**3GPP TSG RAN WG1 #116bis R1-24XXXX**

**Changsha, Hunan Province, China, April 15th – 19th, 2024**

**Agenda Item: 9.6.1**

**Source: Moderator (vivo)**

**Title:** **Summary #1 of discussions on LP-WUS and LP-SS design**

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

1. Introduction

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

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

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

1. Proposals for Online Sessions
	1. Proposals for online session

***Proposal X:***

1. LP-WUS design
	1. Waveform generation for LP-WUS

In RAN1 #116 meeting, RAN1 agreed to support both OOK-1 and OOK-4. One FFS point is how to specify OOK-1 and OOK-4. The specification of OOK-1 and OOK-4 involve blocks in waveform generation and signal characteristic at least for some of the blocks.

### 3.1.1 LP-WUS waveform generation

As shown in Figure 1, for OOK-4, DFT/LS block is needed before IFFT operation. signal generation and modification block and truncation and modification may be needed or not.

* The signal S1 before DFT, i.e., the signal at point 1 is a time domain signal.
* The signal S2 at point 2 is the input for IFFT, which is frequency domain signal.
* The signal S3 at point 3 is the output of IFFT, which is time domain signal.

 For OOK-1, one approach is to reuse same block as OOK-4 with M=1. Another approach is to directly generate signal S2, i.e., frequency domain signal for LP-WUS.

For signal S1, following aspects are discussed by companies:

* Sequence design for signal S1:
1. The sequence in each OOK ON symbol with variation in phase via such as ZC, M-sequence or QAM sequence can achieve more flattened spectrum, which can improve OOK-based detector performance, as concluded in TR.
2. The sequence in each OOK ON symbol should have good correlation property for OFDM-based detector performance, if the sequence is the overlaid OFDM sequence carrying information bits.

More details are summarized in next sub-section.

* Pulse shaping for signal S1[4][9][28]:

Concentrated waveform by pulse shaping can improve the robustness with respect to timing error, for OOK-based LP-WUR. The OFDM-based LP-WUR performance may be degraded by concentrated waveform due to shorter OFDM sequence length. The impact on OFDM-based LP-WUR detection performance needs to be evaluated.

***[M][FL1] Question 3.1-1:*** *what’s your view on pulse shaping for signal S1?*

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| **Company** | **Support pulse shaping or not** | **Reason to object/support, e.g., OOK/OFDM-based LP-WUR performance, gNB/UE complexity, standard impact** |
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Figure 1 Waveform generation blocks

* DFT shift for signal S1 [3] [4] [9] [28]:

In NR waveform generation, cyclic shift of SC is needed to ensure that SC are continuous in the spectrum after IFFT. In legacy, NR receiver is aware of this and would perform inverse operation during FFT. OOK receiver may not perform inverse operation, which changes the signal’s envelope and phase and thus LP-WUR detection performance is degraded. To avoid performance degradation, pre-compensated to account for the cyclic shift can be applied for signal S1, e.g., the overlaid OFDM sequence design can implement the pre-compensation. The impact on OOK-based and OFMD-based LP-WUR detection performance needs to be evaluated.

***[M][FL1] Question 3.1-2:*** *what’s your view on DFT shift for signal S1?*

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| **Company** | **Support DFT shift or not** | **Reason to object/support, e.g., OOK/OFDM-based LP-WUR performance, gNB/UE complexity, standard impact** |
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For signal S2, to reduce gNB hardware complexity, companies propose to consider mapping the signal S2 to existing constellation, e.g., to existing 16QAM or 64QAM constellation or to existing NR sequence constellation, e.g., ZC sequence. The impact on LP-WUR detection performance needs to be evaluated [2] [8][14].

***[M][FL1] Question 3.1-3:*** *what’s your view on mapping frequency domain samples to existing NR DL channel/signal constellation?*

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| **Company** | **Support or not** | **Reason to object/support, e.g., OOK/OFDM-based LP-WUR performance, gNB/UE complexity, standard impact** |
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For signal S3, [5] proposes to discuss whether NR and LP-WUS is multiplexed before or after IFFT operation. If LP-WUS and NR is multiplexed before IFFT operation, LP-WUS and NR is mapped in different PRBs with single IFFT, denoted as option 1 in the figure. If LP-WUS and NR is multiplexed after IFFT operation, separate IFFTs is needed, denoted as option 2 in the figure. The motivation to support separate IFFT is to minimize the LP-WUS detection performance degradation caused by NR interference.

***[M][FL1] Question 3.1-4:*** *what’s your view on LP-WUS and NR multiplexing before or after IFFT operation?*

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| **Company** | **Support LP-WUS and NR multiplexing before or after IFFT?** | **Comment** |
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### 3.1.2 Specify signals in time or frequency domain

According to inputs form companies, there can be 3 approaches to specify LP-WUS signal generation as listed below:

* Approach 1: Specify Time domain signal before DFT

The signal **S1**=[S11, S12, … S1,M] is time domain signal before DFT in a OFDM symbol, where S1,m denotes OOK ON or OOK OFF. To flatten the spectrum for OOK waveform as well as carry information bits for OFDM-based LP-WUR, **SOi** for generating OOK ON can be a sequence with variation in phase via such as ZC, M-sequence or QAM sequence. Nm\_o sequences for **SOi** can carry one or multiple information bits in an OOK ON chip, for a given M value, where Nm\_o ≥1.

Based on approach 1, time domain signal before DFT is specified and the DFT block should also be specified. It can be up to gNB to pre-calculate and store the frequency-domain sequences based on the specified time signal to avoid DFT operation each time.

* Approach 2: Specify Frequency domain signal before IFFT

The signal **S2**=[S21, S22, … SN] is frequency domain signal in one OFDM symbol. Nm\_t sequences for frequency domain signal **S2** are associated with different combination of OOK ON/OFF combination pattern in time domain for a given M. Furthermore, for one time domain ON/OFF pattern, to support OFDM sequences carrying information, Nm\_o^Non sequences are needed. Thus, total number of sequences to be specified for each M value is Nm\_t\*(Nm\_o^Non) for **S2**, where Nm\_t is number of time domain ON/OFF pattern for a M value and Non is the number of OOK ON symbols per OFDM symbol.

Based on approach 2, frequency domain signal is specified without DFT to reuse existing gNB implementation.

* Approach 3: Specify Time domain signal after IFFT

The signal **S3**=[S31, S32, … S3N’] is time domain signal after IFFT in one OFDM symbol. Nm\_t sequences for time domain signal **S3** are associated with different combination of OOK ON/OFF combination pattern in time domain for a given M. Furthermore, for one time domain ON/OFF pattern, to support OFDM sequences carrying information, Nm\_o^Non sequences are needed. Thus, total number of sequences to be specified for each M value is Nm\_t\*(Nm\_o^Non) for **S3**, where Nm\_t is number of time domain ON/OFF pattern for a M value and Non is the number of OOK ON symbols per OFDM symbol.

Based on approach 3, time domain signal after IFFT is specified without DFT. It’s up to gNB implementation to generate signals complied with the specified signal.

***[M][FL1] Question 3.1-5:*** *what’s your view on 3 approaches above?*

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| **Company** | **Which option do you support for OOK-1** | **Which option do you support for OOK-4** | **comment** |
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Based on 3 approaches above, one subsequent question is, whether OOK-1 and OOK-4 uses same approach or different approaches.

Alternative 1: Generic generation framework, i.e., the same approach is applied for OOK-1 and OOK-4 [2] [3] [4] [5] [7][9][10] [15] [17] [22][25] [26] [27].

Alternative 2: Separate generation framework, i.e., different approach is applied for OOK-1 and OOK-4 [6][8] [12] [13] [19] [20] [26]

***[M][FL1] Question 3.1-6:*** *Do you think separate generation framework for OOK-1 and OOK-4 increase gNB complexity?*

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| **Company** | **Y/N** | **Comment** |
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***[M][FL1] Question 3.1-7:*** *For UE implementation complexity, at least for OFDM-based LP-WUR, do you think Alt 2 requires different reception behavior for OOK-1 and OOK-4 while same reception behavior is supported by Alt 1?*

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| **Company** | **Y/N** | **Comment** |
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***[M][FL1] Question 3.1-8:*** *For standard impact, do you think Alt 1 has less standard impact due to unified frame work?*

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| **Company** | **Y/N** | **Comment** |
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* 1. OOK-1/OOK-4 waveform

### 3.2.1 M values for OOK-4

Companies’ views are quite diverged on whether supporting OOK-1 as a special case of OOK-4 with M=1, the discussion in this section focuses on the case of OOK-4 with M>1 first.

* [2] [3] [6] [7] [12] [19] [27] [28] supports M=2 and 4. [7][28] point out that maximum value of M can be limited according to SCS for LP-WUS [7][28], considering OOK chip duration with given M decreases with increase of SCS, which would be too sensitive to timing error, if M=4 is supported for large SCS, e.g., 60KHz SCS.
* [9][11] supports M=2 as baseline, and FFS M=4, due to performance degradation for M=4 with timing error 2us according to their evaluation. [18] supports M=2, considering up to 30kHz symbol rate would be sufficient for LP-WUS.

Based on majority view, FL suggests the following proposal:

#### *[H][FL1] Proposal 3.2-1: For OOK-4 with M >1, support M=2 & M=4.*

*- FFS maximum value of M depending on SCS*

*- FFS M=1 for OOK-4*

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| **Company** | **Y/N** | **Comments** |
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### 3.2.2 SCS

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 [3] [6] [8] [9] [12] [13] [17] [20] [23] [24]. The decision of LP-WUS SCS does not only impact on gNB implementation, it also impacts UE implementation. From UE’s perspective, apparently, it is reasonable to assume that LP-WUS SCS does not change from one OFDM symbol to another to avoid additional complexity [6][17]. Regarding how the UE derives the SCS, it can be either determined according to configuration by gNB [3] [6] [9] [12][23] or pre-defined rule [3] [6] [17], such as according to initial DL BWP SCS [17], or SSB SCS [6][17], or active BWP [6].

#### *[M][FL1] Proposal 3.2-2: 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*

* *The single SCS is same as SSB SCS*
* *The single SCS is same as initial DL BWP SCS, for RRC idle/inactive state*
* *The single SCS is same as active BWP, for RRC connected state*

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| **Company** | **Y/N** | **Comments** |
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* 1. Overlaid OFDM sequence for LP-WUS

### 3.3.1 Assumption on OFDM-based LP-WUR

Companies have different assumptions on whether the OFDM-based LP-WUR is capable to retrieve information bits in frequency domain (with FFT) or time domain (without FFT).

* OFDM-based LP-WUR has FFT processor to decode information bits in frequency domain by FFT: [3] [5] [11]

According to table 7.1.1a-8 in TR [1], the relative power consumption for ON state is in the rage of 1~30.

* OFDM-based LP-WUR does not have FFT processor, so the LP-WUR only decode information bits in time domain: [2][4][6][7][8][9][10][12][13][14][19][28]

According to table 7.1.1a-9 in [1] TR, the relative power consumption for ON state is in the rage of 0.15~30.

From device complexity and power consumption perspective, it is important to design the overlaid OFDM sequence targeting time-domain correlation for OFDM-based LP-WUR. The basic assumption of the OFDM-based LP-WUR is fundamental for all design aspects of the overlaid OFDM sequences.

Table 7.1.1a-8 [31]: Relative power consumption and noise figure for OFDM-based signal with time-domain correlation

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| Source reference | [7A-1] | [7A-3] | [7A-5] | [7A-6] | [7A-7] | [7A-8] | [7A-9] |
| Power consumption(ON state) | 0.15~0.2 | 10 | 10~20 | 10~30 | 1~5 | 10~20 | ~5 |
| Noise figure (dB) | 15 | 9.5 | 9.5 or 12 | 9 | 7~10 | 9 | 15~25 |

Table 7.1.1a-9 [31]: Relative power consumption and noise figure for OFDM-based signal with frequency-domain correlation

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| Source reference | [7A-2] | [7A-3] | [7A-5] | [7A-7] | [7A-10] | [7A-10] |
| Power consumption(ON state) | 10 | 30 | 20~30 | 1~5 | 10 | 4 |
| Noise figure (dB) | 7~12 | 7 | 9.5 or 12 | 7~10 | 9 | 12 |

Therefore, FL suggests following proposal:

#### *[H][FL1] Proposal 3.3-1: Overlaid OFDM sequence design targets sequence correlation in time domain by OFDM-based LP-WUR.*

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| **Company** | **Y/N** | **Comments** |
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According to proposal 3.3-1, FL suggests companies to report the OFDM sequences that the OFDM-based LP-WUR detects in time domain, when companies provide evaluation results for the candidate overlaid OFDM sequences, because the OFDM-based LP-WUR actually performances sequence correlation in time domain. It is noted that, this does NOT imply that the overlaid OFDM sequence is to be specified in time domain, how to specify the overlaid OFDM sequence is separately discussed in section 3.3.1.

***[H][FL1] Proposal 3.3-2****: For evaluation purpose, companies report the OFDM sequences that the OFDM-based LP-WUR detect in time domain.*

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| **Company** | **Y/N** | **Comments** |
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### 3.3.2 How to carry information by OFDM sequence(s)

For the overlaid OFDM sequences, the number of candidates overlaid sequences that can be transmitted over each ON symbol can be one or more, per gNB configuration.

**Case #1: gNB configures single candidate overlaid OFDM sequence on each OOK ON symbol** [14][4][2][6][7][9] [15] [26][16][28]

In each OOK ON symbol, gNB configures only one specific candidate overlaid OFDM sequence. OFDM-based LP-WUR can retrieve 1 bit per OOK codeword, according to the location of the detected OFDM sequence, where each OOK codeword includes single, two or four OOK symbols, if no Manchester coding is applied, or Manchester coding rate =1/2 or Manchester coding rate =1/4 is applied, respectively. OFDM-based LP-WUR has to receive all OOK symbols of the LP-WUS to retrieve information bits without early termination.

**Case #2: gNB configures Multiple candidate overlaid OFDM sequence on each OOK ON symbol** [3] [4] [6] [5] [7] [9][10] [14] [15] [16] [17] [19] [24] [26] [28]

For case#2, there are two options as listed below. Assuming total information carried by LP-WUS is a set of bits **X** = [x1, x2, … xL]. The LP-WUS occupies N OFDM symbols (M\*N OOK symbols, M is number of OOK symbols per OFDM symbol)

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



Figure 2 Option 1 from [2] (L=8, L1=3, L2=5)

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



Figure 3 Option 2 from [2] (L=8)

Views on different options from companies are listed as below:

* [2][5][7][14][24]: For option 1, it increases the complexity at the receiver side because the LP-WUR uses different approaches to get the information bits.
* [7]: For option 1, the reliability of obtained bits may not be uniform.
* [2][7]: Option 1 is applicable only if Manchester coding is applied.
* [2][4]: Option 1 achieves earlier termination than option 2.

#### *[M][FL1] Proposal 3.3-2: RAN1 to discuss how to carry information by OFDM sequence(s) for following two cases.*

* *Case 1: one specific overlaid sequence is transmitted on each OOK symbol, and OFDM-based LP-WUR obtains LP-WUS information by the location of OOK symbol carrying the overlaid sequence.*
* *Case 2: one sequence is selected from multiple candidate overlaid OFDM sequences on each ON symbol, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Down-select between following two options.*
	+ *Option 1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and location of the OFDM sequence(s)/OOK symbols.*
	+ *Option 2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s).*

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| **Company** | **Y/N** | **Comments** |
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As discussed above, OFDM based LP-WUR may obtain all information bits by reception of first N1 OFDM symbols of the LP-WUS. Early termination of reception of LP-WUS would be possible which saves power. Companies [2] [4] [6] [12] [14] [15] [24][28] also discuss whether/how to transmit overlaid OFDM sequence(s) in the remaining (N-N1) OFDM symbols of the LP-WUS to further improve OFDM detection performance, i.e., whether repetition of the information bits can be supported.

#### *[M][FL1] Proposal 3.3-3: RAN1 to discuss whether gNB can transmit information bits of LP-WUS repeatedly by overlaid OFDM sequence(s) in the OFDM symbols of the LP-WUS.*

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| **Company** | **Y/N** | **Comments** |
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### 3.3.3 Overlaid OFDM sequence design metrics

For overlaid OFDM sequence design, the following metrics are considered by companies:

* Not compromise OOK detection performance [2][6][8][10][12]. According to evaluation results in [2], different ZC sequence have different impact on OOK performance in case of large timing/frequency error, while [6] [8] shows different OFDM sequence does not affect OOK performance without timing/frequency error.
* Achieve desirable OFDM detection performance [2] [4] [6][8] [10]

i.e., good correlation property, robustness against time and frequency offset

* Robust to neighboring cell interference, e.g., support different overlaid OFDM sequence for different cell [4] [10], or support repeated ZC sequence to target a specific low frequency envelope channel [19]
* Low receiver complexity [10]

Some companies suggested one of existing NR sequences, e.g., ZC sequence, M sequence, Gold sequence, DFT/FFT sequence can be reused. Some companies suggested to use new sequences, e.g., Golay sequence [10], Kasami sequence [22].

#### *[M][FL1 ] Proposal 3.3-4: The following aspects should be considered for overlaid OFDM sequence design:*

* *The sequence should not compromise OOK detection performance.*
* *The sequence should have good cross-correlation property and/or auto-correlation property.*
* *The sequence based on existing NR OFDM sequence can be the starting point.*
* *The sequence is robust to inter-cell interference.*
* *The sequence facilitates simpler sequence correlation operation*

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| **Company** | **Y/N** | **Comments** |
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* 1. How to carry information bits by OOK symbols

Payload of LP-WUS can be carried by one of [2][19][7][10][3][26][28][25][27][17][23][5][6][8][14][16]

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

Furthermore, time/frequency domain resource may be used together with option 1/2 [10][16][24][22] [5].

Option 1 encodes each information bit carried by one or multiple OOK symbols (if Manchester coding or other coding scheme is used).

Option 2 configures a set of OOK sequences with good correlation properties, and one sequence is assigned for a specific UE/UE group/UE subgroup.

Different companies have different preference. [2][19][7][10][3][26][28][25][27][17][23] support option 1, [5] [6] support option 2. [8] [14] are open for further discussion. To help better understanding of two options, benefit for each option provided by companies is summarized as below.

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

For easy understanding of option 1 and option 2, Examples from [2] is copied as below.







Figure 4 How to carry information bits by LP-WUS

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

* Option 1: Encoded bits
* Option 2: OOK Sequence selection

Time/frequency domain occasions can be combined with option above.

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| **Company** | **Y/N** | **Comments** |
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* 1. Necessity of preamble

The necessity of preamble is discussed by companies [5] [6] [8][19] [14][4] [9] [10][26][16]. Most companies discuss the necessity of preamble for timing acquisition. Some companies [16][24][22] think the preamble is also useful for channel/interference estimation, AGC stabilization and can serve as delimiter for LP-WUS reception, i.e., UE continues to detect LP-WUS only if the preamble is detected.

For timing acquisition purpose, the necessity of preamble is determined by the tolerable timing error for LP-WUS detection and whether the maximum timing error between last LP-SS and the LP-WUS can be smaller than the tolerable error.

According to timing/frequency error model in TR 38.869, timing error is derived by equation (1)

 Te= ΔT+ Tr (1)

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

According to analysis from companies, different companies have different understanding on Value of Fr, T and Tr. Discussion on Fr is under section 4.6. Maximum value of T is maximum time distance between the last LP-SS and the LP-WUS. It depends on the decision of maximum LP-SS periodicity and LP-WUS periodicity.

Currently, the views are diverged, e.g., some companies prefer 320ms as upper bound of LP-SS periodicity while other companies prefer 320ms as lower bound of LP-SS periodicity. The range of Tr depends on LP-SS sequence design.

#### *[M][FL1] Proposal 3.5-1: Further discuss the necessity of preamble by considering at least timing acquisition function by the preamble.*

* *FFS necessity of other function of preamble, e.g., channel/interference estimation, AGC stabilization, as delimiter for LP-WUS reception*

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| **Company** | **Y/N** | **Comments** |
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#### *[M][FL1] Proposal 3.5-2: For the necessity of preamble for timing acquisition, following aspects are considered:*

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

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| **Company** | **Y/N** | **Comments** |
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* 1. Coding

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

* Line code: Manchester coding can be decoded with simple algorithm and negligible power consumption, providing substantial gain in LP-WUS detection performance to achieve comparable coverage of Msg 3 PUSCH as studied in Rel-18. Besides, Manchester encoding facilitates the threshold evaluation to determine the ON/OFF decision at each symbol. [5][6][4][7][8][3][26][2][16][21] support Manchester coding. [9] supports Manchester coding at least when there is no preamble in LP-WUS. Further study other coding scheme with presence of preamble
* FEC: simple channel coding is proposed by some companies [4][9]. [4] proposes hamming or RM code. FEC can further improve performance, however, this may increase the complexity of LR.

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

#### *[H][FL1] Proposal 3.6-1: Support Manchester coding for the following options:*

* *Option 1: Manchester coding for LP-WUS using encoded bits*
* *Option 2: Manchester coding for LP-WUS using OOK sequence selection*

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| **Company** | **Y/N** | **Comments** |
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1. LP-SS design
	1. General design aspects

The following general aspects are proposed by companies to be considered for LP-SS design:

* CP impact [4]
* Larger gurad band for better robustness to larger frequency error than LP-WUS [4]
* Good auto-correlation [2][3][4] and cross-correlation [2][3]
* Limited length of consecutive '0's to avoid losing AGC [4]
* Balanced '0's and '1's [2][4][18]

***[M][FL1] Proposal 4.1-1:*** *Consider the following aspects for LP-SS design:*

* *CP impact*
* *Larger gurad band for better robustness to larger frequency error than LP-WUS*
* *Good auto-correlation and cross-correlation*
* *Limited length of consecutive '0's to avoid losing AGC*
* *Balanced '0's and '1's*

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| **Company** | **Y/N** | **Comments** |
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* 1. Waveform-selection of OOK-1 and/or OOK-4

OOK-1 and/or OOK-4 with supported values of M

For the supported valve of M, [6] proposes to use the same OOK-4 M value between LP-SS and LP-WUS to keep the transmitter and LP-WUR operation simple in comparison to the case that different M values are used.

[4][19] provide evaluation results showing that better time accuracy, i.e., less residual time error could be achieved by larger M attributing to narrower auto-correlation mainlobe by shorter OOK symbol duration, i.e., M=8 can achieve finer time accuracy than M=4. However, [9] proposes that acccuracy of timing synchronization has no relation with the modulation order, i.e., M but depending on the oversampling factor used at the LR.

Further, evaluation results in [3] show that the time accuracy provided by OOK-1 or OOK-4 with M=1 is far from the DL synchronization requirement for SNR=10dB and thus, the binary sequence cannot be carried by OOK-1 or OOK-4 with M=1, while the evaluation results in [8] show that timing error correction from preamble based on OOK-1 is 1us at 90% CDF curve for a preamble length of 8 symbols for SNR=0dB.

Therefore, companies are encouraged to further study and evaluation the performance provided by different values of M for LP-SS.

* OOK-1 is supported by [2][6][8][13][14][17][20][21][28]
* OOK-4 with the following M:
	+ M=1: [2][4][5][9][24][28]
	+ M=2: [2][4][5][6][8][9][11][16][19][24]
	+ M=4: [2][4][5][6][8][9][16][19][24]
	+ M=8: [4][19]
	+ M=16: [3]
	+ M is not mentioned: [17][20][22][23]

***[H][FL1] Proposal 4.2-1:*** *Support the following options for LP-SS*

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

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| **Company** | **Y/N** | **Comments** |
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* 1. Waveform-down selection between with and without overlaid OFDM sequences for LP-SS

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

* Option 1: Do not specify the overlaid OFDM sequences(s)
* Option 2: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation without targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Option 3: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Companies support option 1 with the following reasons:
	+ Per WID, OFDM detector can perform RRM measurement and sync based on existing SSB in time domain without FFT.[2][7][8][22]
	+ OFDM detector can achieve required RRM accuracy and sync accuracy with shorter reception time based on SSB than LP-SS for better power consumption and shorter latency. [2][13]
	+ If LP-SS is transmitted far from the LP-WUS monitoring occasion, OFDM-based LP-WUR would require more power consumption since it needs to stay awake for a longer period to receive LP-SS. [7]
	+ Support of SSB and overlaid OFDM sequence for LP-SS increases work load for RAN4 on LP-WUR RRM measurement evaluation. [2] [7] [13]
	+ 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. [7]
	+ 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. [7]
	+ The potential drawback in overlaid LP-SS is that the overlaid signal may degrade synchronization performance of OOK receivers due to the overlaid structure which should consider both OFDM based receivers and OOK based receivers.[22]
* Companies support option 2 with the following reasons:
	+ Provide good OOK detection performance [3][6][20].
	+ If the overlaid OFDM sequence for the LP-SS does not carry information, network can configure fixed known sequence(s) [3][6].
* Companies support option 3 with the following reasons:
	+ gives a possibility for LP-WUR with I/Q branches to be able to utilize LP-SS for time/frequency [4][16][21][25]
	+ synchronization and/or RRM measurement without RF retuning, if complete overlapping of LP-WUS/LP-SS and SSBs in the same BW within the gNB carrier BW is not guaranteed [4][9][17]
	+ Different SCS between SSB and LP-WUS may impose additional burden on LRs to adjust the reception strategy [9]
	+ The SSS sequence within SSB are based on m-sequence, which has very low processing gain (correlation gain) when the receiver is having a frequency offset comparable to 0.5× SCS. This may increase the initial synchronization of LRs unless there is an assistance from MR to synchronize the XO.[9]
	+ The performance of the sequence-based receiver using SSB for synchronization and measurement still needs to be verified. [10]
	+ There is essentially no additional specification work or complexity to specify the overlaid sequence for LP-SS, given that it is being specified for LP-WUS anyway.[10][14]
	+ specifying the sequence(s) does not make gNB implementation more complicated [4]
	+ does not require any addition resource overhead [4]
	+ OFDM sequence overlaid on an OOK bit can at least improve performance of coverage. [16]
	+ The overlaid OFDM sequence can carry the same partial cell ID information as OOK symbols for the LP-SS [3][6]
	+ 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. [14]

Based on companies’ comments, it seems that option 2 is a good compromise.

***[M][FL1] Proposal 4.3-1:*** *For the overlaid OFDM sequence(s) for LP-SS, support*

*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.*

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| **Company** | **Y/N** | **Comments** |
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* 1. LP-SS channel structure

In previous meeting, it has been agreed that the ‘ON-OFF’ pattern for OOK symbols of LP-SS is based on binary sequence(s), regarding the number of binary sequence(s), there could be two alternatives for differentiating neigboring cells: 1) single sequence shared by multiple cells in TDM manner; 2) multiple sequences used for differfent cells. Based on companies’ input, there is a good support on multiple sequences [2][6][8][11] by considering that neigboring cells may not always synchronized well with each other and even with all neighboring cells synchronized well, due to potentially wide range timing offset caused by frequency offset, the LP-WUR may mistakenly synchronize with the LP-SS transmitted by the neighbour cell if same LP-SS is transmitted by the serving and neighbour cell.

***[H][FL1] Proposal 4.4-1:*** *Support to specify multiple LP-SS sequences:*

* *The LP-SS sequence used in a cell is*
	+ *Option 1: configured*
	+ *Option 2: determined by (Physical Cell ID of the serving cell) modulo (the number of LP-SS sequences)*
* *FFS the number of LP-SS sequences*

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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, summarized below:

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| --- | --- | --- | --- | --- |
|  | Measurement accuracy requirement for RSRP or RSRQ | # of required samples | SNR (dB) | Length of LP-SS (symbols) |
| [4] | RSRP: +3dB | 4 | -3 | 8  |
| [9] | RSRP: +3dB | 4 | -9, -3, 0, 6 | 8  |
| [2] | RSRP: +4dB | 2 | -3 | 2  |
| [2] | RSRQ: +2dB | 3 | -3 | 2  |
| [19] | RSRP: +2.5dB | Not reported | Not reported | 4  |
| [8] | RSRP: +3dB | Not reported | -6, -9 | 2~6  |
| [11] | RSRP: +2dB | 1 | -4 | 8 |

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 not enough but 320ms can be a good choice.

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

* At least 320ms periodicity is supported. [2][12]
* The periodicities of LP-SS are not larger than 320ms [4]
* The periodicity of LP-SS is suggested to be 320ms [14] [33]
* Start with the following with higher values preferable: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms.[8]
* At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity [3]
* 640ms, 960ms [29]

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

* *FFS: other values*

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| **Company** | **Y/N** | **Comments** |
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* 1. The feasibility of frequency error correction by LP-WUR

For time synchronization, both LP-SS and preamble preceding LP-WUS (if supported) can provide sync timing and the sync requirement depends on the time error tolerance by LP-WUR detection. Time error is represented by Te = ΔT+ Tr = Fr × T + Tr, as given in TR38.869, where Tr is residual time error Tr after calibration based on LP-SS and ΔT is the time drift after LP-SS, ΔT = Fr\*T ±0.5 \* F’ \*T2, if it is in transition region, or ΔT = Fe\*T, if it is linear region.

The residual time error (Tr) depends on LP-SS design, sampling rate, and LP-SS detection algorithm, which can be marginal. The time drift ΔT depends on the residual frequency error or the maximum frequency error and the time gap between LP-SS or LP-WUS and the latest detected LP-SS. Depending on whether frequency error correction is supported or not by LP-WUR, there are two options:

* Option 1: LP-WUR don’t support frequency error correction
* The maximum frequency error (Fe) of RTC/Oscillator is assumed
* Option 2: LP-WUR supports frequency error correction or it leverages MR’s assistance for frequency error correction
* The residual frequency error (Fr) after frequency error correction is assumed

Therefore, the assumption on frequency error correction by LP-WUR is critical to evaluate the accumulated time error for certain LP-SS periodicity and determine whether a preceding preamble is needed according to time error tolerance by LP-WUR detection.

Further, the assumption on frequency error correction by LP-WUR is also critical to evaluate the accumulated frequency error for LP-SS and LP-WUS detection, especially for the OFDM-based LP-WUR which is more sensitive to frequency error.

***[H][FL1] Proposal 4.6-1:*** *For LP-WUS and LP-SS evaluation purpose, the following two options for frequency error correction by LP-WUR are considered:*

* *Option 1: LP-WUR don’t support frequency error correction*
* *The maximum frequency error (Fe) of RTC/Oscillator is assumed, companies report Fe value with applied LP-WUR type.*
* *Option 2: LP-WUR supports frequency error correction or it leverages MR’s assistance for frequency error correction*
* *The residual frequency error (Fr) after frequency error correction is assumed, companies report Fr value with applied LP-WUR type and how to achieve.*

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

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

[2][6] [7] [14] [3] [26] prefer to support single bandwidth approximately 5MHz for LP-WUS at least for 30KHz SCS, because 5MHz provides bandwidth for sufficient LP-WUS energy and frequency diversity to meet coverage requirement with reasonable overhead as evaluated in SI phase, and single bandwidth can minimize LP-WUR complexity compared to support of multiple bandwidths.

[17][8] prefer to support single fixed number of PRBs regardless of SCS, so the bandwidth scales proportionally for different SCS. Fixed number of PRBs isto simply waveform generation with fixed length of overlaid OFDM sequences. [2] [6][28] prefer fixed bandwidth, the number of subcarriers is proportionally scaled for SCS.

[9][23] [28] prefer configurable bandwidth to achieve different coverage.

[2][6] [10] [26][3][14][2] prefer to support same bandwidth for LP-SS and LP-WUS to reduce LP-WUR complexity. [4] prefers to support different bandwidth for LP-SS and LP-WUS considering larger guard band for LP-SS due to smaller frequency error for LP-WUS after synchronization by LP-SS.

[2][14][8][9][26][24] prefer flexible location of LP-WUS, e.g., in different BWP or different carrier than MR.

Regarding the bandwidth with or without guard PRBs, [7][26] propose the bandwidth of LP-WUS/LP-SS including guard PRBs is to be determined by RAN1 and number of RBs with and without guard band can be provided by RAN4, while [2] proposes the bandwidth of LP-WUS/LP-SS excluding guard PRBs is to be determined by RAN1 and number of guard band can be provided by RAN4. [HW] suggests to wait for RAN4’s further converge of ACS/ASCS requirement and then RAN1 discusses the proper value of bandwidth considering required guard PRBs.

Considering bandwidth is fundamental for LP-WUS/LP-SS design and evaluations, and these aspects are more relevant to the occupied bandwidth rather than the guard band, FL suggests to firstly determine the bandwidth for LP-WUS/LP-SS without guard band by RAN1 rather than waiting for RAN4’s progress of further narrowing down guard band and then determines occupied PRBs for LP-WUS/LP-SS.

**[H][FL1] *Proposal 5-1:*** *At least support 12 PRBs for LP-SS and LP-WUS with SCS 30kHz, excluding blanked guard RBs, for a channel bandwidth larger than 5MHz*

* *FFS the number of PRBs for 15kHz, i.e., 12 PRBs or 24 PRBs*
* *FFS other number of PRBs for LP-SS and LP-WUS**with a channel bandwidth no larger than 5MHz*

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| **Company** | **Y/N** | **Comments** |
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1. SNR determination
	1. Collection of companies’ reported SNR

For evaluation purpose of LP-WUS and LP-SS to fulfill the coverage target, SNR is determined by setting MIL value for LP-WUS/LP-SS equal to MIL value for PUSCH for message 3. When determining the SNR value from the link budget table, it is mainly impacted by the following factors:

* MIL value of MSG3
* Noise figure (NF) value of LP-WUR
* Antenna gain component 2
* Antenna gain component 3&4

For antenna gain component 2, there are two aspects, which companies may have different assumptions: antenna gain correction factor and number of transmit chains modelled in LLS. Antenna gain correction factor reflects the digital beamforming gain for MSG 3 reception and LP-WUS transmission at gNB side. Considering there may exist different assumptions on digital beamforming for transmission and reception, the different values of antenna gain correction factor reported by companies can be kept. For the number of Tx chains of LP-WUS/LP-SS transmission, it impacts on both beamforming gain (reflected in link budget calculation) and diversity gain (reflected in LLS). For example, when the number of Tx chains increase, the corresponding beaming gain decreases, which results in a smaller SNR value to achieve the same coverage, i.e., MIL value of PUSCH for message 3; on the other hand, the increased number of Tx chain can improve the diversity gain which compensates the decreased beamforming gain, if good transmit diversity gain is applied in LLS.

Therefore, when the number of Tx chains is larger than 1, good transmit diversity scheme shall be considered in the LLS to provide the diversity gain, otherwise, more time and frequency resources are required to achieve the smaller SNR calculated from link budget due to decreased beamforming gain. As there will be 3dB gap of SNR when the number of Tx chains double, companies’ reported values are listed according to different number of Tx chains.

* The number of Tx chains for LP-WUS/LP-SS transmission: 1

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| --- | --- | --- | --- | --- | --- | --- |
|  | 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., 2Note: 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 |
| MediaTek-01  | 4.32 MHz | 12 | -3 | 1 TX chain (64 TxRUs over 192 antenna elements) | 147.79 | 0.3 |
| MediaTek-02 | 4.32 MHz | 12 | 0 | 1 TX chain (64 TxRUs over 192 antenna elements) | 150.79 | 0.3 |
| vivo-01  | 4.32 | 12 | 0 | # of Tx chains for WUS: 1# of Rx chains for MSG3: 2 | non-redcap UE141.85 | 6.59 |
| vivo-03 | 4.32 | 9.5 | 0 | # of Tx chains for WUS: 1# of Rx chains for MSG3: 2 | non-redcap UE141.85 | 8.59 |
| vivo-05 | 4.32 | 12 | -3 | # of Tx chains for WUS: 1# of Rx chains for MSG3: 2 | redcap UE138.85 | 6.59 |
| vivo-07 | 4.32 | 9.5 | -3 | # of Tx chains for WUS: 1# of Rx chains for MSG3: 2 | redcap UE138.85 | 8.59 |
| Huawei, HiSilicon | 4.32 | 15 | 0 | 1 | 149.61 | -3.23 |
| Huawei, HiSilicon | 4.32 | 15 | -3 | 1 | 146.61 | -3.23 |
| Huawei, HiSilicon | 2.16 | 15 | 0 | 1 | 149.61 | -3.23 |
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* The number of Tx chains for LP-WUS/LP-SS transmission: 2

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|  | 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., 2Note: 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 |
| Futurewei-01  | 4.32 MHz | 9 (OFDM-LPWUR) | 0 | 2 | 153.51 | 4.94 |
| Futurewei-02  | 4.32 MHz | 12 (ED-LPWUR) | 0 | 2 | 153.51 | 2.57 |
| Futurewei-03  | 4.32 MHz | 9 (OFDM-LPWUR) | -3 | 2 | 147.31 | 8.14 |
| Futurewei-04  | 4.32 MHz | 12 (ED-LPWUR) | -3 | 2 | 147.31 | 5.77 |
| Qualcomm  | 4.32MHz (i.e.,12 RBs) for LP-WUS transmission for 30kHz SCS | 15dB for OOK | -3dBi for RedCap UE | 2 Tx chains for LP-WUS;4 Rx chains for MSG3 | 147.27 dB for RedCap UE | -4.83 dB |
| Nokia | 4.32 | 12 | -3 | 2 | 144.2 | 3.1  |
| InterDigital | 5 | 12 | 0 | 2 | 135.46 | -13 |
| vivo-02 | 4.32 | 12 | 0 | # of Tx chains for WUS: 2# of Rx chains for MSG3: 2 | non-redcap UE141.85 | 3.58 |
| vivo-04 | 4.32 | 9.5 | 0 | # of Tx chains for WUS: 2# of Rx chains for MSG3: 2 | non-redcap UE141.85 | 5.58 |
| vivo-06 | 4.32 | 12 | -3 | # of Tx chains for WUS: 2# of Rx chains for MSG3: 2 | redcap UE138.85 | 3.58 |
| vivo-08 | 4.32 | 9.5 | -3 | # of Tx chains for WUS: 2# of Rx chains for MSG3: 2 | redcap UE138.85 | 5.58 |
| Everactive-01 (OOK-based LP-WUR) | 4.32 | 12  | 0 | 2 | 142.23 | 4.1 |
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* The number of Tx chains for LP-WUS/LP-SS transmission: 4

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|  | 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., 2Note: 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 |
| Ericsson (OOK)  | 4.32 MHz | 13 | 0 | 4 | 153.2 dB (two retransmissions) | -7 |
| Ericsson (OOK)  | 4.32 MHz | 13 | 0 | 4 | 149.2 dB (no retransmissions) | -3 |
| Ericsson (OFDM)  | 4.32 MHz | 10 | 0 | 4 | 153.2 dB (two retransmissions) | -4.5 |
| Ericsson (OFDM) | 4.32 MHz | 10 | 0 | 4 | 149.2 dB (no retransmissions) | -0.5 |
| Ericsson (OFDM)  | 4.32 MHz | 7 | 0 | 4 | 153.2 dB (two retransmissions) | -2.5 |
| Ericsson (OFDM) | 4.32 MHz | 7 | 0 | 4 | 149.2 dB (no retransmissions) | 1.5 |
| CMCC-01  | 5 | 12 for OOK-based LP-WUR | 0 | 4 | 152.87 | 2.2 |
| CMCC-02  | 5 | 9.5 for OFDM-based LP-WUR | 0 | 4 | 155.87 | 4.2 |
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***[H][FL1]*** *Companies are encouraged to provide more inputs into the tables above****.***

Considering different number of Tx chains directly lead to different values of SNR, e.g., 2 and 4 Tx chains will lead to a 3 dB and 6dB lower SNR value than that obtained by assuming 1 Tx chain. To facilitate aligning the SNR, one way is to scale the reported SNR values by companies a reference number of Tx chain, e.g., 1. After aligning SNR for the reference number of Tx chain, the SNR for other number of Tx chains can be determined by scaling 3dB or 6dB directly.

***[H][FL1] Question 6.1-1:*** *Do you agree to assume a reference number of Tx chain, e.g., 1 to align SNR first and then scale the SNR for other number of Tx chains accordingly? If not, do you have any suggestions on how to align the SNR with different number of Tx chains assumed by companies.*

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| **Company** | **Y/N** | **Comments** |
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Similarly, the SNR values obtained from different NF values assumed by companies could be also scaled by assuming a reference NF value. After aligning SNR for the reference NF, the SNR for other NF can be determined by scaling with the gap to the reference NF.

 ***[H][FL1] Question6.1-2:*** *Do you agree to assume a reference NF, e.g., 12dB to align SNR first and then scale the SNR for other NF values accordingly?* *If not, do you have any suggestions on how to align the SNR with different NF values assumed by companies.*

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| **Company** | **Y/N** | **Comments** |
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For the number of Tx chains of LP-WUS/LP-SS transmission and the number of Rx chains of PUSCH for message3, there is a note assuming the same number applied for both in last meeting. [6] propose to discuss whether it is necessary to include the note in the LP-WUR coverage table, since most companies have assumed the number of Tx chains of LP-WUS/LP-SS transmission is different with the number of Rx chains of PUSCH for message3 and the number of the RX chains for MSG3 should not be changed as it has been used by NR coverage study. Further, matching the number of Tx chains for LP-WUS/LP-SS may require additional study of Tx diversity techniques for the OOK modulation. [2] also thinks it is better to keep the flexibility for selecting number of Tx chains of LP-WUS/LP-SS transmission without constrained to the number of Rx chains of PUSCH for message 3 only, given that for a total number antenna elements, gNB can have different schemes to provide beamforming and diversity gain for WUS transmission and PUSCH for message 3 reception.

 ***[H][FL1] Question 6.1-3:*** *Is it ok to remove the ‘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’?*

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| **Company** | **Y/N** | **Comments** |
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Further, in [4], it is considered that the coverage of Msg3 is a reference target for coverage design and in real deployment, the cell range varies. Thus, the SNR value(s) for LP-WUS design should be a range including the value corresponding to Msg3 PUSCH, so that gNB can have the flexibility for configuration.

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***[H][FL1] Question6.1-4:*** *Do you agree to consider a SNR value range for LP-WUS/LP-SS design to provide gNB configuration flexibility, which includes the value corresponding to Msg3 PUSCH?*

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| **Company** | **Y/N** | **Comments** |
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* 1. Coverage improvement schemes

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

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

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

* *Time domain diversity*
* *Frequency domain diversity*
* *Transparent spatial diversity*
* *Power boosting*
* *Multiple beam transmissions/beam sweeping*
* *Other schemes are not precluded*

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| **Company** | **Y/N** | **Comments** |
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1. Agreements
	1. RAN1 #116

**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

**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.

**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., 2Note: 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  |  |  |  |  |  |  |

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30. R1-2403105, Discussion on LP-WUS and LP-SS design, Lenovo
31. R1-2402617, Discussion on LP-WUS and LP-SS design, Everactive
32. 3GPP TR 38.869, Study on low-power wake up signal and receiver for NR.
33. Appendix : Proposals from contributions

**R1-2402251 vivo**

**Proposal 1: Support unified specification for OOK-4 and OOK-1 based on DFT, with M=1, 2 and 4 for LP-WUS and LP-SS. FFS M=8 for LP-SS.**

**Proposal 2: Support following 3 cases for overlaid OFDM sequence:**

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

**Proposal 3: RAN1 further discusses following two cases for carrying information by OFDM sequence(s) with consideration of detection performance, LP-WUR complexity and power consumption,**

* **Case 3-1: Single OFDM sequence is configured in each OOK ON chip. The overlaid OFDM sequence carry single bit in each OOK chip or each two or four OOK chips, depending on Manchester coding. OFDM-based LP-WUR can obtain the whole information bits by the OFDM sequence across all OOK chips of the LP-WUS.**
* **Case 3-2: Multiple OFDM sequences is configured in each OOK ON chip. OFDM-based LP-WUR can obtain the whole information bits by the OFDM sequences in first several OOK chips of the LP-WUS.**
	+ **Option 1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and location of the OFDM sequence(s)/OOK symbols.**
	+ **Option 2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s).**

**Proposal 4: Information bits repetition by overlaid OFDM sequence(s) in OFDM symbols of the LP-WUS without additional overhead can be considered.**

**Proposal 5: The overlaid OFDM sequence should consider following metrics:**

* **Not compromise OOK detection performance.**
* **Have at least good cross-correlation property.**
* **Have limit impact on existing gNB implementation.**

**Proposal 6: Specify overlaid OFDM sequence in time domain for both OOK-1 and OOK-4.**

* **Existing sequence such as ZC sequence, m sequence and gold sequence can be the starting point.**
* **Mapping frequency domain samples after DFT of time domain overlaid OFDM sequence can be considered.**

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

**Proposal 8: No less than 8 subgroups per PO indicated by LP-WUS should be supported for RRC idle/ inactive state. At least 8 bits is supported.**

**Proposal 9: Up to 16 information bits carried by LP-WUS should be supported for RRC connected state.**

**Proposal 10: The upper bound of number of information bits carried by LP-WUS (not including CRC) should be 16 bits. The number of information bits per LP-WUS within the upper bound can be flexibly configured by gNB.**

**Proposal 11: For common design for RRC idle/inactive and RRC connected mode, RAN1 further discusses pros and cons for OOK sequence selection and encoded bits for LP-WUS payload, with consideration of variable payload sizes up to 16 bits, variable use case (wake-up one and/or multiple UEs simultaneously), target performance, reasonable overhead, robustness to timing and frequency error, latency and standard effort.**

**Proposal 12: To decide the necessity of preamble, RAN1 first discusses the assumption on the frequency error correction by OOK-based LP-WUR using LP-SS and/or by the aid of MR, and LP-SS periodicity.**

**Proposal 13: RAN1 discusses single OOK sequence or multiple OOK sequences is needed for LP-SS, with consideration of RRM and sync accuracy, robustness to inter-cell interference and standard effort.**

* **For single sequence, RAN1 specifies the single sequence, which is applicable to all cells.**
* **For multiple sequences, RAN1 specifies multiple sequences, e.g., 3 or 6 sequences, and gNB configures one sequence for a cell.**
* **The sequence(s) can be chosen from existing NR binary sequence, such as m or gold sequence, or new computer searched sequence which provides good auto-correlation and cross-correlation and balanced 0 and 1, with sequence length =8 or 16.**

**Proposal 14: Support at least 320ms periodicity for LP-SS, FFS other values, if needed.**

**Proposal 15: From RAN1’s perspective, support LP-WUS and LP-SS bandwidth of 12 PRBs for 30KHz and 24 PRBs for 15KHz** **excluding guard RB, for both RRC idle/inactive and RRC connected state, for channel bandwidth larger than 5MHz.**

* **FFS channel bandwidth no larger than 5MHz**

**Proposal 16: Support flexible frequency location of LP-WUS/LP-SS, which can be independent from DL initial BWP as well as the carrier serving MR.**

**Proposal 17: Support Manchester coding for LP-WUS. Not support Manchester coding for LP-SS.**

**Proposal 18: Use the SNR for OOK-based LP-WUR and OFDM-based LP-WUR listed in Table 5 for RAN1 evaluation.**

**Proposal 19: Use table 6 and table 7 in appendix 9.1 as evaluation assumptions for LP-WUS and LP-SS.**

**R1-2402193 ZTE, Sanechips**

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

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

* ***Unified OOK waveform generation scheme at gNB side is suggested***

***Proposal 3: For OOK based LP-WUS, OOK-4 with M=2 and M=4 are prioritized.***

***Proposal 4: For OOK based LP-WUS, BW of 12PRBs@SCS=30KHz is prioritized.***

***Proposal 5: LP-SS, LP-Preamble and LP-WUS with the same BW should be supported***

* ***FFS different bandwidth or different central frequency***

***Proposal 6: 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 7: For OOK-4, if OFDM sequences are used for carrying information, ZC sequence and M sequence are preferred.***

***Proposal 8: For OFDM sequence based LP-WUS, adopting the OFDM sequence receiver with FFT as the baseline for detection performance evaluation.***

***Proposal 9: Adding CRC for LP-WUS payload is necessary for both OOK based and OFDM sequence based LP-WUS transmission.***

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

***Proposal 10: For OOK based LP-WUS, Manchester code with code rate of at least 1/2 and 1/4 should be supported.***

***Proposal 11: For the design of LP-SS, the binary sequence used for LP-SS should have good auto-correlation and very low cross-correlation performance with its cyclic shifted binary sequences.***

***Proposal 12: LP-SS detection with sliding window should be used as baseline for evaluate the detection performance.***

***Proposal 13: For LP-SS, the binary sequence cannot be carried by OOK-1 or OOK-4 with M=1.***

***Observation 7: For OOK-4 with M =2,4,8,16 based LP-SS,***

* ***LP-SS with scrambling code has better time estimation performance than that without scrambling code***
* ***OOK-4 with M =8,16 has better time estimation performance than that with M=2,4***
* ***OOK-4 with M =8,16 has almost the same time estimation performance***

***Proposal 14: For the design of LP-SS, the following structures are prioritized***

* ***OOK-4 with M=8, 128-length M sequence***
* ***OOK-4 with M=16, 256-length M sequence***
* ***Phase random sequence is used as scrambling code to improve detection performance***

***Proposal 15: For the overlaid OFDM sequence(s) for LP-SS, if LP-SS does not need to carry information, Option 2 is supported, otherwise, Option 2 or Option 3 is supported.***

***Proposal 16: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity.***

***Proposal 17: Cell specific information can be carried via LP-SS.***

***Proposal 18: LP-Preamble can be positioned ahead of LP-WUS for further time offset correction.***

***Proposal 19: For LP-WUS in RRC\_ IDLE/INACTIVE mode, up to 10 UEs are supported in a UE group.***

***Proposal 20: For LP-WUS, at least 14 bits are necessary to indicate UE group ID.***

***Proposal 21: For OOK based LP-WUS, encoded bit is used for carrying information.***

***Proposal 22: For OFDM sequence based LP-WUS, X bits information is carried by 2^X OFDM sequences.***

* ***X = 2 for a starting point***
* ***CRC is supported***

***Proposal 23: In order to reduce the UE power consumption for blinding decision the OOK-ON symbols carrying OFDM sequence based LP-WUS, the position of the OOK-ON symbols can be predefined or indicated.***

***Proposal 24: For LP-WUS, the SNR to achieve the coverage of PUSCH for message3 and the associated assumptions are listed in Table 4.***

***Proposal 25: For OOK based LP-WUS, at least the following coverage improvement schemes should be further studied:***

* ***Detection with sliding window***
* ***Repetition***
	+ ***Whole payload repetition and bit repetition***
* ***Frequency hopping***

***Proposal 26: LP-SS could be used as a part of LP-WUS to save NW resources.***

***Proposal 27: For LP-WUS, at least the design of structure, payload size and carried information should be considered separately for IDLE/INACTIVE and CONNECTED modes.***

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

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

* ***Unified OOK waveform generation scheme at gNB side is suggested***

***Proposal 3: For OOK based LP-WUS, OOK-4 with M=2 and M=4 are prioritized.***

***Proposal 4: For OOK based LP-WUS, BW of 12PRBs@SCS=30KHz is prioritized.***

***Proposal 5: LP-SS, LP-Preamble and LP-WUS with the same BW should be supported***

* ***FFS different bandwidth or different central frequency***

***Proposal 6: 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 7: For OOK-4, if OFDM sequences are used for carrying information, ZC sequence and M sequence are preferred.***

***Proposal 8: For OFDM sequence based LP-WUS, adopting the OFDM sequence receiver with FFT as the baseline for detection performance evaluation.***

***Proposal 9: Adding CRC for LP-WUS payload is necessary for both OOK based and OFDM sequence based LP-WUS transmission.***

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

***Proposal 10: For OOK based LP-WUS, Manchester code with code rate of at least 1/2 and 1/4 should be supported.***

***Proposal 11: For the design of LP-SS, the binary sequence used for LP-SS should have good auto-correlation and very low cross-correlation performance with its cyclic shifted binary sequences.***

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***Observation 7: For OOK-4 with M =2,4,8,16 based LP-SS,***

* ***LP-SS with scrambling code has better time estimation performance than that without scrambling code***
* ***OOK-4 with M =8,16 has better time estimation performance than that with M=2,4***
* ***OOK-4 with M =8,16 has almost the same time estimation performance***

***Proposal 14: For the design of LP-SS, the following structures are prioritized***

* ***OOK-4 with M=8, 128-length M sequence***
* ***OOK-4 with M=16, 256-length M sequence***
* ***Phase random sequence is used as scrambling code to improve detection performance***

***Proposal 15: For the overlaid OFDM sequence(s) for LP-SS, if LP-SS does not need to carry information, Option 2 is supported, otherwise, Option 2 or Option 3 is supported.***

***Proposal 16: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity.***

***Proposal 17: Cell specific information can be carried via LP-SS.***

***Proposal 18: LP-Preamble can be positioned ahead of LP-WUS for further time offset correction.***

***Proposal 19: For LP-WUS in RRC\_ IDLE/INACTIVE mode, up to 10 UEs are supported in a UE group.***

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***Proposal 21: For OOK based LP-WUS, encoded bit is used for carrying information.***

***Proposal 22: For OFDM sequence based LP-WUS, X bits information is carried by 2^X OFDM sequences.***

* ***X = 2 for a starting point***
* ***CRC is supported***

***Proposal 23: In order to reduce the UE power consumption for blinding decision the OOK-ON symbols carrying OFDM sequence based LP-WUS, the position of the OOK-ON symbols can be predefined or indicated.***

***Proposal 24: For LP-WUS, the SNR to achieve the coverage of PUSCH for message3 and the associated assumptions are listed in Table 4.***

***Proposal 25: For OOK based LP-WUS, at least the following coverage improvement schemes should be further studied:***

* ***Detection with sliding window***
* ***Repetition***
	+ ***Whole payload repetition and bit repetition***
* ***Frequency hopping***

***Proposal 26: LP-SS could be used as a part of LP-WUS to save NW resources.***

***Proposal 27: For LP-WUS, at least the design of structure, payload size and carried information should be considered separately for IDLE/INACTIVE and CONNECTED modes.***

**R1-2401999 Huawei, HiSilicon**

1. ***OOK-1 is specified as a special case of OOK-4 with M=1.***
2. ***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 the Case #2 where there are multiple candidate overlaid OFDM sequences on each OOK symbol, bit block 1 and bit block 2* *are generated from all the N bits information carried by one LP-WUS,***
	* ***The LP-WUS consists of M OFDM symbols, where M can be smaller than the number of OFDM symbols required by all the N bits information being only carried by/modulating ON/OFF patterns***
	* ***Bit block 1 is carried by/modulates the ON/OFF pattern of the M OFDM symbols.***
	* ***Bit block 2 is carried by/modulates the overlaid sequences in the M OFDM symbols.***

***According to bit block 2, one overlaid OFDM sequence selected from a set of candidate OFDM sequences is on each OOK ON symbol.***

***Bit block2 is not carried by/modulates the ON/OFF pattern.***

1. ***For LP-WUS information transmission, the following two cases can be configured by gNB:***
* ***one specific overlaid sequence is transmitted on each OOK symbol, and the LP-WUS information is carried by OOK modulation;***
* ***one sequence is selected from multiple candidate overlaid OFDM sequences on each ON symbol, and bit block 1 and bit block 2 are generated from all the N bits information carried by one LP-WUS.***
1. ***Further discuss and adopt sequence(s) considering the following aspects:***
	1. ***Sequence with good auto-correlation property and cross-correlation property***
	2. ***How to control the interference from LP-WUS transmitted from neighboring cells***
2. ***ZC sequences are considered as a starting point for the design of overlaid sequence(s).***
3. ***Pulse shape and/or spectrum shape are also considered in the design/selection of overlaid sequence(s).***
4. ***Support overlaid sequence(s) with a number of zero value samples at the beginning and the end of the sequence to have a concentrated waveform for time domain pulse shaping of LP-WUS.***
5. ***The value of ACS/ASCS should be further converged in WI phase in RAN4, which may have impact on LP-WUS/LP-SS design in RAN1.***
6. ***The SNR value(s) for LP-WUS design should be a range including the value corresponding to Msg3 PUSCH, so that gNB can have the flexibility for configuration.***
7. ***Time domain repetition and*** ***transmit diversity by precoder cycling are considered to improve the performance of LP-WUS.***
8. ***Coverage recovery schemes that exploits time / frequency diversities are considered.***
9. ***Binary spreading sequences are considered to multiplex WUSs on the same time-frequency resource and to improve the BLER.***
10. ***As the starting point, the waveform of LP-SS can have similar design as LP-WUS, including at least the following aspects：***
	1. ***pulse shaping methods, including the concentrated waveform and the spectrum adjustment***
	2. ***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***
11. ***Consider LP-SS specific design requirement, including at least larger guard band, and number of OOK symbols per OFDM symbol up to M=8.***
12. ***The design of LP-SS should consider the CP impact and the length of binary-valued sequence to generate LP-SS.***
13. ***For the OOK sequence of LP-SS, consider at least the following design principles***
	1. ***Binary sequence with good auto-correlation property***
	2. ***Limited length of consecutive '0's***
	3. ***'0's and '1's inside the binary sequence are balanced***
14. ***A set of candidate values for LP-SS periodicity can be defined, which are not larger than 320ms.***
15. ***Preamble of LP-WUS is not supported.***
16. ***For serving cell RRM measurement offloaded from MR to LP-WUR, LP-RSRP and LP-RSRQ are introduced and specified as LP-SS based metrics.***
17. ***Further discuss whether existing SS-RSRP definition is reused for RRM serving cell measurement by OFDM based LP-WUR or define new LP-RSRP2 and LP-RSRQ2 by using existing SSS for LP-WUR that can receive PSS and SSS.***

**R1- 2402392 CATT**

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

**Proposal 2: Specify a configurable M value for supporting both OOK-1 and OOK-4 waveform.**

**Proposal 3: The OFDM sequence to be modulated on the OOK waveform for LP-WUS should consider existing NR sequence, such as DFT/FFT, M-sequence, and Zadoff-Chu, to minimize the implementation cost and complexity of OFDM receiver by reusing the NR receiver components.**

**Proposal 4: The sequence with interference mitigation property such as low cross-correlation is not the critical criterial for the selection of the OFDM sequence overlaid on the OOK waveform since the inter-cell interference mitigation is not expected to be critical for LP-WUS signals with smaller coverage area.**

**Proposal 5: The LP-WUS is multiplexed with NR DL channel/signals after the IFFT to minimize the LP-WUS detection performance degradation with timing and frequency error. The IFFT sequence is the best candidate of the OFDM sequence overlaid on OOK waveform with the IFFT size is the 2x sub-multiple of IFFT size of system bandwidth.**

**Proposal 6: Option 1: Sequence-based OFDM sequence should be supported for overlaid OFDM sequence design.**

**Proposal 7: Option 2: The overlaid OFDM sequence carry all information bits of LP-WUS should be the design principle of the information carried by OFDM sequence.**

**Proposal 8: The Manchester channel coding scheme should be the candidate as the LP-WUS channel coding scheme.**

**Proposal 9: It is recommended to support a LP-WUS structure with wake-up information preceded by a fixed preamble sequence for assisting synchronization.**

**Proposal 10: Walsh sequence has the best BLER performance with error correction capability through simple addition operation for LP-WUS information module.**

**Proposal 11: For RRC\_IDLE/INACTIVE modes, the sequence based LP-WUS with orthogonal sequence grouping should be sufficient in indicating the paging subgroup or bundling subgroups.**

**Proposal 12: 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 13: The OOK waveform for LP-SS is same with LP-WUS would be simpler for LP-WUR detection and low standardization complexity, e.g., same configuration of M value.**

**Proposal 14: The LP-SS should be multiplexed with NR channels/signals after the IFFT in order to retrieve LP-SS without needing the FFT processing at the receiver. If the LP-SS is designed with the OOK-1 waveform modulated by IFFT sequence, it can mitigate the inter-channel interference to neighboring NR channel/signals to the NR UE when it performs IFFT processing even though the timing and frequency offset estimation is more challenged when OOK-1 waveform modulated by OFDM sequence.**

**Proposal 15: For structure of LP-SS, a fixed known preamble sequence concatenated with truncated cell ID information module could be considered in the LP-SS sequence design.**

**Proposal 16: Using the same length of preamble and information module with Walsh sequence for both LP-WUS and LP-SS would provide the benefit of same coverage.**

**R1-2403203 Qualcomm Incorporated**

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

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

***Proposal 3: Support OOK-4 with M = 2 and 4 for LP-WUS***

* ***Transmission of one OOK symbol in a OFDM symbol is based on OOK-1.***

***Proposal 4: Network uses a fixed SCS for LP-WUS***

* ***For idle/inactive modes, the LP-WUS SCS can be the same as that for SSB. Do not introduce new SCS for LP-WUS design including those only used for SSB but not for other NR channels in a frequency band.***
* ***For connected mode, the LP-WUS SCS can be same as the SCS of the active DL BWP.***

***Proposal 5: The overlaid OFDM sequence(s) carries full wakeup information of the LP-WUS OOK symbols.***

***Proposal 6: Do not consider joint detection of wakeup information from OOK symbols and overlaid OFDM sequences of the same LP-WUS.***

***Proposal 7: If the overlaid OFDM sequence carries full wakeup information of the LP-WUS OOK symbols in partial duration of the LP-WUS, the overlaid OFDM sequences can be repeated in the rest of the LP-WUS duration.***

***Proposal 8: If the overlaid OFDM sequence does not carry UE wakeup information, gNB can configures fixed known sequence(s) as the overlaid OFDM sequence.***

***Proposal 9: For OOK-4, the overlaid OFDM sequence is a time domain sequence transmitted in each OOK ON symbol. For OOK-1, the overlaid OFDM sequence is a frequency domain sequence transmitted in the NR symbol.***

***Proposal 10: Selection of overlaid OFDM sequence is based on OFDM-based LP-WUR performance.***

***Proposal 11: At least for idle and inactive modes, support the sequence-based LP-WUS design with one sequence associated with one or multiple UE groups.***

***Proposal 12: The maximum number of UE subgroups associated with a LP-WUS occasion is 8. Network configures the actual number.***

***Proposal 13: Manchester coding is adopted for generating the LP-WUS OOK symbols.***

***Proposal 14: For the UE, network configures the same OOK modulation scheme (i.e., OOK-1 or OOK-4) and same M for OOK-4 for LP-SS and LP-WUS transmissions in the cell.***

***Proposal 15: Support the same constant SCS for LP-SS and LP-WUS over time in the cell.***

***Proposal 16: Network configures the number of candidate LP-SS OOK sequences***

* ***The LP-SS sequence transmitted in the serving cell is determined by (Physical Cell ID of the serving cell) modulo (configured number of candidate LP-SS sequences)***
* ***If the number of candidate LP-SS sequences is not configured, a default value 3 is assumed.***

***Proposal 17: Support to use m-sequence for the OOK symbols of the LP-SS. The sequence length should be chosen to meet the coverage requirement.***

***Proposal 18: Overlaid OFDM sequence is supported for the LP-SS***

* ***The overlaid OFDM sequence can carry the same partial cell ID information as OOK symbols for the LP-SS***
* ***If the overlaid OFDM sequence for the LP-SS does not carry information, network can configure fixed known sequence(s).***

***Proposal 19: Support hybrid LP-SS transmission with periodic LP-SS and preamble of the LP-WUS.***

***Proposal 20: Whether preamble is included in the LP-WUS is determined by the gap between the LP-WUS monitoring occasion and the last LP-SS monitoring occasion before it.***

***Proposal 21: If multiple LP-SS transmissions within I-DRX cycle are required to meet the serving cell RRM measurement accuracy requirement, it is preferable to configure smaller LP-SS periodicity to enable evenly distributed LP-SS monitoring in the I-DRX cycle.***

***Proposal 22: The SNR for LP-WUS to achieve the coverage of PUSCH for message3 is -4.83dB with 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., 2Note: 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 |
| Qualcomm  | 4.32MHz (i.e.,12 RBs) for LP-WUS transmission for 30kHz SCS | 15dB for OOK | -3dBi for RedCap UE | 2 Tx chains for LP-WUS;4 Rx chains for MSG3 | 147.27 dB for RedCap UE | -4.83 dB |

***Proposal 23: Discuss whether it is necessary to include the note “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” in the LP-WUR coverage table.***

**R1-2402475 Samsung**

**Proposal 1: The overlaid OFDM sequence(s) should be specified and transmitted over OOK symbol of LP-WUS to guarantee the LP-WUS reception performance of OFDM-based LR.**

**Proposal 2: The overlaid OFDM sequence should be designed to be transmitted over a single ON pulse of the OOK symbol without split transmission.**

**Proposal 3: Support to specify multiple candidates of OFDM sequence to carry multi-bit information over ON pulse of OOK symbol, at least for reduction of LP-WUS monitoring time of OFDM-based LP-WUR.**

* **FFS: how many sequences to be specified considering the achievement of the target coverage, total number of information bits carried by LP-WUS, and LP-WUR detection complexity.**
* **FFS: whether to consider the position of ON pulse as the information at the OFDM-based LP-WUR.**

**Proposal 4: The overlaid OFDM sequences shall be designed based on the type of sequence used in NR synchronization signal/reference signal/random access channel.**

* **Candidates for the sequences type: M-sequence, Gold sequence, Zadoff-Chu sequence.**

**Proposal 5: To specify OOK symbol with the overlaid sequence, the following approaches can be further discussed.**

* **Approach 1: Specifying the values for subcarrier mapping in frequency domain.**
* **Approach 2: Specifying the sequence transmitted in the time domain after IFFT processing.**
* **Note: For both approach 1 and 2, the additional blocks such as DFT/LS and truncation are not specified. Whether to use the additional block and how to generate the specified values is up to gNB implementation.**

**Proposal 6: Supported M values can be 1, 2, and 4.**

* **The maximum value of M can be limited according to SCS used for LP-WUS (e.g., 60kHz SCS).**

**Proposal 7: Support Manchester coding for LP-WUS.**

**Proposal 8: The information carried by LP-WUS and the maximum number of information bits for RRC IDLE/INACTIVE state and RRC connected state can be discussed in 9.6.2 and 9.6.3, respectively.**

* **How to transmit the information and how to support the given number of information bits can be discussed in 9.6.1.**

**Proposal 9: Support a message-based channel structure for LP-WUS received by OOK-based LP-WUR with the following potential options for indicating wake-up information:**

* **Option 1: Bit-field-based Indication**
* **Option 2: Vector-based Indication**

**Proposal 10: Target FAR should be decided to design LP-WUS**

* **If a message-based channel structure is supported, proper length of CRC can be discussed to satisfy the target FAR.**

**Proposal 11: Support a bandwidth of 5MHz for LP-WUS including guard RBs.**

* **The number of RBs with and without guard band for LP-WUS corresponding to the applied channel BW and applied SCS can be provided by RAN4.**

**Proposal 12: 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 13: Down-selection between OOK-1 and OOK-4 for LP-SS, and the supported M values for LP-SS can be discussed after the decision on the existence of the overlaid OFDM sequence for LP-SS.**

**Proposal 14: Whether to design single or multiple ON/OFF patterns for LP-SS should be discussed.**

* **If multiple ON/OFF patterns are designed, the gNB transmits one of them selected based on cell ID information.**
* **If multiple ON/OFF patterns are designed, the number of patterns can be 3 at the starting point.**
* **FFS: the type of sequence, the length of sequence can be discussed based on the evaluation for LP-SS.**

**Proposal 15: Support 320ms for the periodicity of LP-SS**

* **Other values can be discussed based on the evaluation of the synchronization and RRM measurement accuracy.**

**Proposal 16: Consider the evaluation assumption for the overlaid OFDM sequence as follows:**

* **For overlaid OFDM sequences evaluation, N should be provided where N is the number of overlaid OFDM sequence(s) which can be transmitted over ON pulse of OOK symbol**
* **According to N, multiple information bits can be carried within 1 ON pulse of OOK symbol.**

**Proposal 17: At least for evaluation of the overlaid OFDM sequence, the definition of FAR should be aligned between companies considering the number of cases in which LP-WUS for the target UE group are not transmitted.**

**Proposal 18: For evaluation of LP-WUS/LP-SS, the residual error after the reception of designed LP-SS should be considered to evaluate LP-WUS performance.**

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

**R1-2403276 Ericsson**

**Proposal 1 Following principles should be considered for LP-WUS and LP-SS design**

**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.**

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

**c. It should be possible to reuse any unused LP-WUS time and frequency resources for other transmissions.**

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

**Proposal 3 Different SCS case for LP-WUS and other NR transmissions in the same CP-OFDMA symbol is not considered further.**

**Proposal 4 Including a preamble part before the data part of LP-WUS transmissions should be considered.**

**Proposal 5 Performance of sequence-based and payload-based LP-WUS structures should be studied further.**

**Proposal 6 OOK-1 generation should be specified in the frequency domain. That is, for ON symbols of OOK-1, sequences used as input of IFFT of the gNB transmitter are specified.**

**Proposal 7 To generate OOK-1, existing NR sequences should be reused to minimize impacts on the gNB transmitter and specifications.**

**Proposal 8 For OOK-4, the supported values of M should be 2 and 4.**

**Proposal 9 WUS payload size should be at most 8 bits in Idle/Inactive. Similar payload size should be considered for Connected mode.**

**Proposal 10 WUS bandwidth close to bandwidth of PSS/SSS (~11 RBs) should be supported. This corresponds to ~2 MHz and ~4 MHz bandwidths for 15 kHz SCS and 30 kHz SCS.**

**Proposal 11 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).**

**Proposal 12 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.**

**Proposal 13 Consider following values for configuring LP-SS periodicity: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms (higher values preferred).**

**Proposal 14 OOK-1 should be supported for LP-SS. OOK-4 can be additionally supported.**

**Proposal 15 Same SCS should be used for LP-SS, LP-WUS, and other NR transmissions in the same CP-OFDMA symbol.**

**R1-2402906 Nokia Shanghai Bell**

1. Consider aligned or scalable design for LP-WUS/LP-SS to support multiple BW options depending on the deployment scenario. Thus, consider the feasibility of LP-WUS BW equal to or below $5$MHz for evaluations.
2. The position of LP-WUS/LP-SS within the carrier BW should be flexible and configurable by the NW.
3. 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.
4. Unified generation scheme should be considered for OOK waveform.
5. Specify the waveform in the frequency domain with a possibility of using a pulse shaping function.
6. Consider OOK waveform with $M=\{1,2\}$ as the baseline for evaluations as it favours both envelope and sequence detectors with or without the use of Manchester encoding.
7. The use of Manchester encoding for OOK based scheme should be considered if there is no preamble field in LP-WUS frame structure.
8. Explore if there are more efficient alternatives to Manchester encoding. e.g., a preamble followed by $8$b/$10$b or in general $k/n$ bit encoding for rest of the signal.
9. Evaluate further the options of applying pulse shaping in the ON duration of OOK symbols accounting impact on the gNB transmission.
10. The time-frequency resources used for LP-WUS should be the same irrespective of the device type used as LR, i.e., LR type specific LP-WUS transmission should be avoided.
11. The number of overlay sequences used to provide more information in a single ON duration of OOK signal should consider the underlying modulation order, i.e., $M$, used by OOK signal.
12. A relationship between the different sequences used in neighbouring OOK ON symbols can be achieved by rotating the phase of the time domain samples of the sequence on symbol N relative to the phase rotation of the sequence on previous symbol N-1.
13. The phase rotation between the sequences used in successive ON symbols, N and N+1 is dictated by the symbol transmitted in symbol N.
14. Specify modulated overlay sequence as an alternative to pack more information bits within the ON duration of OOK signal that benefits the LR with sequence detectors.
15. RAN1 should evaluate whether LP-WUS requires a preamble or not and if required, the preamble design should be discussed.
16. RAN1 should evaluate whether LP-WUS requires a CRC field or not and if required, then the size and the polynomial used should be defined.
17. RAN1 should evaluate the content and the structure of LP-WUS payload.
18. As the performance of payload-based and sequence-based LP-WUS structure depends on the length of the message content, RAN1 should first decide the range of the information content of the LP-WUS message.
19. Unified waveform design between LP-SS and LP-WUS should be prioritized.
20. The modulation order used by LP-SS should be restricted to $M=\{1,2\}$ with Manchester encoding to ensure better coverage and facilitate accurate measurements for RRM purposes.
21. 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 RRM.
22. We suggest discussing if LP-SS beams shall be time multiplexed in different beam directions.
23. If LP-SS shall be time multiplexed in different beam directions, then RAN1 shall consider embedding beam tracking reference signals to the LP-SS signal to mitigate the power consumption in the LR spend on beam tracking.
24. LP-SS should provide both time and frequency synchronization to LRs of all types with minimal real-time constraints on the reception.
25. RAN1 to decide whether LR can utilize the estimated time/frequency offset using LP-SS for internal XO corrections to improve the detection of LP-WUS.
26. A minimum of $X\geq 4$ LP-SS samples are required to estimate LP-RSRP reliably irrespective of the operating SNR.
27. The LP-SS payload shall have at least $8$ or $16$ bits for $M=2$ and $M=4$, respectively together with Manchester encoding to obtain reliable LP-RSRP or LP-SINR estimation in the fading channel.
28. Consider $M\in \{2,4\}$ for LP-SS with at least 4 symbols to ensure reliable estimation in each LP-SS MO.

**R1-2402890 Apple**

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

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

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

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

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

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

**Observation 1: If frequency tracking capability cannot be assumed for an OOK-based receiver, preamble would be necessary to provide sufficient timing synchronization.**

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

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

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

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

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

**Proposal 8: Consider the following factors for the design of overlaid sequences on LP-WUS:**

* **The performance impact on OOK-based receiver**
* **The performance of sequence-based receiver**
	+ **The auto-correlation and cross-correlation properties of the sequences in time domain**
* **The size of sequence pool with good correlation properties, to support multiple sequences per cell and potentially different sets of sequences for different cells**
	+ **Including the performance impact from a larger number of sequences**
* **The robustness against time and frequency offset**
* **The receiver complexity**

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

**Proposal 10: The following should be considered for the LP-SS binary sequence design:**

* **Detection/synchronization performance and RRM measurement accuracy**
	+ **The binary sequence should have good auto-correlation property.**
	+ **Different cells should be able to use different binary sequences for LP-SS, and these sequences should have good cross-correlation properties.**
* **Overhead**

**Proposal 11: Option 3 is adopted, i.e., specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.**

**R1-2402952 MediaTek Inc**

**Design of LP-WUS

Proposal 1: Based MIL value of 147.79 for MSG3 and 12 dB noise figure for LP-WUR, target SNR for LP-WUS design is set to 0.3 dB.**

**Table 1: Target SNR values for MSG3 coverage**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 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., 2Note: 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 |
| MediaTek-01  | 4.32 MHz | 12 | -3 | 1 TX train (64 TxRUs over 192 antenna elements) | 147.79 | **0.3** |
| MediaTek-02 | 4.32 MHz | 12 | 0 | 1 TX train (64 TxRUs over 192 antenna elements) | 150.79 | **0.3** |

 **Proposal 2: Harmonized waveform design should aim for minimization of RF reception time for both OFDM and OOK LP-WURs.**

 **Proposal 3: Bit-by-bit modulation over OOK-4 with M = 2 is supported for LP-WUS.**

 **Proposal** 4**: To keep simple and effective detection for OFDM LP-WUR, support overlaid OFDM sequence with the following characteristics:**

* **Sparsity in frequency domain: Immune to mutual RE interference**
* **Energy based detection in frequency domain: Immune to different phase rotations by OOK patterns**



 **Proposal 5: Utilize the following low density sequence design for overlaid OFDM sequences.**

|  |
| --- |
| * **Low density sequence**: 12 non-zero REs are selected out of 133 REs, as shown below

* **Conveying information bits via circular shifts and energy detection:**
	+ UE detects the circular shift of the above sequence to identify the information bits carried
		- There are 16 possible circular shift offsets of $8m$ REs, $m=0, …, 15$, to convey 4 information bits
		- Circular shift is over sequence length of 133 REs
	+ Detection of a candidate circular shift can be done by accumulating the **energy** of the non-zero RE positions determined by $Λ(l)$ and the candidate circular shift offset.
 |

 **Proposal 6: Adopt the following LP-WUS design for conveying 4 information bits over 12 symbols, based on**

* **OOK-4 with M =2: Each information bit is carried by 3 repetitions of 2 Manchester coded chips**
* **Low-density overlaid OFDM sequence: 4 information bits carried by selecting 1 out of 16 sequences**



**Design of LP-SS**

 **Proposal 7: For effectively offloading MR serving cell measurements, LP-WUR measurement requirements considers -4 dB SNR which is the test SNR of early measurement requirements for idle-mode UEs.**

 **Proposal 8: LP-SS design targets 90%-percentile measurement accuracy with RSRP difference < 2dB at -4 dB SNR for one-shot measurement.**

 **Proposal 9: LP-SS design targets 90%-percentile synchronization accuracy with residue timing error < 3 us
at -4 dB SNR for one-shot synchronization.**

**Table 2: Tolerance to timing error by waveform (quoted from Secion 8.3.1 of TR 38.869 [3])**

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

 **Proposal 10: OFDM + OOK-4 waveform design used for LP-WUS can be reused for LP-SS.**

 **Proposal 11: For a given LP-SS sequence utilizing OOK-4 with M = 2 as LP-WUS, at least 8 OFDM symbols are required for achieving target RRM and sync accuracy performance.**

**Table 3: LP-SS length required for achieving target RRM and sync accuracy at -4 dB SNR**



**Proposal 12: At least 3 or 4 LP-SS sequences are supported for Rel-19.**

 **Proposal 13: Further investigate how to adapt LP-SS waveform design (including OOK sequence and overlaid OFDM sequences) so as to avoid confusion with LP-WUS for both OFDM and OOK LP-WURs, after LP-WUS design is converged.**

**R1-2402675 Xiaomi**

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

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

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

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

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

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

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

***Proposal 7：The full discussion of option 1 in RAN1 is imperative, while the potential benefits of option 2 can be explored if sufficient time permits.***

***Proposal 8：LP-WUS information could be carried by overlaid OFDM sequence(s) over OOK symbol in LP WUS with shorter duration for shorter latency. Or overlaid sequences could be detected throughout the entire duration of LP-WUS to ensure reliability and coverage.***

***Proposal 9：*** ***The number of OFDM sequences overlaid on one OOK symbol should be minimized.***

***Proposal 10：*** ***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 11： The selection of sequences should consider the performance of UE with both OOK-based and OFDM-based receivers.***

***Proposal 12：***

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

***Proposal 13：In RRC idle/inactive state***

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

***Proposal 14：In RRC connected state***

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

***Proposal 15：The binary sequence of the ON-OFF pattern needs to be defined by considering several crucial aspects, including appropriate length matching with LP-SS duration, and utilization of OOK modulation type.***

***Proposal 16：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.***

***Proposal 17：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 18： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.***

***Proposal 19:***

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

***Proposal 20：Both options for LP WUS and NR channel multiplexing can be considered in RAN1. Collisions handling is needed to prevent potential collisions between LP-WUS/LP-SS and legacy NR channels.***

***Proposal 21：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***

***Proposal 22: The frequency domain resources allocated for supporting LP WUS should not be fewer than N RBs, where N = 12 as a starting point for discussion.***

**R1-2402519 China Telecom**

***Observation 1: Different SCS between LP-WUS/LP-SS and NR signals can increase the chip rate of WUS signal and improve the generation flexibility.***

***Observation 2: Different SCS between LP-WUS/LP-SS and NR signals increases the NW overhead and degrades the spectrum efficiency***

***Proposal 1: The following aspects can be considered for the Overlaid OFDM sequence design:***

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

***Proposal 2: The specification of the LP-WUS can contain at least the following section:***

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

***Proposal 3: The specification of the OOK-1 for the LP-WUS may contain at least the following section:***

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

***Proposal 4: The specification of the OOK-4 for the LP-WUS may contain at least the following section:***

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

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

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

***Proposal 6: Different SCS of a CP-OFDM symbol used for LP-WUS/LP-SS generation to the SCS used for other NR transmissions in the same CP-OFDM symbol is not supported.***

***Proposal 7: OOK-1 is preferred for the LP-SS generation method due to its robustness.***

* ***OOK-4 is not precluded if more information bits is required in the LP-SS signals.***

***Proposal 8: Not considering overlaid OFDM sequence design in the LP-SS design.***

***Proposal 9: The LP-SS sequence design can refer to the LP-WUS overlaid OFDM sequence design method with the following adjustment:***

* ***Shorten the sequence length***
* ***Eliminate the information bits.***

***Proposal 10: Whether a preamble is needed should be based on the specific scenario.***

* ***Option 1 is selected if T1+T2 > tolerance value***
* ***Option 2 is selected if T1+T2 < tolerance value***

***Proposal 11: Only duty-cycled monitoring is better to be utilized in the monitor mechanism.***

**R1-2402574 CMCC**

**Proposal 1: For OOK-4, consider mapping frequency domain samples of OOK to the existing constellation, e.g., QPSK, 16QAM, 64QAM.**

**Proposal 2: For OOK-based LP-WUS, the required SNR to achieve the coverage of PUSCH for message3 is 2.2 dB. For OFDM-based LP-WUS, the required SNR to achieve the coverage of PUSCH for message3 is 4.2 dB.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 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., 2Note: 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 |
| CMCC-01  | 5 | 12 for OOK-based LP-WUR | 0 | 4 | 152.87 | 2.2 |
| CMCC-02  | 5 | 9.5 for OFDM-based LP-WUR | 0 | 4 | 155.87 | 4.2 |

Note: The same beamforming gain for Msg3 and LP-WUS is assumed.

**Proposal 3: Support power boosting to enhance the LP-WUS coverage.**

**Proposal 4: Support the overlaid OFDM sequence(s) carry all information bits of LP-WUS (i.e., option 2).**

**Proposal 5: The following alternatives can be considered for overlaid OFDM sequence on LP-WUS:**

* **Alt 1: total information on every ‘ON’ duration, e.g., 8-bit information is repeated in every ‘ON’.**
* **Alt 2: total information on one ‘ON’ duration, e.g., 8-bit information is carried on the first or last ‘ON’.**
* **Alt 3: total information is split and carried on multiple ‘ON’ duration, e.g., 4 ‘ON’ duration and each carries 2-bit information.**

**Proposal 6: It is recommended to choose existing NR OFDM sequence such as ZC sequence, M sequence and golden sequence.**

**Proposal 7: Preamble is needed for LP-WUS to tolerate time error. The preamble can reuse the sequence design of LP-SS which can reduce the specification effort.**

**Proposal 8: The following options can be considered for LP-WUS structure design:**

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

**Proposal 9: Support Manchester coding for LP-WUS.**

**Proposal 10: The bandwidth of LP-WUS should at least be confined to 5MHz and is the same in RRC IDLE/INACTIVE and CONNECTED states.**

**Proposal 11: Support flexibility configuration of LP-WUS bandwidth location. Both inside and outside initial DL BWP can be considered.**

**Proposal 12: Support LP-WUS and signals/channels used by MR could be located in different band/carrier.**

**Proposal 13: Support both OOK-1 and OOK-4 (M<=4) for LP-SS.**

**Proposal 14: Support Option 3 to overlaid specific OFDM sequence on LP-SS to assist sync and measurement.**

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

**Proposal 16: Consider the following information to be carried in LP-SS:**

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

**R1-2402539 EURECOM**

**Proposal 1: Specify LP-WUS in time-domain.**

**Proposal 2: Support** $M=1,2,4$ **with** $M=1$ **being OOK-1.**

**Proposal 3: Consider jointly encoding more than one bit via Manchester Coding.**

**Proposal 4: Allow configuration of joint Manchester Encoding for** $M=4$**.**

**Proposal 5: Further discuss how the information bits are mapped to multiple overlaid OFDM sequences.**

**Proposal 6: For multiple ON-Sequences, jointly encode the payload with OOK and sequence encoding.**

**Proposal 7: Consider WUR-type dependent wake-up to reduce unnecessary wake-ups.**

**Proposal 8: OFDM sequence(s) are overlaid over the entire WUS duration.**

**R1-2402114 Spreadtrum Communications**

LP-WUS design: Waveform

***Proposal 1: Down-select one waveform generation for OOK-1:***

* ***OOK-1 is generated in frequency domain as defined in SI captured in TR***
* ***OOK-1 is generated in time domain as a special case OOK-4 with M=1 for LP-WUS***

LP-WUS design: Manchester coding

***Proposal 2: Manchester coding can be supported for OOK-1 based LP-WUS.***

***Proposal 3: Manchester coding can be supported for OOK-4 based LP-WUS.***

LP-WUS design: Preamble

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

LP-WUS design: OOK sequence or encoded OOK bits to carry information

***Proposal 5: Consider the following mechanisms for information carrying by LP-WUS, and down-selection can be considered in future.***

* ***Conventional sequence design***
* ***Encoded bits with CRC***
* ***Conventional sequence design for small number of information bits (e.g. less than 4), and encoded bits with CRC for large number of information bits (e.g. no less than 4)***

LP-WUS design: Association between LP-WUS and PF/PO

***Proposal 6: LP-WUS has large overhead, LP-WUS may not be associated with PF/PO.***

LP-WUS design: Information carried by overlaid OFDM sequence

***Proposal 7: For LP-WUS, multiple OFDM sequences overlaid on an OOK symbol may have low priority currently.***

LP-SS design: Waveform

***Proposal 8: OOK-4 with M=2 or 4 can be supported for R19 LP-SS.***

LP-SS design: Manchester coding

***Proposal 9: Manchester coding can be supported for LP-SS.***

LP-SS design: Information carrying

***Proposal 10: If information can be carried by LP-SS, the number of OOK sequences for LP-SS should be not large.***

LP-SS design: With or without overlaid OFDM sequence

***Proposal 11: For LP-SS with or without overlaid OFDM sequence, Option 3 can be supported.***

LP-SS design: Information carried by overlaid OFDM sequence

***Proposal 12: 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: SNR target

***Proposal 13: The target SNR to achieve coverage of Msg 3 PUSCH could be about -6dB.***

Coverage: Tradeoff between coverage and power consumption

***Proposal 14: We should jointly consider power consumption and determination of coverage target for LR.***

Coverage: Comparing two types of LR

***Proposal 15: 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.***

***Proposal 16: Whether coverage target is determined by LR with capability of OFDM sequence detection or LR without capability of OFDM sequence detection should be discussed.***

Overhead: Tradeoff between overhead and coverage

***Proposal 17: We should jointly consider determination of overhead target and determination of coverage target for LR.***

Overhead: General techniques for overhead reduction

***Proposal 18: Reference signal at the head of LP-WUS can reduce bandwidth of guard-band for LP-WUS.***

***Proposal 19: LP-SS periodicity and reference signal at the head of LP-WUS can be studied to reduce bandwidth of guard-band for LP-WUS.***

Overhead: Comparing two types of LR

***Proposal 20: Whether resource overhead can be different for different type of LR should be discussed.***

**R1-2402337 OPPO**

* **LP-WUS signal**

**Function of the LP-WUS signal**

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

**Payload of LP-WUS**

***Proposal 2: Manchester coding/modulation is used for LP-WUS signal. CRC bits are adopted, and the range of CRC bits could be 8~12.***

***Proposal 3:******Per UE-group and / or per UE-subgroup indication for LP-WUS targets to 8-bits or 16-bits payload.***

***Proposal 4: We prefer option 1, i.e. encoded bits scheme to carry information by LP-WUS.***

**How to specify OOK-1 and OOK-4**

***Proposal 4: Support unified design, i.e. OOK-4 with M = 1,2,4. OOK-1 could be specified as the case of OOK-4 with M = 1.***

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

**How to determine the SCS of LP-WUS**

***Proposal 5: It is not clear that UE how to determine the SCS of LP-WUS. Following could be as the starting point.***

* ***Option 1: gNB explicitly configure the SCS used for LP-WUS.***
* ***Option 2: UE determine the SCS used for LP-WUS based on the reference signal or BWP. E.g. the SCS used for LP-WUS could be same as which in initial DL BWP.***

***Proposal 6: The SCS used for LP-WUS remains unchanged during the whole transmission of LP-WUS.***

**CP impact of OOK-4**

***Proposal 7: UE does not handle the CP, and perform envelope detection based on the whole LP-WUS, i.e. regard the CP as one part of OOK symbol from UE perspective.***

***Proposal 8: For OOK-4 with M>1, the length of CP before the first OOK symbol and the first OOK symbol is equal to the length of remaining OOK symbol within the same CP-OFDM symbol as shown in figure 3. For example, the length of CP before the first OOK symbol is N0, the length of the first OOK symbol is N1, the length of remaining OOK symbol is N2, N0 + N1 = N2.***

***Proposal 9: For further reduce the influence for OOK demodulation caused by CP, gNB can generate the CP of M OOK symbols within one CP-OFDM symbol based on the waveform of first OOK symbol as shown in figure 4.***

**How to overlay the OFDM sequence over the OOK symbol**

***Proposal 10: Specify time domain OFDM sequence overlaid over OOK symbols. Considering the following two options:***

* ***Option1: Specify time domain OFDM sequence per OFDM symbol.***
* ***Option2: Specify time domain OFDM sequence per OOK symbol.***

**How to carry information by OFDM sequences**

***Proposal 11: If OFDM sequence overlaid over OOK symbols could carry information, it should first decide the content of information carried by OFDM sequence. The information may be same as the indication information of LP-WUS, or carry additional information while include the same indication information of LP-WUS, or different from indication information of LP-WUS.***

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

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

**How to determine the overlaid OFDM sequence(s)**

***Proposal 14: 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.***

***Proposal 15: If the number of overlaid OFDM sequences transmitted within one OFDM symbol duration is larger than 1, the overlaid OFDM sequence mapped from OOK bits within the OFDM symbol could be transmitted with repetition.***

**The bandwidth of LP-WUS**

***Proposal 16: The BW of LP-WUS for RRC IDLE/INACTIVE state could be same as that for RRC CONNECTED state.***

***Proposal 17: Allocated fixed number of PRBs for LP-WUS signal instead of a fixed BW size, such as 6PRBs or 12PRBs.***

***Proposal 18: LP-WUS and LP-SS could share the same BW and similar frequency location. The transmission of LP-WUS and LP-SS is TDM, without further guard bands in between two signals.***

**How to determine the monitoring occasion of LP-WUS**

***Proposal 19: 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.***

**SNR (dB) to achieve the coverage of PUSCH for message3**

***Proposal 20: The SNR to achieve the coverage PUSCH for message3 with MIL = 151.13dB is 3.45 for OOK based LP-WUR, while the SNR is 5.07 for OFDM based LP-WUR.***

* **LP-SS signal**

**LP-SS waveform**

***Proposal 21: Single M values is selected for LP-SS OOK1/4 waveform.***

**LP-SS overlaid sequences**

***Proposal 22: Introducing same type of overlaid sequences on top of LP-SS OOK symbols as that for LP-WUS.***

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

**LP-SS in time and frequency**

***Proposal 23: 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.***

**LP-SS modulation and coding**

***Proposal 24: LP-SS introduce Gold or M sequences and Manchester coded/modulated into OOK symbols.***

**R1-2402544 Panasonic**

**Proposal 1: OOK-1 and OOK-4 are specified under a same framework, which support at least M = 1.**

**Proposal 2: Symbol rate of LP-WUS should be determined first and then SCS. 30 kHz symbol rate of LP-WUS with OOK-4, M=2 in 15 kHz SCS and OOK-1 in 30 kHz SCS should be supported.**

**Proposal 3: The supported symbol rate(s) and SCS value(s) of LP-SS should be allowed to be aligned with that of LP-WUS.**

**Proposal 4: The binary sequence design for LP-SS should consider the distinction of different PCIDs and SFN. ON/OFF ratio should be equal. The number of the required OFDM sequence is determined by the performance requirement of measurement, assuming SFN level synchronization has been acquired by MR.**

**Proposal 5: For LP-SS, overlaid OFDM sequence(s) is considered only if wake-up time can be reduced, rather than mandating the OFDM-based LP-WUR performance. Otherwise, Option 1 should be taken.**

**Observation 1: For timing error of up to TO=4 us, correlation detection has performance gain of about 2-3 dB than envelope detection at 1% BLER, even in the case with smaller time-segment length, such as M=4.**

**Observation 2: Envelope detection is robust to carrier frequency error of up to 100 ppm.**

**Observation 3: Correlation detection is sensitive to carrier frequency error, but for the smaller error, correlation detection performs better than envelope detection in all M.**

**Observation 4: In both envelope detection and correlation detection, BLER performances get worse for larger number of information bits.**

**Observation 5: At 1% BLER, performance gap between 4-bit and 16-bit transmission for LP-WUS is within about 2dB.**

**Proposal 6: Repetition would be needed for better coverage performance in the case with larger M and larger number of information bits.**

**R1-2402046 Futurewei**

LP-WUS Design (Structure)

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

***Proposal 2: Consider Table 1 for the SNR to achieve PUSCH Msg3 coverage of Normal and RedCap NR UEs considering both OFDM-based and ED-based LP-WURs.***

LP-WUS Design (Waveform)

***Proposal 3: A LP-WUR-enabled UE supports both OOK-1 and OOK-4 based LP-WUS design with M ∈ {1,2,4} to provide network deployment flexibility and better spectral efficiency.***

***Proposal 4: Reuse existing definition of low-PAPR sequence to generate the overlaid OFDM sequence(s) over OOK symbols.***

***Proposal 5: Support OOK-1 and OOK-4 based LP-WUS design with low frequency envelope channels to enable ED-based LP-WURs robustness against narrowband and inter-cell interference.***

LP-SS Design

***Proposal 6: Support low density sequences generated using waveform Option OOK-4 with M>1 for LP-SS design.***

***Observation 14: The maximum time offset between an LP-SS and an LP-WUS without a preamble***

***Proposal 7: Consider a preamble to precede the transmission of an LP-WUS if LP-SS periodicity is >= 320 ms and the time offset between LP-WUS and last LP-SS is, e.g., > 50 ms.***

**R1-2402728 Honor**

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

***Proposal 2: Specifies only the overlaid sequence for OOK-1.***

***Proposal 3: Specifies the two steps of sequence mapping and DFT for OOK-4.***

***Proposal 4: Further discuss how the UE obtains the OOK waveform generation scheme.***

***Proposal 5: The SCS used for LP-WUS generated CP-OFDM symbols is not supported to be different from the SCS used for other NR transmissions in the same CP-OFDM symbol.***

***Proposal 6: Prioritize M sequence.***

***Proposal 7: Support both duty-cycled monitoring and continuous monitoring.***

***Proposal 8: Discuss the schemes for OOK and OFDM sequences to carry LP-WUS information: separate carrying, priority carrying and repeated carrying.***

***Proposal 9: Prioritize OOK-1 for LP-SS.***

***Proposal 10: The subcarrier spacing of LP-SS is not supported to be different from that of LP-WUS.***

***Proposal 11: Adopt option 2 for the overlaid sequence of LP-SS.***

**R1-2402610 InterDigital, Inc**

***Proposal 1.*** *OOK-1 based LP-SS is supported (Option 1).*

* *OOK-4 based LP-SS with M>1 is not supported.*

***Proposal 2.*** *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 3.*** *For LP-WUS signal structure, time domain repetition and Manchester coding are supported.*

***Proposal 4.*** *Support up to 10 repetitions of LP-WUS with Manchester coding to achieve comparable performance with PUSCH for Msg 3.*

***Proposal 5.*** *For the SNR to achieve coverage of PUSCH for Msg3, SNR with the following associated assumptions is used.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 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., 2Note: 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 |
| InterDigital | 5 | 12 | 0 | 2 | 135.46 | -13 |

**R1-2402976 Sony**

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

***Proposal 2 - The number of bits per OFDM symbol, M, cannot be a fixed value and needs to be decided based on LP-WUS bit rate and according to channel delay spread, preventing ISI and the tolerable time/frequency errors by the LP-WUR.***

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

***Proposal 4 – Consider OOK-4 transmission scheme for the transmission of the LP-SS.***

***Proposal 5 – Support LP-SS structure with two fields using OOK-4 transmission structure and sequences from m-sequence family with good auto- and cross correlation properties.***

***Proposal 6 – For the LP-SS, do not specify the overlaid OFDM sequences(s).***

**R1-2401982 TCL**

**Proposal 1: RAN1 to consider the configuration of SCS for LP-WUS in association to a BWP.**

**Proposal 2: Support option 1 which involves using encoded bits to carry the information bits in the LP-WUS payload**

**Proposal 3: Support OOK-4 waveform for LP-SS.**

**Proposal 4: RAN1 to consider the configuration of SCS for LP-SS in association to a BWP.**

**Proposal 5: Consider a unified set of periodicities which is suitable for both idle/inactive and connected state UEs.**

**Proposal 6: Consider, a configurable BW size within the range of 5MHz and 20MHz for LP-WUS and LP-SS in both idle/inactive and connected state.**

**Proposal 7: Study a dedicated BWP for the placement of LP-WUS and LP-SS, with the maximum bandwidth within the range of 5MHz to 20MHz.**

**Proposal 8: The configurable BW of LP-WUS and LP-SS and its associated dedicated BWP can be configured to the UE during initial access.**

**Proposal 9: To locate LP-WUS in the time domain, a reference point and an offset from the reference point be used:**

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

**Proposal 10: Study the following indication method for LP-WUS successful detection;**

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

**Explicit derivation of LP-WUS detection, where the MR sent ACK message before receiving the signaling/data.**

**R1-2403126 LG Electronics**

**Proposal #1: RAN1 strive to design LP-WUS configurable sufficiently**

**Proposal #2: Regarding FFS points for OOK-1 and OOK-4 waveform generation,**

* **Specifying OOK-4 is how to define the number of samples per bit and the corresponding sequence length in the before-DFT domain**
* **The supported value of M can be discussed after the channel structure of LP-WUS and overlaid OFDM sequence have been outlined to some extent**
* **Deprioritize the discussion on the use of different SCS**

**Proposal #3: Specify 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 sub-group ID can be included**
* **CRC part: It can be optionally attached according to the length of message part**

**Proposal #4: Discuss the necessity of preamble part with its potential benefit for LP-WUS transmission on top of the need for timing error compensation**

**Proposal #5: Discuss on which type of information is delivered by overlaid OFDM sequence**

**Proposal #6: Discuss on the sequence length (and detailed mapping to OFDM symbol) of overlaid OFDM sequence considering LP-WUR sampling rate**

**Proposal #7: Deprioritizing the followings**

* **Overlaid sequence carried part of information bits instead of carrying full information**
* **Applying the frequency domain overlaid sequence for OOK-4**

**Proposal #8: Discuss on the separate transmissions for preamble part and message part of LP-WUS**

**Proposal #9: Discuss on the bandwidth and frequency location of LP-WUS with consideration of at least the following aspects**

* **NW flexibility and LP-WUR complexity**
* **Configurable BW (i.e., not a single value)**
* **Dedicated frequency resources for LP-WUS**
* **Association with MR BWP**

**Proposal #10: Study on how to define/construct OOK symbols within OFDM symbol for OOK-4**

**Proposal #11: To support various scenarios, OOK-4 with M=1,2,4,[8] needs to be supported for LP-SS**

**Proposal #12: Given that Manchester coding may degrade correlation property of LP-SS sequence, applying Manchester coding to LP-SS needs to be discussed with LP-SS sequence design**

**Proposal #13: Discuss necessity to support overlaid OFDM sequence for LP-SS.**

**Proposal #14: Consider LP-SS burst for multi-beam operation of LP-SS such as SSB burst for multi-beam operation of SSB.**

**Proposal #15: Discuss how to configure the LP-SS transmission/monitoring occasions (together with LP-WUS monitoring occasions) considering synchronization, RRM measurement, and multi-beam operation**

**Proposal #16: Multiple LP-SS periodicities need to be supported for various scenarios**

**Proposal #17: Consider the separate periodicity for synchronization and RRM measurement, respectively.**

**Proposal #18: Discuss the bandwidth and frequency location of LP-SS with consideration of both NW flexibility and LP-WUR complexity**

**Proposal #19: For inter-cell interference mitigation, using different cyclic shift for single LP-SS sequence is preferred**

**R1-2402760 NEC**

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

***Proposal 2: study the inter-symbol-interference (ISI) issue and the CP-to-OOK interference issue due to the sync error, consider utilizing zero-CP or partial zero-CP to avoid the interference.***

***Proposal 3: support flexibly configuring frequency locations of one or more LP-WUS bands within a carrier, UE can select an LP-WUS band based on its UE ID or a PF/PO it is intended to monitor.***

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

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

***Proposal 6: for the binary sequence of LP-SS, reuse the existing sequence generation method in NR, e.g., m-sequence, gold sequence.***

***Proposal 7: for the overlaid OFDM sequence(s) for LP-SS, support option 3, i.e., specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync [and RRM measurement] for OFDM-based LP-WUR using the overlaid sequence of LP-SS.***

***Proposal 8: support QCL relationship between an LP-SS and an SSB.***

***Proposal 9: support FDM multiplexing of an LP-SS and its QCLed SSB.***

***Proposal 10: support repetition of an LP-SS in an LP-SS periodicity.***

**R1-2403253 NTT DOCOMO, INC**

**Proposal 1:**

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

**Proposal 2:**

* **For the overlaid OFDM sequences of LP-WUS, consider following cases:**
* **Case 2: OFDM sequence does not carry information. gNB configures single known sequence.**
* **Case 3: OFDM sequence carries information. gNB configures a set of Ns known sequences, one of the Ns sequences can be transmitted to carry log2 (Ns) bits.**
	+ **Option 1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and OOK symbols.**
	+ **Option 2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s).**

**Proposal 3:**

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

**Proposal 4:**

* **Further study the necessity of preamble preceding LP-WUS, considering the following aspects**
	+ **Tolerable timing error for LP-WUS**
	+ **the maximum time gap between synchronization signal (LP-SS or PSS/SSS) and LP-WUS**
	+ **Time/frequency error model, i.e. Fr and Tr.**

**Proposal 5:**

* **For the residual frequency error, further study the following options**
	+ **Option 1: LP-WUR can correct the frequency error, e.g., MR can assist to calibrate LP-WUR to correct the frequency error or LP-WUR can only correct the frequency error based on LP-WUS synchronization signal**
	+ **Option 2: LP-WUR cannot correct the frequency error**
	+ **For evaluation, companies report which option is assumed, Fr value and how Fr value is obtained.**

**Proposal 6:**

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

**Proposal 7:**

* **At least support a bandwidth of 5MHz including blanked guard RBs for LP-WUS and LP-SS in both RRC idle/inactive and RRC connected states.**
	+ **FFS the applied SCS, and the applied channel bandwidth**
	+ **FFS other bandwidth size for LP-WUS and LP-SSS.**
	+ **Note: The bandwidth size is assumed to be an integer number of PRBs**
	+ **Location of LP-WUS/LP-SS BW is configurable within a NR carrier**

**R1-2402740 Sharp**

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

**Proposal 2: The M for OOK-4 symbol generation can be one of {1,2,4}.**

**Proposal 3: Support encoded bit-based payload for LP-WUS.**

**Proposal 4: The number of information bits for one LP-WUS can be a power of 2, i.e. {1,2,4,8,16}.**

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

**Proposal 6: Discuss whether LP-WUS/LP-SS can be deployed in the FR2 band.**

**R1-2403376 Nordic Semiconductor ASA**

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

* *M=1,2 for 30kHz SCS carrier*
* *M=2,4 for 15kHz SCS carrier.*

***Proposal-2:*** *Specify 8 OOK sequences (as in Table 1) in time domain, each corresponding to 1 OFDMA symbol length*

* *FFS what overlaid- sequences are used to generate values of OOK “1”.*
* *FFS need for CP-handling, spectral shaping.*

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

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

***Proposal-4:*** *Maximum number of payload bits of LP-WUS is 8 without CRC. Overlaid sequence provides both detection time reduction and coverage by repetition for the OFDMA receiver (see example Table 3).*

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

***Proposal-6:*** *LP-WUS BW is 12/24RB (including GB decided by RAN4) for 30/15kHz SCS. Support 6/12RB LP-WUS can be considered.*

***Proposal-7:*** *LP-SS is* OOK-4 M=1/OOK-1*, while preamble can be configured with higher chip-rate. LP-WUS overlaid sequence is reused for LP-SS.*

**R1-2403105 Lenovo**

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

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

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

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

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

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

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

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

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

***Proposal 11: 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 12: 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 13: 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.***

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**Proposal 1: LP-WUS OOK-1 and OOK-4 signal must use all the subcarriers within the LP-WUS bandwidth for waveform generation.**

**Proposal 2: Use ZC-sequence for overlaid OFDM sequence in OOK-1 LP-WUS.**

**Proposal 3: Use 4.1dB of the required SNR for OOK-based LP-WUR for RAN1 evaluation.**

**Proposal 4: Support power boosting to enhance LP-WUS coverage.**