**3GPP TSG RAN WG1 #117 R1-xxxxxxx**

**Fukuoka City, Fukuoka, Japan, May 20th – 24th, 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# 117.

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 Tuesday online session
2. LP-WUS design
	1. OOK-1/OOK-4 waveform

M values for OOK-4

In last meeting, RAN1 made following agreement.

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| **Agreement**For OOK-4 with M >1, support M=2 & M=4 (working assumption) for LP-WUS. * FFS whether value of M depends on SCS
* FFS M=1 for OOK-4
 |

For working assumption of M for OOK-4, many companies [4][6][8][7][3][18][15][22][12][19][23] proposed to confirm the working assumption, considering M=4 can reduce LP-WUS overhead and meet coverage requirement. [11] does not support M=4 by providing that no performance gap between M = 2 and M = 4 for OOK-4 for OOK WUR when the same symbol duration is assumed according to the simulation result. FL agrees the performance would be same for M=2 and M=4 with same resource overhead for certain SNR, but for scenarios with higher SNR, M=4 may not need repetition thus higher data rate can be achieved. Furthermore, with larger M value can enable earlier termination for OFDM-based LP-WUR because of larger number of OOK ON symbols in an OFDM symbol.

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

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| **Agreement**For OOK-4 with M >1, support M=2 & M=4 (working assumption) for LP-WUS. * FFS whether value of M depends on SCS
* FFS M=1 for OOK-4
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| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 | Y |  |
| EURECOM | Y | Confirm WA. Support M=4 for both 15 and 30KHz SCS. We prefer a unified design for OOK-1 and OOK-4. |
| Everactive | Y |  |
| Xiaomi | Y |  |
| Qualcomm | Y |  |
| TCL | Y |  |
| Spreadtrum | Y |  |
| HONOR | Y |  |
| Sharp | Y |  |
| docomo | Y |  |
| Samsung |  | We are OK to M=4 with 15kHz SCS, and prefer to keep FFS for M values with 30kHz SCS. If it is not accepted, we prefer to keep working assumption M = 4 before it is clearly observed that OOK-4 with M=4, 30kHz SCS with the timing error can achieve the target coverage.  |
| OPPO | Y |  |
| LGE | Y |  |
| vivo | Y |  |

Regarding the FFS point of dependency of M on SCS, i.e., whether M=4 for 15& 30kHz or only 15kHz,[4][2][6][8][3][18][15][22][27] propose to support M=4 for both 15& 30KHz SCS,[7][17][23] propose M=4 is only supported for 15kHz SCS for now. [7] suggests to further evaluate whether M=4 for 30KHz SCS can meet Msg 3 PUSCH coverage after RAN1 decides candidate SNR for the coverage.

How to specify OOK-1 and OOK-4

Companies discuss how to specify OOK-1 and OOK-4, mainly about separate or unified specification for OOK-1 and OOK-4.[4][2][7][3][10][13], [24][17][16][26][11][27] supports unified specification,[15], [12], [6], [19] supports separate specification.[8] is open for further discussion. This issue is highly relevant to overlaid OFDM sequence discussed in section 1.2. Therefore, FL suggests to come back to this issue after progress of frequency or time domain overlaid OFDM sequence.

SCS configuration for LP-WUS

Companies discuss whether LP-WUS/LP-SS SCS can be different from NR signal in same OFDM symbol and how to derive LP-WUS/LP-SS SCS[8][[3][[6][[9][12][[16][[23][22]. 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][16]. Regarding how the UE derives the SCS, it can be either determined according to configuration by gNB[3][[6][9][12][[22][16] or pre-defined rule[3][16][[22][[23][[12], such as according to initial DL BWP SCS, or SSB SCS, or active BWP.

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

- The single SCS is configured by gNB

- The single SCS is determined by pre-defined rule

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 |  | SCS used for LP-WUS is signaled by gNB. |
| Qualcomm |  | We prefer single SCS is configured by gNB |
| TCL | Y | We are generally fine with two options, but we prefer the second option “The single SCS is configured by gNB “ |
| Spreadtrum |  | No spec impact. Except for SSB, signals/channels in an active BWP have the SCS configured for the active BWP. LP-WUS follows this rule. No harm to gNB transmission. |
| Sharp | Y |  |
| OPPO | Y | Different SCS used for LP-WUS transmission and reception will increase the complexity of UE and gNB implementation. We suggest modifying the main bullets as following.Proposal 3.1-2: Single SCS for LP-WUS ~~is used by LP-WUR~~ transmission and reception, further discuss following options - The single SCS is configured by gNB- The single SCS is determined by pre-defined rule  |
| LGE |  | Does SCS configuration by gNB mean that LP-WUS is not associated with BWP? If there is a BWP association with LP-WUS, it would be natural to use the same SCS as initial BWP or active BWP. |
| Vivo  |  | We prefer single SCS is configured by gNB for simplicity.  |

* 1. Overlaid OFDM sequence for LP-WUS
		1. Time or frequency domain sequence

Regarding the overlaid OFDM sequence is a time or frequency domain sequence, 3 options are discussed by companies:

* Option 1: overlaid sequence(s) are the sequence(s) of an OOK on symbol or OFDM symbol before DFT processing (signal S1)[4], [2], [3], [14], [16], [10], [8], [19], [12], [15]
* For both OOK-1 and OOK-4: [4], [2], [3], [14], [16], [10]
* Only for OOK-4: [6], [8], [19], [12], [15]
* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing (signal S2)[8], [7], [6], [19], [12], [15]
* For both OOK-1 and OOK-4: [8], [7]
* Only for OOK-1: [6], [19], [12], [15]
* Option 3: overlaid sequence(s) are the sequence(s) of an OFDM symbol after IFFT processing (signal S3)[7], [5]
* For both OOK-1 and OOK-4: [7], [5]



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

**Table 1 Pros/cons for 3 options provided by companies**

|  |  |  |
| --- | --- | --- |
|  | Pros provided by companies  | Cons provided by companies |
| Option 1 | 1. Smaller number of sequences to be specified than option 2/3, e.g., 4 sequences vs 64 sequences, assuming M=4, and 2 bits carried by the sequence per OOK ON symbol.
2. Existing NR/LTE sequence can be reused
 | 1. restriction on gNB implementation, because of specified DFT
2. Discussion on how to generate OOK when M=1 is needed
 |
| Option 2 | 1. More flexible for gNB implementation than option 1
2. For OOK-1, existing gNB implementation can be reused
 | 1. For OOK-4 M>1larger number of sequences to be specified than option 1
2. For OOK-4 M>1, existing NR sequence cannot be directly reused
 |
| Option 3 | 1. More flexible for gNB implementation than option 1
2. Zero- CP is possible, if LP-WUS and NR signal are generated by separate chain.
 | * For OOK-4 M>1, larger number of sequences to be specified than option 1
* For OOK-4 M>1, existing NR sequence cannot be directly reused and unclear how to specify.
 |

Regarding Cons (1) for option 1 and Pros (1) for option 2/3, as explained by several proponent companies of option 1, DFT block does not require gNB to perform on-the-fly DFT computations. gNB can store the frequency domain symbols without any need for additional on-the-fly computations, which is similar as option 2/3. Therefore option 1 does NO restriction on gNB implementation. Regarding Pros (2) for option 3, it is unclear to FL whether Zero-CP is feasible by existing gNB hardware module and how to guarantee the orthogonality between LP-WUS and NR signal.

For option 1, companies discuss whether the overlaid OFDM sequence before DFT is per OOK ON symbol or per OFDM symbol.[4][[2][[6][[3][[10][25][[8] supports the overlaid OFDM sequence per OOK ON symbol,[16] supports both overlaid OFDM sequence per OOK ON symbol and per OFDM symbol. Considering majority support for per OOK ON symbol and [16] is fine with both approaches, FL suggests to support option 1 with overlaid OFDM sequence per OOK ON symbol.

[H][FL1] Question 3.2-1: For overlaid OFDM sequences in time or frequency domain, which option do you support, and which option you do not support?

* Option 1: overlaid sequence(s) are the sequence(s) of an OOK on symbol before DFT processing
* Option 2: overlaid sequence(s) are the sequence(s) of an OFDM symbol before IFFT processing
* Option 3: overlaid sequence(s) are the sequence(s) of an OFDM symbol after IFFT processing
* FFS: same or different options are applied for OOK-1 and OOK-4 M>1.
* Note1: multiplexing LP-WUS and NR signal before or after IFFT is to be separated discussed.

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| **Company** | **Option(s) you support** | **Option(s) you do NOT support** | **Comments** |
| Nokia1 | Option 2 | Option 3 | The position of OOK symbol within a NR OFDM symbol does not introduce combinations. |
| EURECOM | 1 | 2 and 3 | We support a unified design in time-domain. |
| Everactive | 1,2 | 3 | The impact of any overlaid sequence on the OOK symbols should be measured and minimized. Specifically, for LRs with an ED in the receive path. |
| Xiaomi | 1,2 |  | Perhaps once we figure out how to standardize OOK-1, the answer to this question will become more consistent. |
| Qualcomm | Option 1 |  | All options would work but option 1 is the cleanest design for OOK-4. |
| Spreadtrum | 1,2 | 3 | We do not know how to write it in 38.211 for Option 3 |
| HONOR | 1,2 | 3 | Option2 is the simplest for OOK-1. |
| Sharp |  |  | Is there any essential difference between option2 and option3? We think they are equivalent for signals received by UE. |
| Samsung | Option 2, 3 |  | To clarify the option 3, our suggestion is to specify the overlaid OFDM sequence of an OOK on symbol that can be used at the OFDM-based LR, which is different from the option 3 in the Question. For example, assuming that 256 samples per OFDM symbols is used at the receiver side after filtering and downsampling and M=2, 128 samples can be used to detect the overlaid OFDM sequence to be transmitted over a OOK symbol. Therefore, 128-length sequence (**s**) can be specified in this example, and these value can be used directly as the coefficient of correlator if the time domain processing is used at the LR. In this case, least square method and zero padding can be considered to find the proper value (**k**∈K1) for the subcarrier mapping considering the different IFFT size by the gNB implementation. For example, to generate ON and OFF pulse within 1 OFDM symbol, signal **t = [s’ 0]**∈M1can be considered to find **k**, where **s’** is oversampling vector of **s** (if IFFT size (N) is larger than 256) using the least square equation ( where ∈NK is the subset of IFFT matrix according to the subcarrier used for LP-WUS).Furthermore, for option 3, CP should be added if the single IFFT is used and it can be removed at the receiver, which is similarly assumed during SI. From our understanding the main benefits for option 3 is not to specify any additional procedure before IFFT processing. In addition, at the receiver side, there is no need to consider these kinds of gNB procedure to find out which sequence will be detected at the correlator.Our preference is not to specify the additional processing before IFFT processing, option 2 or suggested option3 in our explanation. |
| OPPO | Option 1, 1a (as comments) |  | For option 1, as summarized by FL, overlaid sequence(s) are the sequence(s) of an OOK on symbol or OFDM symbol before DFT processing (signal S1).If overlaid sequence(s) are the sequence(s) of an OOK on symbol, considering the configuration of M and SCS will cause to different duration of OOK on symbol, the number of sequences to be specified may be impacted by the value of M and SCS. If the overlaid sequence(s) are the sequence(s) of an OFDM symbol, the number of sequence(s) maybe not impacted by M value. We suggest one more option 1a as following.Option 1a: overlaid sequence(s) are the sequence(s) of an OFDM symbol before DFT processing |
| LGE | 1,2 |  | Considering LP-WUR w/ or w/o FFT, both Options 1 and 2 can be supported |
| vivo | Option 1 | Option 3 | Fail to see benefit of option 3. To capture option 3 in the spec, for each sequence, we may either go with element-by-element hard-coded in spec, or we add LS equation as provided by Samsung? Neither way is not a typical way for 3GPP spec.  |

[H][FL1] [TBD] Proposal to be made based on response collected in Question 3.2-1.

As shown in Figure 1 above, there can be two alternatives for LP-WUS and NR multiplexing. Alternative 1 is aligned with waveform generation captured in TR38.869, LP-WUS and NR signal is multiplexed before IFFT. By Alternative 2 proposed by[5], LP-WUS and NR signal is multiplexed after IFFT (figure from [5]’s tdoc is copied as below). [5] explains benefit of multiplexing after IFFT ‘Since the LP-WUR would have the capability of coarse time and frequency synchronization, the filtered LP-WUS signals would contains the inter-channel interference (ICI) from neighboring NR channel/signals caused by the residue of the timing and frequency error. This will have severe degradation on the LP-WUS detection performance’. [14][[2][[13][[4][[3] think multiplexing after IFFT increases hardware complexity, e.g., separate IFFT chains.[14][[2] think interference between NR and LP-WUS can be minor with ASCS, thus less motivates multiplexing after IFFT.

Furthermore, as discussed in last meeting, some companies consider multiplexing before or after IFFT can be gNB implementation.



Figure 2: Figure from [5] to explain how LP-WUS multiplexes with NR after IFFT

[H][FL1] Question 3.2-2: Do you think, multiplexing NR signal and LP-WUS in different PRB can be transmitted with single IFFT operation (multiplexing before IFFT) or separate IFFT operations with different size (multiplexing after IFFT), which can be up to gNB implementation?

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| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 | Y | For option 1 and option 2, NR and LP-WUS can use the same IFFT process to generate TD signal. |
| EURECOM |  | Support multiplexing before IFFT. |
| Xiaomi |  | Prefer multiplexing before IFFT for minimum complexity |
| Qualcomm | Y | We think using same IFFT to generate the OFDM symbol for NR signals and LP-WUS can be supported by gNB if SCS of these are the same, but there is no need to mandate this. |
| TCL  |  | It can be upto gNB implementation. |
| Sharp |  | Support gNB implementation |
| docomo |  | Prefer multiplexing before IFFT. Separate IFFT increases gNB complexity while the benefit is unclear. |
| Samsung | Y | From our understanding, if the different IFFT size is used for LP-WUS generation, the size of IFFT should be provided to UE with OFDM-based LR to know which sequence can be detected in the time domain (if option 1 or option 2 in Question 3.2-1 is assumed). For option 3, whether to use the single IFFT or separate IFFT can be up to gNB implementation. |
| OPPO | Y | Prefer multiplexing before IFFT. |
| LGE | Y | If both directions are supported, it can be gNB implementation |
| vivo | Y | Support gNB implementation |

* + 1. Sequence design

In last meeting, RAN1 agreed a list of sequences as overlaid OFDM sequence candidate for further study and evaluation.

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| **Agreement**For the purpose of further study and evaluation in RAN1, the following candidate sequences for the overlaid OFDM sequence are considered:* Gold sequence
* M-sequence
* ZC sequence
* Chirp sequence
* Walsh sequence
* Golay sequence
* Kasami sequence
* Low density sequence
* DFT/FFT sequence
* QAM symbol-based sequence
* Combinations and optimizations of above are not precluded

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

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

|  |  |
| --- | --- |
|  | Supported company  |
| Existing NR sequence type  | [4], [2], [6], [3], [8], [10], [20], [19], [17], [13], [7]  |
| DFT/FFT sequence | [5] |
| Chirp sequence  | [9] |
| Golay sequence | [10] |
| Walsh sequence | [5] |
| Kasami sequence | [21] |
| Low density sequence  | [11]  |

For existing NR sequence type, including m sequence, gold sequence, ZC sequence, the proponent companies think reusing existing sequence can save tremendous standard effort than using new sequence. Some companies provide LLS simulation results to show feasibility.

For DFT/FFT sequence, [4] does not support considering the sequence because if DFT/FFT sequence mapped in frequency domain, in time domain it is a pulse, which is highly sensitive to timing error. Additionally, due to the short duration of DFT/FFT sequence in the time domain, its transmit energy is quite low considering that the hardware limitation. From FL’s reading of [5]’s description in tdoc ‘the LP-WUS is modulated by the IFFT sequence as the overlaid OFDM sequence with the IFFT size is the 2x sub-multiple of IFFT size of system bandwidth’, IFFT sequence is just IFFT operation for LP-WUS which enables multiplexing with NR after IFFT, rather than the overlaid sequence to carry information. LP-WUS and NR multiplexing is discussed under section 3.2.1. Therefore, FL suggests to delete this option for overlaid sequence, and discuss it under section 3.2.1.

For chirp sequence, [4] does not support the sequence considering chirp sequence is incapable of inter-cell interference randomization because single sequence is uniquely determined by occupied time and bandwidth. [8] does not support the sequence considering the sequence does not create OOK-4 patterns in time domain. [2] does not support the sequence considering chirp sequence itself cannot carry multiple information bits. [9] evaluated chirp sequence and observed performance degradation for TDL-C channel.

For Golay sequence, there is quite limited input. [10] as proponent company provides auto/cross-correlation and analyses LP-WUR complexity reduction due to its low-complexity correlator, but LLS result is not avaible yet.

For Walsh sequence, [4] and [2] does not support the sequence because of its poor auto-correlation property.

For Kasami sequence, there is quite limited input. [21] as proponent company evaluates Kamasi sequence at SNR=16 dB.

For low density sequence, [11] proposes the sequence because it could offer required performance for OOK WUR and OFDM WUR while maintaining low complexity. [2] does not support the sequence considering large range of power boosting is needed since 12 out of 144 subcarriers of LP-WUS bandwidth are transmitted with non-zero value, which is infeasible according to existing NR RAN4 requirement. Moreover, it is unclear how to extend the low-density sequence for OOK-4 with M=4 case, thus the design is not preferred.

FL suggests to agree existing NR sequence as baseline, based on majority view, provided LLS results, and minimum standard effort. Meanwhile, it is not intended to exclude new sequence type, if clear benefit of new sequence type is proved, or critical issue by using baseline sequence is identified.

[H][FL1] Proposal 3.2-2: Overlaid OFDM sequence based on existing NR sequence type, including gold sequence, m sequence and ZC sequence is the baseline:

* Further down-select among gold sequence, m sequence and ZC sequence.
* Other sequence type is not considered unless essential issue is figured out by using baseline sequence.
* FFS the overlaid OFDM sequence is time or frequency domain sequence.

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| **Company** | **Y/N** | **Comments** |
| Nokia1 | Y |  |
| EURECOM | Y | We agree with the proposal. |
| Everactive | Y |  |
| Xiaomi | Y | Fine with the proposal. |
| Qualcomm | Y |  |
| TCL | Y |  |
| HONOR | Y |  |
| docomo | Y |  |
| Samsung | Y |  |
| OPPO | Y |  |
| LGE | Y | Fine with the proposal |
| vivo | Y |  |

#### [H][FL1] Question 3.2-3: For Overlaid OFDM sequence based on existing NR sequence type, what is your view on how to reuse this sequence?

* Option 1: existing sequence can be directly reused as overlaid OFDM sequence, e.g., binary sequence such as m or gold sequence with ±1 value
* Option 2: QAM-based sequence based on existing sequence, e.g., QAM-based sequence is based on exiting m or gold sequence to randomize phase[3] or interleaved version of ZC sequence[8].

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 |  | How the above two options behave in the presence of pulse shaping if there is. |
| EURECOM |  | The options have to be evaluated for the next meeting.  |
| Everactive | 1 is preferred  | The impact of any overlaid sequence on the OOK symbols should be measured and minimized. Specifically, for LRs with an ED in the receive path. |
| Xiaomi  |  | Prefer option 1. |
| Qualcomm |  | It is straightforward how option 1 would work, option 2 with 4 QAM transmits two sequences in I and Q simultaneously.  |
| TCL |  | Prefer option 1.  |
| docomo |  | Prefer option 1. |
| Samsung |  | We are open to further discussion for both options. |
| OPPO |  | The impact for pulse shaping and performance should be considered. |
| LGE | Y | Prefer Option 1. For now, it’s not clear to us how QAM-based sequence is generated based on the existing sequence |
| vivo |  | Option 1 is more straightforward. For option 2, whether still correlation property can be maintained needs further study.  |

To further down-select sequence, some metrics can be consideredd. For example, good cross-correlation property is fundamental for carrying multiple bits. Good auto-correlation property may be also needed considering timing error, e.g., in case of reception with sliding window. Some companies also mention larger sequence pool to enable different sequences in different cells, for inter-cell interference, while some companies doubt the necessity of this metric considering it may not improve OOK detector performance, while OOK detector is bottleneck. Furthermore, whether the sequence is processed in time or frequency domain may also have impact on performance of different sequences. It would be helpful to take these metrics into account.

Others

Companies also discuss other aspects for overlaid OFDM sequence design.

1. Discussion on concentrated OOK waveform to improve robustness to timing error or inter-OOK-symbol leakage[4][[9][14][[13].

Whether the concentrated OOK waveform is needed[14], e.g., considering presence of preamble, and whether up to gNB implementation[13] or reflected by sequence design[4][[9] can be further discussed.

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

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

1. Discussion on mapping frequency samples to existing NR QAM or sequence constellation[2][[8][[14][15][13].

[[2][[8][15][13] thinks it is beneficial to support mapping frequency samples to existing NR QAM or sequence constellation to reuse existing gNB hardware[2][[8][15][13] and to improve robustness to frequency errors[8].[14] does not support, because arbitrary values are allowed in frequency domain by existing NR, e.g. consider precoded signals for MU-MIMO which surely are different from QAM constellation or existing sequences. Mapping frequency samples of LP-WUS to NR QAM or sequence constellation results in performance degradation for both OOK-based and OFDM-based LP-WUR.

* + 1. How to carry information by OFDM sequence(s)

In last meeting, RAN1 agreed to consider 4 options.

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

Other options are not precluded. |

There are two cases:

Case #1: overlaid OFDM sequence does not carry information, i.e., option 1 & option 1-2

Case #2: OFDM sequence carries information, i.e., option 2,3,4.

For case #2, [4], [3], [6], [7], [14], [10], [24], [17], [23], [11] support option 2, [2][8][[13][16][[23] support option 3. FL observes there are different understandings on option 3. Before further down-selection between options, FL suggests to first align understanding for option 3.

[H][FL1] Question 3.2-4: what is your understanding of option 3 ?

* Understanding 1: One long sequence mapped to multiple OOK ON chips (more than one OOK ON chips, but not necessarily the number of OOK chips in one OFDM symbol)
* Understanding 2: The information may not be carried on all OOK ON symbols, e.g., full information is carried in first N1 symbols, while remaining symbols can be up to gNB implementation to transmit or not transmit information by the specified overlaid OFDM sequence.

Figure 3-a provides an example.

* Understanding 3: The overlaid OFDM sequence mapped from OOK bits within the OFDM symbol could be transmitted with repetition.

Figure 3-b provides an example.

* Other understandings

|  |  |  |
| --- | --- | --- |
| **Company** | **Which one is your understanding?** | **comments** |
| Nokia1 | Understanding 2 | With retransmission in the later part. |
| EURECOM | 1 | Understandings 2 is Option 2-2/3 and Understanding 3 is some variation of Option 2.We think for Option 2 there should be a separate proposal addressing the issue of WHAT information is transmitted in the sequences since there are more ON symbols available than required for OFDM-based receiver. |
| Everactive | 3 | gNB must transmit all OOK symbols, assuming an OOK LR. gNB can repeat the OFDM overlaid sequence as necessary. |
| Xiaomi  | Understanding 1 |  |
| Qualcomm | 1 | We think it refers to understanding 1. Understanding 2 and 3 also exist in option 2. Understanding 1 at least should be discussed first. Understanding 2 and 3 can be discussed as a separate topic that applies to 2.  |
| TCL | Understanding 1 |  |
| Spreadtrum | 1 |  |
| HONOR | Understanding 3 |  |
| docomo | Understanding 1 | Understanding 2 and Unserstanding3 can be regarded as some variations of option 2-2 hence they can be discussed under option 2-2. |
| Samsung | Understanding 1 | If option 3 is clarified as the understanding 2, we can combine option 2 and option 3 focusing on carrying the information via multiple OFDM sequence candidates, and which sequence can be transmitted over the remainder OOK symbols can be further discussed. |
| OPPO | Understanding 3 | Considering gNB generates the OOK waveform per M OOK symbol, i.e. per OFDM symbol. gNB could also determine the overlaid OFDM sequence based on the OOK bits transmitted within the same OFDM symbol. In this way, gNB only need to determine the OFDM sequence once time when generating the M OOK symbol within one OFDM symbol.For understanding 2, the remaining OOK symbols also need to transmit the overlaid OFDM sequence, at least for the spectrum flatten. In this way, it is not clear for the reason of different design of the overlaid OFDM sequencesUnderstanding 1 and 3 may be as two different options. |
| LGE | Understanding 1 | In Option 1 and Option 2, the sequence length of the overlaid OFDM sequence matches one OOK symbol or one OFDM symbol. In Option 3, the length of the sequence can be matched to one or more OOK symbols.  |
| Vivo  | Understanding 2.  | Comparing option 2 and understanding 3 of option 3, both can be up to gNB to support repetition or not. But the difference is, in case of no repetition, in the remaining OFDM symbols, e.g., last 2 OFDM symbols in figure 3-a, gNB still has to transmit overlaid OFDM sequence from configured overlaid OFDM sequence set in OOK ON symbols by option 2, but gNB can transmit any OFDM sequence/signal in OOK ON symbols by option 3, e.g., a one symbol PDCCH.  |



Figure 3-a: example of understanding 2



Figure 3-b: example of understanding 3

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

For RRC idle:

In last meeting, RAN1 agreed to consider 3 options.

|  |
| --- |
| **Agreement**Regarding the LP-WUS information for idle/inactive UEs, at least consider the following：* Option 1: A bitmap with each bit corresponding to [one or more] subgroups
* Option 2: A codepoint value corresponding to one or more subgroup(s)
* Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s)
* Combination of above options are not precluded
* FFS how to carry LP-WUS information, e.g., by encoded bits (with/without CRC) and/or by OOK sequence selection for ‘ON-OFF’ pattern for OOK symbols of LP-WUS.
* FFS how to carry LP-WUS information by overlaid OFDM sequences.
	+ It doesn’t preclude considering the configuration where a single candidate overlaid OFDM sequence is used
* Other options are not precluded
 |

Companies discuss these options with quite diverged views. Company views are summarized as below. It is noted that, how to carry these information bits by overlaid OFDM sequence as discussed in section 1.2.3 has many candidate solutions for now. Therefore, the following only captures options for OOK-based LP-WUR. The discussion for OFDM-based LP-WUR can be triggered later.

* Option 1: A bitmap with each bit corresponding to one subgroups [2], [9], [14], [15], [19], [12], [16], [26], [27]
	+ Subgroup number N per LP-WUS provided by proponent companies: 8 or 16.
	+ Length of a LP-WUS is N+[8] CRC, single LP-WUS to wake up ≥1 subgroups
* Option 2: A codepoint value corresponding to one or more subgroup(s)[4], [6], [3], [22], [11], [27]

Under option 2, different sub-options are discussed by companies

* + Option 2-1 codepoint by encoded bits: Each codepoint is associated with one subgroup:
	+ Subgroup number N provided per LP-WUS by proponent companies: 8 ~ 256.
	+ Length of a LP-WUS: log2(N)+[X], multiple LP-WUSs to wake up >1 subgroups
	+ Option 2-2 codepoint by OOK sequence: Each codepoint is associated with one or multiple subgroups:
	+ Subgroup number N provided by companies: 8~32
	+ Length of a LP-WUS: N or 2\*N, multiple LP-WUSs to wake up >1 subgroups
* Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s)[4], [9], [3], [5], [22], [27]
	+ Option 3-1: codepoint by encoded bits
	+ Option 3-2: codepoint by OOK sequence

[[18], [7]. [10] and [17] are open for further study. Some companies[10][[20] mentioned down-selection among these options largely depend on the maximum number of subgroups to be supported.

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

|  |  |
| --- | --- |
|  | Benefit of the option provided by proponent companies  |
| Option 1:  | * Simplify standard effort to reuse PEI design logic [Spreatrum][[2][[8]
* Better flexibility and the possibility of simultaneously addressing multiple subgroups[8][[2].
* Reduced overhead for preamble, one preamble for any combination of UE subgroups is sufficient for bitmap while one preamble for each UE subgroup is needed for codepoint[8].
* Shorter latency[15]
* Smaller number of MOs to be monitored[2]
 |
| Option 2: | * Better resource efficiency: due to low probability of paging more than one UE, it is more efficient to transmit LP-WUS for one UE rather than bitmap for any combination of UE subgroups[4][[6]
* Capable of supporting larger number of subgroups, e.g., up to 256 subgroups per PO and more than 256 subgroups per LO[4]
* More flexible: MO resource can share among multiple POs allowing gNB implementation to adapt well to the CDF curve of multiple concurrent paging events[4]
* Early termination of detection[4]
* No impact of information bits for other UEs, but bitmap leads a UE to drop the LP-WUS no matter the bit for itself or other UEs is wrong base on CRC result, thus bitmap leads to worse MDR[4][[6]
 |
| Option 3:  | Similar as option 2. In addition, option 3 can save more resource than option 2 considering OFDM-based LP-WUR, in repetition and multi-beams transmission.  |

[M][FL1] Proposal 3.3-1: For RRC idle/inactive state, down-select among following options for OOK-based LP-WUR

* Option 1: A bitmap with each bit corresponding to one subgroups
	+ Subgroup number N per LP-WUS provided by proponent companies: 8 or 16.
	+ Length of a LP-WUS is N+[8] CRC, single LP-WUS to wake up ≥1 subgroups
* Option 2: A codepoint value corresponding to one or more subgroup(s)

Under option 2, different sub-options are discussed by companies

* + Option 2-1 codepoint by encoded bits: Each codepoint is associated with one subgroup:
	+ Subgroup number N provided per LP-WUS by proponent companies: 8 ~ 256.
	+ Length of a LP-WUS: log2(N)+[X], multiple LP-WUSs to wake up >1 subgroups
	+ Option 2-2 codepoint by OOK sequence: Each codepoint is associated with one or multiple subgroups:
	+ Subgroup number N provided by companies: 8~32
	+ Length of a LP-WUS: N or 2\*N, multiple LP-WUSs to wake up >1 subgroups
* Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s)
	+ Option 3-1: codepoint by encoded bits
	+ Option 3-2: codepoint by OOK sequence

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Qualcomm | N | We think Option 2-1 and Option 2-2 are just specific ways to generate the sequence, i.e., for Option 2-2, the binary sequence does not exclude binary sequence generated by encoded bits. Besides, the length for sequence can be flexible designed included log2(N)+[X] or N or 2\*N for any sequence design. Hence, we suggest to treat Option 2-1 and Option 2-2 as the same option in down-selection with length >= log2(N) when the number of candidate sequences is N. |
| TCL | Y | We support the proposal.  |
| Spreadtrum | Y |  |
| OPPO |  | Subgroup number N per LP-WUS, and how to transmit the indication information (e.g. signle LP-WUS could wake up ≥1 subgroups or only wake up 1 subgroup) would have the impact on the down selection.  |
| vivo  | Y | We prefer to keep option 2-1 and option 2-2 as separate options. Because 1. overhead is different, e.g., log2 (N) vs N for one LP-WUS
2. performance is different, e.g., option 2-2 with well-designed sequence can be more robust than option 2-1.

Feasibility of support maximum number of subgroups is different. For example, if 256 subgroups to be supported, option 2-2 requires at least 256 sequences and each sequence is with length of at least 256 chips, while option 2-1 may only require a length of few tens of chips. Apparently, 256 chips per LP-WUS would be infeasible especially for TDD system.  |

For RRC connected:

In last meeting, RAN1 agreed to consider 5 options.

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

Companies provide views on these options are summarized as below

* Option 1: A bitmap with each bit corresponding to [one or more] UEs[2], [14], [10], [12], [19], [16], [26], [11]
* Option 2: A codepoint value corresponding to one or part of UE identity, e.g., C-RNTI[4], [22]
* Option 3: A codepoint value corresponding to [one or more] UEs[4], [22], [19]
* Option 4: Multiple codepoint values with each corresponding to [one or more] UE(s)

[[4], [5], [22], [26]

* Option 5: Multiple bit blocks with each corresponding to [one or more] UE(s)[26]
* Combination of option 1 &2/3/4[2]

Some companies [2][15] mentioned that, proper option highly depends on mechanism of LP-WUS, e.g., option 1 or option 5 is useful if LP-WUS is to replace DCP, otherwise option 2/3/4 or combination of option 1 & 2/3/4 can be useful.

* + 1. How to carry the information bits to be carried by LP-WUS

Payload of LP-WUS can be carried by one of

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

Different companies have different preference. [2][18][7][10][3][25][27][24][26][16][22] support option 1, [5] [6] support option 2. [8] [13] 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 by option 2
	+ It can also be complicated for the receiver to find the sequence with the highest correlation out of 256 sequences
	+ It requires less standard effort, because of no sequence design.
* Benefit for option 2
	+ the sequence-based LP-WUS enables more controllable performance/coverage by different number of candidate sequences and various sequence length
	+ Lower overhead due to no CRC or FEC
	+ Better synchronization
	+ Common design for LP-WUS and LP-SS

Considering selection of option 1 or option 2 depends on the number of subgroups, and whether codepoint or bitmap is supported, FL suggests to joint discuss this issue under section 1.3.1

* 1. Preamble

The necessity of preamble is discussed by companies [5] [6] [8][18] [13][4] [9] [10][25][16]. Most companies discuss the necessity of preamble for timing acquisition. Some companies [16][23][21] 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. The maximum timing error between last LP-SS and the LP-WUS is discussed under section 4.5.

FL suggests to discuss preamble issue after progress in section 4.5.

* 1. Coding

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

* Line code: Manchester coding can be decoded with simple algorithm and negligible power consumption, providing substantial gain in LP-WUS detection performance to achieve comparable coverage of Msg 3 PUSCH as studied in Rel-18. Besides, Manchester encoding facilitates the threshold evaluation to determine the ON/OFF decision at each symbol. Furthermore, Manchester coding is also useful for overlaid OFDM sequence as it can provide a significant ‘on’ pulse.

[4][[6][[8][[7][[2][[15][[20][[13][[5][[3][25] support Manchester coding.[9] supports Manchester coding at least when there is no preamble in LP-WUS.[14] thinks even with presence of preamble, Manchester coding is useful considering optimal threshold would vary during WUS duration and threshold estimation by preamble would consume additional power.

* FEC: simple channel coding is proposed by some companies[8][[4][[9][[26], e.g., hamming or RM code. FEC can further improve performance, however, this may increase the complexity of LR.

Among proponent companies, no company questions the benefit of Manchester coding for encoded bits. For LP-SS,[9][[6] propose to support Manchester coding, while the necessity of Manchester coding for LP-SS is questioned by[2][[14][[23].[2] provides simulation results which show no gain provided by Manchester coding for LP-SS.

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

- Support Manchester coding for LP-WUS

- Not support Manchester coding for LP-SS

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 |  | What is the downside of using MC for LP-SS.? |
| EUREOM |  | We support Manchester Coding for LP-WUS. However, we encourage companies to provide their views on Manchester Coding for M=4. In our opinion, encoding 2 bits jointly results in a 3dB SNR gain with minimal impact on PAPR. |
| Everactive | Y | Assuming we use an OOK sequence in the LP-SS that has an equal number of 1’s and 0’s |
| Xiaomi | Y |  |
| Qualcomm |  | This can be considered as the baseline. |
| TCL | Y |  |
| Spreadtrum | Y for LP-WUS, N for LP-SS | Manchester coding is just spreading or pulse shaping, instead of channel coding. It can be applied to LP-SS. |
| docomo | Y |  |
| Samsung | Y | For LP-WUS, we only support 1/2 Manchester coding. |
| OPPO |  | Manchester coding could make sure the equal number of 1 and 0. Support Manchester coding for LP-WUS. Open for support or not support Manchester coding for LP-SS.s |
| LGE | Y | Fine with the proposal |
| vivo  | Y  | Rely to NOKIA: according to our evaluation, LP-SS with Manchester coding does not improve performance while the coding leads to doubled overhead.  |

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

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

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

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

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

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

Regarding the M value for OOK-4, [4][18] 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.

On the other hand,[8] provides results indicating that OOK-4 with M=8 does not necessarily outperform OOK-4 with M=2 or 4. Also, a larger value of M results in a higher complexity for gNB and UE. Hence, M>4 should not be supported for LP-SS.[9] also provides evaluation results showing that the estimated timing offset can be restricted within by using , and the estimated timing offset error is limited within by using M=4, which is more than sufficient to ensure reliable detection of LP-WUS with [6] discusses the sync performance by using edge detection and states that if the unpredictable timing drift between two LP-SS occasions is much smaller than the maximum tolerable timing error, the cross-occasion timing filtering is feasible to track the main part of the timing error and as a result there is no much benefit in using a higher M value, they also propose that network configures the same OOK modulation scheme (i.e., OOK-1 or OOK-4) and same M for OOK-4 for LP-SS and LP-WUS transmissions in the cell.

#### [H][FL1] Proposal4.1-1 Confirm the working assumption with the following updates:

**Working Assumption**

Support the following options for LP-SS

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** |  | **Y/N** | **Comments** |
| Nokia1 |  | Y |  |
| Everactive |  | Y |  |
| Xiaomi |  | Y |  |
| Qualcomm |  | Y |  |
| TCL |  | Y |  |
| Spreadtrum |  | Y |  |
| HONOR |  | Y |  |
| docomo |  | Y |  |
| Samsung |  | Y |  |
| OPPO |  | Y |  |
| LGE |  |  | If M=4 is supported for LP-WUS, M=8 for LP-SS would be helpful for better timing synchronization performance. So, we hope to keep M=8. |
| vivo |  | Y | We can be open to M=8, but not M=16, because marginal gain of M=16 compared with M=8.  |

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

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

* Option 1: Do not specify the overlaid OFDM sequences(s)
* Option 2: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation without targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Option 3: Specify the overlaid OFDM sequence(s) targeting for OOK waveform generation and also targeting for sync and RRM measurement for OFDM-based LP-WUR using the overlaid sequence of LP-SS.
* Companies support option 1 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][21]
	+ Reuse existing transmissions (e.g., parts of SSB, TRS etc.) as ON symbols of LP-SS whenever possible[8]
	+ 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]
	+ 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]
	+ 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.[21]
* Companies support option 2 with the following reasons:
	+ Provide good OOK detection performance [3][6][19].
	+ If the overlaid OFDM sequence for the LP-SS does not carry information, network can configure fixed known sequence(s) [3][6].
	+ It is up to UE implementation for whether and how to use the overlaid sequence of LP-SS for RRM measurement and synchronization[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][20][24]
	+ 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][16]
	+ 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][13]
	+ 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. [13]

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

**[M][FL1]** **Proposal 4.2-1:** 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.

Note: it is up to UE implementation to use the overlaid sequence of LP-SS for RRM measurement and synchronization.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Qualcomm | Y | At least from RAN1 perspective, we do not mandate performance requirements for LP-SS overlaid sequence based RRM measurement and sync. |
| Spreadtrum |  | Option 3 is preferred. Overlaid OFDM sequence is there, and it is up to UE how to use it |
| LGE | Y | Support the proposal |
| vivo | N | We still prefer option 1. We don’t see any necessity for LP-SS with overlaid OFDM sequence.  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. LP-SS channel structure

|  |
| --- |
| **Agreement**Support to specify multiple binary LP-SS sequences for the ‘ON-OFF’ pattern:* The LP-SS sequence used in a cell is
	+ Option 1: a sequence is configured
	+ Option 2: a sequence is determined by predefined rule
	+ FFS: Whether both options will be supported or only one will be supported
* FFS: the number of LP-SS sequences

Note: Multiple sequences are used to differentiate LP-SS from different cells |

In last meeting, it has been agreed that multiple binary LP-SS sequences are supported, regarding the number of LP-SS sequences, companies proposed the following:

* 3 sequences:[6][27][12]
* around 4 sequences [8]
* >=3 sequences:[11]
* 8 or 16 sequences:[4]

Therefore, FL suggests the following:

#### **[H][FL1] Proposal 4.3-1** Further down-select the number of binary LP-SS sequences for the ‘ON-OFF’ pattern:

* Option 1: 3 sequences
* Option 2: 8 or 16 sequences

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** |  | **Y/N** | **Comments** |
| Nokia1 |  |  | As there is no actual detection associated to the LP/SS reception, the number of binary sequences would not seem to relate to complexity. Hence, we think higher number of sequences may be preferable for interference rejection. It would be good to consider in this context how would we achieve e.g. balanced amount of 0 and 1. |
| Xiaomi | Option1 |  | We're leaning toward option1, and we're willing to talk about other numbers if necessary. |
| Qualcomm |  |  | 3 can be baseline, the actual number of binary LP-SS sequences used by network should be close to this. |
| Spreadtrum | Option 1 |  |  |
| docomo |  | Y |  |
| Samsung |  |  | Before the decision on the exact value for the number of binary LP-SS sequence, we should discuss how to determine the appropriate number of LP-SS sequence. |
| OPPO |  | Y |  |
| LGE | Option 1 |  | Prefer Option 1. In our view, there is no specific reason to define large number of sequences for LP-SS. 3 sequences are sufficient to differentiate cells. |
| vivo |  |  | We slightly prefer option 1, but open for larger value, if 3 is not sufficient for interference randomization/cell confusion.  |

For the LP-SS sequence type for the ‘ON-OFF’ pattern,[8][24][[16][[6][[21][[17][[2] propose the existing pseudorandom sequences such as m-sequence or Gold sequence based LP-SS which provides both good auto-correlation and cross-correlation property, while[18] proposes to use low density sequences generated using waveform Option OOK-4 with M>1 for LP-SS design and[5] proposes to use Walsh sequence for common design of LP-SS and preamble. Regarding the length of sequence,[9][[2] propose to use 8 or 16, and[3] propose to use 128-length M sequence with M=8, 256-length M sequence with M=16 for SCS=30kHz,[12] propose to use 4 or 8 symbols. Considering the type of LP-SS sequence depends on inputs for this are quite limited currently, this could be further discussed later.

#### **[H][FL1] Proposal 4.3-2** The LP-SS sequence is based on the existing sequences, further down-select from the following:

* Gold sequence
* M sequence
* FFS: the length of LP-SS sequence

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** |  | **Y/N** | **Comments** |
| Nokia1 |  |  | Is the intention is to select among the possible m-sequence/gold sequence with balanced number of 1/0? |
| Everactive |  |  | These sequences have length 2^n-1, therefore does not have equal 0’s and 1’s. Will need a sequence with balanced 0 and 1, if we are not using Manchester encoding. |
| Qualcomm |  | Y |  |
| Spreadtrum |  | Y |  |
| docomo |  | Y |  |
| Samsung |  | Y |  |
| OPPO |  | Y |  |
| LGE |  | Y | Support the proposal |
| vivo |  |  | In addition, we think the computer searched sequence can also be considered. |

#### **[H][FL1] Proposal 4.3-3** The LP-SS sequence used in a cell is:

* Option 1: a sequence is configured

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** |  | **Y/N** | **Comments** |
| Nokia1 |  | Y |  |
| Xiaomi  |  | Y |  |
| Qualcomm |  | Y |  |
| Spreadtrum |  | Y |  |
| docomo |  | Y |  |
| Samsung |  | Y |  |
| OPPO |  | Y |  |
| LGE |  |  | Both Option 1 and Option 2 can be supported to configure LP-SS. Option 1 can be considered as a baseline, but when the configuration is not provided indicated to UE, Option 2 can be used |
| vivo |  | Y |  |

* 1. Periodicities of LP-SS

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

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

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 [13] [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 [28]

Based on above, FL suggests the following:

#### **[H][FL1] Proposal 4.4-1 LP-SS periodicity is configurable at least from the following:**

* 160ms
* 320ms
* 640ms
* 1280ms
* 2560ms

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 |  | We don’t see the need for 160ms. |
| Everactive |  | We prefer to eliminate 1280ms and 2560ms. These will place higher restrictions on the reference oscillator used in the LR. |
| Xiaomi |  | The need for 160ms needs to be clarified, it is recommended to add FFS before 160ms. |
| Qualcomm | Y |  |
| TCL | Y |  |
| Spreadtrum | Y |  |
| docomo |  | It is unclear whether all the values are supported or further down-selection will be done. |
| Samsung |  | We prefer to have this agreement for evaluation purpose at this stage. Further evaluation on the performance for synchronization and RRM measurement should be performed to decide the configurable values for LP-SS periodicity. |
| LGE | Y | Fine with the proposal |
| vivo | Y | Though we think currently only 320ms is clearly needed, we are open for discussion on multiple values and further down-selection may be needed.  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. The feasibility of time error and frequency error correction by OOK-based LP-WUR

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

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

For option 1 where neither frequency error correction nor clock calibration is assumed, the maximum frequency error value Fe depends on the options of oscillator and/or RTC as in TR.

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| **Oscillator max frequency error (Fe) [ppm], Oscillator frequency drift (F’) [ppm/s]****(Fe, F’)** | option 1: (200, 0.1)option 2: (50, 0.1)option 3: (10, 0.05)option 4: (5, 0.05)Other values are not precluded for studying, reported by companies |
| **RTC max frequency error (Fe) [ppm]** | 20RTC drift report by company |

For frequency error and/or time error correction by OOK-based LP-WUR, candidate solutions proposed by companies are listed as below:

* Option 2-1: MR can be used to correct the frequency error of LP-WUR[4][[2].

It depends on how frequent MR is waked up, e.g, if MR is statistically waked up once every 128s by assuming typical paging rate 1%, the maximum residual frequency error Fr for LR accumulated after 128s will be 12.8 ppm; while if MR performs relaxed RRM measurement with 8 times, the maximum residual frequency error Fr for LR accumulated after 8 I-DRX cycles can be reduced to 1.02ppm[2]. For both timing and frequency error evaluation purpose, the residual frequency error (Fr) can be <= 5ppm[4].

* Option 2-2: Frequency error correction by LR with parallel branches[4][8].

It requires specific receiver architecture, e.g., envelope receiver with parallel branches in frequency domain, and also, to reduce the impact of frequency selectivity of wireless channel, concentrate transmission power on a small number of subcarriers has been proposed[4]. Based on this option, if the working point of LP-WUS (e.g. 1% MDR) is within the range of 5dB~15dB and if the initial CFO is 10ppm, after the synchronization signal reception with 95 probability the residual frequency error can be within ±2.5 ppm.[4]

* Option 2-3: Frequency error/time error calibration by LR through clock calibration[6][[2][18]

Based on this option, the frequency error/time error can be calibrated by counting the clock cycles within a known period, i.e., the time duration between two adjacent LP-SS, and then the frequency error can be corrected through adding or subtracting clock cycles by comparing the counted number of clock cycles to the ideal ones within the same period. For example, if the interval between two LP-SS period corresponds to clock cycles but it takes the LP-WUR clock cycles to find the next LP-SS after the last one, a frequency error is identified in the clock The frequency drift is positive if and negative otherwise. The relative frequency drift is measured by .[6] However, this requires reference clock running or oscillator running during the period of calibration which may increase power consumption of LR, and the calibration resolution depends on the frequency of the reference clock or oscillator, which depends on UE implementation. With higher frequency, higher calibration resolution can be achieved, and vice vera.[2] For the oscillator frequency of 3.84MHz, an average of 6.5 ppm residual frequency error is assumed by including LP-SS detection errors.[18].

As summarized above, it is feasible for OOK-based LP-WUR to perform time error and/or frequency error correction depending options, however, the correction resolution highly depends on specific UE implementation, for example, in option 1, it requires the necessity of main radio assistance and the residual frequency error relies on the frequency of waking up; in option 2, it requires specific LP-WUR receiver architecture, and in option 3, it requires reference clock running or oscillator running during the period of calibration and the residual frequency error relies on the frequency of reference clock or oscillator.

Moderator has the following observation:

#### **Observation** 4.5-1 It’s feasible to perform frequency error and/or time error by OOK-based LP-WUR. How much the frequency error and/or time error can be corrected by OOK-based LP-WUR depends on different UE implementation.

Further, considering that the frequency error and/or time error of oscillator may have impact on both the sampling clock and the detection timing by OOK-based LP-WUR. It is crucial for OOK-based LP-WUR to estimate and correct the frequency error and/or time error to a certain extent. Thus, FL suggests:

#### **[H][FL1] Proposal 4.5-1** The LP-WUS and LP-SS design shall assume the residual/initial frequency error is up to X ppm for OOK-based LP-WUR. X to be down-selected between:

* Option 1: X = [5] ppm
* Option 2: X= maximum frequency error Fe which can be up to 20ppm.

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** |  | **Y/N** | **Comments** |
| Nokia1 |  |  | We prefer option 1. |
| Everactive |  | Option 1 | This is assuming the LR has already calibrated it’s reference oscillator.  |
| Xiaomi |  | Option2 | Whether MR Can correct LR time-domain offset or frequency-domain offset actually depends on the implementation of UE. In this case, Option2 is more reasonable. |
| Qualcomm |  | Y | Both Option 1 and Option 2 are possible depending on stability of the oscillator or RTC and whether/how frequency can be compensated.  |
| docomo |  | Y | Prefer option1. |
| Samsung |  | Y |  |
| OPPO |  | Option2 | The residual/initial frequency error of LP-SS and LP-WUS should be considered separately.  |
| vivo |  | Y |  |

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

In last meeting, RAN1 agreed to support X =11 or 12 PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.

|  |
| --- |
| **Agreement**From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz* X to be down-selected between 11 and 12 PRBs
* FFS the number of PRBs for 15kHz
* FFS if other number of PRBs needed, for LP-SS and LP-WUS with a channel bandwidth equal or less than 5MHz

FFS: Whether the above is applicable to FR2 |

Companies view on X values for 30kHz SCS is summarized as below.

* X=11: [4], [8], [9], [19], [23]
* X=12: [4], [6], [3], [18], [15], [23], [11], [27]

|  |  |
| --- | --- |
|  | Benefit  |
| X=11 | 1. Lower overhead, while similar performance as 12 PRB
2. Aligned BW of LP-WUS and SSB to simplify receiver design
3. Same value as existing maximum transmission bandwidth configuration for 5MHz channel bandwidth
 |
| X=12 | 1. Wider BW provide better performance
2. Easier to scale to other value
3. Lower UE power consumption due to shorter time duration
 |

Considering performance difference of 1 PRB would be none material while having same value as existing maximum transmission bandwidth configuration is quite critical for LP-WUS in a 5MHz channel bandwidth, FL proposes to go with X=11 PRBs.

Regarding the FFS for 15kHz, company views are split between same number of PRBs or same bandwidth as 30kHz SCS.

* Same number of PRBs: [4], [8], [9], [16], [25], [11], [6] for FR2
* Same bandwidth: [2], [3], [5], [15], [22], [27], [7], [6] for FR1.

|  |  |
| --- | --- |
|  | Benefit |
| Same number of PRBs as 30kHz SCS: | 1. simplify the signal design, e.g., same length of overlaid OFDM sequence
2. Lower LP-WUS overhead
3. Applicable for all supported channel bandwidth, similar as PSS/SSS for below 5MHz channel bandwidth
 |
| Same bandwidth as 30kHz SCS | 1. better performance.
2. Easier LP-WUR implementation for filter design
 |

[H][FL1] Proposal 5-1: Update agreement in last meeting as below:

From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz

* X ~~to be down-selected between~~ = 11 ~~and 12~~ PRBs
* ~~FFS~~ the number of PRBs for 15kHz is 11 PRBs
* FFS if other number of PRBs needed, for LP-SS and LP-WUS with a channel bandwidth equal or less than 5MHz

FFS: Whether the above is applicable to FR2

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Nokia1 | Y |  |
| Everactive | N | We do not agree with 11 PRBs for 15kHz SCS. This will cut the bandwidth in half, to 2.5MHz.  |
| Xiaomi |  | General fine with the proposal. We suggest adding a note as follows: Whether to support 11 PRBs for LP-WUS and LP-SS with SCS 30kHz in 5MHz should be subject to discussion regarding the guard band in RAN4. |
| Qualcomm | N | For SCS=15kHz we prefer to keep the bandwidth same as or similar to that of SCS=30kHz. |
| TCL | N | 12 PRB with SCS 30KHz can be easily accommodated in 5MHz and we support to keep x = 12 PRB |
| HONOR | Y |  |
| docomo | Y |  |
| Samsung | Y |  |
| LGE | Partial Y | For 30 kHz, we support X=11 PRB for CBW >= 5MHz.For 15 kHz, we also prefer to keep the same bandwidth as that for 30 kHz. |
| vivo |  | We can be fine with 11 PRBs for 30kHz SCS, considering minor performance differenceBut for 15kHz, we prefer to keep same bandwidth as 30kHz, e.g., 22 PRBs.  |

1. SNR determination
	1. Collection of companies’ reported SNR

|  |
| --- |
| **Conclusion:** For calibration purposes, companies are encouraged to report the SNR to achieve the coverage of PUSCH for message3, at least with the following assumptions: * Carrier frequency: 2.6 GHz
* The number of Tx chains: 1
* MIL of MSG 3: use the average one in R17 coverage, i.e.,153.51 dB for non-redcap UE
* Transmit antenna gain correction factors for WUS: up to company report
* Noise Figure: All three values +2dB, +5dB, +8dB on top of NF of MR (7dB) are to be reported, SNR for different assumptions on NF are determined separately
 |

According to the conclusion agreed in last meeting, companies’ reported SNR and the corresponding antenna correction factor are summarized as below for different values of noise figure, respectively.

NF of LR: 7dB (NF of MR) +2dB

* -4.04dB≤ SNR ≤- 4dB: 2 samples
* -0.05dB ≤ SNR ≤ 2.28dB: 4 samples
* 5.28dB ≤ SNR ≤7.95dB : 3 samples
* **Median SNR value: 1.77dB**



NF of LR: 7dB (NF of MR) +5dB

* -6.5dB≤ SNR ≤ -6.41dB: 2 samples
* -3.19dB ≤ SNR ≤ -0.1dB: 7 samples
* 2.6dB ≤ SNR ≤5.58dB: 7 samples
* **Median SNR value: -0.26dB**



NF of LR: 7dB (NF of MR) +8dB

* -9.05dB≤ SNR ≤ -9dB: 2 samples
* -5.07dB ≤ SNR ≤ -2.75dB: 5 samples
* -0.05dB ≤ SNR ≤2.94dB: 4 samples
* **Median SNR value: -3.23dB**



***[H][FL1]*** *Companies are encouraged to provide more inputs into the excel sheet****.***

* 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
* Time domain repetition [4][[20][NEC][17][[26][[12]
* Spatial diversity with time domain repetition [4], which requires to be used with time domain repetition and precoder is transparent to OOK based receiver
* Frequency domain diversity with time domain repetition [4]
* Time domain spreading code[4]
* Multiple beam transmissions/beam sweeping [2][12][16][30][26]

***[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*

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
| Qualcomm | Y | At least time domain repetition can be considered for LP-WUS and LP-SS. |
|  |  |  |
|  |  |  |
|  |  |  |

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  |  |  |  |  |  |  |

* 1. RAN1 #116bis

**Agreement**

For OOK-4 with M >1, support M=2 & M=4 (working assumption) for LP-WUS.

* FFS whether value of M depends on SCS
* FFS M=1 for OOK-4

**Agreement**

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

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

**Agreement**

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

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

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

**Agreement**

From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz

* X to be down-selected between 11 and 12 PRBs
* FFS the number of PRBs for 15kHz
* FFS if other number of PRBs needed, for LP-SS and LP-WUS with a channel bandwidth equal or less than 5MHz

FFS: Whether the above is applicable to FR2

**Agreement**

For timing error evaluation purpose, the following two options for residual frequency error are considered:

* Option 1: The maximum frequency error (Fe) of RTC/oscillator is assumed, companies report Fe value and the applied LP-WUR type.
* Option 2: The residual frequency error (Fr) after frequency error correction/clock calibration by LR or after assistance from MR is assumed, companies report Fr value, how to achieve it and the applied LP-WUR type.

**Agreement**

For frequency error evaluation purpose, the following two options for residual frequency error are considered:

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

**Working Assumption**

Support the following options for LP-SS

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

FFS how OOK-1 and OOK-4 are specified

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

**Agreement**

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

* Option 1: A bitmap with each bit corresponding to [one or more] subgroups
* Option 2: A codepoint value corresponding to one or more subgroup(s)
* Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s)
* Combination of above options are not precluded
* FFS how to carry LP-WUS information, e.g., by encoded bits (with/without CRC) and/or by OOK sequence selection for ‘ON-OFF’ pattern for OOK symbols of LP-WUS.
* FFS how to carry LP-WUS information by overlaid OFDM sequences.
	+ It doesn’t preclude considering the configuration where a single candidate overlaid OFDM sequence is used
* Other options are not precluded

**Agreement**

Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, at least consider the following：

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

**Conclusion:**

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

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

**Agreement**

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

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

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

**Agreement**

Regarding the overlaid OFDM sequence(s) of LP-WUS, consider the following options:

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

Other options are not precluded.

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27. R1-2404966, Discussion on LP-WUS and LP-SS design, Sharp
28. R1-2405254, On LP-WUS and LP-SS design, Nordic Semiconductor ASA
29. R1-2404942, Discussion on LP-WUS and LP-SS design, Lenovo
30. R1-2404320, Discussion on LP-WUS and LP-SS design, Everactive
31. Appendix : Proposals from contributions

**R1-2404186 vivo**

**Proposal 1: Support unified specification for OOK-4 and OOK-1**

* **Support LP-WUS waveform generation based on DFT.**
* **Support M=1, 2 and 4 for LP-WUS and LP-SS. FFS M=8 for LP-SS.**
* **Support LP-WUS and NR signal multiplexing before IFFT.**

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

* **Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence.**
* **Option 3: One sequence is selected from multiple candidates overlaid OFDM sequences on one or more OOK ‘ON’ symbols, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s).**
	+ **Option 3-1: 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 3-2: The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by the overlaid OFDM sequence(s)**

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

**Proposal 4: Overlaid OFDM sequence design targets time domain sequence generation using existing NR sequence.**

**Proposal 5: Overlaid OFDM sequence design at least for LP-WUS shall allow OFDM-based LP-WUR processing in at least time domain.**

* **The sequence can also be detected in frequency domain, but no optimization for frequency domain detection**

**Proposal 6: Overlaid OFDM sequence is on each OOK ON symbol.**

**Proposal 7: Up to 4 or 8 candidates overlaid OFDM sequences per OOK ON symbol for information conveying can be supported.**

**Proposal 8: Prioritize existing NR sequences, e.g., ZC-sequence, m-sequence or** **gold sequence.**

**Proposal 9: Do not specify overlaid OFDM sequence.**

**Proposal 10: Support bitmap for RRC idle/inactive state, where each bit is corresponding to one subgroup.**

**Proposal 11: Support a flexible frame work for bitmap and codepoint for RRC connected state. A LP-WUS can include X bits for codepoint plus Y bits for bitmap, where X and Y is configurable.**

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

**Proposal 12: 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 13: For multiple binary LP-SS sequences,**

* **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.**
	+ **Metrics for good auto-correlation can be maximize (1st peak cor-1st troughs near the 1st peak) or maximize (1st peak cor/2nd largest peak cor within the sliding window), depending on the assumption of sliding window size**
* **The number of LP-SS sequences can be e.g., 3 or 6 to differentiate different cells based on further evaluation. gNB configures one of the sequences for a cell.**

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

**Proposal 15: Support same LP-WUS/LP-SS bandwidth for 15kHz and 30kHz, i.e., 2\*X PRBs and X PRBs respectively. Further discuss X=11 or 12 after determination of M value for LP-SS.**

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

**Proposal 18: Consider the SNR values below for LP-WUS/LP-SS to achieve the coverage of PUSCH for message3 in table 7.**

 **Table 7 Proposed values for LP-WUS/LP-SS coverage**

|  |  |  |  |
| --- | --- | --- | --- |
| **NF** | **Assumed Antenna gain correction factors for MSG3 (MIL of 153.51dB without retransmission):**  | **Assumed Antenna gain correction factors for LP-WUS/LP-SS:**  | **SNR** |
| 7+2dB | 0dB | 2.67dB | 5.28 |
| 7+5dB | 0dB | 2.67dB | 2.91 |
| 7+8dB | 0dB | 2.67dB | 0.27 |

**R1-2404563 ZTE, Sanechips**

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

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

***Proposal 3: OFDM sequence can only be overlaid on the OOK-ON symbols.***

***Proposal 4: For time domain based OOK-1/OOK-4 waveform generation, OFDM sequence should be added before DFT operation and it is generated per OOK-ON symbol.***

***Proposal 5: For OFDM sequence based LP-WUS, adopting the OFDM sequence receiver with FFT as the baseline for detection performance evaluation.***

***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: Support 12 PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz***

* ***24 PRBs for SCS=15kHz***

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

* ***Proposal 9: For binary sequence carried by LP-SS, at least the following design principles should be considered:***
* ***Good auto-correlation and lower cross-correlation features***
* ***At least one bit ”1” is transmitted in M OOK symbols within one OFDM symbol***
* ***Restricted the length of consecutive bit “0”***

***Proposal 10: 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 11: LP-SS detection with sliding window should be used as baseline for evaluating the detection performance.***

***Proposal 12: For synchronization, the binary sequence of LP-SS based on OOK-1 or OOK-4 with M=1 is not suggested due to the worse sync performance.***

***Proposal 13: For the design of LP-SS, the following structures are prioritized***

* ***SCS=30kHz, OOK-4 with M=8, 128-length M sequence***
* ***SCS=30kHz, OOK-4 with M=16, 256-length M sequence***
* ***Phase randomized Gold sequence is used as scrambling code to improve detection performance***

***Proposal 14: 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 15: At least {160,320,640,1280,2560}ms should be considered for LP-SS periodicity.***

***Proposal 16: Cell specific information can be carried via LP-SS.***

***Proposal 17: LP-Preamble is supported and can be added before LP-WUS for further time error correction.***

***Proposal 18: For OOK based LP-WUS, at least OOK-4 with M=2 and M=4 are supported.***

***Proposal 19: How to solve the impact of time error caused by LP-WUR oscillator on OOK-1/OOK-4 detection performance should be studied.***

***Proposal 20: Modify option 1 and option 1-2 as follows***

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

***Proposal 21: Regarding the overlaid OFDM sequence(s) of LP-WUS,***

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

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

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

* ***8-Length CRC is a starting point, for example, for a CRC length of L=8***

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

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

***Proposal 25: Compared to msg3, the additional correction factor candidates could be {0, 1, 2} dB for LP-WUS.***

***Proposal 26: For overlaid OFDM sequence design, study with existing Gold sequence, M-sequence and ZC sequence as starting point.***

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

***Proposal 27: Phase randomized Gold sequence should be supported for LP-WUS and LP-SS if the OFDM sequence is used to improve the OOK based LP-WUR detection performance.***

***Proposal 28: 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 29: LP-SS could be used as a part of LP-WUS to save NW resources.***

***Proposal 30: For LP-WUS, at least the design of structure, payload size and carried information should be considered separately for IDLE/INACTIVE and CONNECTED modes.***

**R1-2403948 Huawei, HiSilicon**

1. ***For OOK-4, support M=4 for both 15kHz SCS and 30kHz SCS, and confirm the working assumption for M=4.***
2. ***OOK-1 is specified as a special case of OOK-4 with M=1.***
3. ***For LP-WUS, UEs are configured to monitor one or multiple LP-WUS occasions and each occasion can convey a block of information bits.***
* ***The bit length of the block of information is configurable or determined only from RRC configurations.***
* ***One LP-WUS occasion comprises of one or multiple OFDM symbols.***
	+ ***Note: The OFDM symbol refers to the symbols after the processing “iFFT+CP” in S7.2.1.1 of TR 38.869***
* ***FFS details of the pre-DFT sequences that refers to the input to the DFT/LS processing block in S7.2.1.1 of TR 38.869***
	+ ***The size of pre-DFT sequence set***
	+ ***Sequence generation/selection***
* ***FFS the mapping from a block of information bits to pre-DFT sequences and OFDM symbols***
	+ ***FFS: whether the series of pre-DFT sequences to wake up a UE only depends on UE-specific predetermined information***
1. ***It is preferred to specify the overlaid sequence OOK-1 and OOK-4 in time domain.***
2. ***Regarding the overlaid OFDM sequence(s) of LP-WUS, If overlaid OFDM sequence does not carry information, option 1-2 is supported for potential inter-cell interference mitigation.***
3. ***Regarding the overlaid OFDM sequence(s) of LP-WUS, both Option 2-1 and Option 2-2 are supported.***
	* ***In order to reduce resource overhead, transmission duration of a LP-WUS targeting to wake up OFDM based receiver can be shorter than the transmission duration required for ED based receiver.***
4. ***Further discuss and adopt sequence(s) considering the following aspects:***
	* ***Sequence with good auto-correlation property and cross-correlation property***
	* ***How to control the interference from LP-WUS transmitted from neighboring cells***
5. ***ZC sequences are considered as a starting point for the design of overlaid sequence(s).***
6. ***Clarify how*** ***Gold sequence and M-sequence act as overlaid OFDM sequences, e.g. mapping to the phase information of a QPSK/QAM sequence.***
7. ***Walsh sequence, DFT/FFT sequence and Chirp sequence are not be further considered as overlaid OFDM sequence for the following reason:***
* ***Walsh sequence has poor auto-correlation property, and it is questionable how Walsh sequences can be used as overlaid OFDM sequence.***
* ***DFT/FFT is sensitive to time error and its transmit energy is limited due to its short duration in time domain.***
* ***Chirp sequences can’t be used to mitigate interference between cells.***
1. ***Pulse shape and/or spectrum shape are also considered in the design/selection of overlaid sequence(s).***
2. ***Support overlaid sequence(s) with a number of zero value samples at the beginning and the end of the sequence to have a concentrated waveform for time domain pulse shaping of LP-WUS.***
3. ***For 15kHz SCS, support the same number of PRBs as 30kHz SCS for LP-WUS and LP-SS.***
4. ***For 30kHz SCS, support 12 PRBs for LP-WUS and 11 PRBs for LP-SS.***
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. ***Further discuss whether and how to align the essential assumptions to calculate MIL, e.g. antenna correction factor.***
7. ***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.***
8. ***Time domain repetition and*** ***transmit diversity by precoder cycling are considered to improve the performance of LP-WUS.***
9. ***Coverage recovery schemes that exploits time / frequency diversities are considered.***
10. ***Binary spreading sequences are considered to multiplex WUSs on the same time-frequency resource and to improve the BLER.***
11. ***Regarding the LP-WUS information for idle/inactive UEs, support the codepoint mapping method, i.e. option 2 and/or option 3.***
* ***It is supported that the same LO resources can be monitored by UEs from different PO’s.***
* ***Note: multiple paging signals for respective UEs can be conveyed by multiple MO’s.***
1. ***Regarding the LP-WUS information for idle/inactive UEs, support the codepoint mapping method, i.e. option 2, option 3 and/or option 4.***
2. ***As the starting point, the waveform of LP-SS can have similar design as LP-WUS, including at least the following aspects：***
	* ***pulse shaping methods, including the concentrated waveform and the spectrum adjustment***
	* ***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***
3. ***Consider LP-SS specific design requirement, including at least larger guard band, and number of OOK symbols per OFDM symbol up to M=8.***
4. ***The design of LP-SS should consider the CP impact and the length of binary-valued sequence to generate LP-SS.***
5. ***For the OOK sequence of LP-SS, consider at least the following design principles***
	* ***Binary sequence with good auto-correlation property***
	* ***Limited length of consecutive '0's***
	* ***'0's and '1's inside the binary sequence are balanced***
6. ***The number of binary sequences for LP-SS can be 8 or 16.***
7. ***Some LP-SS transmissions are used for frequency error correction. For such LP-SS, transmission energy is concentrated on a narrow band for such LP-SS transmissions.***
8. ***For both timing and frequency error evaluation purpose, the residual frequency error (Fr) can be <= 5ppm by frequency error correction by LR or after assistance from MR.***
9. ***A set of candidate values for LP-SS periodicity can be defined, which are not larger than 320ms.***
10. ***Preamble of LP-WUS is not supported.***

**R1-2404410 CATT**

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

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

**Proposal 3: Specify a configurable M value for supporting both OOK-1 and OOK-4 waveform. OOK type is OOK-1 for M=1 and OOK-4 for M>1, respectively.**

**Proposal 4: 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.**

**Proposal 5: The IFFT size of LP-WUS should be the 2x sub-multiple of IFFT size of system bandwidth, the NR channel decoding performance would not encounter the ICI and be degraded after the IFFT processing.**

**Proposal 6: The overlaid OFDM sequence should carry all information bits of LP-WUS in the design principle of the information carried by OFDM sequence and depending on the performance of the detection performance of the OOK-based LP-WUR whether the LP-WUS and NR signals/channels are multiplexed before or after IFFT.**

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

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

**Proposal 9: Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s) should be supported to obtain better detection and less resource overhead comparing with option 1.**

**Proposal 10: Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s) should be supported for both ON-OFF pattern of OOK symbols and overlaid OFDM sequence.**

**Proposal 11: Walsh sequence has the best detection performance with error correction capability through simple addition operation for LP-WUS information module.**

**Proposal 12: For RRC\_IDLE/INACTIVE mode, the sequence based LP-WUS with orthogonal sequence grouping should be sufficient in indicating the paging subgroup or bundling subgroups.**

**Proposal 13: 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 14: 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 15: 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 16: 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 17: 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.**

**Proposal 18: The number of PRB should be scaled proportionally for different SCS within a fixed bandwidth, which would not degrade the coverage of LP-WUS and LP-SS for narrow bandwidth under larger SCS.**

**R1-2405164 Qualcomm Incorporated**

***Proposal 1: Support time domain signal (i.e., S1) for LP-WUS with OOK-4.***

***Proposal 2: Confirm the Working Assumption that OOK-4 with M=4 is supported for LP-WUS.***

***Proposal 3: Network configures a single SCS for LP-WUS within the channel bandwidth.***

***Proposal 4: Support multiple candidate overlaid OFDM sequences for LP-WUS when the overlaid sequence carries no information of LP-WUS.***

***Proposal 5: RAN1 defers the discussion on whether and how OFDM-based LP-WUR can obtain the whole LP-WUS information by OOK ON/OFF pattern and overlaid OFDM sequences until how information is carried by LP-WUS OOK symbols is determined.***

***Proposal 6: Support the option that overlaid sequences are specified in each OOK ON symbol.***

***Proposal 7: Overlaid OFDM sequence is selected from Gold sequence, M-sequence and ZC sequence.***

***Proposal 8: Support sequence-based LP-WUS design with one sequence associated with one or multiple UE subgroups***

* ***At most one sequence is transmitted in each LP-WUS MO within the LO***
* ***In the LP-WUS MO, gNB may transmit a UE subgroup specific sequence or a common sequence***
* ***Multiple LP-WUS MOs can be configured in each beam in the LO, different LP-WUSs can be transmitted in these MOs to wake up different UE subgroups.***

***Proposal 9: The maximum number of UE subgroups associated with a LP-WUS monitoring occasion is 8. Network configures the actual number.***

***Proposal 10: Support preamble in the LP-WUS.***

***Proposal 11: Manchester coding is adopted for the sequence-based LP-WUS OOK symbols.***

***Proposal 12: 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 13: How OOK-1 and OOK-4 are specified is irrespective of LP-SS or LP-WUS.***

***Proposal 14: Network configures the LP-SS binary sequence in broadcast information in the cell. For LP-SS evaluation in the multi-cell scenario, 3 binary sequences are assumed.***

***Proposal 15: Support to use M-sequence for the generation of LP-SS OOK symbols.***

***Proposal 16: Overlaid OFDM sequence(s) is supported for the LP-SS***

* ***Network configures the overlaid sequence(s) in the cell***
* ***Performance requirements are not specified for RRM measurement and synchronization based on LP-SS overlaid OFDM sequence for OFDM-based LP-WUR.***

***Proposal 17: Support 12 PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.***

* ***This can be updated based on RAN4 conclusion on minimum number of guard RBs.***

***Proposal 18: Support 24 PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.***

***Proposal 19: For FR2, support 12 PRBs for LP-WUS and LP-SS (blanked guard RBs are not included).***

***Proposal 20: Do not specify the overlaid OFDM sequence for channel bandwidth less than 5MHz.***

***Proposal 21: The required SNR for LP-WUS to achieve the coverage of PUSCH for message 3 under the reference conditions concluded in RAN1 #116bis are provided in the following table***

* ***Antenna gain correction factor at antenna gain component 2 of transmitter is 8dB.***

|  |  |  |  |
| --- | --- | --- | --- |
| ***Bandwidth for LP-WUS signal (MHz)*** | ***NF for LP-WUR (dB)*** | ***Gain of antenna element (dBi) assumed for LP-WUR*** | ***Required SNR (dB)*** |
| ***4.32MHz with12 RBs for 30kHz SCS*** | ***15*** | ***0*** | ***-5.06 for Non-RedCap*** |
| ***4.32MHz with12 RBs for 30kHz SCS*** | ***12*** | ***0*** | ***-2.42 for Non-RedCap*** |
| ***4.32MHz with12 RBs for 30kHz SCS*** | ***9*** | ***0*** | ***-0.05 for Non-RedCap*** |

**R1-2404124 Samsung**

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

* **Do not consider for OFDM-based LP-WUR to obtain the whole information bits by OOK ON/OFF pattern (option 1-2).**

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

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

**Proposal 3: Support to specify multiple candidates of OFDM sequence to carry multi-bit information on one ON 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: how to configure and generate the multiple candidates of OFDM sequence corresponding to information bits for UEs.**
* **FFS: whether to consider the position of ON pulse as the information at the OFDM-based LP-WUR (down-selection between option 2-1 and 2-2).**

**Proposal 4: Suggest to further down-select options in the agreement regarding to the overlaid OFDM sequence(s) of LP-WUS as Table 1.**

**Proposal 5: For the study purpose, the existing sequence types in NR signal should be a baseline for the performance comparison of the new type of sequences.**

* **Baseline sequence: M-sequence, Gold sequence, Zadoff-Chu sequence.**
* **Sequences excluding the baseline sequence are considered as the new type of sequences. Proponent should compare the performance of the new type of sequence with that of the baseline.**
* **New type of sequences shall not be considered unless essential issue is figured out by using baseline sequence.**

**Proposal 6: 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 at the gNB.**
* **Approach 2: Specifying the sequence transmitted in the time domain directly used at the OFDM-based LP-WUR.**
* **Note: For both approach 1 and 2, the additional blocks such as DFT/LS and truncation before IFFT processing are not specified. Whether to use the additional block and how to generate the specified values is up to gNB implementation.**

**Proposal 7: For the supported M value of OOK-4 with M>1,**

* **Both M = 2 and M = 4 are supported for 15kHz SCS;**
* **Only M = 2 is supported for 30kHz SCS.**
* **FFS: the target residual timing/frequency error before the reception of LP-WUS to achieve the target coverage (i.e., the robustness against to time/frequency error considering the target coverage achievement).**

**Proposal 8: Support 1/2 Manchester coding for LP-WUS.**

**Proposal 9: The LP-WUS information should be carried by encoded bits for OOK-based LP-WUR.**

**Proposal 10: Further study is necessary for the down-selection between bitmap-based indication and codepoint-based indication for a LP-WUS considering the following aspects:**

* **The number of subgroup for the single LP-WUS, the maximum information bit size for the single LP-WUS, the amount of resource, and the subgroup paging rate for inactive/idle UEs.**

**Proposal 11: Target FAR should be decided to design LP-WUS**

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

**Proposal 12: The following two approaches can be further discussed to decide the LP-WUS/LP-SS bandwidth with 15kHz SCS.**

* **Approach 1: the same bandwidth to LP-WUS/LP-SS with 30kHz SCS;**
* **Approach 2: the same number of PRBs to LP-WUS/LP-SS with 30kHz SCS.**

**Proposal 13: 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 14: 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 15: To determine the binary LP-SS sequence for the cell, the sequence is configured by the gNB among the multiple binary LP-SS sequences (option 1 in the agreement regarding to the multiple binary LP-SS sequence).**

**Proposal 16: Further discussion is needed on how to determine the appropriate number of binary LP-SS sequences (e.g., the assumption for inter-cell interference in LP-SS performance evaluation).**

**Proposal 17: The following aspects should be considered to decide the periodicity of LP-SS.**

* **The target residual timing error before LP-WUS reception to achieve the target coverage.**
* **Serving cell RRM measurement accuracy by OOK-based LP-WUR.**

**Proposal 18: 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.**

**R1-2405374 Ericsson**

[**Proposal 1 Following principles should be considered for LP-WUS and LP-SS design**](#_Toc166250284)

[**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.**](#_Toc166250285)

[**b. It should be possible to multiplex the LP-WUS/LP-SS with other NR transmissions in time or frequency domain without causing interference.**](#_Toc166250286)

[**c. It should be possible to reuse any unused LP-WUS time and frequency resources for other transmissions.**](#_Toc166250287)

[**Proposal 2 Paging misdetection performance of the UE should not be impacted when LP-WUS is used by the UE for power savings.**](#_Toc166250288)

[**Proposal 3 Different SCS case for LP-WUS and other NR transmissions in the same CP-OFDMA symbol is not considered further.**](#_Toc166250289)

[**Proposal 4 Including a preamble part before the data part of LP-WUS transmissions should be considered.**](#_Toc166250290)

[**Proposal 5 Following should be considered for LP-WUS payload mapping to OOK symbols:**](#_Toc166250291)

[**a. It should be possible to flexibly map different payload sizes (e.g., 1 to 8 bits) to flexible number of OFDM symbols that are available for LP-WUS transmission.**](#_Toc166250292)

[**b. Existing encoding and rate-matching approaches should be reused as much as possible.**](#_Toc166250293)

[**c. Manchester encoding can be considered before mapping coded bits to OOK symbols.**](#_Toc166250294)

[**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.**](#_Toc166250295)

[**Proposal 7 To generate OOK-1, existing NR sequences should be reused to minimize impact on the gNB transmitter and specifications.**](#_Toc166250296)

[**Proposal 8 With the support of OOK-1, OOK-4 with M=1 should not be supported.**](#_Toc166250297)

[**Proposal 9 For OOK-4, the value of M should not depend on the SCS in FR1.**](#_Toc166250298)

**Proposal 10 The overlaid OFDM sequences for WUS should be based on the existing NR sequences (among Gold sequence, M-sequence, ZC sequence, QAM symbol-based sequence) to minimize impacts on the gNB transmitter and specifications.**

[**Proposal 11 For OFDM sequence overlaid on OOK-1, support Gold sequences.**](#_Toc166250300)

[**Proposal 12 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).**](#_Toc166250301)

[**Proposal 13 WUS payload size should be at most 8 bits in Idle/Inactive. Similar payload size should be considered for Connected mode.**](#_Toc166250302)

[**Proposal 14 For channel bandwidth of at least 5 MHz, the WUS bandwidth should be 11 PRBs for both 15 kHz and 30 kHz SCS corresponding to 1.98 MHz and 3.96 MHz, respectively.**](#_Toc166250303)

[**Proposal 15 For channel bandwidth less than 5 MHz, the WUS bandwidth should be 11 PRBs for 15 kHz SCS.**](#_Toc166250304)

[**Proposal 16 For enabling energy efficient LP-SS transmissions from gNB, it should be possible for gNB to transmit LP-SS without using a specific predefined overlaid OFDM sequence.**](#_Toc166250305)

[**Proposal 17 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.**](#_Toc166250306)

[**Proposal 18 Consider following values for configuring LP-SS periodicity: 320ms, 640ms, 1280ms, 2560ms, 5120ms, 10240ms.**](#_Toc166250307)

[**Proposal 19 The LP-SS OOK sequence should be generated based on the existing pseudorandom sequences such as m-sequence or Gold sequence where 1 and -1 are mapped to ON and OFF OOK symbols respectively.**](#_Toc166250308)

[**Proposal 20 For LP-SS, confirm the working assumption from RAN1#116bis. For the FFS on M values for OOK-4, M=1,8,16 with OOK-4 should not be supported. Same SCS should be used for LP-SS, LP-WUS, and other NR transmissions in the same CP-OFDMA symbol.**](#_Toc166250309)

**R1-2404705 Nokia Shanghai Bell**

[**Proposal 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 MHz for evaluations.**](#_Toc166234160)

[**Proposal 2: The location of LP-WUS/LP-SS within carrier BW should be flexible and configurable by the NW.**](#_Toc166234161)

[**Proposal 3: The BW of LP-SS/LP-WUS shall be the same as PSS/SSS, i.e., 11 PRBs, enabling common LP-WUS design for all channel bandwidths.**](#_Toc166234162)

[**Proposal 4: If the NW supports more than one SCS for NR transmission, then the choice of SCS used for LP-WUS should be left to the NW that shall be informed to the UE.**](#_Toc166234163)

[**Proposal 5: Unified generation scheme should be considered for OOK waveform.**](#_Toc166234164)

[**Proposal 6: Specify the OOK waveform in the frequency domain for a single ON duration pulse and overlay sequence as the position of ON pulse does not alter the spectral shape of the signal.**](#_Toc166234165)

[**Proposal 7: Consider OOK waveform with as the baseline for evaluations as it favours both envelope and sequence detectors with or without the use of Manchester encoding.**](#_Toc166234166)

[**Proposal 8: The use of Manchester encoding for OOK based scheme should be considered if there is no preamble field in LP-WUS frame structure.**](#_Toc166234167)

[**Proposal 9: Evaluate further the options of applying pulse shaping in the ON duration of OOK symbols accounting impact on the gNB transmission.**](#_Toc166234168)

[**Proposal 10: Use of common the time-frequency resources for LP-WUS irrespective of the device type used as LR should be enabled, i.e., LR type specific LP-WUS transmission should be avoided.**](#_Toc166234169)

[**Proposal 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., , used by OOK signal.**](#_Toc166234170)

[**Proposal 12: A relationship between the different sequences used in neighboring 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.**](#_Toc166234171)

[**Proposal 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.**](#_Toc166234172)

[**Proposal 14: Consider a single ZC sequence with multiple cyclic shifts to carry overlay information as it is easier to decode at LR and the cross-correlation is merely an autocorrelation performance. Additionally, it facilitates the unified design.**](#_Toc166234173)

[**Proposal 15: RAN1 should evaluate whether LP-WUS requires a preamble or not and if required, the preamble design should be discussed.**](#_Toc166234174)

[**Proposal 16: RAN1 should evaluate whether LP-WUS requires a CRC field or not and if required, then the size and the polynomial used should be defined.**](#_Toc166234175)

[**Proposal 17: RAN1 should evaluate the content and the structure of LP-WUS payload.**](#_Toc166234176)

[**Proposal 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.**](#_Toc166234177)

[**Proposal 19: RAN1 should be consider the trade-off between system footprint and coverage when determining the LP-WUS payload size .**](#_Toc166234178)

[**Proposal 20: Unified waveform design between LP-SS and LP-WUS should be prioritized.**](#_Toc166234179)

[**Proposal 21: The modulation order used by LP-SS should be restricted to with Manchester encoding to ensure better coverage and facilitate accurate measurements for RRM purposes.**](#_Toc166234180)

[**Proposal 22: As the LP-SS benefit all kind of LR types, overlaying a sequence in the ON duration and aligning the waveform design to LP-WUS should be selected. Thus, we prefer option 2 to assist synchronization if not RRM.**](#_Toc166234181)

[**Proposal 23: We suggest discussing if LP-SS beams shall be time multiplexed in different beam directions.**](#_Toc166234182)

[**Proposal 24: 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.**](#_Toc166234183)

[**Proposal 25: To ensure better coverage, detection, and timing estimation, the LP-SS should be designed with Manchester encoded OOK scheme using .**](#_Toc166234184)

[**Proposal 26: A minimum of LP-SS samples are required to estimate LP-RSRP reliably irrespective of the operating SNR.**](#_Toc166234185)

[**Proposal 27: The LP-SS payload shall have at least or bits for and , respectively together with Manchester encoding to obtain reliable LP-RSRP or LP-RSRQ estimation in the fading channel.**](#_Toc166234186)

[**Proposal 28: Consider for LP-SS with at least 4 symbols to ensure reliable estimation in each LP-SS MO.**](#_Toc166234187)

**R1-2404296 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, support Option 1: preamble + payload [+ CRC].**

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

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

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

**Proposal 5: Further consider carrying full or partial cell ID information in the LP-WUS.**

**Proposal 6: Further investigate Golay sequences as a candidate for the overlaid sequences.**

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

* **Option 1a: a single overlaid sequence is on each OOK ‘ON’ symbol. OFDM-based LP-WUR can obtain the whole information bits by the presence of the overlaid sequence.**
	+ **FFS whether the single overlaid sequence is pre-defined and the same across all the cells, or each cell has a pre-defined rule to select the single overlaid sequence out of multiple candidate sequences.**
* **Option 2-2a: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol. The overlaid OFDM sequence(s) carry all information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits at least by the overlaid OFDM sequence(s).**
	+ **FFS how to carry the information bits to enable early detection of LP-WUS by OFDM-based LP-WUR**

**Observation 1: The required SNR for LP-WUS to match the coverage of PUSCH Msg3 is about -0.3 dB assuming noise figure of 15 dB based on the provided assumptions.**

* **The required SNR for LP-WUS is -4.04 dB, -6.41 dB, and -9.05 dB for NF of 9 dB, 12 dB, and 15 dB, respectively, using the agreed assumptions for calibration.**

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

**R1-2405073 MediaTek Inc**

**Proposal 1: M=2 for OOK-4 is sufficient to optimize OOK WUR complexity and performance.**

**Proposal 2: M should be independent on SCS configurations for OOK-4 generation and detection since M=2 is sufficient for both 15kHz and 30kHz SCS given the target SNR of 0dB.**

**Proposal 3: Support the unified OFDM sequence design for OOK-4 M=1 and M=2 for simplicity.**

**Proposal 4: Support the frequency domain detection for an OFDM WUR to benefit the use of CP and eliminating the use of the sliding window technique.**

**Proposal 5: Support Option 1: A LP-SS sequence used in a cell is configured, with ≥3 LP-SS sequences used to differentiate LP-SS from different cells.**

**Proposal 6: Support the allocation of 12 PRBs for LP-WUS and LP-SS with SCS 30kHz. For ≤5MHz channels, allocate <11 PRBs to include guard RBs, aligning with 5G NR specifications.**

**Proposal 7: Support the allocation of 12 PRBs for LP-WUS and LP-SS with SCC 15kHz, ensuring no new sequences are needed to support different SCS.**

**Proposal 8: Adopt OOK-1 and OOK-4 with M=2 for LP-SS, ensuring simplicity and meeting LP-WUS needs without unnecessary complexity.**

**Proposal 9: Support Option 2: A codepoint value corresponding to one or more subgroup(s) for LP-WUS information, ensuring simplicity and efficiency for small payloads.**

**Proposal 10: Adopt Option 1: Use a UE-specific bitmap, ensuring simplicity and scalability.**

**Proposal 11: Two suggestions for 1 TX chain, NF = 12dB, MIL: 153.51dB. Option 1: Δ1=6dB, Δ2=0dB, Required SNR: -0.42dB. Option 2: Δ1=8dB, Δ2=0dB, Required SNR: -2.42dB.**

**Proposal 12: Consider low-density sequences for OFDM overlay regarding adaptability for OOK-1 and OOK-4 and low complexity using energy detection for OFDM WUR.**

**Proposal 13: Support Option 2, specifically Option 2-2, which uses a single sequence to carry all information, thus eliminating the need for OOK detection and simplifying the process.**

**R1-2404627 Xiaomi**

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

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

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

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

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

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

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

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

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

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

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

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

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

***Proposal 13：***

* ***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 14：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 15：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 16：In RRC idle/inactive state***

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

***Proposal 17：In RRC connected state***

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

***Proposal 18：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 19：The binary sequence of the ON-OFF pattern in a cell could be configured by the gNB. And the number of LP-SS sequences could be 3 at the starting point.***

***Proposal 20：Longer period than SSB such as 320ms can be considered for period of LP-SS as a starting point for discussion.***

***Proposal 21：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 22： LP-SS time domain pattern for beam sweeping should be designed referring to SSB pattern.***

***Proposal 23:***

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

***Proposal 24：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 25：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 26：Support modification as follows:***

***From RAN1 perspective, support X PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth ~~equal or~~ larger than 5MHz***

* ***X to be down-selected between 11 and 12 PRBs***
* ***FFS the number of PRBs for 15kHz***
* ***FFS if other number of PRBs needed, for LP-SS and LP-WUS with a channel bandwidth equal or less than 5MHz***
* ***FFS the channel bandwidth is equal to 5MHz***

***FFS: Whether the above is applicable to FR2***

**R1-2404465 CMCC**

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

**Proposal 1. Support to specify time domain signal S1 before DFT for LP-WUS/LP-SS generation.**

**Proposal 2. The multiplexing between legacy NR signal and LP-WUS/LP-SS should be before IFFT.**

**Proposal 3: For OOK-4, consider mapping frequency domain samples of OOK to the existing constellation, e.g., QPSK, 16QAM, 64QAM. Further study the performance compared to the non-QAM mapping.**

**Proposal 4: Support Option 1 and Option 3 as overlaid OFDM sequence(s) of LP-WUS.**

**Proposal 5: The target SINR of OOK-based LP-WUR to achieve the coverage of PUSCH for message3 is 5.58 dB.**

**Proposal 6: Preamble is needed for LP-WUS to accommodate time error. The preamble can reuse the sequence design of LP-SS which can reduce the specification effort.**

**Proposal 7: 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 8: Support Manchester coding for LP-WUS.**

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

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

**Proposal 11: The LP-SS sequence used in a cell is a sequence of LP-SS is determined by predefined rule.**

**Proposal 12: Support Option 3 to overlaid specific OFDM sequence on LP-SS to assist sync and measurement.**

**Proposal 13: The periodicity of LP-SS is suggested to be 320ms.**

**R1-2403879 EURECOM**

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

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

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

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

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

**Observation 1: Correlation receiver achieves significant gain over energy detection.**

**Observation 2: For , joint Manchester Coding achieves significant performance gain for all receiver types.**

**Proposal 6: Only Option 1 and Option 2 should be further considered.**

**Proposal 7: Evaluate how the information bits are mapped to multiple overlaid OFDM sequences.**

**Observation 3**:

* **COR-WUR performs better than COR-WUR-OOK due to the processing gain of carrying out longer correlations.**
* **Transmitting the *same* payload as the OOK waveform with the overlaid OFDM sequences but in a *different bit sequence* yields a significant performance gain.**
* **Using joint Manchester Coding and increasing the number of sequences results in a significant performance gain**

**Proposal 8: For multiple ON-Sequences, jointly encode the payload with OOK and sequence encoding.**

**Observation 4: A time-domain overlay code can significantly improve performance of the overlaid OFDM sequence transmission.**

**Proposal 9: Consider Zadoff-Chu sequences as base line.**

**Proposal 10: Encode information per bit and not jointly via non-orthogonal sequences.**

**Proposal 11: LP-WUS information payload is encoded sequentially where, for instance, every bit corresponds to a sub-group, Option 1.**

**Observation 5: Manchester coding is required to avoid complex threshold estimation for low-power receivers.**

**Proposal 12: Consider jointly encoding multiple bits via Manchester Coding.**

**Observation 6: PAPR increase of joint Manchester coding for compared to independent Manchester encoding depends on the ratio of channel BW to WUS BW and is minor (~0.1dB) for many system configurations.**

**Proposal 13: Allow configuration of *joint* Manchester Encoding for .**

**R1-2404035 Spreadtrum Communications**

LP-WUS design

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

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

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

***Proposal 4: Manchester coding can be supported for OOK-1 based LP-WUS.***

***Proposal 5: Manchester coding can be supported for OOK-4 based LP-WUS.***

***Proposal 6: At least for OOK-4, preamble for LP-WUS can be considered.***

***Proposal 7: For idle/inactive UEs, Option 1 (i.e. bitmap) can be supported for information content carried by LP-WUS.***

***Proposal 8: For connected UEs, after mechanism of LP-WUS for connected UEs is determined, information content carried by LP-WUS can be decided.***

***Proposal 9: Consider the following mechanisms for information carrying by LP-WUS, and down-selection can be considered in future.***

* ***OOK sequence***
* ***OOK bits with CRC***
* ***OOK sequence or OOK bits with CRC according to the number of information bits***

***Proposal 10: For LP-WUS, multiple OFDM sequences overlaid on an OOK symbol may have low priority.***

***Proposal 11: Single overlaid OFDM sequence is selected from multiple candidate overlaid OFDM sequences. The single overlaid sequence is on each OOK ‘ON’ symbol or OFDM symbol duration. OFDM-based LP-WUR can obtain the whole information bits by OOK ON/OFF pattern.***

***Proposal 12: If there is no preamble for LP-WUS, each element of the overlaid OFDM sequence is quantized to QPSK or QAM constellation point in frequency domain.***

LP-SS design

***Proposal 13: OOK-1 can be supported for R19 LP-SS.***

***Proposal 14: OOK-4 with M=2 or 4 can be supported for R19 LP-SS.***

***Proposal 15: It is assumed during our discussion/design that LP-SS waveform is the same as LP-WUS waveform, but this restriction may not have spec impact.***

***Proposal 16: Manchester coding can be supported for LP-SS.***

***Proposal 17: Support Option 2 (predefined rule) for OOK sequence generation for LP-SS.***

***Proposal 18: For LP-SS with or without overlaid OFDM sequence, Option 3 can be supported.***

***Proposal 19: 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.***

Bandwidth for LP-WUS and LP-SS

***Proposal 20: Support 12 PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.***

***Proposal 21: Support 24 PRBs for LP-WUS and LP-SS with SCS 15kHz (blanked guard RBs are not included) for a channel bandwidth equal or larger than 5MHz.***

***Proposal 22: Agreements on PRB number does not applicable to FR2.***

Coverage

***Proposal 23: For calibration of the target SNR, confirm there is no precoder cycling in time or frequency domain for gNB transmitting LP-WUS.
Proposal 24: We should jointly consider power consumption and determination of coverage target for LR.***

***Proposal 25: For fair comparison, we can assume the similar sampling rate for LR with capability of OFDM sequence detection and LR without capability of OFDM sequence detection.***

Overhead

***Proposal 26: We should jointly consider determination of overhead target and determination of coverage target for LR.***

***Proposal 27: Resource overhead gap for two types of LR can be further evaluated.***

**R1-2404852 OPPO**

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

* **LP-WUS signal**

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

***Observation 1****: For OOK-4 with M = 1. OOK=0 also means all SCs of LP-WUS are zero power. OOK = 1 means all SCs are modulated by one sequence mapped from “OOK = 1”. DFT process could be absent if the sequence mapped from “OOK = 1” could be prestored at gNB. Thus OOK-4 with M = 1 can also be regarded as OOK-1.*

***Observation 2:*** *OOK-1 can be assumed as a special case of OOK-4, i.e. OOK-4 can fallback to OOK-1 when M is equal to 1, in this case single-bit OOK will be transmitted in one OFDM symbol.*

***Proposal 1: Support unified design, i.e. 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.***

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

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

***Proposal 3: It is not clear how UE can determine the SCS of LP-WUS. Following could be considered.***

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

**CP impact of OOK-4**

***Observation 3:*** *If gNB can adjust the length of sub-sequence mapped from M OOK bits within one CP-OFDM symbol to make the length of CP and first OOK symbol is equal to the length of remaining OOK symbol. When the first OOK symbol's state is same as that of the last symbol within the same CP-OFDM symbol, the CP will not introduce an opposite state. Otherwise, the CP will slightly hurt the performance of OOK demodulation. In this way, UE could not handle the CP.*

***Proposal 5: 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 6: 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.***

***Proposal 7: 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.***

**Function of the LP-WUS signal**

***Observation 4:*** *The content of LP-WUS should include the wake-up indication information.*

* + *In IDLE/INACTIVE mode, it could be used to indicate which UE(s) need to wake up the MR for RACH process, including the paging message reception.*
	+ *In CONNECTED mode, it could be used to indicate which UE(s) need to wake up the MR for PDCCH monitoring.*

***Observation 5:*** *In IDLE/INACTIVE mode, it is not necessary for LP-WUS to carry additional information (e.g., cell information, SI change and ETWS/CMAS information, tracking area information, RAN area information, etc.) beyond the wake-up indication. Other information beyond the wake-up indication could be indicated through other signals (e.g., LP-SS signal, paging PDCCH).*

***Proposal 8: 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**

***Observation 6****: OOK modulation with Manchester coding will consume significant time domain resources, especially for the OOK-1 waveform. E.g. 8 bits CRC and 16 bits payload need be carried by 48 OFDM symbols (larger than 3 slots) in OOK-1.*

***Proposal 9:******Per UE-group and / or per UE-subgroup indication for LP-WUS targets to 8-bits or 16-bits payload.***

***Proposal 10: Encoded bits scheme has more flexibility in transmitting wake-up indications for single or multiple UE groups, we prefer encoded bits scheme to carry LP-WUS information.***

***Observation7****: Considering the LP-WUS information needs to be carried by encoded bits and/or by OOK sequence selection for ‘ON-OFF’ pattern. The LP-WUS information in bitmap format (Option 1) required fewer time domain resource compared with the multiple codepoint values (Option 3).*

***Observation8****: When the LP-WUS information needs to indicate all the wake-up states, bitmap format has more flexibility and fewer resource overhead than codepoint format.*

***Proposal 11: Regarding the LP-WUS information for idle/inactive UEs, support Option 1 (A bitmap with each bit corresponding to [one or more] subgroups).***

***Proposal 12: Considering unified design of LP-WUS information, support option 1 regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs (A bitmap with each bit corresponding to [one or more] UEs).***

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

***Observation 9:*** *There are two methods for specifying time domain OFDM sequence overlaid over OOK symbol.*

* + *Option 1: Time domain OFDM sequence overlaid over OOK symbol* ***per OFDM symbol.***
	+ *Option 2: Time domain OFDM sequence overlaid over OOK symbol* ***per OOK symbol.***

***Observation 10:*** *If specify time domain OFDM sequence overlaid over OOK symbol per OFDM symbol, the length of time domain OFDM sequence could remain unchanged regardless of how many OOK symbols transmitted within one OFDM symbol, while the complete sequence maybe divided into M sub-sequences.*

***Observation 11:*** *If specify time domain OFDM sequence overlaid over OOK symbol per OOK symbol, the OFDM sequence overlaid could be transmitted without divided, while the length of each time domain OFDM sequence maybe changed due to the number of OOK symbols transmitted within one OFDM symbol.*

***Observation 12:*** *For OOK waveform generated via OOK-1, it can also specify time domain OFDM sequence overlaid over OOK symbol. gNB can pre-store the frequency-domain sequence which transform from the time domain OFDM sequence to modulate the SCs for LP-WUS. And UE could perform OFDM sequence correlation detection based on the time domain OFDM sequence.*

***Proposal 13: 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 14: 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 15: Prefer the overlaid OFDM sequence(s) carry all information bits of LP-WUS.***

***Observation 13:*** *If OFDM sequence overlaid over OOK symbols could carry information, the number of candidate OFDM sequences increases exponentially with the number of indication bits carried per OFDM sequence when the entire indication information is mapped to one OFDM sequence.*

***Observation 14:*** *If OFDM sequence overlaid over OOK symbols could carry information, the number of candidate sequences could be significantly reduced when every segment of the whole indication bits is mapped to one independent OFDM sequence.*

***Proposal 16: If overlaid OFDM sequence(s) could carry information, it is better to make segments of the whole information bits. And Each segment of the whole information bits can be mapped to one independent OFDM sequence.***

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

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

***Proposal 17: Support option 3, i.e. one sequence is selected from multiple candidates overlaid OFDM sequences on one or more OOK ‘ON’ symbols.***

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

**The bandwidth of LP-WUS**

***Proposal 18: The BW of LP-WUS for RRC IDLE/INACTIVE state could be same as that for RRC CONNECTED state.***

***Proposal 19: Allocated fixed number of PRBs for LP-WUS and LP-SS signal regardless of the SCS.***

***Proposal 20: 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 21: 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 22: The SNR to achieve the coverage PUSCH for message3 with MIL = 153.51dB is 1.44dB @NF=15dB, 4.08dB @NF=12dB, 6.45dB @NF=9dB, summary as following table.***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bandwidth | NF | Transmit antenna gain correction factors | Gain of antenna element (dBi) assumed for LP-WUR | The SNR (dB) to achieve the coverage of Msg3 |
| 5MHz (4.32MHz for LP-WUS for 30kHz SCS) | 15 dB | 1.5dB | 0dBi for non-redcap UE | 1.44 |
| 12 dB | 4.08 |
| 9 dB | 6.45 |

**Consideration on timing error and frequency error**

***Proposal 23: The timing/frequecy error of LP-SS and LP-WUS need to consider separately.***

* ***Before LP-SS, timing/frequency error should consider: (1) the residual frequency error (Fr) after frequency error correction/clock calibration by LR based on LP-SS, and (2) timing drifting and frequency drifting between two LP-SS signals.***
* ***Before LP-WUS, timing/frequency error should consider: (1) the residual frequency error (Fr) after frequency error correction/clock calibration by LR based on LP-SS, and (2) timing drifting and frequency drifting between LP-SS and LP-WUS.***
* **LP-SS signal**

**LP-SS waveform**

***Proposal 24: LP-SS select one waveform from OOK1/4, single M values is selected for the waveform.***

**LP-SS overlaid sequences**

***Proposal 25: 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 26: 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 27: LP-SS introduce Gold or M sequences modulated into OOK symbols. FFS coding on top of sequence.***

***Proposal 28: LP-SS uses a binary sequence associated to the cell ID by configuration.***

**R1-2404760 Panasonic**

Based on the discussion, the following proposals are highlighted:

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

**Proposal 2: To support only either 30 kHz or 60 kHz symbol rate of LP-WUS.**

**- If 30 kHz symbol rate is taken, to discard the working assumption of M=4 in OOK-4.**

**- If 60 kHz symbol rate is taken, to discard the agreement to support OOK-1.**

**Proposal 3: If OOK-1 is supported, it should be specified as OOK-4 with M = 1.**

**Observation 1: Neither 11 nor 12 PRBs for LP-WUS/LP-SS would bring obvious benefit for system resource allocation efficiency if booked resource for SSB is 20 PRBs.**

**Proposal 4: RAN1/4 need to further study the required GB to handle CFO and in-band emission first. Then channel bandwidth of LP-WUS and LP-SS is to be determined. Send LS to RAN4 if necessary.**

**Proposal 5: For LP-WUS information design, same scheme should be utilized for RRC IDLE/INACTIVE and CONNECTED UEs. The required detection number of bits for CONNECTED should be concluded.**

**Proposal 6: ZC sequence should be adopted for overlaid OFDM sequence.**

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

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

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

**Proposal 9:**

* **When LP-SS is only required to calibrate certain timing error within an OOK symbol/chip duration, simple design to employ a few candidates of Gold sequence (as the pseudo random code defined in TS38.211) by configuration is sufficient.**
* **If larger range of timing error correction is required, the binary sequence mapped to partial PCI and SFN can be studied for better synchronization and RRM measurement performance against inter-cell interference, although that may increase the LP-WUR complexity.**

**Proposal 10: Repetition should be supported for LP-WUS to enhance coverage performance, such that performance requirement is met even for OOK-based receiver.**

**R1-2403864 FUTUREWEI**

This contribution discusses the LP-WUS and LP-SS design options and considerations. The following summarizes our observations and proposals.

LP-WUS Design (Structure)

***Proposal 1: Support at least the alternative to carry up to 16 bits of LP-WUS information using encoded bits with an 8-bit CRC when bitmap based wake-up indication is considered and without CRC when codepoint based wake-up indication is considered.***

***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 ∈ {2,4} regardless of SCS 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.***

***Proposal 6: Continue consideration of X=12 PRBs for LP-WUS and LP-SS with SCS 30kHz (blanked guard RBs are not included) for a channel bandwidth larger than 5MHz.***

LP-SS Design

***Proposal 7: Support low density sequences generated using waveform Option OOK-4 with M>1 for LP-SS design.***

***Proposal 8: Assuming no frequency error correction by LR, consider a preamble to precede the transmission of an LP-WUS if LP-SS periodicity is >= 320 ms and the time offset between LP-WUS and last LP-SS is, e.g., > 50 ms.***

**R1-2404579 Honor**

In this contribution, we provide our views on waveform, detection scheme, and information carrying. The following observations and proposals are given:

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

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

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

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

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

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

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

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

***Proposal 9：Support option 3 for the overlaid OFDM sequence(s) of LP-WUS.***

***Proposal 10: Support option 1 for idle/inactive UEs.***

***Proposal 11: Support both option 1 and option 3, and the network side can flexibly indicate the specific solution.***

***Proposal 12: Support 11 PRBs for LP-WUS and LP-SS with SCS 30kHz or 15kHz.***

***Proposal 13: Confirm the following working assumption:***

***Support the following options for LP-SS***

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

***Proposal 14: Adopt option 2 for the overlaid sequence of LP-SS.***

**R1-2404312 InterDigital, Inc**

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

* *Do not support additional M values.*

***Proposal 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****. In specifying binary LP-SS sequences, support Option 1 with sequences of serving cell and non-serving cells being configured for UEs.*

***Proposal 4****. Procedures for handling inconsistencies in RRM measurements based on LP-SS and RRM measurements based on NR-SS should be supported.*

***Proposal 5.*** *For LP-WUS signal structure, time domain repetition and Manchester coding are supported.*

***Proposal 6.*** *Support up to 10 repetitions of LP-WUS with Manchester coding to achieve comparable performance with PUSCH for Msg 3.*

***Proposal 7.*** *For the SNR to achieve coverage of PUSCH for Msg3, the following SNR values are considered for additional noise figure values +2dB, +5dB and +8dB, respectively.*

|  |  |  |  |
| --- | --- | --- | --- |
| NF (dB) | Assumed Antenna gain correction factors for MSG3 (MIL of 153.51dB without retransmission):  (dB) | Assumed Antenna gain correction factors for LP-WUS/LP-SS:  (dB) | The SNR to achieve the coverage of PUSCH for message3 (dB) |
| 7+2 | 0 | 2.67 | 2.28 |
| 7+5 | 0 | 2.67 | -0.1 |
| 7+8 | 0 | 2.67 | -2.75 |

***Proposal 8.*** *Down select M-sequence and ZC sequence for further consideration of overlaid OFDM sequence.*

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

***Proposal 10:*** *On hold the discussion on LP-WUS information until further details on the supported functionalities are available.*

**R1-2404509 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).***

**R1-2404059 TCL**

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

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

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

**Proposal 4: For the LP-WUS information in idle/inactive state support:**

* **Option 2: A codepoint value corresponding to one or more subgroup(s)**
* **Option 3: Multiple codepoint values with each corresponding to one or more subgroup(s)**

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

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

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

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

**Proposal 8: For the LP-SS sequence used in a cell support option 2: a sequence is determined by pre-defined rule.**

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

**Proposal 10: For a channel bandwidth of 5MHz for LP-WUS and LP-SS support:**

* **The maximum number of 12 PRBs with SCS 30kHz.**
* **The maximum number of 24 PRBs with SCS of 15KHz.**

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

**Proposal 12: Study a dedicated BWP for the placement of LP-WUS and LP-SS, with the maximum bandwidth within the range of 5MHz to 20MHz.**

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

**Proposal 14: 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.**

**R1-2404897 LG Electronics**

In this contribution, we have discussed on the various aspects for LP-WUS and LP-SS design, and the followings are proposed.

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

**Proposal #2: Support M=4 and M=1 for OOK-4 generation for LP-WUS**

* **Confirm M=4 at least for 15 kHz SCS**
* **Support M=1 for both 15 kHz and 30 kHz SCSs**
* **Applicable M can be determined based on the configured SCS for LP-WUS**
	+ **For 15 kHz SCS, M=1, 2, 4**
	+ **For 30 kHz SCS, M=1, 2**

**Proposal #3: Regarding SCS for LP-WUS, the followings need to be supported for coexistence of LP-WUS and NR signal/channel**

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

**Proposal #4: 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 identity or sub-group ID can be included**
* **CRC part: It can be optionally attached according to the length of message part**

**Proposal #5: Discuss the necessity of preamble part with consideration of its potential benefit for LP-WUS transmission on top of the need for timing error compensation**

**Proposal #6: Support Option 2-2 and Option 3**

* **Option 2-2 can be supported with repeatedly transmission of the overlaid OFDM sequence over all OOK symbols**
* **Option 3 can be supported so that gNB selects optimal sequence type and sequence length**

**Proposal #7: Discuss on the sequence length (and detailed mapping to OFDM symbol) of overlaid OFDM sequence considering LP-WUR sampling rate**

**Proposal #8: Support configurable TDRA for LP-WUS**

* **Discuss relations of LP-WUS and LP-SS occasions**
* **Preamble, if supported, can be transmitted separately from message part of LP-WUS**
	+ **FFS: time offset**

**Proposal #9: Support both 11 PRB and 12 PRB as the bandwidth of LP-WUS and LP-SS with 30 kHz SCS for a channel bandwidth equal or larger than 5 MHz.**

* **gNB configures one bandwidth according to channel bandwidth and SCS**

**Proposal #10: Discuss on the bandwidth and frequency location for LP-WUS and LP-SS with consideration of at least the following aspects**

* **NW flexibility and LP-WUR complexity**
* **Association with MR BWP**

**Proposal #11: Discuss the dedicated frequency resources for LP-WUS and LP-SS**

**Proposal #12: To support various scenarios, Option 2 should be supported for LP-SS**

* **To support low and high data rate, OOK-4 with M=1,8 should also be supported**

**Proposal #13: Whether to apply Manchester coding to LP-SS can be discussed with LP-SS sequence design together**

**Proposal #14: Support both Option 2 and Option 3 for overlaying OFDM sequence for LP-SS**

**Proposal #15: Discuss about overlaid OFDM sequence candidates for LP-SS considering overlaid OFDM sequence candidates for LP-WUS**

**Proposal #16: LP-SS sequence used in a cell can be configured by gNB**

* **When LP-SS sequence configuration is absent, predefined rule can be used (FFS: predefined rule)**

**Proposal #17: Consider LP-SS burst for multi-beam operation of LP-SS such as SSB burst for multi-beam operation of SSB.**

**Proposal #18: 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 #19: Multiple LP-SS periodicities need to be supported for various scenarios**

**Proposal #20: Consider the separate periodicity for synchronization and RRM measurement, respectively.**

**R1-2404664 NEC**

In this contribution, we discuss the LP-WUS and LP-SS design, and the following proposals are made:

***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: regarding the overlaid OFDM sequence(s) of LP-WUS, support option 2-2, i.e. the overlaid OFDM sequence(s) carry all information bits of LP-WUS. However, UE is allowed to not receive all the OOK symbols of LP-WUS, and UE can acquire all the information bits based on the OOK on-off pattern and the overlaid sequence of partial OOK symbols of the LP-WUS.***

***Proposal 7: for the binary sequence of LP-SS, reuse the existing sequence generation method in NR, e.g., m-sequence, gold sequence.***

***Proposal 8: 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 9: support QCL relationship between an LP-SS and an SSB.***

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

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

**R1-2405051 NTT DOCOMO, INC**

**Proposal 1:**

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

**Proposal 2:**

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

**Proposal 3:**

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

**Proposal 4:**

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

**Proposal 5:**

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

**R1-2404966 Sharp**

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

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

**Proposal 3: The maximum number of information bits for one LP-WUS can be up to 16.**

**Proposal 4: Support bitmap with each bit for one subgroup for LP-WUS for idle/inactive UE**

**Proposal 5: Support encoded bit with CRC to carry LP-WUS information.**

**Proposal 6: Further consider bitmap and multiple codepoint options(option1/4/5) for LP-WUS information for connected UE.**

**Proposal 7: Support more bandwidth size options for LP-WUS.**

**Proposal 8: Time domain repetition and simple FEC schemes can be considered for LP-WUS.**

**Proposal 9: Discuss whether LP-WUS/LP-SS can be deployed in the FR2 band.**

**R1-2405254 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.*
* *for M=1, specify OOK=4 instead of OOK-1, unless anybody can justify performance benefit from OOK-1.*

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

* *specify two different non-zero-sequence length for 15 kHz.*
* *specify two different non-zero-sequence length for 30 kHz.*
* *FFS need for CP-handling, pulse shaping.*

***Proposal-3:*** *Select Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol or OFDM symbol duration, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s).*

* *Option 2-1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and location of the OFDM sequence(s)/OOK symbols.*
* *Maximum number of payload bits of LP-WUS is 8 without CRC. Overlaid sequence provides both detection time reduction and coverage by repetition for the OFDMA receiver (see example Table 3).*
* *Overlaid sequence carries 1bit of information as baseline.*

***Proposal-4:*** *For sub-group mapping to payload bits: if CRC is not introduced, select Option 1, otherwise focus on Option 2/3.*

***Proposal-5:*** *LP-WUS BW is* ***12****/24RB (including GB decided by RAN4) for 30/15kHz SCS. Support 6/12RB LP-WUS can be considered if good use-case is identified.*

***Proposal-6:*** *LP-SS is* OOK-4 M=1/OOK-1*, while preamble can be configured with higher chip-rate. LP-WUS overlaid is reused for LP-SS.*

***Proposal-7:*** *Both Option 1 and Option 2 for LP-SS sequence design should be supported. Number of distinct sequences could be 3 (cell-ID mod 3* *as baseline).*

**R1-2404942 Lenovo**

***Proposal 1: Consider OOK-4, M=1 as the LP-SS waveform with overlaid sequence for the baseline LP-SS design.***

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

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

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

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

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

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

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

***Proposal 8: Consider hybrid LP-SS design containing mixture of wider pulse duration using OOK-4, M=1 and narrower pulse duration using OOK-4, M>1 to tolerate higher timing errors at the beginning and at the same time achieve finer synchronization for the same devices.***

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

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

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

***Proposal 12: Usage of DFT-s-OFDM or OFDM based OOK using single bit OOK per OFDM symbol at the transmitter side can be left to the BS implementation.***

***Proposal 13: Consider both OOK-1 and OOK-4 as the LP-WUS waveform depending on the payload size with overlaid sequence for the baseline LPWUS design.***

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

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**Proposal 1: Support the value of M scales with SCS. Specifically SCS=15kHz, M=4 and**

**SCS=30kHz, M=2.**

**Proposal 2: Support the value of M ≤ 4 for both LP-WUS and LP-SS**

**Proposal 3: Support the value of X PRBs to be 12 with 30kHz SCS**

**Proposal 4: Support the value of 2X (24) PRBs for 15kHz SCS**

**Proposal 5: Support using ZC sequence for overlaid OFDM sequence in OOK-1 LP-WUS**

**Proposal 6: Support Manchester coding for both LP-WUS and LP-SS**

**Proposal 7: Use 3.1dB of the required SNR for OOK-based LP-WUR for RAN1 evaluation**