**3GPP TSG RAN WG1 #118bis R1-240xxxx**

**Hefei, China, October 14th – 18th, 2024**

**Source: Moderator (vivo)**

**Title:** **Summary #1 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# 118bis.

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

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

### M values for OOK-4

In RAN1 118 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.   * M=4 for 15KHz SCS * M=4 for 30KHz SCS (working assumption) * FFS M=1 for OOK-4 |

For working assumption of M for OOK-4 for 30kHz SCS,

* [2][3][4][5][8][12][16][18][19] [21] [26] [27] proposed to support M=4, to reduce LP-WUS overhead/increase data rate,
  + [2][27] support M=4 for RRC connected state, but do not support M=4 for 30kHz SCS for RRC idle/inactive state, considering no performance gain compared with over OOK-1/OOK-4 M=1 or M=2 at Msg 3 PUSCH coverage, and potentially larger LP-SS overhead to meet tighter synchronization requirements.
* [15][17] does not support M=4 for 30kHz SCS, with concern on LP-WUR complexity.

[2][3] [18] [27] consider M=4 can be beneficial for scenarios with higher SNR or small synchronization error, to improve spectrum efficiency though no detection performance gain compared with M<4 [2] [3] [8] [27]. Higher SNR and better synchronization is typical in RRC connected mode, but in RRC idle mode, target SNR would be lower to meet Msg 3 PUSCH coverage, and larger synchronization error than RRC connected mode, consequently the benefit of M=4 is unclear in RRC idle mode. Besides, [7] discusses candidate M values for FR2 SCS, considering keeping same maximum data rate for FR1 and FR2.

**[M][FL1] Proposal 3.1-1**: Confirm the working assumption in below agreement:

**Agreement**

For OOK-4 with M >1, support M=2 & M=4 ~~(working assumption)~~ 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** |
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### 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 [5][8][9] [12] [16] [22] [23] [25]. Regarding how the UE derives the SCS, it can be either determined according to configuration by gNB [3] [9] [16][12][22] [25] or pre-defined rule [3] [5] [12][23], such as according to initial DL BWP SCS, or SSB SCS, or active BWP, or a configured carrier for LP-WUS.

**[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** |
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* 1. Overlaid OFDM sequence for LP-WUS

### Time or frequency domain sequence

In RAN1 118 meeting, RAN1 agreed option 1-1 for OOK-4 M>1, and to down-select between option 1-1 and option 2 for OOK-1/OOK-4 M=1.

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| **Agreement**  For overlaid OFDM sequences for LP-WUS, 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   **Agreement**  For overlaid OFDM sequences for LP-WUS, further down-selection between following two options for OOK-1 and OOK-4 with M=1(if supported)   * Option 1-1: Overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing * Option 2: Overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing * Note: Different options for OOK-1 and OOK-4 with M=1 (if supported) is not precluded – in which case, it should be deemed necessary |

Company views on two options for OOK-1 or OOK-4 with M=1 is summarized as below:

* Option 1-1: time domain sequence before DFT/LS for OOK-4 with M=1

[2], [3], [4], [5], [6], [9], [10], [13], [14], [16], [17], [21], [24], [27]

* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing for OOK-1

[5], [8], [12], [13], [15], [17], [19], [21], [23], [25], [29]

[7] thinks no matter what option is selected, it is useful to apply the same option to generate both OOK-1 and OOK-4. [18] thinks either option 1-1 or option 2 is fine, considering they can be equivalent, especially when ZC sequence is applied.

**Table 1 Pros/cons for 2 options for OOK-1/OOK-4 M=1 provided by companies**

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| --- | --- | --- |
|  | Pros provided by companies | Cons provided by companies |
| Option 1 | 1. Unified design for M=1 and M>1 2. Lower PAPR due to the mapping in time domain compared to frequency domain | 1. Performance slightly degrades than option 2, i.e., around 0.5dB for OOK-1 with gold seq, but no degradation for OOK-1 with ZC seq. |
| Option 2 | 1. For OOK-1, gNB implementation is simpler, reusing existing gNB implementation 2. The sequence length does not vary with M | 1. More complicated for UE processing, due to different scheme for M=1 and M>1 case |

Regarding whether both OOK-1 and OOK-4 M=1 are to be supported, [17] [24] [25] [26] propose to support only one of OOK-1 and OOK-4 M=1, to avoid duplication. [5] proposes to support both OOK-1 and OOK-4 M=1. [2], [3], [4],[6], [8], [9], [10], [14], [16], [24], [17], [15], [25], [27], [29], [12], [19], [17], [23] show their preferred overlaid sequence option (option 1-1 or option 2 above) for only OOK-1 or OOK-4 M=1. [5][13][21] show their preferred options for both OOK-1 and OOK-4 M=1. Based on majority view, FL suggests to support only one of OOK-1 and OOK-4 M=1.

**[H][FL1] Proposal 3.2-1:** For overlaid OFDM sequences for LP-WUS in time or frequency domain, down-select between following two options for OOK-1 and OOK-4 M=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.

Note1: OOK-1 is considered as specific case of OOK-4 with M=1.

* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing for OOK-1

Note2: OOK-4 with M=1 is not specified.

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| **Company** | **Which option do you support** | **Which option you can NOT live with** | **Comments** |
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### 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 |

For selection of proper sequence type, companies provide following principles:

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

It is important to ensure the selected sequence does not affect OOK detection performance. [2][6] [18] [25] provide evaluation result showing different sequences do not affect OOK detection performance.

* Good Correlation property to ensure OFDM detector performance, robust to synchronization error: [2] [4] [5][7][8] [10]
* Sufficient number of sequences with good cross-correlation to avoid false alarm: [2][4][7][10]
* Inter-cell interference/confusion: [2] [3] [4][18]
* Sensitivity to quantization to QAM constellation: [9]
* UE reception complexity: [2][5][10]
* gNB transmission complexity: [5] [8] [20][27]

Based on above principles, companies’ preference on each sequence type is captured as below.

* ZC sequence: [2][4][6] [12] [13][14] [15] [17] [18] [20][27].
* M sequence: [17][19][23]
* Gold sequence: [8][11]
* Either ZC or M sequence: [3], [9]
* Either M or Gold sequence: [5], [21]

Several companies provide LLS results for different overlaid OFDM sequences. FL observes following trend:

* For OOK-1 or OOK-4 with M=1:
* 0 ~0.2dB degradation of ZC sequence compared with Gold or M with 0us timing error, ~0.5dB degradation of ZC compared with Gold with 2us timing error
* For OOK-4 with M>1:
* 0~ 3dB degradation of Gold sequence compared with ZC sequence, with 0us ~ 2us timing error.
* Similar performance for M and Gold with 0us timing error, and 0~2dB degradation of M sequence compared with ZC sequence, with up to 2us timing error.

**Table 2 LLS results for different overlaid OFDM sequences**

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|  | OOK-1 or OOK-4 M=1 | OOK-4 M=2 | OOK-4 M=4 |
| [4] |  |  | Gold vs M vs ZC   * Gold is worst for both 0us and 2us timing error case, with 2dB and 3dB degradation compared with ZC * ZC is best for both 0us and 2us timing error case. * ZC and M has similar performance for 0us   Using time domain sequence & Time domain receiver  TDL-C channel |
| [2] |  | Gold vs M vs ZC   * Similar performance for all sequence types, for single sequences case, with 0.23us and 1.86us timing error. * ZC and M has similar performance and 2dB gain over Gold sequence, for multiple sequence case, with 0.23us timing error * ZC has 1dB gain over M sequence, and 3 dB gain over Gold sequence, for multiple sequence case, with 1.86us timing error   Using time domain sequence & Time domain receiver  TDL-C channel | Gold vs M vs ZC   * ZC and M has similar performance and up to 0.5dB gain over Gold sequence, for single sequence case, with 0.23us timing error * Similar performance for all sequence types, for multiple sequences case, with 0.23us timing error.   Using time domain sequence & Time domain receiver  TDL-C channel |
| [19] | Gold vs M vs ZC   * M and Gold has similar performance, and 0.2dB gain over ZC, with 0us timing error   Using Frequency domain sequence & Time domain receiver  TDL-C channel |  |  |
| [20] | Gold vs M vs ZC   * Comparable performance for all sequence types, with 2us timing error   TDL-C channel | Gold vs M vs ZC   * Much better performance of ZC and M than Gold, with 2us timing error   TDL-C channel | Gold vs M vs ZC   * Much better performance of ZC and M than Gold, with 2us timing error   TDL-C channel |
| [10] |  | Gold vs M vs ZC   * Similar performance for all sequences for single sequence case. * Slightly different (0~0.5dB) for sequences for different repetition number   Using Time domain receiver  AWGN channel | Gold vs M vs ZC   * Similar performance for all sequences for single sequence. * Slightly different (0~0.5dB) for sequences for different repetition number   Using Time domain receiver  AWGN channel |
| [25] | Gold vs M vs ZC   * Almost identical performance for all sequence types   TDL-C channel | Gold vs M vs ZC   * Almost identical performance for all sequence types   TDL-C channel | Gold vs M vs ZC   * Almost identical performance for all sequence types   TDL-C channel |
| [8] | * Gold vs M: ~ 0.5dB gain of Gold sequence (SSS) over M gold sequence (PSS) for multiple sequences case * Gold vs ZC: same performance with 0 us timing error, while ~ 0.5dB gain of Gold sequence over ZC sequence with 2us timing error, for multiple sequences case.     Using frequency domain sequence & Time domain receiver  TDL-C channel |  |  |

For OOK-4 M>1, considering good support for ZC sequence and better ZC sequence performance than gold sequence and M sequence provided by evaluation results so far, FL proposes to agree on ZC sequence for OOK-4 M>1.

For OOK-1 with overlaid sequence in frequency domain, it is observed that Gold sequence shows better performance than M sequence based on evaluation results provided by companies. FL suggests gold sequence for this case, if supported. For OOK-4 M=1 with overlaid sequence in time domain, considering good support for ZC sequence targeting for the same design with OOK-4 with M>1, and similar performance for all sequence types, FL suggests ZC sequence for this case, if supported. As captured in proposal 3.2-1, only one of OOK-1 and OOK-4 M=1 is to be supported.

**[H][FL1] Proposal 3.2-2:** For overlaid OFDM sequence,

* For OOK-4 M>1, support ZC sequence for overlaid sequence.
* For OOK-4 M=1 (if supported) or OOK-1 (depending on decision on proposal 3.2-2)
  + Support ZC sequence for overlaid sequence before DFT/LS for OOK-4 M=1
  + Support Gold sequence before IFFT for OOK-1

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| **Company** | **Y/N** | **Comments** |
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Companies also discuss the number of sequences per OOK ON chip or per OFDM symbol carrying information bits, with range of 2 to 16 for OOK-4 [2], [3], [11], [9], [16], [18], [25], [27] and up to 256 sequences for OOK-1 [8]. If we also consider inter-cell interference [2] [3] [4], the number of sequences to be specified may be even larger. Besides, the number of sequences may also depend on M value, which determines the sequence length thus determines the number of sequences with good correlation property.

**[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 prefer same or different number of overlaid sequences to carry LP-WUS information bits per OOK ON chip/OFDM symbol for different M value (M=1,2,4)?

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| **Company** | **Comments** |
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There are also some discussions on details of how to generate multiple sequences [2][18][4][11], e.g., using different root, polynomial, or different cyclic shift, or root + cyclic shift. Considering it depends on the sequence type and the number of sequences, these aspects can be discussed after progress of sequence type and the number of sequences.

### 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][15] support option 1, [3] [4] support option 1-2. There is also some company’s discussion on clarification of two options. Clarification points include following:

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. [2][13][15] think option 1-2 requires larger standard effort and higher implementation complexity, i.e., how to rotate overlaid sequences in different OOK ON chip/OFDM symbols.

**[M][FL1] Proposal 3.2-3:** 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** |
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For case #2, [2] [3] [4][5][11][13][14][12][10][17][18][23][24] support option 2, [8][16] [19] support option 3.

Based on majority view, FL suggests to go with option 2. Considering RAN1 has already agreed ‘time domain overlaid sequence before DFT/LS for OOK-4 M>1’ and excluded ‘overlaid sequence(s) are the sequence(s) of an OFDM symbol before DFT/LS processing’, ‘or OFDM symbol duration’ can be deleted to avoid confusion. For OOK-1/OOK-4 with M=1, one sequence on each OOK ‘ON’ symbol is equivalent to one sequence in an OFDM symbol duration. In addition, the note ‘the overlaid OFDM sequence in each OOK ‘ON’ symbol can be different according to information bits to be carried by the overlaid OFDM sequence’ is added to avoid confusion that the one sequence on a OOK ‘ON’ symbol has to carry all information bits and the sequence is repeated in each OOK ‘ON’ symbol.

**[H][FL1] Proposal 3.2-4:** 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 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 for potential down-selection.
* 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)

Note: the overlaid OFDM sequence in each OOK ‘ON’ symbol can be different according to information bits to be carried by the overlaid OFDM sequence.

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| **Company** | **Y/N** | **Comments** |
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For option 2, companies show different views on option 2-1 and option 2-2.

* Support Option 2-1: [11], [18]
* Support Option 2-2: [2], [3], [5], [8],[10], [13], [14], [17], [23], [24]
* Support both option 2-1 and option 2-2 by gNB configuration: [4]

**Table 3 Pros and Cons for option 2-1 and option 2-2 provided by companies**

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|  | Reasons to support corresponding option |
| Option 2-1 | earlier termination for OFDM-detector than option 2-2, i.e., less OFDM symbols to be received. |
| Option 2-2 | * low detection complexity * balanced performance for each information bits * only workable option when transmitted number of bits is larger than the number of information bits (option 2-1 does not work in this case) * applicable with and without Manchester coding (option 2-1 does not work without Manchester coding) * Simpler design and Easier for repetition |

FL suggests to further down-select between option 2-1 and option 2-2 after progress of Proposal 3.2-4.

Besides, companies[2], [4], [8], [9], [14], [16], [27] also discuss benefit of repetition for overlaid OFDM sequences. It also depends on Proposal 3.2-5.

### Other aspects for overlaid OFDM sequence design

1. Discussion on concentrated OOK waveform to improve robustness to timing error and reduce spectral leakage: [3], [4], [9] , [18], or reduce impact of CP : [3][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: [3] [4] [9] [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] [13] [14].

[13] thinks it is beneficial to support mapping frequency samples to existing NR QAM or sequence constellation to reuse existing gNB hardware [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 increases, and the impact is different for different overlaid sequence types. If QAM mapping is needed for EVM requirements, QAM 256 should be considered to limit performance degradation no larger than 0.5dB. [14] 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.

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

### RRC idle mode

In RAN1 118 meeting, RAN1 agreed to support codepoint schemes for RRC idle/inactive state. Maximum number of MOs X are to be further discussed.

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| **Agreement**  For RRC idle/inactive state, support the following option for at least indicating subgroup information using LP-WUS:   * 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   + UE monitoring one or more MOs (up to X MOs) for the same beam within an LO is supported     - Value of X is larger than 1. FFS on additional details of X. |

Companies [2] [8][10] [11][18][19] [22] discussed X value, considering following aspects:

1. X should be sufficient to trigger multiple UEs independently, to prevent scheduling delay: [8], [18]

* [8] provides probability of simultaneously waking-up X subgroups, for different UE paging rate, showing up to 4 subgroups to be paged in case of high paging rates, e.g., 5% per UE paging rate & 80% per PO group paging rate.

1. X should be sufficient to reduce false alarm wake-up caused by the codepoint for all subgroups, to guarantee desirable power saving gain: [2]
2. X should be not too large to ensure sufficient time domain resources to transmit X LP-WUSs in front of associated PO per i-DRX cycle: [2]
3. X should be not too large to ensure false alarm rate caused by wrongly detected codepoint while keep a reasonable duration per LP-WUS: [18].
4. X should be not too large to reduce UE complexity: [2], [11]

Candidate X values proposed by companies are summarized as below:

* Up to 44: [22]
* Up to 4: [2][8] [18] (if 12 bits per LP-WUS)
* Up to 3: [10]
* Up to 2: [10], [11], [18] (if 8 bits per LP-WUS)

Companies also discussed details of codepoint design,

* One codepoint to wake-up one subgroup: [8] [10][16]
* One codepoint to wake-up one subgroup (totally N codepoints for N subgroups), and one codepoint to wake-up all subgroups: [2] [5]

Some companies discussed one LP-WUS is associated with one or multiple POs [9] [11] [16]. Some companies discussed maximum number of subgroups per LP-WUS [5][20].

Considering all these issues above is under 9.6.2 discussion, FL suggests not handle with these issues in 9.6.1 here to avoid duplication.

### RRC connected mode

In RAN1 118 meeting, RAN1 agreed to down-select between bitmap and codepoint for RRC connected mode.

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| **Agreement**  Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs (for non-CA case), select at least one from the following   * Option 1: A bitmap with each bit corresponding to [one or more] UEs * Option 3: A codepoint value corresponding to [one or more] UEs * FFS details for extension of option 1 and/or 3 when UE is configured with CA |

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

* Option 1: [2], [9], [10], [11], [12], [13], [17], [19], [24], [26], [30]
* Option 3: [4], [5], [6], [7] , [8], [16], [21], [22], [19], [20], [31]

**Table 4 Argument for option 1 and option 3 provided by companies**

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| --- | --- |
|  | Reasons to support corresponding options provided by companies |
| Option 1 | 1. Lower overhead compared with codepoint, with same target coverage, especially when traffic arrival probability is medium to high. 2. Smaller number of MOs than codepoint, e.g., 1 vs more than 10 MOs 3. Easier resource management than codepoint, due to smaller maximum number of LP-WUS to be transmitted per cycle, especially for TDD 4. Better power saving gain due to lower false wake up rate 5. Simple and straightforward design by spec 6. Simple for UE reception, by monitoring single MO. |
| Option 3 | 1. Flexible link adaptation for each UE. Lower overhead compared with bitmap, if a LP-WUS with bitmap is designed for the worst coverage UE in a group, while a LP-WUS with codepoint is designed for each UE with different coverage. 2. Unified Codepoint for both RRC idle/inactive and connected mode. 3. Configuration signalling overhead for bit location in the bitmap 4. Complicated and sensitive to timing error, if coherent detection is used for bitmap |

Besides the above arguments in table 4, some companies provide evaluation results.

* Overhead evaluation:
  + [2] provides overhead comparison between codepoint and bitmap for 8, 12 and 16 UEs per group, showing similar ~ 2 times overhead for codepoint compared with bitmap, with UE traffic arrival probability of 30~ 80%.
  + [8] provides overhead comparison between codepoint and bitmap for 1~ 8 UEs per group, showing 50% ~ 1.24 times overhead for codepoint compared with bitmap, with UE traffic arrival probability of 40%.
  + [6] provides overhead comparison between codepoint and bitmap for 8 UEs per group, showing similar overhead for these two cases.

* False wake up probability:
  + [9] provides false wake up probability comparison between codepoint and bitmap with same overhead of 8 or 16 bits, with single MO, showing larger false wake up probability by codepoint, with UE traffic arrival probability ≥ 10%
* Number of MOs:
  + [2] calculates number of MOs for codepoint case, assuming one-to-one and one-to-all codepoint mapping, targeting false wake-up rate caused by one-to-all codepoint mapping ≤ 10% and 1% respectively. The number of MOs is 3~12 with UE traffic probability of 30% ~ 80% with FAR ≤10%, and the number of MOs is 5~ 14 with UE traffic probability of 30%~ 80%.

Besides, [2] provides UE decoding complexity for bitmap vs codepoint with conclusion that the complexity is comparable for codepoint and bitmap for OOK detector with or without CRC, and also comparable complexity for codepoint and bitmap for OFDM detector without CRC. [2] also provides simulation results to show bitmap without CRC for OFDM detector can achieve desirable performance with FAR ≤1%.

Considering almost half-half support for each option so far, FL encourages companies to further check evaluation results provided by companies so far, and share your view, if any.

**[H][FL1] Question 3.3-1:** Do you have any comment on evaluation results, e.g., provided by companies as shown above?

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| **Company** | **Comments** |
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**[H][FL1] Question 3.3-2:** How do you think of UE detection complexity for LP-WUS based on codepoint or bitmap

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| **Company** | **Comments** |
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**[H][FL1] Question 3.3-3:** For bitmap (option 1) and codepoint (option 3), which option do you support?

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| --- | --- | --- | --- |
| **Company** | **Which option do you support** | **Which option you can NOT live with** | **Comments** |
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Some companies [11][19][17] also discuss LP-WUS for CA case. FL suggests to discuss CA case after progress of single cell case.

* 1. LP-WUS structure

Payload of LP-WUS can be carried by one of

* Option 1: Encoded bits

It is applicable to both bitmap and codepoint.

* Option 2: OOK sequence selection

It is only applicable to codepoint.

Different companies have different preference. [2], [3], [7], [8], , [10], [15], [22], [12], [24], [23] support option 1, [6], [5], [21] support option 2.

To help better understanding of two options, benefit for each option provided by companies is summarized as below.

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

The benefit of option 2 highly depends on the maximum number of subgroups per LP-WUS N. For example, for RRC idle/inactive state, if N>64, overhead of option 2 for codepoint is much larger than option 1 for codepoint, and there is no common design for LP-WUS and LP-SS since LP-SS sequence length larger than 64 causes too large overhead.

Considering maximum number of subgroups per LP-WUS N is under discussion in 9.6.2. FL suggests to down-select between option 1 and option 2, after decision on maximum value N in 9.6.2.

For option 1, companies also discuss whether CRC is needed. Some companies [3] [7] [8] [9] considers CRC for both codepoint and bitmap, if supported, while some companies, e.g., [4] considers no CRC for codepoint case. FL suggests to discuss this issue after bitmap or codepoint for RRC connected mode, and progress of encoded bits and sequence.

* 1. Coding

RAN1 agreed to support Manchester coding for LP-WUS, while FFS for other coding schemes. Besides, whether support Manchester coding for LP-SS is also open.

|  |
| --- |
| **Agreement**  Support Manchester coding for LP-WUS   * FFS other coding schemes |

Regarding other coding schemes for LP-WUS, two type of coding schemes are proposed by companies

* FEC (may also including rate matching) [2][4][8][9]: [2][8] proposes RM code.
* Pulse position coding [14]

The intention of other coding schemes includes:

1. To improve coverage
2. To improve FAR, e.g., L1 information bits is extended to L bits to meet 1% FAR target.

For LP-SS, [4][5][9][23] think it is beneficial to use Manchester coding for LP-SS, e.g., for sequences with balanced 0&1 [4][23], 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] analyze that increasing the length of binary sequence would be more beneficial for LP-SS performance rather than applying Manchester coding. [8] analyzes Manchester coding can limit the sequence design as the maximum number of possible sequences decreases.

FL encourages more input for above two issues.

**[M][FL1] Question 3.5-1:** Regarding other coding schemes for LP-WUS,

* Do you think other coding scheme is necessary for LP-WUS?
* If other coding scheme is necessary for LP-WUS, which coding scheme do you prefer?

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| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
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**[M][FL1] Question 3.5-1:** Regarding Manchester coding for LP-SS,

* Do you support Manchester coding for LP-SS?
* If you support Manchester coding for LP-SS, what is the benefit for Manchester coding for LP-SS?

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| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
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1. LP-SS
   1. Binary sequence design for LP-SS

|  |
| --- |
| RAN1#118 Agreement  To determine the binary sequences for LP-SS, the evaluation assumes the following:   * Sync accuracy: timing estimation error smaller than T us for P=90 % of the time for at least SNR=-3dB and SNR=-6dB (lower priority),   + T=2us(optional), 5us for OOK-1.   + T=1us(optional), 2us for OOK-4 with M=2.   + T=0.5us(optional), 1us for OOK-4 with M=4.   + Other values of SNR, T, M are up to company report.   + Additionally, companies can submit results on SINR with details on how the interference was modelled.   + Assume one-shot estimation.   + The time error is based on 20ppm maximum frequency error for the detection of the first LP-SS.   + Note: Companies can assume other values inside of 20ppm maximum as long as the values are justified. * RRM measurement accuracy: measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s for at least SNR=-3dB and SNR=-6dB (lower priority), X, Y, and Z is up to company report, other values of SNR are up to company report.   + As a starting point, the time error is based on 5-10ppm residual frequency error.   + Note: 5-10ppm assumes frequency error correction is performed, e.g., RTC calibration and/or MR assistance.   + Note: Companies can assume other values outside of 5-10ppm as long as the values are justified. * The frequency error: up to company report. * Sampling rate: 3.84MHz (optional) or 7.68MHz assumed for 30kHz SCS. * Channel: AWGN and TDL-C 300ns is assumed. * Consider cross-correlation for 4 binary sequences under time and frequency error.   Companies are encouraged to provide details on other additional simulation assumptions, high level description of their receiver algorithm, and assessment on power consumption. |

According to the agreements in last meeting, the binary sequences for LP-SS are to be determined to satisfy both sync accuracy requirement and RRM measurement accuracy requirement, and also, when the specific sequences are provided by companies, the sequence length (also the occupied OFDM symbols), the sequence type, and the sequence characteristics including auto-correlation and cross-correlation are known.

Companies’ inputs on the binary sequences for satisfying sync requirements and RRM measurement requirements are summarized below in terms of sequence length, sequence type, and principles for sequence selection.

**The required LP-SS sequence length/occupied OFDM symbols to satisfy sync accuracy requirement:**

* For **SNR=-3dB**, **TDL-C channel**, timing estimation error smaller than T us for P=90 % of the time, the following is observed:
  + For OOK-1 or OOK-4 with M=1, 5 companies consider up to 8 symbols are required to achieve T=5us, and 4 companies consider up to 8 symbols are required to achieve T=2us, and 4 companies consider 16-32 symbols are required to achieve T=2us.
  + For OOK-4 with M=2, 8 companies consider up to 8 symbols are required to achieve T=2us, and 6 companies consider up to 16 symbols are required to achieve T=1us
  + For OOK-4 with M=4, 8 companies consider up to 8 symbols are required to achieve T=1us, and 2 companies consider up to 16 symbols are required to achieve T=0.5us

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | OOK-4 with M=2 | | OOK-4 with M=4 | |
|  | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS |
| [4] | 5us | 8 | 2us | 8 | 1us | 8 |
| [6] | 2us | 8 | 2.5/1.3us | 4/8 | 2.1/1.1/0.9us | 2/4/8 |
| [8] | 2.3/1.7/1.5us | 4/6/8 | 2.2us | 4 | 1.4/1.2/1.1us | 4/6/8 |
| [3] | 5/2/1us | 8/16/32 | 5/2/1us | 8/8/16 | 5/2/1us | 4/8/8 |
| [2] | 5/3/2us | 8/12/20 | 2/1us | 4/6 | 1/0.5us | 4/7 |
| [11] | 5/2us | 16/24 | 2/1us | 6/12 | 1/0.5us | 8/16 |
| [7] | 4.54/2.34/1.88/1.56us | 7/15/31/63 | 3.8/1.8/1.5/1.11us | 4/8/16/32 | 23.1/3.1/1.6/1.3us | 2/4/8/16 |
| [16] | <2/<1us | 7/15 | <2us | 14 | <1us | 14 |
| [17] | 2us | 24 | 1us | 2 | 1us | 3 |
| [19] | 2us/1us | 8/32 | 2us/1us | 4/16 | 2us/1us | 2/8 |
| [23] |  |  | 1.5/1.1/0.9 | 4/8/16 | 1.2/1/0.8 | 4/8/16 |
| Summary | **T= 5us:**  4: [8];  8: [4], [3], [2],  [7];  16: [11]  **1us<T<=2us:**  6: [8]  8: [8], [6], [16], [19]  16[3],20[2],24[11,17],32[7]  **T<=1us:**  32: [3], [19]  15: [16] | | **1us<T<= 2us:**  4: [2], [19],[23];  6: [11];  8: [4], [3], [6],  [7];  14: [16];  16: [7]  **T=1us:**  2:[17]  6: [2]  12: [11]  16: [3], [19], [23] | | **0.5us<T<= 1us:**  3:[17]  4: [2];  8: [4], [3], [6],  [11], [19], [23];  14: [16]  **T=0.5us:**  7: [2]  16: [11] | |

* For **SNR=-3dB, AWGN channel**, timing estimation error smaller than T us for P=90 % of the time, the following is observed:
  + The number of OFDM symbols required in AWGN channel to satisfy the same sync accuracy is no more than that required in TDL-C channel

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | OOK-4 with M=2 | | OOK-4 with M=4 | |
|  | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS |
| [6] | 1.3us | 8 | 1.8/0.6us | 4/8 | 1.1/0.6/0.4us | 2/4/8 |
| [10] | NA | NA | 1.1us | 8 | NA | NA |
| [17] | 5us | 48 | 2us | 3 | 1us | 1 |
| [19] | NA | NA | NA | NA | 1us | 4 |
| summary | **T=1.3us**  8: [6] | | **1us<T<=2us**  4: [6]  8: [10]  **T<=1us**  8: [6] | | **0.5us<T<=1us**  4: [6][FW]  **T<=0.5us**  8: [6] | |

* For **SNR=-6dB**, **TDL-C channel**, timing estimation error smaller than T us for P=90 % of the time, the following is observed:
  + To satisfy the sync accuracy requirement @ SNR=-6dB, one company shows that 50 OFDM symbols, 22symbols, and 30 symbols are required for LP-SS to achieve 5us, 2us, 1us for OOK4 with M=1, M=2, and M=4, respectively.
  + Two companies show the sync accuracy requirement @ SNR=-6dB for M=2 and M=4 is not satisfied with up to 8 occupied OFDM symbols for LP-SS.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | OOK-4 with M=2 | | OOK-4 with M=4 | |
| Source | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS | T | OFDM symbols for LP-SS |
| [11] | 5/2us | 50/100 | 2us/1us | 22/40 | 1us/0.5us | 30/40 |
| [6] | NA | NA | 2.4 | 8 | 2.4/1.7us | 4/8 |
| [8] | 4.6us | 4 | 4.1us | 4 | 2.6us | 4 |

**The required LP-SS sequence length/occupied OFDM symbols to satisfy RRM measurement accuracy requirement:**

* For **SNR=-3dB**, **TDL-C channel**, measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s, the following is observed:
  + For OOK-1 or OOK-4 with M=1, 5 companies consider up to 8 OFDM symbols achieve the RSRP and RSRQ measurement accuracy within ±4dB, one company consider 16 OFDM symbols achieve the RSRP and RSRQ measurement accuracy within ±2dB, and one company consider 24 OFDM symbols to achieve the RSRP and RSRQ measurement accuracy within ±4dB.
  + For OOK-4 with M=2, 7 companies consider up to 8 OFDM symbols achieve the RSRP and RSRQ measurement accuracy within ±4dB
  + For OOK-4 with M=4, 7 companies consider up to 8 OFDM symbols achieve the RSRP and RSRQ measurement accuracy within ±4dB

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | | | OOK-4 with M=2 | | | | OOK-4 with M=4 | | | |
|  | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS |
| [4] |  |  |  |  |  |  |  |  | 2.2/3.1/4.3 | 1/2/4 | 1.28 | 8 |
| [6] | <2 | NA | NA | 8 | <2 | NA | NA | 4/8 | 2.1/<2/<2 | NA | NA | 2/4/8 |
| [8] | RSRP:1.26  RSRQ:2.96 |  |  | 4 | RSRP:1.28  RSRQ:2.97 |  |  | 4 | RSRP:1.32  RSRQ:2.87 |  |  | 4 |
| [3] | <3 | 1 | NA | 8 | <3 | 1 | NA | 8 | <3 | 1 | NA | 4 |
| [2] | RSRP<4  RSRQ<2 | 2/3 | NA | 8 | RSRP<4  RSRQ<2 | 2/3 | NA | 4 | RSRP<4  RSRQ<2 | 2/3 | NA | 4 |
| [17] | <4 | 2 | NA | 24 | <4 | 4 | NA | 2 | <4 | 4 | NA | 3 |
| [19] | <4 | 1 | NA | 4 | <4 | 1 | NA | 8 | <4 | 1 | NA | 4 |
| [7] | RSRP<2 | 1/4 | NA | 16 | RSRP<2 | 1/4 | NA | 8 | <3 | 1/4 | NA | 8 |

* For **SNR=-3dB, AWGN channel**, measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s, the following is observed:
  + The number of OFDM symbols required in AWGN channel to satisfy the same RRM measurement accuracy is no more than that required in TDL-C channel

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | | | OOK-4 with M=2 | | | | OOK-4 with M=4 | | | |
|  | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS |
| [6] | <2 | NA | NA | 8 | <2 | NA | NA | 4/8 | <2 | NA | NA | 2/4/8 |
| [8] | RSRP:1.15  RSRQ:0.98 |  |  | 2 | RSRP:1.2  RSRQ:1 |  |  | 2 | RSRP:1.84  RSRQ:1.11 |  |  | 2 |
| [10] |  |  |  |  | 0.8 | 1 | NA | 8 | 1.2 | 1 | NA | 4 |
| [18] |  |  |  |  |  |  |  |  | 2.32/2.06 | NA | NA | 4 |
| [17] | <4 | 1 | NA | 48 | <4 | 1 | NA | 3 | <4 | 2 | NA | 1 |

* For **SNR=-6dB**, **TDL-C channel**, measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s, the following is observed:
  + For OOK-1 or OOK-4 with M=1, 2 companies consider up to 8 OFDM symbols achieve the RSRP and/or RSRQ measurement accuracy within ±4dB
  + For OOK-4 with M=2, 2 companies consider up to 8 OFDM symbols achieve the RSRP and/or RSRQ measurement accuracy within ±4dB
  + For OOK-4 with M=4, 2 companies consider up to 8 OFDM symbols achieve the RSRP and/or RSRQ measurement accuracy within ±4dB

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | | | OOK-4 with M=2 | | | | OOK-4 with M=4 | | | |
|  | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS |
| [6] | 2.1 | NA | NA | 8 | 2.2 | NA | NA | 4/8 | 4/2.2/2.2 | NA | NA | 2/4/8 |
| [8] | RSRP:2.68  RSRQ:2.19 |  |  | 4 | RSRP:2.12  RSRQ:4.1 |  |  | 4 | RSRP:2.15  RSRQ:4.04 |  |  | 4 |

* For **SNR=-6dB, AWGN channel**, measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s, the following is observed:
  + The number of OFDM symbols required in AWGN channel to satisfy the same RRM measurement accuracy is no more than that required in TDL-C channel

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | OOK-1 or OOK-4 with M=1 | | | | OOK-4 with M=2 | | | | OOK-4 with M=4 | | | |
|  | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS | X (dB) | Y | Z | OFDM symbols  for LP-SS |
| [6] | <2 | NA | NA | 8 | <2 | NA | NA | 4/8 | 2.5/<2/<2 | NA | NA | 2/4/8 |
| [8] | RSRP:2.33  RSRQ:1.84 | NA | NA | 2 | RSRP:2.01  RSRQ:1.87 | NA | NA | 2 | RSRP:2.13  RSRQ:2.01 | NA | NA | 2 |

Based on the collection of companies’ results for sync accuracy and RRM measurement accuracy above, FL observes the following trend:

* For SNR=-3dB, TDL-C channel and AWGN channel, timing estimation error smaller than T us for P=90 % of the time:
* for OOK-1 or OOK-4 with M=1, up to 8 symbols are required to achieve T=5us, and up to 32 symbols are required to achieve T=2us.
* for OOK-4 with M=2, up to 8 symbols are required to achieve T=2us, and up to 16 symbols are required to achieve T=1us
* for OOK-4 with M=4, up to 8 symbols are required to achieve T=1us, and up to 16 symbols are required to achieve T=0.5us
* At the same SNR, the number of OFDM symbols required to achieve RRM measurement accuracy (RSRP and/or RSRQ) is smaller than that required to achieve sync accuracy.

Subsequently, it is understood that the LP-SS length is dominant by sync accuracy requirement. Considering 8 symbols correspond to 8-length, 16-length, and 32-length LP-SS sequence for OOK-1 or OOK-4 with M=1, OOK-4 with M=2, and OOK-4 with M=4, as well as 16 symbols correspond to 32-length, and 64-length LP-SS sequence for OOK-4 with M=2, and OOK-4 with M=4, and the given length LP-SS sequence can be applied to different M values with different occupied OFDM symbols. To facilitate LP-SS binary sequence selection, FL suggests the following.:

**[H][FL1] Proposal 4.1- x:** To determine the binary sequences for LP-SS, consider the following length L for LP-SS:

* L=8
* L=16
* L=32
* FFS the L value(s) applied to OOK-1 and OOK-4 with M=1(if supported), 2, 4

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| **Company** | **Y/N** | **Comments** |
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**Binary sequence type for LP-SS**

Among the three potential sequence types for further down-selection: gold sequence, M sequence, and computer searched sequence, so far companies show interest in different types, which are summarized as below:

* Support M sequence or sequences based on M sequence with the following reason [4][11][9][5][12][16][19][23]:
  + Good auto-correlation and cross-correlation property
  + Limited length of consecutive '0's
  + The number of '0's and '1's inside an M-sequence are almost balanced
  + modified m-sequences with circular extensions to maintain balanced binary distribution in OFDM symbols [11]
* Gold sequence [5][29][12] [16][17][21]:
* Computer search sequence with the following reason [6][2][18] [8][3]:
  + For such short binary sequences, randomly generated Gold or M sequences do not guarantee good cross-correlation property [6]

Later, to determine the specific LP-SS binary sequences, the sequences with different types provided by companies would be compared for selection. Companies are encouraged to provide more details on the preferred sequence type and sequences.

**Metrics for sequence comparison**

For LP-SS binary sequence design, companies propose the following design principles and metrics:

* Balanced 0 & 1 within the sequence and within each OFDM symbol of the sequence [2] [3] [4] [6] [8] [9]
  + 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
  + Improving TO estimation performance in fast fading wireless environment;
  + Ensuring the AGC performance;
  + Improving LP-RSRP/LP-RSRQ calculation accuracy;
  + Ensuring the power allocation implementation at gNB side unchanged;

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.

* Good auto-correlation for better timing estimation [2]  [3] [4] [6] [7]
  + Mainlobe width [2] [4]
  + First valley value [4]
  + Maximum side lobe value [4]
  + 1st peak cor/2nd largest peak cor [2]
  + The ratio of the mainlobe value to first sidelobe should be larger than N, wherein N is the length of the selected binary sequence; the sidelobe value is calculated based on its lags/shifts wherein the lags/shift value at least includes +/- 1. [3]
* Low cross-correlation of multiple sequences for mitigating inter-cell interference [2] [4] [7] [8]
  + 1st peak auto-cor/1st peak cross-cor [2]
  + Maximum cross-correlation values [4]

One company [3] thinks orthogonality is not necessary or auto-correlation is prioritized; TDM/FDM of LP-SS resources can be used for inter-cell interference mitigation by gNB implementation.

* Limited consecutive '0's and consecutive ‘1’s to avoid losing AGC [3] [4][8]
* The number of transitions (1 to 0 and 0 to 1) is an indication of the number of runs of 0’s or 1’s in the sequence. More transitions result in fewer and shorter runs. Energy detector circuits often use a decoupling capacitor to limit offset, so a higher number of transitions ensures more of the signal passes. [29]

To facilitate comparison and selection of LP-SS binary sequences among companies’ proposed sequences later, it will be helpful to align some metrics for comparing performance of the LP-SS binary sequences. Considering LP-SS design targets for both sync accuracy and RRM measurement accuracy, the achieved accuracy performance for both sync and RRM measurement could be considered for comparison directly. FL suggests the following:

**[H][FL1] Proposal 4.1-1:** To determine the binary sequences for LP-SS, consider the following for performance comparison:

* Sync accuracy T’ within sliding window: the achieved sync accuracy T’ -timing estimation error smaller than T’ (T’≤T) us for P=90 % of the time for at least SNR=-3dB
* RRM measurement accuracy X: the achieved measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s

Note 1: The sliding window length is determined by the time error anticipated by LP-SS, where time error is determined by the sum of timing estimation error T and time drift based on residual frequency error (∆T=20ppm\*P), assume P=320ms, 1280ms and T=5us, 2us, 1us for M=1,2,4 for comparison.

Note 2: Assume Y=1,4 and Z=1.28s for comparison

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
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* Detection algorithm at receiver side

Besides, for the detection algorithm for LP-SS at receiver side, [4] proposes to consider mis-matched correlation (bipolar) or unipolar correlation as the detection algorithm, while [3] considers unipolar correlation performs better than bipolar.

**[M][FL1] Question-1:** What’s your opinion on detection algorithm for LP-SS at receiver side? Bipolar correlation or unipolar correlation or both?

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| **Company** | **Bipolar correlation or unipolar correlation or both** | **Comments** |
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* 1. LP-SS with or without overlaid OFDM sequences
* Companies support option 1 [8][2][7] with the following reasons:
* 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. [8]
* 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 [3][9][5][13][19] 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] [5] [10][15][16][20] with the following reasons:
* Regardless which one of ZC sequence, M sequence and Gold sequence is adopted for LP-WUS overlaid sequences, technically it can also serve the purpose for synchronization and RRM measurement for LP-SS.
* 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 reuses the overlaid OFDM sequence(s) specified for LP-WUS.
* Whether to transmit LP-SS by using a specified overlaid OFDM sequence is configurable.
* From RAN1 perspective, it’s up to UE implementation to use the overlaid OFDM sequence(s) for sync and RRM measurement if configured.

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| **Company** | **Y/N** | **Comments** |
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* 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 as collected in section 4.1, 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:

* Support at least 160 and 320ms periodicity for LP-SS. [2]
* The periodicities of LP-SS are not larger than 320ms [4]
* The periodicity of LP-SS is suggested to be 320ms [7][13][12]
* Consider following values for configuring LP-SS periodicity: 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]
* At least 80ms, 160ms, 320ms [22]

Based on above, FL suggests the following:

**[H][FL1] Proposal 4.3-1:** For LP-SS periodicity, support at least:

* 320ms
* FFS 80ms,160ms, 640ms,1280ms, 2560ms, 5120ms, 10240ms

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| **Company** | **Y/N** | **Comments** |
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1. Necessity of Additional synchronization signal

LP-SS can provide synchronization. Whether additional synchronization signal is needed, highly depends on whether LP-SS alone is sufficient for synchronization requirement for LP-WUS detection.

[3][6][5][8][10][11][12][13][15][18][23] support additional synchronization signal. In addition to timing acquisition, AGC stabilization, or channel/interference estimation can be supported by the additional synchronization signal.

[2][4] think LP-SS alone can be sufficient based on certain assumption of residual timing/frequency error. The example of table 8 provided by [2] is copied as below. On the other hand, some companies consider other combinations of larger LP-SS periodicity T, sync accuracy Tr and residual frequency error Fe, resulting the necessity of additional sync signal.

**Table from [2]: Necessity and overhead for additional aperiodic sync signal based on 1st set of timing estimation error Tr**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Sync accuracy (timing estimation error Tr) | Residual frequency error Fe | LP-SS periodicity  T | Maximum timing error for LP-WUS detection Te=Tr+Fe\*T | necessity of additional aperiodic sync signal  (whether Te > tolerance value) | Overhead for sync (note 5，6) |
| M=1, 30kHz SCS  M=2, 15kHz SCS  (tolerance :5us) | 2us | 5ppm | 320ms | 3.6us | no | 0.45% |
| 2us | 5ppm | 160ms | 2.8us | no | 0.89% |
| 3us | 5ppm | 320ms | 4.6us | no | 0.27% |
| 3us | 5ppm | 160ms | 3.8us | no | 0.54% |
| M=2, 30kHz SCS  M=4, 15kHz SCS  (tolerance :3us) | 1us | 5ppm | 320ms | 2.6us | no | 0.13% |
| 1us | 5ppm | 160ms | 1.8us | no | 0.27% |
| Note 5: As evaluated in section 5, for M=1 &30kHz SCS or M=2 &15kHz SCS, LP-SS length = 20 for Tr =2us, LP-SS length = 12 for Tr =3 us. For M=2 &30kHz or M=4&15kHz, LP-SS length = 12.  Note 6: Since necessity of additional aperiodic sync signal is ‘no’ for all cases, overhead for sync only includes LP-SS with corresponding periodicity T. | | | | | | |

[9] thinks LP-SS alone can be sufficient, if Manchester coding is used, because additional performance gains provided by additional synchronization signal is marginal.

[2][4] also compare overall overhead for LP-SS alone with shorter periodicity and LP-SS with longer periodicity with additional synchronization signal, showing increased overhead for later case. Overhead calculation by [4] is copied as below for reference.

**Table from [4] Resource overhead of LP-SS and/or preamble**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Total overhead (ms) | | periodicity of LP-SS (ms) | | |
| 320 | 640 | 1280 |
| no preamble | | 16 | 8 | 4 |
| with preamble=1ms   # of LP-WUS per 1.28s | 30 | 136 (=120+16) | 128 (=120+8) | 124 (=120+4) |
| 50 | 216 | 208 | 204 |
| 100 | 416 | 408 | 404 |
| with preamble=0.5 ms   # of LP-WUS per 1.28s | 30 | 76 | 68 | 64 |
| 50 | 116 | 108 | 104 |
| 100 | 216 | 208 | 204 |
| with preamble=0.25 ms   # of LP-WUS per 1.28s | 30 | 46 | 38 | 34 |
| 50 | 66 | 58 | 54 |
| 100 | 116 | 108 | 104 |

Considering there are different cases with and without need of additional synchronization signal, FL suggests to support additional synchronization signal by configuration. Meanwhile, FL also acknowledges the overhead issue of additional synchronization signal and additional standard effort for the additional synchronization signal.

**[H][FL1] Proposal 5-1:** Support additional synchronization signal

* The additional synchronization signal is configurable.
* Strive to minimize the difference between sequence design for periodic LP-SS and the additional synchronization signal.
* Strive to minimum overhead increase by the additional synchronization signal
* FFS the location of additional synchronization signal.

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| **Company** | **Y/N** | **Comments** |
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1. Frequency resource for LP-WUS and LP-SS

For FR1, the number of PRBs for LP-WUS and LP-SS with SCS 15kHz is not determined yet. Companies’ views on X values for 15kHz SCS for a channel bandwidth equal or larger than 5MHz is summarized as below:

* X=11: [4][7] [8] [9] [26] [27]
* X=22: [2] [3] [5][6][16][17][22][23][26][27]

Besides, [8] also proposes X=11 PRBs for 15kHz SCS for a channel bandwidth smaller than 5MHz, while [6] proposes not specify the overlaid OFDM sequence for channel bandwidth less than 5MHz and [3] proposes FFS bandwidth far smaller than 5MHz for LP-WUS and LP-SS.

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

|  |  |
| --- | --- |
|  | Benefit |
| 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. |

Considering X=11PRBs can share the common design for overlaid OFDM sequence for both 15kHz and 30kHz and leave sufficient room for guard RBs for ACS which is under discussion in RAN4 RF, FL suggests the following.

**[H][FL1] Proposal 6-1**: From RAN1 perspective, support X=11 PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5 MHz

* FFS X for LP-SS and LP-WUS with SCS 15kHz for a channel bandwidth less than 5MHz

In RAN P #105 meeting, the following has been endorsed regarding FR2 support [1], and it is requested to make a progress on the FFS “Whether the above is applicable to FR2”

|  |
| --- |
| Endorsed WF in RAN P #105   * Confirm in RAN#105 that Rel-19 LP-WUS work item scope includes both FR1 and FR2. * Request RAN1 to make a progress on the FFS “Whether the above is applicable to FR2” (under RAN1#117 agreement on LP-WUS and LP-SS bandwidth) in RAN1#118bis.   + Reuse the FR1 design when possible * No additional guidance in RAN#105 for RAN4 work and TU allocation |
| **RAN1 #117 Agreement**  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 the number of PRBs for 15kHz * 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 |

Companies’ view on the number of PRBs for LP-WUS and LP-SS for FR2 is summarized as below:

* X=11 for 60kHz and 120kHz [4][7][8] [17][26] with the following reason:
  + According to the SI, the WUS bandwidth should be less than 20 MHz. By using 11 PRBs in FR2, it is ensured that the WUS bandwidth is less than 20 MHz [8]
* X=22 for 60kHz and X=11 120kHz: [2][6]
* RAN1 waits FR1 design process and needs to evaluate whether reusing FR1 design is feasible [3][5]

Considering how to apply the number of PRBs for LP-WUS and LP-SS in FR1 to FR2 is related to X values supported for 15kHz and 30kHz SCS, e.g., which value(s) used for FR2, if number of PRBs for 15kHz and 30kHz is different.

This will be determined later in this meeting after progress on X value for SCS 15kHz.

References

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2. R1-2407869, LP-WUS and LP-SS design, vivo
3. R1-2408074, Discussion on LP-WUS design, ZTE, Sanechips
4. R1-2407664, Signal Design of LP-WUS and LP-SS, Huawei, HiSilicon
5. R1-2408055, Design of LP-WUS and LP-SS, CATT
6. R1-2408858, LP-WUS and LP-SS Design, Qualcomm Incorporated
7. R1-2408654, Discussion on LP-WUS and LP-SS design, Samsung
8. R1-2408820, LP-WUS and LP-SS design, Ericsson
9. R1-2408537, LP-WUS and LP-SS design, Nokia, Nokia Shanghai Bell
10. R1-2408476, LP-WUS and LP-SS design, Apple
11. R1-2408691, On LP-WUS and LP-SS Design, MediaTek Inc.
12. R1-2407977, Discussion on LP-WUS and LP-SS design, Xiaomi
13. R1-2407913, Discussion on LP-WUS and LP-SS design, CMCC
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17. R1-2408344, Discussion on the LP-WUS and LP-SS design, Panasonic
18. R1-2407614, Discussion on LP-WUS and LP-SS Design, FUTUREWEI
19. R1-24082436 Discussion on LP-WUS and LP-SS design, Honor
20. R1-2408280, Discussion on LP-WUS and LP-SS design framework for Low power WUS, InterDigital, Inc.
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22. R1-2407634, LP-WUS and LP-SS Design, TCL
23. R1-2408679, Discussion on LP-WUS and LP-SS design, LG Electronics
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25. R1-2408794, Discussion on LP-WUS and LP-SS design, NTT DOCOMO, INC
26. R1-2408253, Discussion on LP-WUS and LP-SS design, Sharp
27. R1-2408917, On LP-WUS and LP-SS design, Nordic Semiconductor ASA
28. R1-2408968, Discussion on LP-WUS and LP-SS design, Lenovo
29. R1-2408399, Discussion on LP-WUS and LP-SS design, Everactive
30. R1-2408075, Discussion on LP-WUS operation in IDLE/INACTIVE mode, ZTE
31. R1-2408795, Discussion on LP-WUS operation in IDLE/INACTIVE modes, Docomo

Appendix 1: Proposals from contributions

**R1-2407869 vivo**

Proposal 1: For candidate M values,

* Support M=1 for OOK-4.
* Do not support M=4 OOK-4 for 30kHz SCS for RRC idle mode, FFS for RRC connected mode.
* 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 2-2: 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 for OOK-4 with M=1.

Proposal 5: Support ZC sequence for overlaid OFDM sequence. Multiple sequences based on ZC sequence can be generated by different root + different cyclic shift.

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

* Support up to 4 sets of candidates overlaid OFDM sequences, considering inter-cell interference for up to 4 cells.

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

Proposal 8: Support at most 4 MOs per LP-WUS LO for a beam to keep sufficiently low false wake-up caused by the codepoint waking up all subgroups, e.g., ≤1%, while keep reasonable complexity and overhead.

Proposal 9: Support codepoint to wake-up one subgroup and a codepoint to wake-up all subgroups.

Proposal 10: Support at least bitmap for RRC connected mode.

Proposal 11: Support encoded bits for LP-WUS, for both bitmap and codepoint scheme.

Proposal 12: Consider LP-SS binary sequences in table 3 for sync accuracy (2us, 1us, 0.5us) and (5us, 2us, 1us) for M=1, 2, 4, respectively.

Proposal 13: Support at least 160 and 320ms periodicity for LP-SS. FFS other values, if needed.

Proposal 14: RAN1 to further discuss the necessity of additional aperiodic synchronization signal taking overhead and required synchronization accuracy into account.

* If additional aperiodic synchronization signal is to be supported, the mechanism to reduce the overhead while guarantee sufficient synchronization accuracy should be considered.

Proposal 15: 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 16: Support 11 PRBs and 22 PRBs for LP-WUS and LP-SS with SCS 120kHz and 60kHz (blanked guard RBs are not included) respectively.

Proposal 17: Not support Manchester coding for LP-SS, or LP-WUS if payload is carried by OOK sequence selection.

Proposal 18: Support simple coding scheme to improve LP-WUS detection performance, such as RM code, or repetition.

**R1-2408074 ZTE, Sanechips**

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

*Proposal 2: For overlaid OFDM sequences for LP-WUS, Option1-1 is supported for OOK-1 and OOK-4 with M=1.*

*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: In order to maintain bandwidth equals to 5MHz, to support 22 PRBs for LP-WUS and LP-SS with SCS of 15kHz (PRBs for guardband are not included).*

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

*Proposal 6: RAN1 waits FR1 design process and needs to evaluate whether reusing FR1 design is feasible.*

* *Proposal 7: 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*
* *Binary sequence consisting of “1 and 0” is assumed for both LP-SS transmission and LP-SS reception.*
* *Regarding auto-correlation result for LP-SS*
  + - *The ratio of the mainlobe value to first sidelobe should be larger than N, wherein N is the length of the selected binary sequence.*
    - *The sidelobe value is calculated based on its lags/shifts wherein the lags/shift value at least includes +/- 1.*
* *For 4 selected binary sequences,*
  + *Orthogonality is not necessary or auto-correlation is prioritized.*

*Proposal 8: TDM/FDM of LP-SS resources can be used for inter-cell interference mitigation by gNB implementation.*

*Proposal 9: In order to meet different TO correction accuracy requirements, LP-SS binary sequence with different length may be specified.*

*Proposal 10: For LP-SS, at least OOK4 with M=4 should be supported.*

*Proposal 11: For the overlaid OFDM sequence(s) for LP-SS, Option 2 is supported.*

*Proposal 12: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity*

*Proposal 13: Introduce preamble before LP-WUS*

*Proposal 14: the preamble should use large M value {4 or 8} for OOK-4 waveform.*

*Proposal 15: study the sequences design for the preamble*

* *Several binary sequences no more than 4*
* *Overlaid sequences but not carry information.*

*Proposal 16: Support preamble preceding LP-WUS*

* *They are consecutively allocated.*

*Proposal 17: 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 18: Binary sequence based LP-WUS is not supported for carrying information for LP-WUS.*

* *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, for a CRC length of L=8*

*Proposal 19: For OOK based LP-WUS, OOK-4 with M=4 should be supported for SCS=30KHz.*

*Proposal 20: 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 21: 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 22: 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 23: 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*

**R1-2407664 Huawei, HiSilicon**

1. *For OOK-4, confirm the working assumption of M=4 is confirmed for 30kHz SCS.*
2. *OOK-1 is specified as a special case of OOK-4 with M=1.*
3. *The SCS of LP-WUS is the same as that of initial DL BWP and the LP-WUS can be configured with a bandwidth that is not fully confined within initial DL BWP.*

* *FFS: how to configure the SCS and bandwidth of LP-WUS.*

1. *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. *For overlaid OFDM sequences for LP-WUS, support Option 1-1 for both OOK-4 M=1 and OOK-1.*
2. *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.*
3. *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.*
4. *Further discuss and adopt sequence(s) considering the following aspects:*
   * *Sequence with good auto-correlation property and cross-correlation property*
   * *How to minimize the interference from LP-WUS transmitted from neighboring cells*
5. *ZC sequences are adopted for the design of overlaid sequence(s).*

* *FFS details, e.g. length, roots*

1. *Pulse shape and/or spectrum shape are also considered in the design/selection of overlaid sequence(s).*
2. *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.*
3. *For 15kHz SCS, support 11 PRBs for LP-WUS and LP-SS BW.*
4. *For FR2, support 11 PRBs for LP-WUS and LP-SS BW.*
5. *Time domain repetition and* *transmit diversity by precoder cycling are considered to improve the performance of LP-WUS.*
6. *Coverage recovery schemes that exploits time / frequency diversities are considered.*
7. *Binary spreading sequences are considered to multiplex WUSs on the same time-frequency resource to improve the BLER.*
8. *Regarding the LP-WUS information for connected UEs, support the codepoint mapping method, i.e. option 3.*
9. *Overlaid sequence for LP-SS is specified.*
10. *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*
11. *The design of LP-SS should consider the CP impact and the length of binary-valued sequence to generate LP-SS.*
12. *For LP-SS, support at least 8 OFDM symbols for OOK-4 with M=1/2/4.*
13. *In order to determine the specific LP-SS sequence, it is necessary to first define the metric for comparison, e.g., correlation characteristics such as the main lobe width or the first valley value, the maximum side lobe value, and maximum cross-correlation values.*
14. *For both timing and frequency error evaluation purpose, the residual frequency error (Fr) can be <= 5ppm after assistance from MR.*
15. *A set of candidate values for LP-SS periodicity can be defined, which are not larger than 320ms.*
16. *Preamble of LP-WUS is not supported.*

**R1-2408055 CATT**

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

Proposal 2: OOK-4 waveform of LP-WUS can be specified by a configurable M value.

Proposal 3: 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 modes and the active BWP for RRC\_CONNECTED mode.

Proposal 4: The single SCS is determined by pre-defined rule, is preferred for simple and no specification impact to RRC configuration signaling.

Proposal 5: Support Option 1-1 for OOK-4 with M=1 same as that of agreement for OOK-4 with M>1.

Proposal 6: Support Option 2 for OOK-1 for existing gNB implementation can be reused for OOK-1.

Proposal 7: Either Gold-sequence or M-sequence can be supported for overlaid OFDM sequence of OOK-1 and OOK-4.

Proposal 8: Only one overlaid sequence per OOK ON symbol should be supported.

Proposal 9: Not support Option 1 and 1-2 for overlaid OFDM sequence not carrying information.

Proposal 10: Support Option 2-2: the overlaid OFDM sequence should carry all information bits of LP-WUS in the design principle of the information carried by OFDM sequence.

Proposal 11: It is recommended to support a LP-WUS structure with wake-up information preceded by a fixed preamble sequence for assisting synchronization.

Proposal 12: A codepoint value can be supported by concatenated multi sequences for capacity enhancement and would not increase resource overhead heavily.

Proposal 13: The maximum number of subgroups per LP-WUS should be no more than 16.

Proposal 14: Support Option 3: A LP-WUS indicates a codepoint to one or more UEs.

Proposal 15: For RRC\_IDLE/INACTIVE modes, the sequence based LP-WUS with multiple orthogonal sequences should be sufficient for indicating the paging subgroup or bundling group of paging subgroups.

Proposal 16: 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 17: Unified OOK waveform for LP-SS and LP-WUS can be supported for low standardization complexity.

Proposal 18: Both Option 1: OOK-1 and Option 2: OOK -4 with M=1/2/4 can be supported for LP-SS waveform.

Proposal 19: The Manchester coding can be the supported for LP-SS as coverage enhancement same with LP-WUS.

Proposal 20: Support Option 2 and Option 3: Specify the overlaid OFDM sequence for LP-SS.

Proposal 21: Either Gold-sequence or M-sequence can be supported for binary LP-SS sequence design.

Proposal 22: The preamble of LP-WUS is needed at least for the periodicity of LP-SS is larger than 66ms.

Proposal 23: 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.

Proposal 24: the frequency domain resources for LP-WUS under FR2 should be lower priority.

Proposal 25: Support at least coverage enhancement scheme for LP-WUS and LP-SS: time domain repetition and multiple beam repetition/sweeping for coverage enhancement.

**R1-2408858 Qualcomm Incorporated**

*Proposal 1: Support codepoint based LP-WUS for UE connected mode*

* *LP-WUS MOs in the same LP-WUS occasion can be associated with LP-WUSs for different UE subgroups.*

*Proposal 2: For overlaid OFDM sequences for LP-WUS, support option 1-1 for OOK-1 and OOK-4 with M=1*

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

*Proposal 3: Support ZC sequences as the overlaid sequences for LP-WUS*

* *The maximum number of candidate sequences per OOK on symbol is 4.*

*Proposal 4: Support preamble in the LP-WUS.*

*Proposal 5: Support computer searched sequences for binary LP-SS 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.*

**R1-2408654 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: 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 3: 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 4: Support to have a common waveform generation for both OOK-1 and OOK-4 in the specification.

* OOK-1 can be treated as the special case of OOK-4 with M=1.

Proposal 5: Further consideration on M values for other SCSs (e.g., 60kHz SCS, 120kHz SCS) is necessary if FR2 band is considered.

Proposal 6: For OOK-based LP-WUR, the LP-WUS codepoint information should be carried by message-based (encoded bit).

* Support CRC attachment following the encoded bits to satisfy the target FAR.
* Support to apply the same design to trigger PDCCH monitoring of RRC connected UEs

Proposal 7: Support to have the same number of PRBs for LP-WUS/LP-SS regardless of SCSs.

* 11 PRBs for 15kHz, 30kHz, 60kHz, (FFS: 120kHz).

Proposal 8: Do not support larger M value for LP-SS (i.e., M=8, 16).

Proposal 9: Support to 15 or 31 length binary sequence length for LP-SS.

* 15 or 31 length is targeting to sync accuracy requirement for OOK-1 and OOK-4 with M=2 LP-WUS reception.
* FFS: sync accuracy requirement for OOK-4 with M=4 LP-WUS reception.

Proposal 10: Support at least 320ms LP-SS periodicity.

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: Do not support Manchester coding for LP-SS.

Proposal 13: For the LP-SS binary sequence used in a cell, additional support of sequence determination by predefined rule is not needed.

Proposal 14: 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.

**R1-2408820 Ericsson**

[Proposal 1 Following principles should be considered for LP-WUS and LP-SS design](#_Toc178949505)

[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.](#_Toc178949506)

[b. It should be possible to multiplex the LP-WUS/LP-SS with other NR transmissions in time or frequency domain without causing interference.](#_Toc178949507)

[c. It should be possible to reuse any unused LP-WUS time and frequency resources for other transmissions.](#_Toc178949508)

[Proposal 2 Paging misdetection performance of the UE should not be impacted when LP-WUS is used by the UE for power savings.](#_Toc178949509)

[Proposal 3 Different SCS case for LP-WUS and other NR transmissions in the same CP-OFDMA symbol is not considered further.](#_Toc178949510)

[Proposal 4 Including a preamble part before the data part of LP-WUS transmissions should be considered for OOK-based LP-WUS. The presence of preamble should be configurable.](#_Toc178949511)

[Proposal 5 Following should be considered for LP-WUS payload mapping to OOK symbols:](#_Toc178949512)

[a. It should be possible to flexibly map different payload sizes (e.g., 1 to 8 bits) to variable number of OFDM symbols that are available for LP-WUS transmission.](#_Toc178949513)

[b. Existing encoding (e.g., Reed-Muller block code in TS 38.212) and rate-matching approaches should be reused as much as possible.](#_Toc178949514)

[c. Manchester encoding is applied before mapping coded bits to OOK symbols.](#_Toc178949515)

[Proposal 6 WUS payload size should be 4-5 bits in Idle/Inactive. Similar payload size should be considered for Connected mode.](#_Toc178949516)

[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.](#_Toc178949517)

[Proposal 8 For channel bandwidth less than 5 MHz, the WUS bandwidth should be 11 PRBs for 15 kHz SCS.](#_Toc178949518)

[Proposal 9 For FR2, the WUS bandwidth should be 11 PRBs for both 60 kHz and 120 kHz SCS corresponding to 7.92 MHz and 15.84 MHz, respectively.](#_Toc178949519)

[Proposal 10 OOK-1 generation should be specified in the frequency domain (Option 2). That is, for ON symbols of OOK-1, sequences used as input of IFFT of the gNB transmitter are specified.](#_Toc178949520)

[Proposal 11 For the OFDM sequence overlaid on OOK-1 in the frequency domain, support Gold sequences.](#_Toc178949521)

[Proposal 12 With the support of OOK-1, OOK-4 with M=1 should not be supported.](#_Toc178949522)

[Proposal 13 To have flexibility in WUS transmission, it is beneficial to support M={2, 4} for both 15 and 30 kHz SCS. Thus, the working assumption in “M=4 for 30KHz SCS (working assumption)” can be confirmed.](#_Toc178949523)

[Proposal 14 For OOK-4, the value of M should not depend on the SCS in FR1 and FR2.](#_Toc178949524)

[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](#_Toc178949525)

[Proposal 16 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).](#_Toc178949526)

[Proposal 17 The number of UE monitoring occasions (MOs) should be 4 (X=4), as for high paging rates it is likely to page up to 4 UE subgroups per PO.](#_Toc178949527)

[Proposal 18 Codepoint should be prioritized over bitmap in the connected mode.](#_Toc178949528)

[Proposal 19 Manchester encoding should not be mandatory for LP-SS especially for a short sequence length.](#_Toc178949529)

[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.](#_Toc178949530)

[Proposal 21 Consider following values for configuring LP-SS periodicity: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms.](#_Toc178949531)

[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.](#_Toc178949532)

[Proposal 23 Same SCS should be used for LP-SS, LP-WUS, and other NR transmissions in the same CP-OFDMA symbol.](#_Toc178949533)

[Proposal 24 For LP-SS, confirm the working assumption from RAN1#116bis. Support OOK-1 and OOK-4 [M=2,4] where the value of M does not depend on the SCS.](#_Toc178949534)

[Proposal 25 LP-SS duration should be 4-6 OFDM symbols.](#_Toc178949535)

[Proposal 26 For LP-SS durations of 4 or 6 OFDM symbols, consider binary sequences provided in Table 10 or Table 11 of this document.](#_Toc178949536)

**R1-2408537 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 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., 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: OOK4 based generation should be preferred for all values used, i.e., option 1-1 should be preferred for as well.

Proposal 6: Consider OOK waveform with as the baseline for evaluations as it favours both envelope and sequence detectors with or without the use of Manchester encoding.

Proposal 7: Pulse shaping should be considered for ON duration of OOK symbols to avoid power leakage from ON to OFF symbol duration.

Proposal 8: The number of overlay sequences used to provide more information in a single ON duration of OOK signal should consider the underlying modulation order, i.e., , used by OOK.

Proposal 9: 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 .

Proposal 10: The phase rotation between the sequences used in successive ON symbols, N and N+1 is dictated by the symbol transmitted in symbol .

Proposal 11: A subgroup specific sequence should be considered for overlaying to limit the number of correlations to unity, i.e., LR uses only one sequence for correlation.

Proposal 12: Use of multiple overlay sequences to carry information shall be restricted to only.

Proposal 13: Either m-sequence or ZC sequence should be considered for overlaid sequences due to better correlation and sequence generation properties.

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 QAM mapping is needed for EVM requirements, then shall be considered, since the degradation is limited to .

Proposal 16: As Manchester encoding is used for LP-WUS, preamble should be ignored as the additional performance gains for having it is marginal.

Proposal 17: A shorter length CRC is preferrable for LP-WUS message, since the data is encoded with Manchester encoding that is already capable of providing data integrity check to an extent.

Proposal 18: For connected mode, with traffic arrival probability , bitmap scheme with subgroups up to together with bit CRC is optimal to reduce the false wake-up probability.

Proposal 19: For idle/inactive mode, code point based mapping with subgroups up to can provide lowest total wake-up probability.

Proposal 20: Unified waveform design between LP-SS and LP-WUS should be prioritized.

Proposal 21: Binary sequence generation based on m-sequence should be considered as it provides better auto-/cross-correlation among different sequences from the same class.

Proposal 22: 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 23: RAN1 should consider LP-SS spanning NR symbols with together with averaging across multiple LP-SS MOs to improve detection accuracy.

Proposal 24: By utilizing the timing estimates from multiple LP-SSs, having a predefined periodicity, the RTC can assumed to be calibrated to an accuracy of with the help of NCO.

Proposal 25: RAN1 to consider adopting LP-SS either with Manchester encoding to ensure uniform power distribution over all ON duration pulses, or without Manchester encoding by ensuring uniform distribution of 1’s and 0’s and to avoid clustering of 0’s and 1’s.

Proposal 26: RAN1 should ensure proper handling of LP-RSRP, since the difference between the average energy over ON to OFF duration of LP-SS may degrade due to uneven power distribution of OOK symbols if Manchester encoding is not used.

Proposal 27: The LP-SS payload shall have at least or bits for and , respectively together with the averaging over LP-SS observations to ensure reliable LP-RSRP.

**R1-2408476 Apple**

In contribution, we have discussed LP-WUS and LP-SS design, and proposed the following:

Proposal 1: OOK-1 is specified as a special case of OOK-4 with M=1, using Option 1-1, i.e., overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing.

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

Proposal 2: For the LP-WUS information for idle/inactive UEs, one codepoint value corresponds to one subgroup.

Proposal 3: For the maximum number of subgroups per PO and the maximum number of MOs per beam per LO for LP-WUS, down-select between the following 2 options:

* Option 1: max of 32 subgroups per PO, max of 2 MOs per beam per PO
* Option 2: max of 64 subgroups per PO, max of 3 MOs per beam per PO

Proposal 4: For connected UEs, Option 1 (A bitmap with each bit corresponding to [one or more] UEs) is used for the LP-WUS information to trigger PDCCH monitoring.

* 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: Consider the support of a preamble for LP-WUS.

Proposal 7: For LP-WUS, support payload [+ CRC].

Proposal 8: Further consider the following option for carrying information on the overlaid sequences:

* Option 2a: 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

**R1-2408691 MediaTek Inc**

Proposal 1: Use 4 bits for payload to support 16 codepoint values, multiple POs, and up to 2 MOs per LP-WUS beam for RRC IDLE/INACTIVE.

Proposal 3: Support LP-WUS for CA in RRC CONNECTED mode using a bitmap to wake up specific carriers, enabling flexible scheduling and power savings.

Proposal 4: Support using frequency domain Gold sequences before DFT processing for OOK-4 M>1 and allow UE to choose time or frequency domain detection.

Proposal 5: Use LPSS with m-sequence and circular extension, optionally including Manchester code, and prevent catastrophic errors at SNR=-6dB by using:

* OOK-1: At least 34 symbols for T=2us and 18 symbols for T=5us.
* OOK-4 (M=2): At least 16 symbols for T=1us and 12 symbols for T=2us.
* OOK-4 (M=4): At least 20 symbols for T=0.5us and 16 symbols for T=1us.

Observation 8: Residual frequency errors significantly impact synchronization accuracy, especially with LPSS timing detection errors.

Proposal 6: Support OOK-4 (M=4) with 20 OFDM symbols for the LPSS design to reduce constraints on LPWUS designs and ensure better synchronization performance.

Proposal 7: For both time error and frequency error, the overlaid OFDM sequence design of LP-WUS assumes that the residual frequency error is 2ppm for OFDM-based LP-WUR after frequency error correction without considering impact of drift.

Proposal 8: Support OFDM-WUR to jointly detect info-bit of LPWUS from OOK patterns and OFDM sequences, enabling early termination to save energy by not monitoring the complete LPWUS.

**R1-2407977 Xiaomi**

*Observation1：OOK-1 is more robust to timing error, and of lower complexity compared to OOK-4, but with lower bit rate.*

*Observation2：Whether OOK-1 or OOK-4 is used depends on the bitrate carried in LP-WUS/LP-SS without considering overlaid OFDM sequence(s) over OOK symbol.*

*Observation 3: The OOK symbols carried by OFDM symbols in OOK-4 are susceptible to the issue of CP.*

* *A UE equipped with an OOK receiver is unable to effectively utilize the energy corresponding to CP during reception of OOK-4 symbols.*

*Observation 4: The support for OOK-1 based on M=1 will result in unnecessary DFT during the generation of LP-WUS/LP-SS, thereby increasing the implementation complexity of the gNB.*

*Proposal 1：OOK-1 and OOK-4 should be specified respectively for LP-WUS.*

*Proposal 2：Support to confirm the Working Assumption that OOK-4 with M=4 for 30kHz SCS is supported for LP-WUS.*

*Proposal 3：Both OOK-1 and OOK-4 should be supported for LP-SS. For OOK-4, M should be configured as 2, 4, 8.*

*Observation 5: Different SCS configurations offer distinct advantages from diverse perspectives, thus the SCS of a CP-OFDM symbol used for LP-WUS generation can be different from one of the SCS(s) used for other NR transmissions in the same CP-OFDM symbol for more configuration possibilities.*

*Proposal 4：Different SCS between LP-WUS/LP-SS and other NR channel/signals in an OFDM symbol could be supported in RAN1.*

*Proposal 5: The active BWP SCS can serve as a reference for LP WUS.*

* *For same SCS to active BWP SCS, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be the same as the active BWP SCS.*
* *For different SCS from active BWP SCS, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be configured with offset based on the active BWP SCS.*

*Observation 6：Besides LP-SS, preamble of LP-WUS can provide fine granularity synchronization, or reduce the required overhead of LP-SS.*

*Proposal 6：Preamble could be supported in LP WUS for better synchronization performance when longer periodicity of LP-SS is configured.*

*Observation 7：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS.*

*Observation 8：The OOK pattern of preamble does not need to change, which is more suitable for overlaid OFDM sequence(s) over OOK symbol.*

*Proposal 7：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS*

*Observation 9：Overlaid OFDM sequence(s) over OOK symbol is capable of carrying more information, such as more granular wake-up indications, which has no effect on OOK based UEs, but allows OFDM based UEs to get more accurate information. It is beneficial to avoid the possibility of OFDM based UEs being woken up unnecessary.*

*Observation 10：Overlaid OFDM sequence(s) over OOK symbol carrying more information than OOK modulation may lead to additional protocol standardization work.*

*Proposal 8：The full discussion of option 1 in RAN1 is imperative, while the potential benefits of option 2 can be explored if sufficient time permits.*

*Observation 11：The UE with OFDM-based* *receiver may detect the overlaid sequences throughout the entire duration of LP-WUS to ensure reliability and coverage.*

*Proposal 9：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 10：Support option 2 as a baseline solution for the overlaid OFDM sequence(s) of LP-WUS.*

*Observation 12：The excessive utilization of OFDM sequences in one OOK symbol not only leads to increase blind detection for UEs but also adversely impacts the performance of OOK reception.*

*Observation 13：The payload of LP-WUS/LP-SS directly impacts the overall number of sequences overlaid on OOK symbols.*

*Proposal 11：* *The number of OFDM sequences overlaid on one OOK symbol should be minimized.*

*Proposal 12：* *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 13：Support overlaid OFDM sequence based on ZC-sequence for LP-WUS.*

*Observation 14：Compared to OOK WUR, OFDM WUR may support full cell coverage.*

*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*

*Observation 15：The gNB schedules RRC connected UEs more frequently, leading to an increased likelihood of multiple UEs being awakened. Bitmap-based mechanisms require far fewer transmissions than CodePoint-based ones for the same number of awakened UEs.*

*Proposal 15：SSSG switching/ BWP switching could be considered in LP WUS in RRC connected state..*

*Proposal 16：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 17：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.*

*Observation 16：For the UE of OFDM based receiver, it can obtain synchronization by receiving PSS/SSS as well as LP-SS.*

*Observation 17：For the UE of OOK based receiver, a preamble can be configured to LP WUS in order to alleviate the degradation of synchronization performance due to long LP-SS periods.*

*Proposal 18：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.*

*Observation 18：The determination of the duration of LP-SS necessitates consideration of various time-domain pattern designs. To streamline the design process, reference can be made to SSB pattern design.*

*Proposal 19：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 20： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.*

*Observation 19：To limit resource overhead, and also based on SI evaluations, bandwidth no more than 5MHz is preferred.*

*Proposal 21:*

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

*Observation 20：* *The coexistence of LP-WUS/LP-SS and legacy NR channels in the same band and carrier necessitates the collision handling mechanisms.*

*Observation 21：Considering limited supported bands for LP-WUR, LP-WUS/LP-SS can be in different bands from legacy NR channels.*

*Proposal 22：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.*

*Observation 22：In most cases, LP WUS with Manchester encoding exhibits slightly inferior performance compared to PUSCH Msg3. To ensure reliable transmission, the enhancement of LP WUS coverage is imperative.*

*Proposal 23：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*

*Observation1：OOK-1 is more robust to timing error, and of lower complexity compared to OOK-4, but with lower bit rate.*

*Observation2：Whether OOK-1 or OOK-4 is used depends on the bitrate carried in LP-WUS/LP-SS without considering overlaid OFDM sequence(s) over OOK symbol.*

*Observation 3: The OOK symbols carried by OFDM symbols in OOK-4 are susceptible to the issue of CP.*

* A UE equipped with an OOK receiver is unable to effectively utilize the energy corresponding to CP during reception of OOK-4 symbols.

*Observation 4: The support for OOK-1 based on M=1 will result in unnecessary DFT during the generation of LP-WUS/LP-SS, thereby increasing the implementation complexity of the gNB.*

*Proposal 1：OOK-1 and OOK-4 should be specified respectively for LP-WUS.*

*Proposal 2：Support to confirm the Working Assumption that OOK-4 with M=4 for 30kHz SCS is supported for LP-WUS.*

*Proposal 3：Both OOK-1 and OOK-4 should be supported for LP-SS. For OOK-4, M should be configured as 2, 4, 8.*

*Observation 5: Different SCS configurations offer distinct advantages from diverse perspectives, thus the SCS of a CP-OFDM symbol used for LP-WUS generation can be different from one of the SCS(s) used for other NR transmissions in the same CP-OFDM symbol for more configuration possibilities.*

*Proposal 4：Different SCS between LP-WUS/LP-SS and other NR channel/signals in an OFDM symbol could be supported in RAN1.*

*Proposal 5: The active BWP SCS can serve as a reference for LP WUS.*

* For same SCS to active BWP SCS, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be the same as the active BWP SCS.
* For different SCS from active BWP SCS, the SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation can be configured with offset based on the active BWP SCS.

*Observation 6：Besides LP-SS, preamble of LP-WUS can provide fine granularity synchronization, or reduce the required overhead of LP-SS.*

*Proposal 6：Preamble could be supported in LP WUS for better synchronization performance when longer periodicity of LP-SS is configured.*

*Observation 7：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS.*

*Observation 8：The OOK pattern of preamble does not need to change, which is more suitable for overlaid OFDM sequence(s) over OOK symbol.*

*Proposal 7：Overlaid OFDM sequence(s) can apply to OOK symbols in both preamble and the data part of a LP-WUS*

*Observation 9：Overlaid OFDM sequence(s) over OOK symbol is capable of carrying more information, such as more granular wake-up indications, which has no effect on OOK based UEs, but allows OFDM based UEs to get more accurate information. It is beneficial to avoid the possibility of OFDM based UEs being woken up unnecessary.*

*Observation 10：Overlaid OFDM sequence(s) over OOK symbol carrying more information than OOK modulation may lead to additional protocol standardization work.*

*Proposal 8：The full discussion of option 1 in RAN1 is imperative, while the potential benefits of option 2 can be explored if sufficient time permits.*

*Observation 11：The UE with OFDM-based* *receiver may detect the overlaid sequences throughout the entire duration of LP-WUS to ensure reliability and coverage.*

*Proposal 9：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 10：Support option 2 as a baseline solution for the overlaid OFDM sequence(s) of LP-WUS.*

*Observation 12：The excessive utilization of OFDM sequences in one OOK symbol not only leads to increase blind detection for UEs but also adversely impacts the performance of OOK reception.*

*Observation 13：The payload of LP-WUS/LP-SS directly impacts the overall number of sequences overlaid on OOK symbols.*

*Proposal 11：* *The number of OFDM sequences overlaid on one OOK symbol should be minimized.*

*Proposal 12：* *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 13：Support overlaid OFDM sequence based on ZC-sequence for LP-WUS.*

*Observation 14：Compared to OOK WUR, OFDM WUR may support full cell coverage.*

*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

*Observation 15：The gNB schedules RRC connected UEs more frequently, leading to an increased likelihood of multiple UEs being awakened. Bitmap-based mechanisms require far fewer transmissions than CodePoint-based ones for the same number of awakened UEs.*

*Proposal 15：SSSG switching/ BWP switching could be considered in LP WUS in RRC connected state..*

*Proposal 16：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 17：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.*

*Observation 16：For the UE of OFDM based receiver, it can obtain synchronization by receiving PSS/SSS as well as LP-SS.*

*Observation 17：For the UE of OOK based receiver, a preamble can be configured to LP WUS in order to alleviate the degradation of synchronization performance due to long LP-SS periods.*

*Proposal 18：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.*

*Observation 18：The determination of the duration of LP-SS necessitates consideration of various time-domain pattern designs. To streamline the design process, reference can be made to SSB pattern design.*

*Proposal 19：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 20： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.*

*Observation 19：To limit resource overhead, and also based on SI evaluations, bandwidth no more than 5MHz is preferred.*

*Proposal 21:*

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

*Observation 20：* *The coexistence of LP-WUS/LP-SS and legacy NR channels in the same band and carrier necessitates the collision handling mechanisms.*

*Observation 21：Considering limited supported bands for LP-WUR, LP-WUS/LP-SS can be in different bands from legacy NR channels.*

*Proposal 22：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.*

*Observation 22：In most cases, LP WUS with Manchester encoding exhibits slightly inferior performance compared to PUSCH Msg3. To ensure reliable transmission, the enhancement of LP WUS coverage is imperative.*

*Proposal 23：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

**R1-2407913 CMCC**

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

Proposal 1. For overlaid OFDM sequences for LP-WUS,

* For OOK-1, support Option 2: Overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing
* For OOK-4 with M=1 (if supported), support Option 1-1: Overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing

Proposal 2. For overlaid OFDM sequences for LP-WUS, the overlaid OFDM sequences are specified in time-domain in Option 1-1 for OOK-4 and Option 2 for OOK-1.

Proposal 3.

* Support ZC sequence as overlaid sequence of LP-WUS/LP-SS for OOK-1 and OOK-4 with M=1 (if supported).
* FFS for sequences for OOK-4 with M=2 and 4, which to flat the frequency domain for LP-WUS/LP-SS signal.

Proposal 4. Understanding 3 should be taken for Option 3 of overlaid OFDM sequence(s) of LP-WUS, i.e., the overlaid OFDM sequence mapped from OOK bits within the OFDM symbol could be transmitted with repetition.

Proposal 5. Support Option 1 and Option 2-2 as overlaid OFDM sequence(s) of LP-WUS.

* 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 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 6. Support to specify time domain signal before DFT/LS/IFFT processing for LP-WUS/LP-SS waveform generation considering both OOK-4 and OOK-1.

Proposal 7. The multiplexing between legacy NR signal and LP-WUS/LP-SS should be before IFFT.

Proposal 8. 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 at least for LP-WUS signal generation.

Proposal 9. For RRC connected state, Option 1 can be supported for indicating subgroup information using LP-WUS, i.e., A bitmap with each bit corresponding to [one or more] UEs.

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 information part design:

* Option 1: encoding bits + CRC
* Option 2: sequence 1(wake-up or not) + sequence 2(sub grouping information)

Proposal 12. Bit-level or block-level repetition is necessary for OOK-1 and OOK-4 to achieve the same coverage as Msg3.

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

Proposal 14. The periodicity of LP-SS is suggested to be 320ms.

Proposal 15. 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.

**R1-2408271 EURECOM**

* [Proposal 1: Consider if pulse-shaping is required after sequence design and potential preamble are agreed.](#_Toc178934084)
* [Proposal 2: The DFT-shift is compensated at the LR.](#_Toc178934085)
* [Proposal 3: Do not consider mapping/quantizing WUS in frequency-domain.](#_Toc178934086)
* [Proposal 4: Multiplexing NR and WUS in frequency-domain is the base line.](#_Toc178934087)
* [Proposal 5: Specify OOK-1 and OOK-4 signal generation in time-domain.](#_Toc178934088)
* [Observation 1: Correlation receiver achieves significant gain over energy detection.](#_Toc178934093)
* [Observation 2: For , Pulse Position Coding achieves significant performance gain for all receiver types.](#_Toc178934094)
* [Proposal 6: Only Option 1 and Option 2 should be further considered.](#_Toc178934095)
* [Proposal 7: Support Option 2-2, utilizing multiple overlaid OFDM sequences for the entire WUS transmission.](#_Toc178934099)
* [Proposal 8: Evaluate how the information bits are mapped to multiple overlaid OFDM sequences.](#_Toc178934100)
* [Observation 3:](#_Toc178934101)
* [ COR-WUR performs better than COR-WUR-OOK due to the processing gain of carrying out longer correlations.](#_Toc178934102)
* [ Transmitting the *same* payload as the OOK waveform with the overlaid OFDM sequences but in a *different bit sequence* yields a significant performance gain.](#_Toc178934103)
* [ Using Pulse Position Coding and increasing the number of sequences results in a significant performance gain](#_Toc178934104)
* [Proposal 9: For multiple ON-Sequences, jointly encode the payload with OOK and sequence encoding.](#_Toc178934105)
* [Observation 4: A time-domain overlay code can significantly improve performance of the overlaid OFDM sequence transmission.](#_Toc178934106)
* [Proposal 10: Consider Zadoff-Chu sequences as base line.](#_Toc178934111)
* [Proposal 11: Support Option 1-1: Overlaid sequences are the OOK ON-sequences before DFT/LS processing.](#_Toc178934116)
* [Proposal 12: Specify Manchester Coding as 0 🡪[1 0] and 1🡪[0 1].](#_Toc178934118)
* [Observation 5: with Manchester Coding has the worst coverage compared to .](#_Toc178934119)
* [Proposal 13: For , consider jointly encoding multiple bits into ON pulse position to increase SNR by 3dB.](#_Toc178934120)
* [Observation 6: PAPR increase of Pulse Position Coding for compared to Manchester encoding depends on the ratio of channel BW to WUS BW and is minor (~0.1dB) for many system configurations.](#_Toc178934121)
* [Proposal 14: Allow configuration of *Pulse Position Coding* for .](#_Toc178934122)
* [Proposal 15: Support of Pulse Position Coding for LP-SS.](#_Toc178934123)

**R1-2407714 Spreadtrum Communications**

LP-WUS design

*Proposal 1: M=4 for 30kHz is not supported in R19 LP-WUS.*

*Proposal 2: 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 3: 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 4: Overlaid OFDM sequence is based on ZC sequence.*

*Proposal 5: At least for OOK-4, preamble for LP-WUS can be considered.*

*Proposal 6: For idle/inactive UEs, Option 1 (i.e. bitmap) can be supported for information content carried by LP-WUS.*

*Proposal 7: For connected UEs, after mechanism of LP-WUS for connected UEs is determined, information content carried by LP-WUS can be decided.*

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

*Proposal 9: For LP-WUS, multiple OFDM sequences overlaid on an OOK symbol may have low priority.*

*Proposal 10: 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 11: OOK-1 can be supported for R19 LP-SS similar to LP-WUS.*

*Proposal 12: OOK-4 with M=2 or 4 can be supported for R19 LP-SS.*

*Proposal 13: 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 14: For LP-SS with or without overlaid OFDM sequence, Option 3 can be supported.*

*Proposal 15: 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 16: For calibration of the target SNR, confirm there is no precoder cycling in time or frequency domain for gNB transmitting LP-WUS.*

*Proposal 17. Study potential coverage enhancement techniques for LP-WUS transmission.*

*Proposal 18: We should jointly consider power consumption and determination of coverage target for LR.*

*Proposal 19: 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 20: We should jointly consider determination of overhead target and determination of coverage target for LR.*

*Proposal 21: Resource overhead gap for two types of LR can be further evaluated.*

**R1-2408129 OPPO**

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

* LP-WUS

1. *Confirm the working assumption. Support M=4 for 30KHz SCS.*
2. *Considering the unified design, support M=1 for OOK-4 and specify OOK-1 as the case of OOK-4 with M = 1.*
3. *The SCS used for LP-WUS remains unchanged during the whole transmission of LP-WUS.*
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.*

1. *The content of LP-WUS should include the wake-up indication information, additional information (e.g., cell information, SI change and ETWS/CMAS information, tracking area information, RAN area information, etc.) is not necessary to be carried in LP-WUS.*
2. *The subgroups that different codepoint values corresponding to are not overlapped.*
3. *A codepoint value corresponding to one subgroup from N subgroups for part of, one or more POs.*
4. *Considering unified design of LP-WUS information, support option 3 regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs (A codepoint value corresponding to [one or more] UEs).*
5. *Considering unified design of waveform generation, support option 1-1 for overlaid OFDM sequences, i.e. Overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing.*

* *OOK-1 is specified as OOK-4 with M=1.*

1. *Overlaid OFDM sequence(s) carry all information bits of LP-WUS.*
2. *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 of 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 of overlaid OFDM sequences equal to 1.*
* *If the bit number of each segment is N>1, the number of candidates of overlaid OFDM sequences equal to 2N.*

1. *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.*
* *Considering Manchester coding is used for encoding, four candidates of overlaid OFDM sequences is enough.*

1. *Support fixed bandwidth for LP-WUS and LP-SS regardless the SCS and RRC state, i.e. X=22 for 15kHz.*
2. *LP-WUS and LP-SS could share the same BW. The transmission of LP-WUS and LP-SS is TDM.*
3. *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

1. *LP-SS select one waveform from OOK1/4, single M values is selected for the waveform.*
2. *The impact of CP duration should be considered when design and evaluate the LP-SS.*
3. *The time duration of LP-SS is no longer than one slot.*
4. *Consider following maximum length of LP-SS sequence for different M value.*

* *OOK-1, length of LP-SS sequence is 7.*
* *OOK-4 with M=2, length of LP-SS sequence is 28.*
* *OOK-4 with M=4, length of LP-SS sequence is 56.*

1. *LP-SS introduce Gold, M sequences or Computer searched sequence for modulation into OOK symbols. FFS coding on top of sequence.*
2. *LP-SS uses a binary sequence associated to the cell ID by configuration. FFS: mapping schemes between cell ID and LP-SS sequences.*
3. *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.*

1. *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.*

**R1-2408344 Panasonic**

Based on the discussion, the following proposals are highlighted:

Proposal 1: If OOK-1 is supported and specified, no need to support M=1 for OOK-4, which duplicates the feature design.

Proposal 2: For FR1, OOK-4 M=4 for 15kHz and M=2 for 30kHz are supported. Either 15 or 30kHz is specified for OOK-1.

Proposal 3: For FR2, OOK-4 with M=2 for 60 kHz SCS and OOK-1 for 60kHz SCS are supported.

Proposal 4: For both 15 kHz and 30 kHz, same bandwidth should be supported for LP-WUS for LP-WUS RF complexity reduction.

Proposal 5: For FR2, 60 kHz SCS is supported. 11 PRBs for LP-WUS and LP-SS is supported as baseline.

Proposal 6: We are ok to use either ZC sequence or frequency domain-based M sequence.

Proposal 7: The residual frequency error after frequency error correction should be less than 5 ppm.

Proposal 8: For overlaid OFDM sequences for LP-WUS for OOK-1, we firstly prefer to generate overlaid sequence in an OOK symbol before DFT/LS processing but can also be flexible and accept to specify the overlaid sequence in frequency domain before IFFT processing.

Proposal 9: 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 10: for CONNECTED LP-WUS, we support multiple bit blocks, each of which is a bitmap, where each bit points to one or more UEs. Each block can refer to one or more CCs.

Proposal 11: 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 12:

* 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 studied to immigrate the inter-cell interference, while the complexity of the design is managed with sufficient simplicity.

**R1-2407614 FUTUREWEI**

LP-WUS Design (Structure)

*Proposal 1: Support LP-WUS to carry up to 12 bits of payload (before Manchester encoding) without CRC for codepoint based wake-up indication in RRC IDLE/INACTIVE.*

LP-WUS Design (Waveform)

*Proposal 2: Confirm the working assumption that a LP-WUR-enabled UE supports OOK-4 based LP-WUS design with M=4 regardless of SCS.*

*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 16-bit length, at density ≤ 1, and generated using OOK-4 with M ≥ 4.*

*Proposal 7: For OOK-based LP-WUR in RRC Idle/Inactive and assuming residual frequency error ∈ [5-10] ppm and RAN1#118 agreed 90% target residual time error T∈{0.5,1,2}μs, consider a preamble to precede the transmission of an LP-WUS if LP-SS periodicity is ≥ 320 ms.*

**R1-2408236 Honor**

*Proposal 1：Support M=4 for 30kHZ SCS.*

*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: The overlaid sequence generation method of OOK-4 with M=1 is not supported.*

*Proposal 11: OOK-1 adopts the overlaid sequence generation method of option 2.*

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

*Proposal 13: Support X can be configured by the network side.*

*Proposal 14: Further study the sending rules and detailed design of multiple code points to reduce the number of UE blind detections and energy consumption e.g., sent in the order of code point values.*

*Proposal 15: Support both option 1 and option 3, and the network side can flexibly indicate the specific solution.*

*Proposal 16: Carrier information is carried through the overlaid sequence in the CA scenario.*

*Proposal 17: 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 18: Prioritize M sequence for LP-SS.*

**R1-2408280 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. Procedures for handling inconsistencies in RRM measurements based on LP-SS and RRM measurements based on NR-SS, e.g., due to RRM measurements inaccuracies based on LP-SS, should be supported.*

*Proposal 6. In specifying binary LP-SS sequences, do not support determining the sequences by predefined rule without configuration.*

*Proposal 7. For LP-WUS signal structure, time domain repetition is supported in addition to Manchester coding.*

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

*Proposal 9. Support of M=4 for 30 kHz is confirmed.*

*Proposal 10. Support ZC sequence for overlaid OFDM sequence.*

*Proposal 11:* *Support up to 16 subgroups for LP-WUS.*

* *Up to 32 subgroups can be considered in the following cases:* 
  + *If additional subgroup information based on different MO is supported.*
  + *If different MO indicates different subgroups.*

*Proposal 12: For CONNECTED mode, Option 3 ‘A codepoint value corresponding to [one or more] UEs’ is supported.*

**R1-2408416 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.*

**R1-2407634 TCL**

Proposal 1: The maximum payload size of the LP-WUS can be determined by the number of sub-groups associated with an LP-WUS occasion.

Proposal 2: Consider encoded bits to carry the information bits in the LP-WUS payload.

Proposal 3: Support OOk-1 and OOK-4 (with M=2, 4, and 8) waveform for LP-SS.

Proposal 4: Consider the configuration of SCS for LP-SS in association to a BWP.

Proposal 5: 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 6: Consider the LP-SS periodicities with candidate values of at least 80ms, 160ms, 320ms for UEs in both RRC idle/inactive and connected state.

Proposal 7: For LP-WUS and LP-SS with SCH of 15KHz, support X =22 PRBs and a channel bandwidth of Y = 5MHz.

Proposal 8: For FR2, consider a channel bandwidth equal or less than 20 MHz.

Proposal 9: Consider X = 44 MOs in an LO as a starting point for further discussion.

Proposal 10: For the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, support option 3: A codepoint value corresponding to [one or more] UEs.

Proposal 11: Consider a dedicated BWP for the placement of LP-WUS and LP-SS, with the maximum bandwidth within the range of 5MHz to 20MHz.

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

**R1-24086789 LG Electronics**

Proposal #1: Regarding SCS for LP-WUS, the followings need to be supported for coexistence of LP-WUS and NR signal/channel

* SCS for LP-WUS is determined based on the associated (or overlapped) BWP
  + For Idle/Inactive state, SCS for LP-WUS is same as initial DL BWP SCS
  + For Connected state, SCS for LP-WUS is same as active DL BWP SCS
* Transmission of LP-WUS with different SCS from NR signal can be skipped when the transmissions of LP-WUS and NR signal which have different SCS are overlapped in time

Proposal #2: Support the LP-WUS structure including preamble part, message part and CRC

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

Proposal #3: Discuss the necessity of preamble part with consideration of its potential benefit for LP-WUS transmission on top of the need for timing error compensation

Proposal #4: Support the overlaid sequence in frequency domain for OOK-1

Proposal #5: For the overlaid OFDM sequence on each OOK ON symbol within an OFDM symbol, two sequences with different phases are alternatively used on each OOK ON symbol

Proposal #6: For the case of overlaid OFDM sequence not carrying information, reuse the existing sequence for PSS as the overlaid OFDM sequence.

Proposal #7: For the case of overlaid OFDM sequence carrying information, support the following Option 2 for further discussion

* Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol
  + 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 #8: In case that one sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol, support Option 2-2 as below

* 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 #9: Specify the overlaid OFDM sequence in both time and frequency domain

* The overlaid OFDM sequence for OOK-1 based LP-WUS can be defined in frequency domain while that for OOK-4 based LP-WUS can be defined in time domain

Proposal #10: Discuss on the sequence length (and detailed mapping to OFDM symbol) of overlaid OFDM sequence considering LP-WUR sampling rate

Proposal #11: Support 22 PRBs as the bandwidth of LP-WUS and LP-SS with 15 kHz SCS for a channel bandwidth equal or larger than 5 MHz.

Proposal #12: Support the bandwidth of LP-WUS and LP-SS less than 20 MHz for FR2-1

Proposal #13: Discuss the bandwidth of LP-WUS and LP-SS for FR2-2 with consideration of low power receiver implementation

Proposal #14: Discuss on the frequency location for LP-WUS and LP-SS with consideration of at least the following aspects

* NW flexibility and LP-WUR complexity
* Association with active/initial BWP of MR

Proposal #15: Discuss the dedicated frequency resources for LP-WUS and LP-SS

Proposal #16: Confirm the working assumption for LP-SS waveform generation

Proposal #17: Discuss about how OOK-1 or OOK-4 with M=1 could be used as LP-SS

Proposal #18: Discuss whether and how to configure the value of M for LP-SS considering the value of M and SCS for LP-WUS

Proposal #19: Support M-sequence with proper length as a LP-SS binary sequence

Proposal #20: Consider cell-specific cyclic shift, as a starting point, to further discuss about how to differentiate cells with binary LP-SS sequences

Proposal #21: Support LP-SS transmission through 4 consecutive OFDM symbols regardless of the value of M for LP-SS. The lengths of LP-SS binary sequences are as follows

* 16-bit sequence for OOK-4 with M=4
* 8-bit sequence for OOK-4 with M=2

Proposal #22: Minimum sliding window size should be considered when deciding LP-SS binary sequence length

Proposal #23: Discuss whether to apply Manchester coding to LP-SS considering potential power imbalance issue

Proposal #24: Support the overlaid OFDM sequence for LP-SS

Proposal #25: Both aperiodic LP-SS (preamble of LP-WUS) and periodic LP-SS should be supported

Proposal #26: Multiple LP-SS periodicities need to be supported for various scenarios

**R1-2408217 NEC**

*Proposal 1: support only one of OOK-1 and OO-4 with M =1.*

*Proposal 2: support OOK-4 with M=1 for a unified waveform framework.*

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

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

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

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

*Proposal 7: 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: support FDM multiplexing of an LP-SS and its QCLed SSB.*

**R1-2408794 NTT DOCOMO, INC**

Proposal 1:

* Different SCS between LP-WUS and PDSCH can be considered
* If desirable GB size for LP-WUS and LP-SS is up to gNB implementation, it is supported that the SCS is configured by gNB

Proposal 2:

* In case of OOK-1, option 2 should be supported

Proposal 3:

* Do not support OOK-4 M=1 for LP-WUS (i.e., Support OOK-1 for LP-WUS)

Proposal 4:

* Prior to handle overlaid OFDM sequence type for LP-WUS, the followings should be discussed
  + whether the sequence length is fixed or not
  + how long the sequence length is necessary

Proposal 5:

* For FR1 and FR2, the design of LP-WUS and LP-SS sequence generation can be common

Proposal 6:

* If OOK-1 without preambles is supported, LP-SS periodicity is limited up to 640ms
* If OOK-4 M=2 without preambles is supported, LP-SS periodicity is limited up to 320ms
* If OOK-4 M=4 without preambles is supported, LP-SS periodicity is limited up to 160ms

Proposal 7:

* Zadoff-chu sequence should be supported for LP-SS overlaid OFDM sequences

Proposal 8:

* The number of symbols for LP-SS should be at least 8

**R1-2408253 Sharp**

Proposal 1: Confirm the working assumption of M=4 for SCS 30kHz.

Proposal 2: Only one of OOK-1 and OOK-4 with M=1 shall be supported.

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 type of indication for LP-WUS information for connected UEs.

Proposal 5: Support 11/22 PRBs for LP-WUS with SCS 15kHz.

Proposal 6: Support LP-WUS with 11 PRBs with SCS 120kHz for FR2 band with resuing the sequence for FR1.

**R1-2408918 Nordic Semiconductor ASA**

*Proposal-1: For LP-WUS monitoring*

* *In iDRX, for LO, K=1 is preferred.*
  + *Periodicity of LO equal to iDRX periodicity is supported.*
  + *FFS: LO periodicity different to periodicity of iDRX.*
* *eDRX for MR is supported. eDRX for LR is not supported.*

*Proposal-2: Support “dynamic PTW”, at least for the case where MR is configured with eDRX while LOs are configured with periodicity < eDRX periodicity.*

*Proposal-3: One-to-one mapping between LO and legacy PO (Option 1) is supported, i.e. confirm above working assumption.*

*Proposal-4: In Option 1, for UEs belonging to the same paging group/subgroup and monitoring the same set of legacy LOs, the first monitored legacy PO after LR receives LP-WUS can be different, and is determined based on already agreed UE-reported wake-up time capability. Support Alt.2 (it monitors the first PO after its reported wake-up delay.)*

*Proposal-5: Support 2 wake-up delays capabilities in IDLE mode, starting point is 400ms and 800ms.*

*Proposal-6: Maximum number of supported subgroups is 64, this includes both UE-specific as well as core-assigned sub-groups.*

*Proposal-7: Maximum number of information bits is 8.*

**R1-2408968 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.*

**R1-2408399 Everactive**

Observation 1: If ZC sequence is supported as the overlaid OFDM sequence for OOK-1

and OOK-4 with M=1, then option 1-1 and option 2 will be identical.

Observation 2: Sets of 4 truncated Gold Codes for N=30, 62, and 126 results in a tradeoff

between sidelobe, run length, processing gain, and REs.

Observation 3: To minimize the number of REs or run length, N=30 is best. To maximize

processing gain, N=126 is best.

Observation 4: Balanced codes offer similar performance in the presence of offset and

AWGN with reduced hardware cost. Gold Codes have good performance in an AWGN

environment, but are not balanced.

Proposal 1: Support option 2 for more efficient and flexible gNB implementation.

Proposal 2: If a truncated Gold Code with length N=30 is sufficient for meeting timing and

sensitivity requirements, the 4 LP-SS sequences are:

[110010001010110010010101101101,

010100010100101101110001011101,

101010011100011010101110010100,

101101011000100101101100100110]

Proposal 3: If a truncated Gold Code with length N=126 is sufficient for meeting timing

and sensitivity requirements, the 4 LP-SS sequences are:

[10111100100110110101111001000010111000000001010110010000101101010110101

0101001001110100001010111000011000110111010111101011101,

011101101001100110010000100110100000101000100110011101100111101011010011

100101010100111011001010101011001100010111110100001110,

010010010010001011101010101101101011010000000110000100001011101111010010

111010001111110100111110001001011000101011010111011010,

000101100011001011011001110101010010100101101101000100010010111001110110

010011110110110010010110010110101111110000100011001100]

Proposal 4: Use a truncated Gold Code to result in an even sequence length with a

balanced number of 1’s and 0’s.

Appendix 2: Agreements

Agreements in RAN1 #116

Agreements in 9.6.1

**R1-2401665** Summary of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

Support both OOK-1 and OOK-4 for LP-WUS.

* FFS how OOK-1 and OOK-4 are specified
* For OOK-4, M<=4, FFS supported values
* The SCS of a CP-OFDM symbol used for LP-WUS generation can be the same as one of the SCS(s) used for other NR transmissions in the same CP-OFDM symbol
  + FFS different SCS.

**Agreement**

Further study the following options for LP-SS:

* Option 1: OOK-1
* Option 2: OOK-4 with M=1,2,4,[8]
* The SCS of a CP-OFDM symbol used for LP-SS generation is the same as that used for LP-WUS generation
  + FFS: different SCS

**R1-2401746** Summary#2 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

For LP-SS design from RAN1 perspective, consider at least the following as the design target:

* For RRM measurement performed by LP-WUR based on LP-SS, UE can satisfy measurement accuracy based on X LP-SS samples within a period which is comparable to Y=the length of I-DRX cycle that is larger or equal to 1.28s.
  + FFS: X
  + Note: Y is chosen for evaluating LP-SS design.
  + Network overhead and network power consumption are to be considered

**Agreement**

The ‘ON-OFF’ pattern for OOK symbols of LP-SS is based on binary sequence(s)

* FFS binary sequence(s) details, including the sequence type, the number of sequences, and the sequence length
* FFS overlaid OFDM sequences, if supported

**Agreement**

For the overlaid OFDM sequence(s) for LP-SS, consider the following options 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.
* For Option 3, it is up to RAN4 to make decision on whether/how to define the RRM measurement requirement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.

**R1-2401837** Summary#3 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

For RAN1 evaluation purpose, the SNR to achieve the coverage of PUSCH for message3 is determined for OOK-based LP-WUR and OFDM-based LP-WUR, respectively.

* Companies are encouraged to report the SNR, together with the associated assumptions as listed in the table below.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Bandwidth for LP-WUS signal (MHz) | NF for LP-WUR (dB) | Gain of antenna element (dBi) assumed for LP-WUR:  e.g., -3 dBi for redcap UE and e.g., 0dBi for non-redcap UE | # of Tx chains for LP-WUS/LP-SS transmission, e.g., 2  Note: The number of Tx chains for LP-WUS/LP-SS transmission is assumed the same as the number of RX chains for MSG3 reception | MIL value of MSG3: taking redcap UE /non-redcap UE @dense urban 2.6GHz | The SNR (dB) to achieve the coverage of PUSCH for message3 |
| Companyname-01 |  |  |  |  |  |  |

Agreements in 9.6.2

**R1-2401629** Summary #1 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

Multi-beam operations are supported for LP-WUS and LP-SS for idle mode

**R1-2401631** Summary #3 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

LP-WUS occasions (LOs) are defined for LP-WUS monitoring.

* Each LO has one or more LP-WUS monitoring occasions (MOs), where UE can monitor~~s~~ for LP-WUS transmission in each of the LP-WUS MOs.
  + Different LP-WUS MOs may correspond to different beams in multi-beam operation
  + ~~It is not precluded that~~ FFS whether or not each LO is defined as a time window that covers the corresponding LP-WUS MOs
  + FFS details
* It is at least supported that a UE monitors LOs with a configured periodicity.
* ~~Each UE has a periodicity for LO monitoring, and it is at least supported that a UE monitors one LO per period.~~
  + ~~FFS: A UE does not expect its LP-WUS monitoring occasions overlapping in time~~
  + ~~FFS: monitoring of multiple more than one LOs per period e.g. if LP-WUS common to all UEs is supported or in case of eDRX (if supported)~~
* FFS eDRX, if supported

**Agreement**

For the case where a UE supports PEI and PEI is configured by the gNB, after the UE receives LP-WUS indicating wake-up, it is up to UE implementation whether to monitor PEI or not.

**Agreement**

It is supported that the UE monitors the legacy PO after receiving LP-WUS indicating wake-up.

* FFS: support of UE monitoring dynamic PO

**Conclusion**

For idle/inactive mode, how to map a UE to a subgroup ID for LP-WUS is left to RAN2 to decide.

Agreements in 9.6.3

**R1-2401698** FL summary #1 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)

**Agreement**

* For RRC CONNECTED mode, from RAN1 perspective, further study following LP-WUS procedures to trigger PDCCH monitoring:
  + Case 1: PDCCH monitoring is triggered by LP-WUS with C-DRX configuration
    - Option 1-1: LP-WUS monitoring according to the LP-WUS monitoring configuration before drx-onDurationTimer to trigger the starting of the drx-onDurationTimer.
      * This option may replace DCP functionality
    - Option 1-2: LP-WUS monitoring outside C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
      * PDCCH monitoring possibly irrespective of drx-onDurationTimer
    - Option 1-3: LP-WUS monitoring inside C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
  + Case 2: PDCCH monitoring is triggered by LP-WUS without C-DRX configuration. LP-WUS can be monitored at any time according to the LP-WUS monitoring configuration
    - FFS duty-cycled and/or continuous LP-WUS monitoring
* Combination of options in Case 1 and combination of options in Case 1 and Case 2 are not precluded.

**Agreement**

* For RRC CONNECTED mode, maximum number of LP-WUS information bits is up to X bits
* FFS value X, which is no more than [8 or 16]

**Agreement**

* For RRC CONNECTED mode, minimum time gap between LP-WUS reception and MR to start PDCCH monitoring is introduced considering at least following
* LP-WUS processing time
* MR transition time for ramp up
* Time/frequency synchronization of MR
* FFS whether UE can report supported minimum time gap from candidate values

FFS: Whether the minimum time gap values can be more than one

**R1-2401836** FL summary #2 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)

**Agreement**

* For RRC CONNECTED mode, from RAN1 perspective,
* PDCCH monitoring triggered by LP-WUS is enabled/disabled by gNB RRC signaling
  + FFS whether to support UE assistance.
* LP-WUS monitoring by UE is known to gNB.
  + FFS whether implicit/explicit indication from UE is necessary
* In case LP-WUS monitoring is enabled, following options are further studied
  + Option 1: No additional indication/condition are introduced for activation/deactivation of LP-WUS monitoring
  + Option 2: Activation/deactivation of LP-WUS monitoring by gNB L1/L2 signaling with or without UE assistance.
  + Option 3: Activation/deactivation of LP-WUS monitoring based on condition(s), such as timer.
  + Option 4: Activation/deactivation of LP-WUS monitoring based on implicit indication/condition, e.g. UL transmission.

Agreements in RAN1 #116bis

Agreements in 9.6.1

Summary #1 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**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

**Agreement**

For evaluation purpose on LP-WUS, companies report the overlaid OFDM sequence(s), including:

* Sequence(s) generation and how sequence(s) map in time or frequency domain (including any details with multiplexing and IFFT).
* Number of candidate overlaid OFDM sequences used for information conveying
  + Including details on whether the number of candidate overlaid sequences is per OFDM symbol or per OOK symbol
* How the proposed sequence design is processed by OFDM-based LP-WUR, e.g., in time domain or in frequency domain or in both time and frequency domain.

**Agreement**

Support to specify multiple binary LP-SS sequences for the ‘ON-OFF’ pattern:

* The LP-SS sequence used in a cell is
  + Option 1: a sequence is configured
  + Option 2: a sequence is determined by predefined rule
  + FFS: Whether both options will be supported or only one will be supported
* FFS: the number of LP-SS sequences
* Note: Multiple sequences are used to differentiate LP-SS from different cells

**R1-2403616** Summary #2 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

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 the number of PRBs for 15kHz
* 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

**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.

**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

**R1-2403751** Summary #3 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

Regarding the LP-WUS information for idle/inactive UEs, at least consider the following：

* Option 1: A bitmap with each bit corresponding to [one or more] subgroups
* Option 2: A codepoint value corresponding to one or more subgroup(s)
* Option 3: Multiple codepoint values with each corresponding to one or more subgroup(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
* Other options are not precluded

**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)

**Conclusion:**

For calibration purposes, companies are encouraged to report the SNR to achieve the coverage of PUSCH for message3, at least with the following assumptions:

* Carrier frequency: 2.6 GHz
* The number of Tx chains: 1
* MIL of MSG 3: use the average one in R17 coverage, i.e.,153.51 dB for non-redcap UE
* Transmit antenna gain correction factors for WUS: up to company report
* Noise Figure: All three values +2dB, +5dB, +8dB on top of NF of MR (7dB) are to be reported, SNR for different assumptions on NF are determined separately

**Agreement**

For the purpose of further study and evaluation in RAN1, the following candidate sequences for the overlaid OFDM sequence are considered:

* Gold sequence
* M-sequence
* ZC sequence
* Chirp sequence
* Walsh sequence
* Golay sequence
* Kasami sequence
* Low density sequence
* DFT/FFT sequence
* QAM symbol-based sequence
* Combinations and optimizations of above are not precluded

Companies are encouraged to provide an assessment on performance, required complexity, and power consumption to support their preferred sequence. Companies are encouraged to provide details on their preferred sequence (e.g. references).

**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.

Agreements in 9.6.2

**R1-2402893** Summary #1 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

For multi-beam operation of LP-WUS, UE assumes the same LP-WUS information payload is repeated in all transmitted beams corresponding to LP-WUS

* the selection of the beam(s) for the reception of the LP-WUS is up to UE implementation

**R1-2402894** Summary #2 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

Each LO consists of N \* K LP-WUS MOs, where N is the number of beams corresponding to LP-WUS, and K is the number of LP-WUS MOs for each beam.

* Option 1: K = 1
* Option 2: K can be larger than or equal to 1
  + FFS if more than 1 LP-WUS is transmitted from the same beam, whether the information in these multiple LP-WUS is always the same or can be different

**Agreement**

From RAN1 perspective, at least the following metrics can be supported for RRM serving cell measurement performed by OOK-based receiver based on LP-SS:

* LP-RSRP
  + LP-RSRP is the linear average of received power of LP-SS in OOK ON symbols.
    - FFS: How to determine the received power of LP-SS in OOK ON symbols
* LP-RSRQ
  + LP-RSRQ = LP-RSRP/LP-RSSI
  + For the definition of LP-RSSI for determination of LP-RSRQ, further consider the following options:
    - Option 1: LP-RSSI is the linear average of total received power in all LP-SS OOK symbols.
    - Option 2: LP-RSSI is the linear average of total received power in LP-SS OOK OFF symbols.
    - Option 3: LP-RSSI is the linear average of total received power in LP-SS OOK ON symbols.
* FFS: LP-SINR, ~~Power ratio of OOK-ON symbol and OOK-OFF symbol~~

Note: ~~RAN1 will send an LS to RAN2 and RAN4 on the measurement metrics that can be supported from RAN1 perspective, to facilitate RAN2/RAN4 discussions~~. The exact metrics for OOK-based receiver to be used and defined in the specifications depend on the outcome of [RAN1]/RAN2/RAN4 discussions.

**R1-2402895** Summary #3 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Working Assumption**

From RAN1 perspective, for the entry/exit conditions for LP-WUS monitoring in IDLE/inactive mode,

* The UE may start LP-WUS monitoring if
  + the serving cell measurement performed by the MR is above entry threshold(s), if configured by the gNB~~, and/or~~
  + FFS other conditions, and if any, whether all or one or some of the conditions need to be satisfied
* If UE starts LP-WUS monitoring, it may stop the legacy PO monitoring before UE receives LP-WUS indicating wake-up
* The UE monitors the legacy PO (and may monitor PEI) and may stop LP-WUS monitoring if
  + the serving cell measurement performed by the LR is below exit threshold(s), if configured by the gNB~~, and/or~~
  + FFS other conditions, and if any, whether all or one or some of the conditions need to be satisfied
* FFS the serving cell measurement metrics
* The entry/exit thresholds can be configured separately for different types of LR
* It is left to RAN2 discussion whether the threshold(s) are always configured by the gNB.
* Note: This may be revisited based on the RAN2/RAN4 discussion.

**Conclusion**

LP-SINR is not considered further as a metric for RRM serving cell measurement ~~for OOK-based receiver~~.

Agreements in 9.6.3

**Agreement**

* Update the following agreement in RAN1#116 in red:

**Agreement**

* For RRC CONNECTED mode, from RAN1 perspective, further study following LP-WUS procedures to trigger PDCCH monitoring:
  + Case 1: PDCCH monitoring is triggered by LP-WUS with C-DRX configuration
    - Option 1-1: LP-WUS monitoring according to the LP-WUS monitoring configuration before drx-onDurationTimer to trigger the starting of the drx-onDurationTimer.
      * This option may replace DCP functionality
    - Option 1-2: LP-WUS monitoring outside at least legacy C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
      * PDCCH monitoring possibly irrespective of drx-onDurationTimer
        + Option 1-2-1: PDCCH monitoring may be additionally triggered based on legacy C-DRX cycle and drx-onDurationTimer when monitoring LP-WUS

If this is adopted, it should be configured together with Option 1-1 to achieve power saving gain compared to legacy C-DRX

* + - * + Option 1-2-2: PDCCH monitoring is not triggered by legacy C-DRX cycle and drx-onDurationTimer when monitoring LP-WUS
    - Option 1-3: LP-WUS monitoring inside at least legacy C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
  + ~~Case 2: PDCCH monitoring is triggered by LP-WUS without C-DRX configuration. LP-WUS can be monitored at any time according to the LP-WUS monitoring configuration~~
    - ~~FFS duty-cycled and/or continuous LP-WUS monitoring~~
* Combination of options in Case 1 ~~and combination of options in Case 1 and Case 2 are not precluded~~ should be considered.
* RAN1 does not discuss C-DRX related timers other than drx-onDurationTimer, this topic is up to RAN2
* Note: Above does not preclude to support fallback mechanism to trigger PDCCH monitoring, if any

Agreements in RAN1 #117

Agreements in 9.6.1

**R1-2405499** Summary #1 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**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

**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

**R1-2405519** Summary #2 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**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

**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.

**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

**R1-2405645** Summary #4 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

Further down-select the number of binary LP-SS sequences for the ‘ON-OFF’ pattern:

* 3
* 4
* 8
* 16

**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

**R1-2405708** Summary #5 of discussions on LP-WUS and LP-SS design Moderator (vivo)

**Agreement**

The following SNR values for LP-WUR are reported by companies to achieve coverage of PUSCH for message3 for difference noise figures for calibration purposes:

* NF of LR = NF of MR+ 8dB: the reported SNR value range is [-9.05,2.94] dB
* NF of LR = NF of MR+ 5dB: the reported SNR value range is [-6.5, 5.58] dB
* NF of LR = NF of MR+ 2dB: the reported SNR value range is [-4.04,7.95] dB
* Note 1: The above is observed based on the following assumptions used for calibration:

- Carrier frequency: 2.6 GHz

- The number of Tx chains: 1

- MIL of MSG 3: use the average one in R17 coverage, i.e.,153.51 dB for non-redcap UE

- Transmit antenna gain correction factors for WUS: up to company report

- Noise Figure: All three values +2dB, +5dB, +8dB on top of NF of MR (7dB) are to be reported, SNR for different assumptions on NF are determined separately

**Agreement**

For evaluation of LP-WUS and LP-SS design to achieve coverage of PUSCH for message3 from RAN1 perspective, at least the following SNR values should be considered:

* SNR=-3dB for NF of LR = NF of MR+ 8dB
* SNR= -0.5dB for NF of LR = NF of MR+ 5dB
* SNR=2dB for NF of LR = NF of MR+ 2dB
* Note 1: The NF of MR is assumed as 7dB

**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)

Agreements in 9.6.2

**R1-2404299** Summary #1 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Conclusion**

Regarding the “FFS: How to determine the received power of LP-SS in OOK ON symbols” for LP-RSRP, no additional work in RAN1.

**R1-2404300** Summary #2 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

It is supported that UEs monitoring the same PO are divided into multiple subgroups, where LP-WUS can provide wake-up indication for each subgroup. Consider the following options:

* Option 1: UEs monitoring the same PO monitor the same LO
* Option 2: UEs corresponding to different POs monitor the same LO
* Option 3: UEs monitoring the same PO are divided into multiple sets of subgroups, with UEs within each set of subgroups monitoring the same LO.
* Combinations of the above options can be considered.

**R1-2404301** Summary #3 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

**Agreement**

For LP-SS based LP-RSRQ, LP-RSRP and LP-RSSI are measured within the same bandwidth.

**Agreement**

For LP-RSSI definition for LP-RSRQ, the following is agreed

* Option 1: LP-RSSI is the linear average of total received power in ON and OFF LP-SS OOK symbols.

Note: Above does not constrain LP-SS sequence design for OOK

**Working Assumption**

From RAN1 perspective, for the RRM measurement metrics based on SSS for OFDM-based LP-WUR, use the same definition of SS-RSRP and SS-RSRQ for LP-SSS-RSRP and LP-SSS-RSRQ, respectively.

* Above is applicable for both time-domain processing or frequency-domain processing
* Above does not imply that RAN1 will introduce LP-SSS-RSRP and LP-SSS-RSRQ in the specifications

**R1-2405681** Summary #4 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)

Agreement

For idle/inactive mode, the maximum number of information bits (excluding CRC) in a LP-WUS is Z, where Z <= [8 or 16].

* FFS the exact value of Z

Agreement

For idle/inactive mode, the maximum number of subgroups per PO is X, where 8 <= X <= 256.

* FFS the exact value of X.

Agreements in 9.6.3

**R1-2405471** FL summary #1 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)

**Agreement**

For RRC CONNECTED mode, support UE capability report for determination of minimum time gap between LP-WUS reception and MR to start PDCCH monitoring.

* FFS: exact value(s) of the minimum time gap
* FFS: support of multiple minimum time gaps
* FFS whether the reported value includes the duration for time/frequency synchronization of MR

**R1-2405592** FL summary #2 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)

**Agreement**

For LP-WUS monitoring in RRC CONNECTED mode, a LP-WUS is QCLed with existing NR signal/channel/CORESET for the TCI state

* FFS which existing NR signal/channel/CORESET is the QCL source of LP-WUS
* FFS exact definition of QCL relationship between LP-WUS and existing NR signal/channel/CORESET

**Agreement**

LP-WUS monitoring occasions (MOs) are configured by RRC, where UE can monitor for LP-WUS transmission in RRC CONNECTED mode.

* FFS whether to define a time window for Mos
* It is at least supported that a UE can monitor MOs with a periodicity.
* FFS details of the periodicity, e.g. derived from DRX cycle, separately configured

**R1-2405721** FL summary #3 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)

**Agreement**

Study whether/how LP-WUS works when UE is configured with CA in RRC CONNECTED mode

* + FFS: The cell(s) where PDCCH monitoring triggered by a LP-WUS is applicable
    - Option 1: one or more serving cells based on gNB indication/configuration
    - Option 2: all activated serving cells
    - Note: other options are not precluded

**Agreement**

For RRC CONNECTED mode, LP-WUS can be configured without following existing features.

* + Rel-16 DCP
  + Rel-17 PDCCH skipping
  + Rel-17 SSSG switching
  + Rel-18 cell DTX

Further study whether/how LP-WUS works with following existing features (PDCCH skipping, SSSG switching, cell DTX)

Agreements in RAN1 #118

Agreements in 9.6.1

[**R1-2407287**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407287.zip) **Summary #1 of discussions on LP-WUS and LP-SS design Moderator (vivo)**

Agreement

For RRC idle/inactive state, support the following option for at least indicating subgroup information using LP-WUS:

* 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
  + UE monitoring one or more MOs (up to X MOs) for the same beam within an LO is supported
    - Value of X is larger than 1. FFS on additional details of X.

Agreement

Confirm the Working Assumption that OOK-4 with M=4 for 15KHz SCS is supported for LP-WUS.

|  |
| --- |
| **Agreement**  For OOK-4 with M >1, support M=2 & M=4 ~~(working assumption)~~ for LP-WUS.   * M=4 for 15KHz SCS * M=4 for 30KHz SCS (working assumption) * FFS CC for OOK-4 |

[**R1-2407356**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407356.zip) **Summary #2 of discussions on LP-WUS and LP-SS design Moderator (vivo)**

From Wednesday session

Agreement

Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs (for non-CA case), select at least one from the following

* Option 1: A bitmap with each bit corresponding to [one or more] UEs
* Option 3: A codepoint value corresponding to [one or more] UEs
* FFS details for extension of option 1 and/or 3 when UE is configured with CA

Agreement

For overlaid OFDM sequences for LP-WUS, 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

Agreement

For overlaid OFDM sequences for LP-WUS, further down-selection between following two options for OOK-1 and OOK-4 with M=1(if supported)

* Option 1-1: Overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT/LS processing
* Option 2: Overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing
* Note: Different options for OOK-1 and OOK-4 with M=1 (if supported) is not precluded – in which case, it should be deemed necessary

Agreement

The number of binary LP-SS sequences is 4.

[**R1-2407420**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407420.zip) **Summary #3 of discussions on LP-WUS and LP-SS design Moderator (vivo)**

Presented in Thursday session.

[**R1-2407491**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407491.zip) **Summary #4 of discussions on LP-WUS and LP-SS design Moderator (vivo)**

From Friday session

Agreement

To determine the binary sequences for LP-SS, the evaluation assumes the following:

* Sync accuracy: timing estimation error smaller than T us for P=90 % of the time for at least SNR=-3dB and SNR=-6dB (lower priority),
  + T=2us(optional), 5us for OOK-1.
  + T=1us(optional), 2us for OOK-4 with M=2.
  + T=0.5us(optional), 1us for OOK-4 with M=4.
  + Other values of SNR, T, M are up to company report.
  + Additionally, companies can submit results on SINR with details on how the interference was modelled.
  + Assume one-shot estimation.
  + The time error is based on 20ppm maximum frequency error for the detection of the first LP-SS.
  + Note: Companies can assume other values inside of 20ppm maximum as long as the values are justified.
* RRM measurement accuracy: measurement accuracy within range ± XdB for Q=90% measurements based on Y LP-SS samples within a period comparable to Z=the length of I-DRX cycle that is larger or equal to 1.28s for at least SNR=-3dB and SNR=-6dB (lower priority), X, Y, and Z is up to company report, other values of SNR are up to company report.
  + As a starting point, the time error is based on 5-10ppm residual frequency error.
  + Note: 5-10ppm assumes frequency error correction is performed, e.g., RTC calibration and/or MR assistance.
  + Note: Companies can assume other values outside of 5-10ppm as long as the values are justified.
* The frequency error: up to company report.
* Sampling rate: 3.84MHz (optional) or 7.68MHz assumed for 30kHz SCS.
* Channel: AWGN and TDL-C 300ns is assumed.
* Consider cross-correlation for 4 binary sequences under time and frequency error.
* Companies are encouraged to provide details on other additional simulation assumptions, high level description of their receiver algorithm, and assessment on power consumption.

Agreement

For OOK-based LP-WUR, the LP-WUS design assumes the following:

* As starting point, the time error is based on the 5-10ppm residual frequency error after frequency error correction without considering impact of drift.
* The frequency error: up to company report.
* Note: 5-10ppm assumes frequency error correction is performed, e.g., RTC calibration and/or MR assistance.
* Note: Companies can assume other values outside of 5-10ppm as long as the values are justified.

Agreement

As a starting point, for both time error and frequency error, the overlaid OFDM sequence design of LP-WUS assumes that the residual frequency error is 0.1-5ppm for OFDM-based LP-WUR after frequency error correction without considering impact of drift.

* Note: Companies can use any value within the above range with justification on the value (including impact on power consumption).

Agreement

Support Manchester coding for LP-WUS

* FFS other coding schemes.

Final summary in [R1-2407492](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407492.zip).

Agreements in 9.6.2

[**R1-2406853**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2406853.zip) **Summary #1 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)**

Agreement

The definitions of LP-RSRP and LP-RSSI for LP-RSRQ are updated as follows:

* LP-RSRP is the linear average of received power of LP-SS in OOK ON symbols over the frequency resources defined by the number of REs that carry LP-SS.
* LP-RSSI is the linear average of total received power in ON and OFF LP-SS OOK symbols over the frequency resources defined by the number of REs that carry LP-SS.

Agreement

At least support 1:1 association between LP-WUS MO(s)/LP-SS transmissions and SSB beams.

[**R1-2406854**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2406854.zip) **Summary #2 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)**

From Wednesday session

Agreement

For the wake-up delay, consider the following options:

Option 2: UE reports one value from X candidate values for the wake-up delay via UE capability reporting.

* FFS: X is 2, 3, 4

Above applies for IDLE/INACTIVE mode.

Definition of wake-up delay: Minimum gap time between LP-WUS reception and MR to start PDCCH monitoring.

**Conclusion**

There is no consensus in RAN1 on the support of dynamic PO.

[**R1-2406855**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2406855.zip) **Summary #3 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)**

From Thursday session

Agreement

For the maximum number of subgroups per PO (X), down-select from the following options in RAN1#118bis:

* Option 1: X = 8
* Option 2: X = 16
* Option 3: X = 32
* Option 4: X = 64
* Option 5: X = 128
* Option 6: X = 256

For decision in RAN1#118bis, companies are encouraged to provide the maximum number of information bits per LP-WUS (Z), the number of OFDM symbols occupied by LP-WUS per MO, the number of MOs for their preferred option.

Agreement

On the LO configuration for iDRX, offset value(s) between a LO and a reference PO/PF is/are configured.

* FFS: one or multiple offset values, and if multiple offset values are supported, how a UE decides which value to use
* FFS: the exact definition of the reference PF/PO and the detailed procedure for UE to determine the LO(s) corresponding to Option 1, 2, or 3 (if supported)
* (Working Assumption) For each UE, the periodicity of LO is the same as its iDRX cycle.
* If a UE receives a wake-up indication in a LP-WUS, consider the following alternatives.
  + Alt 1: it monitors the PO associated with the offset.
  + Alt 2: it monitors the first PO after its reported wake-up delay.
  + Other alternatives are not precluded.

Note: The PO mentioned above refers to legacy PO configured for the UE.

[**R1-2407506**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407506.zip) **Summary #4 on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)**

From Friday session

Agreement

Send an LS to RAN2 and RAN4 to convey the following

In RAN1, the common understanding is that UE may not support LP-WUS reception on all the bands supported by the UE. Request RAN2 and RAN4 to check if there is any issue and specification support needed for IDLE/INACTIVE UEs.

[**R1-2407558**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407558.zip) **Draft LS on LP-WUS operation in IDLE/INACTIVE mode Moderator (Apple)**

**Decision:** The draft LS is endorsed. Final LS is approved in in [R1-2407559](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407559.zip).

**Conclusion**

RAN1 will not initiate work on entry/exit conditions based on RRM measurement and RRM measurement offloading/relaxation conditions unless triggered by RAN2 and RAN4.

Agreements in 9.6.3

[**R1-2407301**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407301.zip) **FL summary #1 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)**

[**R1-2407378**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407378.zip) **FL summary #2 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)**

From Thursday session

Agreement

For option 1-2 of LP-WUS CONNECTED mode operation, the followings are assumed from RAN1 perspective.

* LP-WUS monitoring outside at least legacy C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
* UE is configured with legacy C-DRX configurations as Rel-18.
* UE is expected to be configured with LP-WUS monitoring configuration (periodicity and offset can be different from those from C-DRX configuration).
  + FFS potential restriction for LP-WUS configuration in relation with C-DRX configuration.
* LP-WUS triggers the start of a timer during which UE monitors PDCCH.
  + FFS the timer is existing timer and/or new timer.
* UE PDCCH monitoring behaviors related to other legacy DRX timers are not affected.
  + drx-InactivityTimer, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, drx-HARQ-RTT-TimerUL.
* No impact on RRM/RLM/BFD measurement requirements is assumed.
* For periodic CSI/L1-RSRP reporting, UE can be configured with one of the following (same as Rel-16 DCP and option 1-1).
  + Periodic CSI/L1-RSRP is not reported if UE is not indicated to wake-up.
  + Periodic CSI/L1-RSRP is periodically reported regardless if UE is indicated to wake-up or not.
* UE PDCCH monitoring is not triggered by legacy C-DRX cycle and drx-onDurationTimer when monitoring LP-WUS.

Working Assumption

From RAN1 perspective, for RRC CONNECTED mode, PDCCH monitoring is triggered by LP-WUS with C-DRX configuration

* + Support Option 1-1: LP-WUS monitoring according to the LP-WUS monitoring configuration before drx-onDurationTimer to trigger the starting of the drx-onDurationTimer.
  + Support Option 1-2: LP-WUS monitoring outside at least legacy C-DRX active time according to the LP-WUS monitoring configuration to trigger PDCCH monitoring.
  + FFS whether/how to support both Option 1-1 and Option 1-2 simultaneously configured for the same UE.

Note: Above can be revisited considering RAN2 decisions.

[**R1-2407516**](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407516.zip) **FL summary #3 on LP-WUS operation in CONNECTED mode Moderator (NTT DOCOMO)**

From Friday session

Agreement

Select one of the following alternatives in RAN1#118bis:

Alt 1: For RRC CONNECTED mode, UE reports one value for each SCS from X candidate values for the determination of the minimum time gap between LP-WUS reception and MR to start PDCCH monitoring via UE capability reporting.

* FFS: X
* FFS: definition of reported value

Alt2: For RRC CONNECTED mode, UE reports multiple values for each SCS from X candidate values for the determination of the minimum time gap between LP-WUS reception and MR to start PDCCH monitoring via UE capability reporting.

* FFS: X
* FFS: definition of reported value
* Different minimum time gaps correspond to different sleep states
* Companies are encouraged to details on how the reported values are to be used by the network

Agreement

LP-WUS is at least supported for the case where a UE is configured with CA in RRC CONNECTED mode

* FFS: DC

Agreement

For LP-WUS monitoring in RRC CONNECTED mode, SSB and/or CSI-RS can be the QCL source of LP-WUS

* FFS applicable QCL type(s)

Final summary in [R1-2407517](file:///E:\backup+essential+(E)\研究\3GPP\RAN1\%23118\chairmannotes\Docs\R1-2407517.zip).