposal 9: Support bit-map based subgroup indication.

* It is preferred to apply the same options for indicating the wake-up for RRC IDLE/INACTIVE UEs and RRC CONNECTED UEs.

Proposal 10: The following two approaches can be further discussed to decide the LP-WUS/LP-SS bandwidth with 15kHz SCS.

* Approach 1: the same bandwidth to LP-WUS/LP-SS with 30kHz SCS;

- LP-WUS operation is not allowed for the certain channel BW such as 3MHz.

* Approach 2: the same number of PRBs to LP-WUS/LP-SS with 30kHz SCS.

Proposal 11: Do not support to specify overlaid OFDM sequence for LP-SS (e.g., Option 1 in RAN1#116 agreement).

* LP-SS should be designed only for UEs with OOK-based LP-WUR.
* Which sequence is used to generate ON pulse for LP-SS can be up to gNB implementation without any specification.

Proposal 12: Down-selection between OOK-1 and OOK-4 for LP-SS, and the supported M values for LP-SS can be discussed after the decision on the existence of the overlaid OFDM sequence for LP-SS.

Proposal 13: Do not support Manchester coding for LP-SS.

Proposal 14: For the LP-SS binary sequence used in a cell, additional support of sequence determination by predefined rule is not needed.

Proposal 15: To decide the type and length of LP-SS binary sequence, at least the following aspect should be considered:

* Balanced number of ‘0’ and ‘1’.
* Good auto correlation property for a binary sequence.
* Good cross correlation property between multiple binary sequence candidates.

Proposal 16: For LP-SS binary sequence, it is preferred to consider 3 or 4 binary sequences as the candidates of LP-SS binary sequence.

**R1-2407059 Ericsson**

[Proposal 1 Following principles should be considered for LP-WUS and LP-SS design](#_Toc174112305)

[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.](#_Toc174112306)

[b. It should be possible to multiplex the LP-WUS/LP-SS with other NR transmissions in time or frequency domain without causing interference.](#_Toc174112307)

[c. It should be possible to reuse any unused LP-WUS time and frequency resources for other transmissions.](#_Toc174112308)

[Proposal 2 Paging misdetection performance of the UE should not be impacted when LP-WUS is used by the UE for power savings.](#_Toc174112309)

[Proposal 3 Different SCS case for LP-WUS and other NR transmissions in the same CP-OFDMA symbol is not considered further.](#_Toc174112310)

[Proposal 4 Including a preamble part before the data part of LP-WUS transmissions should be considered.](#_Toc174112311)

[Proposal 5 Following should be considered for LP-WUS payload mapping to OOK symbols:](#_Toc174112312)

[a. It should be possible to flexibly map different payload sizes (e.g., 1 to 8 bits) to flexible number of OFDM symbols that are available for LP-WUS transmission.](#_Toc174112313)

[b. Existing encoding and rate-matching approaches should be reused as much as possible.](#_Toc174112314)

[c. Manchester encoding can be considered before mapping coded bits to OOK symbols.](#_Toc174112315)

[Proposal 6 WUS payload size should be at most 8 bits in Idle/Inactive. Similar payload size should be considered for Connected mode.](#_Toc174112316)

[Proposal 7 For channel bandwidth of at least 5 MHz, the WUS bandwidth should be 11 PRBs for both 15 kHz and 30 kHz SCS corresponding to 1.98 MHz and 3.96 MHz, respectively.](#_Toc174112317)

[Proposal 8 For channel bandwidth less than 5 MHz, the WUS bandwidth should be 11 PRBs for 15 kHz SCS.](#_Toc174112318)

[Proposal 9 OOK-1 generation should be specified in the frequency domain (Option 2 in RAN1##117 agreements). That is, for ON symbols of OOK-1, sequences used as input of IFFT of the gNB transmitter are specified.](#_Toc174112319)

[Proposal 10 For the OFDM sequence overlaid on OOK-1, support Gold sequences.](#_Toc174112320)

[Proposal 11 With the support of OOK-1, OOK-4 with M=1 should not be supported.](#_Toc174112321)

[Proposal 12 For OOK-4, the value of M should not depend on the SCS in FR1.](#_Toc174112322)

[Proposal 13 For OOK-4, if overlaid OFDM sequences are specified in time domain, Gold sequence is a better option compared to the ZC sequence as it has a larger set of sequences, and it is already defined in the current specifications for SSS.](#_Toc174112323)

[Proposal 14 For OOK-4, if overlaid OFDM sequences are specified in frequency domain, interleaved ZC sequences should be considered.](#_Toc174112324)

[Proposal 15 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). i.e., low detection complexity and early termination should be ensured for OFDM WUR](#_Toc174112325)

[Proposal 16 Manchester encoding can be supported for LP-WUS.](#_Toc174112326)

[Proposal 17 Regarding carrying information with overlaid OFDM sequence(s) of LP-WUS, support Option 3 and Option 2-2 (as special case of Option 3) where OFDM-based WUR can obtain the whole information bits by the overlaid OFDM sequence(s).](#_Toc174112327)

[Proposal 18 The number of different LP-SS sequences should be 3.](#_Toc174112328)

[Proposal 19 Manchester encoding should not be mandatory for LP-SS especially for a short sequence length.](#_Toc174112329)

[Proposal 20 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.](#_Toc174112330)

[Proposal 21 Consider following values for configuring LP-SS periodicity: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms.](#_Toc174112331)

[Proposal 22 For enabling energy efficient LP-SS transmissions from gNB, it should be possible for gNB to transmit LP-SS without using a specific predefined overlaid OFDM sequence.](#_Toc174112332)

[Proposal 23 For LP-SS, confirm the working assumption from RAN1#116bis. For the FFS on M values for OOK-4, M=1,8,16 with OOK-4 should not be supported. Same SCS should be used for LP-SS, LP-WUS, and other NR transmissions in the same CP-OFDMA symbol.](#_Toc174112333)

**R1-2406422 Nokia Shanghai Bell**

Proposal 1: Consider a scalable design for LP-WUS/LP-SS to support multiple BW options that can fit within NR deployment scenario. Thus, consider the feasibility of LP-WUS BW equal to or below $5$MHz.

Proposal 2: The location of LP-WUS/LP-SS within carrier BW should be flexible and configurable by the NW.

Proposal 3: The BW of LP-SS/LP-WUS shall be the same as PSS/SSS, i.e., $X=11$ PRBs, enabling common LP-WUS design for all channel bandwidths and to maintain consistency for all receiver types.

Proposal 4: If the NW supports more than one SCS for NR transmission, then the choice of SCS used for LP-WUS should be left to the NW that shall be informed to the UE.

Proposal 5: Specify the OOK waveform in time domain for a single ON duration pulse of LP-WUS signal, i.e., option 1-1.

Proposal 6: Specify the OOK waveform in frequency domain for a single ON duration pulse as the position of the pulse within a symbol does not impact the time domain correlation properties. This is equivalent to option 2.

Proposal 7: Consider OOK waveform with $M=\{1,2\}$ as the baseline for evaluations as it favours both envelope and sequence detectors with or without the use of Manchester encoding.

Proposal 8: The use of Manchester encoding for OOK based scheme should be considered if there is no preamble field in LP-WUS frame structure.

Proposal 9: Pulse shaping should be considered for ON duration of OOK symbols to avoid power leakage from ON to OFF symbol duration.

Proposal 10: 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., $M$, used by OOK signal.

Proposal 11: A relationship between the different sequences used in neighbouring OOK ON symbols can be achieved by rotating the phase of the time domain samples of the sequence on symbol N relative to the phase rotation of the sequence on previous symbol N-1.

Proposal 12: The phase rotation between the sequences used in successive ON symbols, N and N+1 is dictated by the symbol transmitted in symbol N.

Proposal 13: Consider a ZC sequence to be overlaid on the ON duration pulse to carry overlay information either using multiple cyclic shifts or by a QAM constellation to reduce the number of sequence correlations by LR, thus reducing the complexity.

Proposal 14: Avoid mapping of LP-WUS frequency domain contents to a QAM constellation as it impairs the time domain OOK reconstruction depending on the size of constellation used.

Proposal 15: If Manchester encoding is used for LP-WUS, the use of preamble can be ignored as the additional performance gains for having it is marginal.

Proposal 16: 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.

Proposal 17: 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.

Proposal 18: UEs served with LP-WUS must have low paging probability to obtain a meaningful power saving benefit.

Proposal 19: By considering false wakeups, false alarms, and payload size, bitmap scheme is preferred if the subgroup paging probability is $\geq 1\%$, otherwise consider codepoint scheme.

Proposal 20: Limit the number of subgroups to 8 to optimize false wakeups and false alarms for a given LP-WUS payload size of 8-16 bits.

Proposal 21: LP-SS/SSS can be used to determine frequency offset by IQ based receiver, which can then be used to correct/adjust/calibrate (TC)XO to reduce the synchronization errors, i.e., both time and frequency inaccuracies.

Proposal 22: LP-SS can be used to calibrate the RTC to limit/reduce the uncertainty involved with the LP-WUS monitoring occasions.

Proposal 23: Unified waveform design between LP-SS and LP-WUS should be prioritized.

Proposal 24: The modulation order used by LP-SS should be restricted to $M=\{1,2\}$ with Manchester encoding to ensure better coverage and facilitate accurate measurements for RRM purposes.

Proposal 25: The number of LP-SS sequences should at least be 8 to provides flexibility for different kind of deployments.

Proposal 26: Binary sequence generation based on m-sequence should be considered as it provides better cross-correlation among different sequences from the same class.

Proposal 27: As the LP-SS benefit all kind of LR types, overlaying a sequence in the ON duration and aligning the waveform design to LP-WUS should be selected. Thus, we prefer option 2 to assist synchronization if not for RRM purposes.

Proposal 28: We suggest discussing if LP-SS beams shall be time multiplexed in different beam directions.

Proposal 29: If LP-SS shall be time multiplexed in different beam directions, then RAN1 shall consider embedding beam tracking reference signals to the LP-SS signal to mitigate the power consumption in the LR spend on beam tracking.

Proposal 30: To ensure better coverage, detection, and timing estimation, the LP-SS should be designed with Manchester encoded OOK scheme using $M\leq 4$.

Proposal 31: A minimum of $X\geq 4$ LP-SS samples are required to estimate LP-RSRP reliably irrespective of the operating SNR.

Proposal 32: The LP-SS payload shall have at least $8$ or $16$ bits for $M=2$ and $M=4$, respectively together with Manchester encoding to obtain reliable LP-RSRP or LP-RSRQ estimation in the fading channel.

Proposal 33: Consider $M\in \{2,4\}$ for LP-SS with at least 4 symbols to ensure reliable estimation in each LP-SS MO.

**R1-2406850 Apple**

Proposal 1: For both OOK-1 and OOK-4, the waveform generation is specified using time-domain sequences.

* Note: This does not prevent gNB from pre-calculating and storing the frequency-domain sequences.

Proposal 2: For the LP-WUS structure, support Option 1: preamble + payload [+ CRC].

Proposal 3: Regarding the LP-WUS information for idle/inactive UEs, further consider the following options:

* Option 1: A bitmap with each bit corresponding to one subgroup
* Option 2a: A codepoint value corresponding to one subgroup, except for one codepoint value that corresponds to all subgroups
* Option 3a: Multiple codepoint values with each corresponding to one subgroup, except for one codepoint value that corresponds to all subgroups

Proposal 4: For connected UEs, LP-WUS consists of a bitmap, with each bit corresponding to one UE. Each UE is configured with its bit location within the LP-WUS.

Proposal 5: Further consider carrying full or partial cell ID information (e.g. via CRC scrambling) in the LP-WUS.

Proposal 6: Support Option 1-1: overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing.

Proposal 7: Further consider the following options for carrying information on the overlaid sequences:

* Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol. The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits at least by the overlaid OFDM sequence(s).
	+ FFS how to carry the information bits to enable early detection of LP-WUS by OFDM-based LP-WUR, e.g., a different bit ordering

Proposal 8: Option 3 is adopted, i.e., specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.

**R1-2406762 MediaTek Inc**

Proposal 1: Support a frequency domain sequence as the overlaid OFDM sequence.

Proposal 2: Support gold sequence as the overlaid OFDM sequence for LP-WUS and LPSS.

Proposal 3: If OFDM WUR cannot find SSB, UE is expected to monitor LPSS (via the overlaid sequences rather than OOK waveform) for timing and frequency synchronizing and RRM measurement.

Proposal 4: If no LP-SS is configured in a cell, UE is not expected to monitor both OOK-based and OFDM-based LPWUS in the cell.

Proposal 5: The residual frequency error after correction can be X = 5ppm for OOK-WUR and Y = 2ppm for OFDM-WUR.

Proposal 6: Support Option 2 and Option 1-2 to capture overlaid OFDM sequence before IFFT.

Proposal 7: Support OFDM-WUR to jointly detect info-bit of LPWUS from OOK patterns and OFDM sequences.

Proposal 8: Support 22 PRBs for SCS 15kHz for LP-WUS and LP-SS.

Proposal 9: M=2 for both LPSS and LPWUS @30kHz/15kHz. M=4 only for both LPSS and LPWUS @15kHz.

Proposal 10: Support LPSS is the cell-specific configuration with up to 3 binary sequences.

Proposal 11: Consider SNR=-6dB for LP-SS evaluation taking account of some measurement margins of 3dB.

Proposal 12: Support Option 2 to enable small payload designs, which is essential to achieve the target coverage.

**R1-2406295 Xiaomi**

*Proposal 1：OOK-1 and OOK-4 should be specified respectively for LP-WUS. For OOK-4, M could be configured as 2 or 4.*

*Proposal 2：Both OOK-1 and OOK-4 should be supported for LP-SS. For OOK-4, M could be configured as 2, 4, 8.*

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

*Proposal 4: Reference NR transmission need to be further discussed to identify the SCS of LP-WUS/LP-SS.*

* *For same SCS to legacy NR channel, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be the same as the SCS used for the reference NR transmission in the same CP-OFDM symbol.*
* *For different SCS from legacy NR channel, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be configured with offset based on the SCS used for the reference NR transmission in the same CP-OFDM symbol.*

*Proposal 5：Preamble could be supported in LP WUS for better synchronization performance when longer periodicity of LP-SS is configured.*

*Proposal 6：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS*

*Proposal 7：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 8：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 9：Support option 2 as a baseline solution for the overlaid OFDM sequence(s) of LP-WUS.*

*Proposal 10：* *The number of OFDM sequences overlaid on one OOK symbol should be minimized.*

*Proposal 11：* *The maximum allowable number of supported OFDM sequences should be specified based on the payload of LP-WUS/LP-SS, and not exceed N, FFS N.*

*Proposal 12： The selection of sequences should consider the performance of UE with both OOK-based and OFDM-based receivers.*

*Proposal 13：The overlaid OFDM sequence(s) for LP-WUS in either the time or frequency domain require further investigation, specifically focusing on Option 1-2 and Option 2.*

*Proposal 14：*

* *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 15：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 16：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 17：Support option 1 for indicating subgroup information using LP-WUS in RRC idle/inactive state.*

* *Encoded bits (with/without CRC) should be used to carry LP-WUS information.*

*Proposal 18：In RRC connected state*

* *A bitmap with each bit corresponding to [one or more] UEs.*
* *Encoded bits (with/without CRC) should be used to carry LP-WUS information.*

*Proposal 19：The binary sequence of the ON-OFF pattern in a cell could be configured by the gNB. And the number of LP-SS sequences could be 3 as baseline.*

*Proposal 20：RAN1 further down-selection from Gold sequence and M sequence for the binary LP-SS sequence type for the ‘ON-OFF’ pattern in a LP-SS.*

*Proposal 21：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.*

*Proposal 22：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 23： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.*

*Proposal 24:*

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

*Proposal 25：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 26：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*

**R1-2405996 CMCC**

In this contribution, we discussed the LP-WUS and LP-SS design, and the following proposals were made.

Proposal 1. Support Option 1-1 to specify overlaid OFDM sequence for LP-WUS/LP-SS.

Proposal 2: Support ZC sequence as overlaid sequence of LP-WUS/LP-SS.

Proposal 3: Understanding 3 should be taken for Option 3 of overlaid OFDM sequence(s) of LP-WUS.

Proposal 4: Support Option 1 and Option 2-2 as overlaid OFDM sequence(s) of LP-WUS.

Proposal 5: Support to specify time domain signal before DFT/LS processing for LP-WUS/LP-SS generation.

Proposal 6: The multiplexing between legacy NR signal and LP-WUS/LP-SS should be before IFFT.

Proposal 7: For OOK-4, consider mapping frequency domain samples of OOK to the existing constellation, e.g., QPSK, 16QAM, 64QAM. Further study the performance compared to the non-QAM mapping.

Proposal 8: For RRC idle/inactive state, Option 2 can be supported for indicating subgroup information using LP-WUS.

Proposal 9: For RRC connected state, Option 1 can be supported for indicating subgroup information using LP-WUS.

Proposal 10: Preamble is needed for LP-WUS to accommodate time error. The preamble can reuse the sequence design of LP-SS which can reduce the specification effort.

Proposal 11: The following options can be considered for LP-WUS structure design:

* Part 1: LP-WUS preamble part.
* Part 2: LP-WUS information part.
	+ Option1: payload + CRC
	+ Option 2: sequence 1(wake-up or not) + sequence 2(additional info, e.g., sub grouping information)

Proposal 12: Support Manchester coding for LP-WUS.

Proposal 13: Support flexible configuration of LP-WUS frequency location. Both inside and outside initial DL BWP can be considered.

Proposal 14: The number of binary LP-SS sequences can be smaller or equal to 8.

Proposal 15: The periodicity of LP-SS is suggested to be 320ms.

Proposal 16: Support overlaid LP-SS signal that can be received by OFDM receiver. The candidate overlaid LP-SS sequence can be as the same as PSS sequence.

**R1-2406083 EURECOM**

Proposal 1: Consider if pulse-shaping is required after sequence design and potential preamble are agreed.

Proposal 2: The DFT-shift is compensated at the LR.

Proposal 3: Do not consider mapping/quantizing WUS in frequency-domain.

Proposal 4: Multiplexing NR and WUS in frequency-domain is the base line.

Proposal 5: Specify OOK-1 and OOK-4 signal generation in time-domain.

**R1-2405919 Spreadtrum Communications**

LP-WUS design

*Proposal 1: OOK-1 is generated in frequency domain as defined in SI captured in TR, i.e. not as a special case OOK-4 with M=1 for LP-WUS.*

*Proposal 2: For idle/inactive UEs, M=4 for OOK-4 can be supported at least for 15kHz SCS.*

*Proposal 3: For connected UEs, M=4 for OOK-4 can be supported.*

*Proposal 4: For OOK-4, sequence for each OOK symbol is generated in time domain and waveform shaping methods at time or frequency domain can be specified.*

*Proposal 5: For OOK-1 (not special case of OOK-4), Option 2 is supported, i.e. overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing.*

*Proposal 6: For OOK-4, Option 1-1 is supported, i.e. overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing.*

*Proposal 7: Overlaid OFDM sequence is based on ZC sequence.*

*Proposal 8: Manchester coding can be supported for OOK-1 based LP-WUS.*

*Proposal 9: Manchester coding can be supported for OOK-4 based LP-WUS.*

*Proposal 10: At least for OOK-4, preamble for LP-WUS can be considered.*

*Proposal 11: For idle/inactive UEs, Option 1 (i.e. bitmap) can be supported for information content carried by LP-WUS.*

*Proposal 12: For connected UEs, after mechanism of LP-WUS for connected UEs is determined, information content carried by LP-WUS can be decided.*

*Proposal 13:* *The maximum number of information bits (excluding CRC) in a LP-WUS is Z, where Z<=8 and Z >=4.*

*Proposal 14: For LP-WUS, multiple OFDM sequences overlaid on an OOK symbol may have low priority.*

*Proposal 15: Single overlaid OFDM sequence is selected from multiple candidate overlaid OFDM sequences. The single overlaid sequence is on each OOK ‘ON’ symbol or OFDM symbol duration. OFDM-based LP-WUR can obtain the whole information bits by OOK ON/OFF pattern.*

LP-SS design

*Proposal 16: OOK-1 can be supported for R19 LP-SS similar to LP-WUS.*

*Proposal 17: OOK-4 with M=2 or 4 can be supported for R19 LP-SS.*

*Proposal 18: It is assumed during our discussion/design that LP-SS waveform is the same as LP-WUS waveform, but this restriction may not have spec impact.*

*Proposal 19: For LP-SS with or without overlaid OFDM sequence, Option 3 can be supported.*

*Proposal 20: For LP-SS, multiple OFDM sequences overlaid on an OOK symbol may have low priority currently, but cell ID can be considered in OFDM sequence generation.*

Coverage

*Proposal 21: For calibration of the target SNR, confirm there is no precoder cycling in time or frequency domain for gNB transmitting LP-WUS.*

*Proposal 22. Study potential coverage enhancement techniques for LP-WUS transmission.*

*Proposal 23: We should jointly consider power consumption and determination of coverage target for LR.*

*Proposal 24: For fair comparison, we can assume the similar sampling rate for LR with capability of OFDM sequence detection and LR without capability of OFDM sequence detection.*

Overhead

*Proposal 25: We should jointly consider determination of overhead target and determination of coverage target for LR.*

*Proposal 26: Resource overhead gap for two types of LR can be further evaluated.*

**R1-2406222 OPPO**

In this contribution, we discussed the signal design for LP-WUS and LP-SS. Observations and proposals are summarized as following.

* LP-WUS

M value for LP-WUS

*Proposal 1: Considering the unified design, support M=1 for OOK-4 and specify OOK-1 as the case of OOK-4 with M = 1.*

* *FFS: whether the DFT process could be absent when M = 1.*

*Proposal 2: For OOK-4, support M=1, 2, 4 for LP-WUS, value of M could be configured independently regardless of the value of SCS.*

How to determine the SCS of LP-WUS

*Proposal 3: The SCS used for LP-WUS remains unchanged during the whole transmission of a LP-WUS.*

*Proposal 4: gNB explicitly configure the single SCS used for LP-WUS.*

*FFS: Whether the same SCS could also be applied for LP-SS, or gNB explicitly configure the single SCS used for LP-SS.*

Function of the LP-WUS signal

*Proposal 5: 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.*

Payload of LP-WUS

*Proposal 6: Per UE-group and / or per UE-subgroup indication for LP-WUS targets to 8-bits or 16-bits payload.*

*Proposal 7: Encoded bits scheme has more flexibility in transmitting wake-up indications for single or multiple UE groups, we prefer encoded bits scheme to carry LP-WUS information.*

*Proposal 8: Regarding the LP-WUS information for idle/inactive UEs, support Option 1.*

* + *Option 1: A LP-WUS indicates a bitmap with each bit corresponding to one subgroup of N subgroups for part of, one or more PO(s).*

*Proposal 9: Considering unified design of LP-WUS information, support option 1 regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs (A bitmap with each bit corresponding to [one or more] UEs).*

Overlaid OFDM sequence for LP-WUS

*Proposal 10: Not only the performance of auto-correlation and cross-correlation, but also the spec impact and BLER performance should be considered for the overlaid OFDM sequence design.*

*Proposal 11: Considering the similar performance of auto-correlation, cross-correlation, BLER, and overlaid OFDM sequence on OFDM symbol not need to change the length of sequence for different value of M. Support option 1-2.*

How to carry information by OFDM sequences

*Proposal 12: Overlaid OFDM sequence(s) carry all information bits of LP-WUS.*

*Proposal 13: If overlaid OFDM sequence(s) could carry information, it is better to make segments of the whole information bits. And Each segment of the whole information bits can be mapped to one independent OFDM sequence.*

* *The number of candidates overlaid OFDM sequences used for information conveying depends on the bit number of each segment.*
* *If the bit number of each segment is 1, the number of candidates overlaid OFDM sequences equal to 1.*
* *If the bit number of each segment is N>1, the number of candidates overlaid OFDM sequences equal to 2N.*

*Proposal 14: Regarding the overlaid OFDM sequence(s) of LP-WUS, one sequence is selected from multiple candidates overlaid OFDM sequences on each OFDM symbol duration which consist of one or more OOK ‘ON’ symbols. (Option 3)*

* *gNB determines the overlaid OFDM sequence(s) based on the OOK bit(s) transmitted within the OFDM symbol.* *In this way, it does not need to separately determine the bits mapping to the overlaid OFDM sequence when generating the M OOK waveform per OFDM duration.*
* *For OOK-4 with M=1 and 2, one sequence is selected from multiple candidates overlaid OFDM sequences on one OOK ‘ON’ symbols.*
* *For OOK-4 with M=4, one sequence is selected from multiple candidates overlaid OFDM sequences on two OOK ‘ON’ symbols within one OFDM symbol, i.e. the overlaid OFDM sequence mapped from OOK bits within the OFDM symbol could be transmitted with repetition.*
* *If Manchester coding is used for encoding, four candidates overlaid OFDM sequences is enough.*

LP-WUS resource allocation and the correlation between LP-WUS and other signals

*Proposal 15: Support fixed bandwidth for LP-WUS and LP-SS regardless the SCS and RRC state.*

*Proposal 16: LP-WUS and LP-SS could share the same BW. The transmission of LP-WUS and LP-SS is TDM.*

*Proposal 17: 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.*

* LP-SS signal

LP-SS waveforms

*Proposal 18: LP-SS select one waveform from OOK1/4, single M values is selected for the waveform.*

LP-SS modulation, coding and sequences

*Proposal 19: LP-SS introduce Gold, M sequences or Computer searched sequence for modulation into OOK symbols. FFS coding on top of sequence.*

*Proposal 20: LP-SS uses a binary sequence associated to the cell ID by configuration. FFS: mapping schemes between cell ID and LP-SS sequences.*

LP-SS overlaid sequences

*Proposal 21: Introducing same type of overlaid sequences on top of LP-SS OOK symbols as that for LP-WUS.*

* *Targeting for sync and RRM measurement, exact measurement requirement is done by RAN4.*
* *Consider a fixed sequence or sequences fully/partially associated with cell ID.*

LP-SS in time and frequency

*Proposal 22: 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.*

**R1-2406785 Panasonic**

Based on the discussion, the following proposals are highlighted:

Proposal 1: M should depend on the SCS and OOK symbol rate with limited options for lower receiver complexity and power saving gain.

Proposal 2: To support only 60 kHz symbol rate of LP-WUS by OOK-4 with M = 2, 4.

- If OOK-1 needs to be specified separately, either 15 or 30 kHz symbol rate and SCS would be supported.

Proposal 3: For both 15 kHz and 30 kHz, same bandwidth should be supported for LP-WUS for LP-WUS RF complexity reduction.

Proposal 4: ZC sequence should be adopted for overlaid OFDM sequence of LP-WUS.

Proposal 5: The residual frequency error after frequency error correction should be less than 5 ppm.

Proposal 6: For overlaid OFDM sequence(s) for LP-WUS in time or frequency domain, Option 1-2 is preferred:

* Option 1-2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before DFT/LS processing
	+ The length of overlaid sequence(s) depends on the number of REs used for LP-WUS

Proposal 7: Option 2-2 should be supported for the overlaid OFDM sequence(s) of LP-WUS.

* Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol or OFDM symbol duration, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Consider the following two sub-options.
* Option 2-2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the overlaid OFDM sequence(s)

Proposal 8: LP-WUS information payload consists of multiple bit blocks for both RRC modes.

* For CONNECTED mode, each block is a bitmap, where each bit points to one or more UEs. Granularities of target UE identification can be different for different blocks. (Option 5)
* For IDLE/INACTIVE mode, each block is a codepoint, where the codepoint points to one or more UE groups/sub-groups. The codepoints are configurable for different blocks. (Option 3)

Proposal 9: The supported symbol rate(s) and SCS value(s) of LP-SS should be aligned with that of LP-WUS, i.e., not to support M = 8 and 16 for LP-SS.

Proposal 10:

* When LP-SS is only required to calibrate certain timing error within an OOK symbol/chip duration, simple design to employ some candidates of Gold sequence (as the pseudo random code defined in TS38.211) by configuration is sufficient.
* Sequence hopping should be supported to immigrate the inter-cell interference, while the complexity of the design is managed with sufficient simplicity. To facilitate sequence hopping, 16 binary LP-SS sequence can be configured in maximum.

**R1-2405806 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 when bitmap based wake-up indication is considered and without CRC when codepoint based wake-up indication is considered.*

LP-WUS Design (Waveform)

*Proposal 2: A LP-WUR-enabled UE supports both OOK-1 and OOK-4 based LP-WUS design with M ∈ {2,4} regardless of SCS to provide network deployment flexibility and better spectral efficiency.*

*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, considering ZC sequence(s) under Option 1-1 and/or Option 2 for overlaid sequences, with low frequency envelope channels to enable ED-based LP-WURs robustness against narrowband and inter-cell interference.*

*Proposal 5: Support OOK pulse compression for better detection performance by OFDM and ED based LP-WURs and overlaid sequences to carry only part of the LP-WUS information bits for shorter OFDM based LP-WUR’s detection time.*

LP-SS Design

*Proposal 6: For LP-SS design, support binary sequences of at least 32-bit length, at least density of 1/2, and generated using OOK-4 with M∈{2,4,8}.*

*Proposal 7: For the residual frequency error after frequency error correction without considering impact of drift, up to 6.5 ppm for OOK-based LP-WUR can be assumed.*

*Proposal 8: Assuming no frequency error correction by LR, 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.*

**R1-2406583 Honor**

*Proposal 1：Confirm the working assumption that for OOK-4, M=4 is supported.*

*Proposal 2: Do not support M=1 for OOK-4.*

*Proposal 3:* *The value of M is independent of SCS.*

*Proposal 4：Specify only the necessary steps for the design of OOK-1 and OOK-4.*

*Proposal 5: Specifies only the overlaid sequence for OOK-1.*

*Proposal 6: Specifies the two steps of sequence mapping and DFT for OOK-4.*

*Proposal 7: Further discuss how the UE obtains the OOK waveform generation scheme.*

*Proposal 8: Prioritize M sequence for overlaid sequence.*

*Proposal 9: Directly use the existing M sequence as the overlaid sequence.*

*Proposal 10: OOK-1 adopts the overlaid sequence generation method of option 2.*

*Proposal 11: OOK-4 prioritizes the sequence generation method of option 1-2, and to achieve a unified architecture, it can also use the method of option 2.*

*Proposal 12：Support option 3 for the overlaid OFDM sequence(s) of LP-WUS.*

*Proposal 13: Support option 1 for idle/inactive UEs.*

*Proposal 14: Support both option 1 and option 3, and the network side can flexibly indicate the specific solution.*

*Proposal 15: Confirm the following working assumption:*

*Support the following options for LP-SS*

* *Option 1: OOK-1*
* *Option 2: OOK-4 with M=2,4*
* *The SCS of a CP-OFDM symbol used for LP-SS generation is the same as that used for LP-WUS generation*

*Proposal 16: Prioritize M sequence for LP-SS.*

*Proposal 17: Adopt option 2 for the overlaid sequence of LP-SS.*

**R1-2406498 InterDigital, Inc**

*Proposal 1. Support time-multiplexed LP-SS transmission in different beam directions for coverage improvement.*

*Proposal 2. If time-multiplexed LP-SS transmission in different beam directions is supported, support mechanisms for power consumption mitigation from transmission/reception of LP-SSs.*

*Proposal 3. Confirm the working assumption on modulation orders for LP-SS to include both Option 1 with OOK-1 and Option 2 with OOK-4 and M = 2 or 4.*

* *Do not support additional M values.*

*Proposal 4. For LP-SS, support overlaid OFDM sequence(s) targeting for OOK waveform generation, sync and RRM measurement for OFDM based LP-WUR using the overlaid sequence (Option 3).*

*Proposal 5. In specifying binary LP-SS sequences, do not support determining the sequences by predefined rule without configuration.*

*Proposal 6. Procedures for handling inconsistencies in RRM measurements based on LP-SS and RRM measurements based on NR-SS should be supported.*

*Proposal 7. For LP-WUS signal structure, time domain repetition and Manchester coding are supported.*

*Proposal 8. Support up to 10 repetitions of LP-WUS with Manchester coding to achieve comparable performance with PUSCH for Msg 3.*

*Proposal 9. Down select M-sequence and ZC sequence for further consideration of overlaid OFDM sequence.*

*Proposal 9: Clarify different among the options for LP-WUS information in both IDLE/INACTIVE and CONNECTED.*

*Proposal 10:* *Support up to 16 subgroups for LP-WUS.*

* *Up to 32 subgroups can be considered if implicit indication is supported.*

*Proposal 11. For IDLE/INACTIVE modes, support Option 2 ‘A LP-WUS indicates a codepoint value corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs'.*

*Proposal 12: For CONNECTED mode, down select Option 2 ‘A codepoint value corresponding to one or part of UE identity’ and Option 3 ‘A codepoint value corresponding to [one or more] UEs’ and further discuss the adequate method triggering UE PDCCH monitoring based on one codepoint.*

**R1-2406480 Sony**

*Proposal 1 – RAN1 to support setting M value to its maximum, i.e., M=4 for 30 kHz SCS and M=8 for 15 kHz (for TDL-C type fading channel), to allow for low system overhead, lower latency and less power consumption at the LP-WUR.*

*Proposal 2 – RAN1 to support to use a unified specification for both OOK-1 and OOK-4, if M other than maximum value is selected.*

*Proposal 3 – RAN1 to support the same SCS configuration as other NR as it has less complexity for gNB.*

*Proposal 4 – For OOK-4, RAN1 to generate LP-WUS with overlaid sequences using option 1-1 scheme where overlaid sequence(s) are the sequence(s) of an OOK ON symbol before DFT/LS processing.*

*Proposal 5 – For OOK-1, RAN1 to generate LP-WUS with overlaid sequences using option 2 scheme where overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing.*

*Proposal 6 – 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 7 – From the alternatives, design LP-WUS to indicate wake-up based on option 2 for UEs in IDLE/INACTIVE mode.*

*Proposal 8 – From the alternatives, design LP-WUS to indicate wake up or sub-sequent action based on option 3 for UEs in CONNECTED mode.*

*Proposal 9 – From the suggested alternatives, RAN1 to select both m-sequence and Gold sequence as overlaid sequence.*

*Proposal 10 – Consider OOK-4 transmission scheme with maximum M value for the transmission of the LP-SS.*

 *Proposal 11 – Consider to have the same value of M for both LP-SS and LP-WUS.*

*Proposal 12 – RAN1 to support use of overlaid OFDM sequences for LP-SS to improve performance of OOK-based LP-WUS.*

*Proposal 13 – Support inclusion of cell ID in the LP-SS transmission.*

*Proposal 14 – RAN1 to select LP-SS sequences from Gold sequence.*

*Proposal 15 – Consider synchronization based on an aperiodic signal/sequence transmitted as part of LP-WUS.*

*Proposal 16 - Adjust periodicity of LP-SS according to duty-cycled monitoring of LP-WUS, the LP-WUS structure.*

**R1-2406104 TCL**

Proposal 1: For the LP-WUS waveform OOK-4 support M=2 and M=4.

Proposal 2: RAN1 to consider the configuration of SCS for LP-WUS in association to a BWP.

Proposal 3: To carry information bits by LP-WUS, Support option 1; which involves using encoded bits to carry the information bits in the LP-WUS payload.

Proposal 4: For RRC idle/inactive state, indicating subgroup information using LP-WUS support option 2 and option 3:

* Option 2: A LP-WUS indicates a codepoint value corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least ceil (log2(X1)), where X1 is the number of codepoints indicating one or more subgroups. X1 is reported by companies, X1 could be smaller, equal to or larger than N.
* Option 3: A LP-WUS indicates multiple codepoint values with each corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs, e.g., N is 8~256
	+ Number of information bits for a LP-WUS is at least K\*ceil (log2(X2)), where X2 is the number of codepoints indicating one or more subgroups. X2 is reported by companies, X2 could be smaller, equal to or larger than N.
	+ K is the number of multiple codepoint values in a LP-WUS where K is larger than 1

Proposal 5: For the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs support:

* Option 2: A codepoint value corresponding to one or part of UE identity, e.g., C-RNTI
* Option 3: A codepoint value corresponding to [one or more] UEs
* Option 4: Multiple codepoint values with each corresponding to [one or more] UE(s)

Proposal 6: Support OOk-1 and OOK-4 (with M=2, 4, and 8) waveform for LP-SS.

Proposal 7: Consider the configuration of SCS for LP-SS in association to a BWP.

Proposal 8: To reduce the configuration overhead for the LP-SS sequence, consider using predefined rules or parameters such as cell ID, frequency band, and sequence type.

Proposal 9: Consider a unified set of periodicities which is suitable for both idle/inactive and connected state UEs.

Proposal 10: For a channel bandwidth of 5MHz for LP-WUS and LP-SS support: The maximum number of 22 PRBs with SCS of 15KHz.

Proposal 11: For FR2, consider a channel bandwidth equal or less than 20 MHz.

Proposal 12: 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 13: The configurable BW of LP-WUS and LP-SS and its associated dedicated BWP can be configured to the UE during initial access.

**R1-2406537 NEC**

*Proposal 1: for LP-WUS and LP-SS generation, support a common design for OOK-1 and OOK-4, where OOK-1 can be a special case of OOK-4 with M=1.*

*Proposal 2: 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 3: 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 4: support message based LP-WUS structure with a preamble and a CRC.*

*Proposal 5: support repetition of LP-WUS to improve the coverage.*

*Proposal 6: for the overlaid sequence for LP-WUS, support option 1-1, i.e., overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing, for both OOK-1 and OOK-4.*

*Proposal 7: regarding the overlaid OFDM sequence(s) of LP-WUS, support option 2-2, i.e. the overlaid OFDM sequence(s) carry all information bits of LP-WUS.*

*Proposal 8: UE is allowed to not receive all the OOK symbols of LP-WUS, and UE can acquire all the information bits based on the OOK on-off pattern and the overlaid sequence of partial OOK symbols of the LP-WUS.*

*Proposal 9: for the binary sequence of LP-SS, reuse the existing sequence generation method in NR, e.g., m-sequence, gold sequence.*

*Proposal 10: for the overlaid OFDM sequence(s) for LP-SS, support option 3, i.e., specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync [and RRM measurement] for OFDM-based LP-WUR using the overlaid sequence of LP-SS.*

*Proposal 11: support QCL relationship between an LP-SS and an SSB.*

*Proposal 12: support FDM multiplexing of an LP-SS and its QCLed SSB.*

*Proposal 13: support repetition of an LP-SS in an LP-SS periodicity.*

**R1-2406941 NTT DOCOMO, INC**

Proposal 1:

* For the overlaid OFDM sequences of LP-WUS, consider following two options:
	+ Option 1: Specify time domain OFDM sequence per OOK ON symbol.
	+ Option 2: Specify frequency domain OFDM sequence per OFDM symbol.

Proposal 2:

* For the overlaid OFDM sequences of LP-WUS, further discuss following directions further analysis including performance evaluation:
* Direction 1: Known sequence(s) for better detection performance
* Direction 2: multiple sequence(s) to carry information

Proposal 3:

* For the LP-WUS payload, consider encoded bits with Manchester coding as baseline, to be confirmed by performance evaluation

Proposal 4:

* For the down selection whether to specify the overlaid OFDM sequence(s) for LP-SS, study further following aspects:
	+ SSB reception for sync/RRM with/without RF retuning
	+ Time gap between LP-SS and LP-WUS

Proposal 5:

* Same BW-size of LP-WUS and LP-SS is assumed for RRC idle/inactive and RRC connected states.
	+ Location of LP-WUS/LP-SS BW is configurable within a NR carrier

**R1-2406881 Sharp**

Proposal 1: Support uniform generation framework for OOK-1 and OOK-4.

Proposal 2: Confirm the working assumption of supporting M = 4 for LP-WUS.

Proposal 3: gNB can configure N (number of subgroups per LP-WUS) greater than, equal to, or less than M (number of subgroups per PO) For UE in idle/inactive mode.

Proposal 4: Support bitmap for LP-WUS information for UE in idle/inactive mode.

Proposal 5: Consider bitmap or multiple block (option1/5) for LP-WUS information for UE in connected mode.

Proposal 6: Support 11/22 PRB for LP-WUS with SCS 15KHz.

Proposal 7: Consider repetition to reach the DL coverage target of LP-WUS.

**R1-2407136 Nordic Semiconductor ASA**

*Proposal-1: IDLE-mode LP-WUS can be configured in a 15-kHz or 30kHz DL NR carrier.*

* *M=1,2 for 30kHz SCS carrier, M=4 can be optionally support for RRC connected mode*
* *M=2,4 for 15kHz SCS carrier, M=1 can be optionally support for RRC connected mode*
* *for M=1, specify OOK=4 instead of OOK-1, unless anybody can justify performance benefit from OOK-1.*

*Proposal-2: Specify OOK sequences (as in Table 1) in time domain*

* *specify two different non-zero-sequence length for 15 kHz*
* *specify two different non-zero-sequence length for 30 kHz*
* *FFS need for CP-handling, pulse shaping.*
* *FFS: 15 and 30kHz sequences are the same.*

*Proposal-3: Down-select between the following alternatives in RAN1#108:*

* *Manchester coding is support for all supported values of M.*
* *Manchester coding is not supported for LP-WUS.*

*Proposal-4: Select Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol or OFDM symbol duration, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s).*

* *Maximum number of payload bits of LP-WUS is 8 without CRC. Overlaid sequence provides both detection time reduction and coverage by repetition for the OFDMA receiver (see example Table 3).*
* *Overlaid sequence carries 1bit of information as baseline.*

*Proposal-5: For sub-group mapping to payload bits select bitmap (Option 1).*

*Proposal-6: LP-WUS BW is 11RB (including GB decided by RAN4) for both 30 and 15kHz SCS.*

*Proposal-7: Number of distinct sequences could be 4 (cell-ID mod 4* *as baseline). Sequence is M-sequence or Gold code.*

**R1-2406814 Lenovo**

*Proposal 1: Consider OOK-4, M=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: Consider hybrid LP-SS design containing mixture of wider pulse duration using OOK-4, M=1 and narrower pulse duration using OOK-4, M>1 to tolerate higher timing errors at the beginning and at the same time achieve finer synchronization for the same devices.*

*Proposal 9: Consider different LP-SS occasions transmission using different OOK waveforms to tolerate timing errors and finer synchronization for same or different devices*

*Proposal 10: RAN1 discuss the effect of timing errors on LP-SS design, such that the initial timing error values at the beginning of LP-SS reception and the residual timing error values after LP-SS detection.*

*Proposal 11: Specification allows same UE to switch between envelope-based detector and correlator based detector to improve power saving and coverage improvements.*

*Proposal 12: 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 13: 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.*

*Proposal 14: The preamble preceding the payload in LP-WUS containing mixture of wider pulse duration using OOK-1/OOK-4, M=1 and narrower pulse duration using OOK-4, M>1 to tolerate higher timing errors at the beginning and at the same time achieve finer synchronization.*

**R1-2406504 Everactive**

Proposal 1: Support 22 PRBs used for 15kHz SCS case to maintain a 5MHz signal

bandwidth.

Proposal 2: Support the maximum PRBs number limited by the bandwidth for the case with

a channel bandwidth of 5MHz for FR1. FR2 needs further study.

Proposal 3: Use frequency-domain ZC-sequence for overlaid OFDM sequence in OOK-1

LP-WUS.

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

**R1-2406597 RUijie networks**

Proposal 1: Support at least 3 as the number of binary LP-SS sequences for the ‘ON-OFF’ pattern.

Proposal 2: For RRC idle/inactive state, support Option 1 for at least indicating subgroup information using LP-WUS:

* Option 1: A LP-WUS indicates a bitmap with each bit corresponding to one subgroup of N subgroups for part of, one or more PO(s), e.g., N is 8~16, 24
	+ Number of information bits for a LP-WUS is at least N, single LP-WUS to wake up one or more subgroups

**R1-2405966 Tejas Networks Ltd**

Proposal 1: For a channel bandwidth of 5MHz with a subcarrier spacing of 15kHz, the number of PRBs = 27.

Proposal 2: For a channel bandwidth of 180kHz with a subcarrier spacing of 15kHz, the number of PRBs = 1.