**3GPP TSG-RAN WG1 Meeting #120 R1-25xxxxx**

**Athens, Greece, February 17th-21st, 2025**

**Source: Moderator (vivo)**

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

**Agenda Item: 9.6.1**

**Document for: Discussion and Decision**

1. Introduction

This contribution summarizes the discussions on LP-WUS and LP-SS design in RAN1# 120.

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

1. Proposals for Online Sessions
	1. Proposals for Monday online session
2. LP-WUS design
	1. OOK-1/OOK-4 waveform

###  M values for OOK-4

RAN1 made following agreement for candidate M value

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

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

* [2][3][4][5][8][12][16][18][19][21][26][27] proposed to support M=4, to reduce LP-WUS overhead/increase data rate,

 [2][27] support M=4 for RRC connected state, but do not support M=4 for 30kHz SCS for RRC idle/inactive state, considering no performance gain compared with over OOK-1/OOK-4 M=1 or M=2 at Msg 3 PUSCH coverage, and potentially larger LP-SS overhead to meet tighter synchronization requirements.

* [15][17] does not support M=4 for 30kHz SCS, with concern on LP-WUR complexity.

FL suggests to go with majority view, to avoid complication of design for different RRC state or SCS for FR1.

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

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

FFS M=1 for OOK-4 |

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| --- | --- | --- |
| Company | Y/N | Comments |
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[2][7][17][23] also discuss M value for FR2. FL suggests to first discuss FR1 values.

### SCS and frequency resource location for LP-WUS/LP-SS

RAN1 made following agreement for LP-WUS/LP-SS SCS

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| --- |
| Agreement For the SCS used for LP-WUS and LP-SS, further discuss the following options: * The single SCS is configured by gNB
* The single SCS is determined by pre-defined rule

Agreement For RRC idle/inactive state, for the case where associated CD-SSB and initial DL BWP have the same SCS at least when the associated CD-SSB and LP-WUS are on the same carrier* The single SCS for LP-WUS/LP-SS is same as the associated CD-SSB
* FFS: Case where associated CD-SSB and initial DL BWP have different SCSs
* FFS: Which initial BWP for RedCap
 |

For the FFS point of Redcap, according to conclusion in RAN1 #118 and agreed CR R1-2407556 in RAN1 #118., the RedCap-dedicated initial DL BWP, if configured, must have the same SCS as the legacy initial DL BWP. And the SCS of active DL BWP must be the same as that of initial DL BWP of RedCap, as agreed in CR R1-2407556 in RAN1 #118. Therefore, the same solution here can apply to both non-RedCap UEs and RedCap/eRedCap UEs.

Therefore, in the following discussion, the same solution is assumed for both Redcap and non-Redcap.

For RRC idle/inactive mode, when associated CD-SSB and initial DL BWP have different SCS, there are 4 solutions provided by companies

* Solution 1: LP-WUS SCS is same as initial DL BWP [2] [3] [4][8] [13][23]

[3] mentions, if SCS of LP-WUS/LP-SS is the same as initial DL BWP, we may need to discuss whether the extended CP could be supported.

* Solution 2: LP-WUS SCS is same as CD-SSB [3] [6][10] [12] [16]

[6] mentions, for FR2, if CD-SSB SCS >120kHz, supports LP-WUS SCS=120kHz because RAN1 only agreed to support up to 120kHz SCS for LP-WUS.

* Solution 3: LP-WUS SCS is configured by gNB [7][17][26]
* Solution 4: Not support the scenario of different SCS for CD-SSB and DL initial BWP [5][27]

|  |  |
| --- | --- |
|  | Argument provided by companies to support the solution  |
| Solution 1 | Avoid interference to legacy UE caused by mixed numerology of LP-WUS and DL initial BWP, considering most of NR transmissions with SCS as initial DL BWP Avoid additional RAN4 impact for guard band |
| Solution 2 | allow the OFDM based LP-WUR to use the CD-SSB for RRM measurement and timing synchronization without switching SCS for reception. Reservation of guard between PRBs with different SCS can be handled by gNB implemented as existing NR operation.  |
| Solution 3 | Provide better flexibility for gNB |
| Solution 4 | No need to consider such complicated scenario, considering mixed SCS cases where SSB is of different SCS than CORESET#0 are not deployed |

**[H][FL1] Proposal 3.1-1:** For RRC idle/inactive, for the case where associated CD-SSB and initial DL BWP have different SCS, down-select between alt 1 and alt 2 for LP-WUS/LP-SS SCS, which is commonly applicable to both Redcap and non-Redcap UE.

* Alt 1: LP-WUS/LP-SS SCS is same as initial DL BWP
* Alt 2: LP-WUS/LP-SS SCS is same as CD-SSB

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| Company | Y/N | Comments |
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For RRC idle/inactive state, companies discuss whether LP-WUS/LP-SS frequency domain resource is confined within DL initial BWP. [2][9] [13] [24] [25] prefer flexible location within the channel BW, which can be out of the DL initial BWP, to avoid potential congestion in the DL initial BWP. [6] [17][25] discuss whether/how to restrict the frequency gap between LP-WUS/LP-SS and CD-SSB. The benefit of restriction the gap is to reduce RF retuning, for OFDM-based receiver. In FL’s understanding, such restriction is unnecessary for OOK-based receiver.

 **[H][FL1] Question 3.1-1:** For RRC idle/inactive, for OFDM receiver, do you think it is necessary to confine the frequency gap between LP-WUS/LP-SS and CD-SSB, if LP-WUS/LP-SS is out of DL initial BWP?

* If yes, what is your preferred value?

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| --- | --- | --- |
| Company | Y/N | Comments |
|  |  |  |

For RRC connected mode, there are three solutions provided by companies

* Solution 1: LP-WUS SCS is same as the active DL BWP in which the LP-WUS is located [4][8][10][11][23]
* Solution 2: LP-WUS SCS is configured by gNB, which can be same or different from the active BWP [2][7]
* Solution 3: LP-WUS SCS is same as CD-SSB [16]

**[H][FL1] Proposal 3.1-2:** For RRC connected, down-select between alt 1 and alt 2 for LP-WUS SCS:

* Alt 1: LP-WUS SCS is same as the active DL BWP in which the LP-WUS is located
* Alt 2: LP-WUS SCS is configured by gNB, which can be same or different from the active BWP

|  |  |  |
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| Company | Y/N | Comments |
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Besides SCS, companies also discuss the frequency resource of LP-WUS and LP-SS, [2][9] [24] [25] prefer flexible location within the channel BW, i.e., not necessarily confined within a BWP.

**[H][FL1] Proposal 3.1-3:** For RRC idle/inactive, down-select between alt 1 and alt 2 for LP-WUS/LP-SS frequency resource:

* Alt 1: LP-WUS/LP-SS frequency resource is confined within initial DL BWP.
* Alt 2: LP-WUS/LP-SS frequency resource is configured within a carrier, which can be out of initial DL BWP.

**[H][FL1] Proposal 3.1-4:** For RRC connected, down-select between alt 1 and alt 2 for LP-WUS frequency resource:

* Alt 1: LP-WUS frequency resource is confined within active DL BWP.
* Alt 2: LP-WUS frequency resource is configured within a carrier, which can be out of active DL BWP.

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| --- | --- | --- |
| Company | Y/N | Comments |
|  |  |  |

* 1. Overlaid OFDM sequence for LP-WUS

### Overlaid Sequence Design

#### 3.2.1.1  value for the overlaid ZC sequence

RAN1 made following agreement for overlaid OFDM sequence generation.

|  |
| --- |
| **Agreement**For the overlaid OFDM sequence in time domain, the sequence is generated based on *,** M=1, is given by the largest prime number such that,is the overlaid OFDM sequence length.
	+ The base overlaid sequence is generated by extension of
	+ ,
	+ With CS(s) applied to the base overlaid OFDM sequence if any:denotes the potential cyclic shift (s)
	+ ,,
* M=2, 4, is down-selected from the following:
	+ Alt1: is given by the largest prime number such that,is the overlaid OFDM sequence length.
		- The base overlaid sequenceis generated by extension of
	+ ,
		- With CS(s) applied to the base overlaid OFDM sequence if any:denotes the potential cyclic shift (s)
	+ ,
		- Note it doesn’t preclude any pulse shaping scheme if any.
	+ Alt2:is given by the largest prime number such that,  is the overlaid OFDM sequence length.
		- The base overlaid sequenceis generated by inserting zeros before and/or after . The total number of zeros is.
	+ For example,,
		- With CS(s) applied to the base overlaid OFDM sequence if any: denotes the potential cyclic shift (s)
	+ For example,,
		- * + where,
		- FFS the value of G, with G>0.
* FFS value(s) of root q and/or CS  for generating the candidate sequences if applied
* FFS on whether changes are needed to handle intra-/inter-cell interference
* Note: the overlaid OFDM sequence in time domain is based on potential modification to ZC sequence as listed above.
	+ Above overrides any previous RAN1 agreement / working assumption
 |

For M=2, 4, two alternatives foris to be down-selected. Company views are summarized as below.

|  |  |
| --- | --- |
|  | Argument  |
| Alt 1 [2][6] [7] [9] [11][13] [14] [16] [19] | * Similar performance as Alt 2 for OOK detector, by receiver implementation, e.g., sliding window
* Better performance than Alt 2 for OFDM detector, due to better correlation property with longer sequence.
* Larger number of candidate sequences using different root and/or CS, due to longer sequence.
* Unified design for M=1 and M>1
* Less standard effort, no need of discussion on number of zero bits.
 |
| Alt 2[3] [4] [18] [23] [24] | Better performance than Alt 1 for OOK detector, due to robustness to timing error and ISI.  |

[2] [3] [4] [6] provides evaluation results for Alt 1 vs Alt 2.

* For OOK-detector:

[2] shows similar performance for Alt 1 and Alt 2, assuming 2us timing error, 16 bits zero insertion.

[3] shows up to 1.5dB loss of Alt 1, assuming 9.36us timing error, 72 bits zero insertion.

[4] shows up to 2dB loss of Alt 1, assuming 2us timing error.

[6] shows 0.4 dB loss of Alt2, assuming zero insertion with duration of 10% OOK chip duration.

[18] shows about 1.2dB loss of Alt 1, assuming 13 bits zero insertion.

* For OFDM detector:

[2] shows about 1dB loss of Alt 2 for 4 candidate overlaid sequences with 4 different CS.

[3] shows same performance for both alternatives, assuming 8 or 16 bits zero insertion for M=2.

[18] shows 0.4dB loss of Alt 1 for single or 4 candidate overlaid sequences with 4 different CS, and >0.4dB loss for 8 candidate overlaid sequence with 4 difference CS + 2 root, using same root for At 1&2, assuming 13 bits zero insertion.

[19] shows about 6dB loss of Alt 2 with multiple overlaid sequences based on different root, assuming 16 bits zero insertion for M=2, and similar performance for Alt 1& 2 with multiple overlaid sequences based on different root +CS, assuming 16 bits zero insertion for M=2.

Based on companies’ evaluation results, for OOK detector, some companies observe performance lose of Alt 1 while some companies observe similar or performance loss of Alt 2. Therefore, FL suggests to go with majority view.

**[H][FL1] Proposal 3.2-1:** M=2, 4, is:

* + Alt1: is given by the largest prime number such that,is the overlaid OFDM sequence length.
		- The base overlaid sequenceis generated by extension of****
	+ ,
		- With CS(s) applied to the base overlaid OFDM sequence if any:denotes the potential cyclic shift (s)
	+ ,
		- Note it doesn’t preclude any pulse shaping scheme if any.

|  |  |  |
| --- | --- | --- |
| Company | Y/N | Comments |
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#### 3.2.1.2  value for the overlaid ZC sequence

RAN1 made following agreement for overlaid OFDM sequence generation.

|  |
| --- |
| **Agreement**At least for M>1, for the overlaid OFDM sequence in time domain, down-select the sequence length *LZC* from the following:* Alt1:, with
	+ FFS how to map the generated overlaid OFDM sequence to the frequency domain
* Alt2:
* Note: X is the number of RBs of LP-WUS/LP-SS bandwidth (blanked guard RBs are not included)
 |

Company views are summarized as below.

|  |  |
| --- | --- |
|  | Argument  |
| Alt 1  [3] [4] [5] [7][13] [23] | * From gNB perspective, gNB can enable fast DFT implementation, which allows the gNB to dynamically generate overlaid OFDM sequences.
* From UE perspective, UE's sampling rate is an integer multiple of LZC, which ensures the performance of the reception detection and easier implementation.
* Better performance due to smaller added sequence element or truncation.
 |
| Alt 2[6][8][9][11] [14] [16] [17] [19] | * Better performance with larger sequence length.
* From gNB perspective, gNB can pre-compute and store DFT result in the gNB memory, so the DFT size does not impact real-time performance of gNB implementation.
* LR can use closes FFT size with 2^n without affecting the detection performance significantly, if LR intends to perform FFT based processing.
* Length-131 sequence is already used in NB-IoT NSSS.
* Less standard effort, without further discussion on how to map to LP-WUS bandwidth.
 |
| No strong preference among Alt 1 and Alt 2: [2] |

If Alt 1 is to be adopted, how to map the sequence after DFT to the LP-WUS bandwidth is to be discussed [4][5][7][13]. [4] [5] proposes to map the frequency sequence after DFT to the center of 132 REs with 2 guard REs at each side. [13] proposes to let gNB configure.

**[H][FL1] Proposal 3.2-2:** At least for M>1, for the overlaid OFDM sequence in time domain, support Alt 2：

* Alt2:

|  |  |  |
| --- | --- | --- |
| Company | Y/N | Comments |
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#### 3.2.1.3 Number of overlaid OFDM sequences per OOK ON chip

RAN1 made following agreement on number of candidate sequences.

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| --- |
| AgreementRegarding the maximum number of candidate overlaid sequences to carry LP-WUS information per OOK ON chip for one cell, down-select from the below:* 4
* 8
* 16
* 32
* 64 for M not larger than 2
* FFS whether the same or different set of candidate overlaid sequences are used for different cells

AgreementRegarding the maximum number of candidates overlaid sequences to carry LP-WUS information per OOK ON chip for one cell:* support maximum 4 candidates overlaid sequences for M=4
 |

The number of candidate sequences for M=1 and M=2 are to be decided.

Based on companies tdoc, preference on maximum number of candidate overlaid sequences for M=1 and M=2 are summarized as below.

* M=1
	+ 4: [3] [6][10] [16][17]
	+ 8: [4][18]
	+ 16: [2][7] [14][23][19] [27]
	+ 32: [8]
	+ 33: [5]
	+ 64: [11]
	+ >4: [12]
* M=2
	+ 4: [3] [6][10] [16][17]
	+ 8: [7] [14] [18] [19] [23] [27]
	+ 16: [2] [4] [8]
	+ 32: [11]
	+ 33: [5]
	+ >4: [Xiaomki]

Aspects companies considering to determine maximum number of candidates overlaid sequences are summarized as below.

1. Detection performance

[2] [3] [8] [9] [11][18] evaluate performance of single transmission for various number of candidate sequence.

[2] shows MDR performance degrades with increase of number of candidate sequences from 1 ~ 64, assumes 0.9us timing error with 2ppm frequency offset and 1.86us timing error with 5ppm frequency offset.

[3] shows, for M=1, <1% MDR can be achieved for 4, 8, 16 sequences, FAR below 1% for 4 sequences, but FAR increases well above 1% for 8 and 16 sequences, with 3us sliding window.

[8] shows MDR performance is the same for number of candidate sequences from 1 ~ 64, assuming 0.2us timing error with about 0.5ppm frequency offset.

[9] shows MDR performance degrades with increase number of candidate sequences from 8~ 64.

[11] shows, 64 sequences for M=1, 32 sequences for M=2 and 4 sequences for M=4 have similar MDR performance.

[18] shows, 4dB performance loss is observed for 8 sequences.

1. Detection complexity

[2][4][6] [7] [10][16] think larger number of candidates overlaid OFDM sequences leads to higher LR complexity, due to more correlation operation, e.g., if UE to detect all possible candidates (ML detection).

[8][11] consider same complexity for all M values in one OFDM symbol, with reference to already agreed 4 sequences for M=4. [8] considers at least 16 correlation per OFDM symbol can be acceptable for complexity, assuming 4 sequence correlation within 1/4 OFDM symbol duration for M=4. [11] considers 64 sequences for M=1 and 32 sequences for M=2, considering number of sequence correlation within an OFDM symbol duration and number of correlations for ON-OFF pattern.

 [5][8] think the receiver can exploit the knowledge of the sequence and improves its detection performance, thus using a single sequence detector is sufficient and the benefit of ML-like detector given additional correlations is not clear.

1. LP-WUS monitoring duration

Larger number of candidates overlaid OFDM sequences reduces LP-WUS monitoring duration, resulting in lower power consumption [2] [8].

[2][8] evaluate LP-WUS monitoring duration, i.e., required number of OFDM symbols to be received by LP-WUR to meet performance requirement at SNR=-3dB, with repetition is considered if needed. [2] shows 8 candidate sequences and 64 candidate sequences require same number of OFDM symbols which is smaller than other 4/16/32 candidate sequences. [8] shows 32 candidate sequences requires minimum number of OFDM symbols compared with 4/8/16 candidate sequences.

[10] thinks early detection is beneficial for UE power saving, but it is rather limited given that LR is on a relatively low power consumption thus this can be put as secondary consideration.

Considering similar complexity for 16, 8, 4 sequences for M=1, 2 and 4 per OOK ON chip, and based on majority support, FL suggests following:

**[H][FL1] Proposal 3.2-3:** Regarding the maximum number of candidates overlaid sequences to carry LP-WUS information per OOK ON chip for one cell:

- support maximum 16 candidates overlaid sequences for M=1

- support maximum 8 candidates overlaid sequences for M=2

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| Company | Y/N | Comments |
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#### 3.2.1.4 Root and CS for overlaid ZC sequence

Companies discuss whether any root between 1~ (Bzc -1) or only some particular root is proper for overlaid OFDM sequence.

 [2] [4]discuss the impact of frequency offset on different root. [4] provides auto-correlation of different root for frequency offset 0~ 6ppm, e.g., root q=1, 2,3 and 32, observing some particular root suffers significant performance degradation. [4] also provides timing offset of different root for 30kHz frequency offset (>10ppm), showing significant timing offset for particular root. Differently, [2] shows similar auto-correlation for all roots for frequency offset 0~ 5ppm, and similar timing offset, e.g., no larger than one sample with 7.68MHz sample rate, for all roots.

[8][18] provides sequence detection performance for different root. [8] shows similar FAR for different roots assuming around 0.5 ppm frequency offset. [18] provides MDR for different roots for single overlaid OFDM sequence, showing ~ 1dB performance difference between all roots, but for multiple overlaid OFDM sequence generated by same root with different CS, much larger gap is observed for certain roots.

Preferred roots provided by [4] and [18] is copies as below. It can be seen that, the optimal root is different for different sequence length, and it also depends on the number of sequences in an OOK ON chip, as well as whether different CS or different root or different CS + root is used to generate multiple sequences as evaluated by [18].

|  |
| --- |
| Proposed roots by [4]  |
| The length of ZC | Optimal ZC root sequences |
| L = 127 | q = 1, 32, 42, 63, 64, 85, 95, 126 |
| L = 61 | q = 1, 15,20, 30, 31, 41, 46, 60 |
| L = 59 | q = 1, 15, 20, 29, 30, 39, 44, 58 |
| L = 53 | q = 1, 13, 18, 26, 27, 35, 40, 52 |
| L = 31 | q = 1, 8, 10, 15, 16, 21,23, 30 |
| L = 29 | q = 1, 7, 10, 14 ,15, 19, 22, 28 |
| L = 23 | q = 1, 6, 8, 11, 12, 15, 17, 22 |
|  |  |
| Proposed roots by [18]  |
| L = 53 | q = 1, 13, 18, 26, 27, 35, 40, 52, for overlaid OFDM sequence case q = 1, 26, 27, 52 for 4 overlaid OFDM sequence case generated by same root + 4 CSq= 1, 13, 18, 26 for 8 overlaid OFDM sequence case generated by same root + 8 CS or 2 roots+4 CS |

Besides, [2] [4] [5] [18] proposes to use complementary roots, e.g., root q and root (Bzc -q) to reduce sequence correlation complexity, similar as NR PRACH or LTE PSS logic.

**[H][FL1] Question 3.2-1: Do you think the specification should provide a specific set of roots, due to robustness to frequency error, i.e., up to 5ppm, or, it can be up to gNB to configure any root between 1~ (Bzc -1) ?**

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| Company | Y/N | Comments |
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For different CS, [2] [4] [8][7] discuss minimum CS separation (or maximum number of CS). [2] [4] analysis that minimum CS separation should be no smaller than 2\*maximum timing error. [8] provides FAR performance for different CS separation, showing at least 5 is needed. [7] suggests to discuss sliding window size before determination of CS separation.

 [5] [11] do not prefer using CS, due to less robustness to long delay spread, while [14][21] [27] prefer to only use different CS for a cell, i.e., not consider different root for multiple sequences in a cell.

**[M][FL1] Question 3.2-2: Do you support using different CS for multiple overlaid OFDM sequences for a cell?**

* **If yes, what is your preferred maximum number of CS for each M value?**
* **If the number of multiple overlaid OFDM sequences is no larger than the maximum number of CS, do you prefer to only use CS or, different CS + different roots for the multiple overlaid OFDM sequences?**

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| Company | Y/N | Comments |
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[2] [4] [7] [8] [14] propose to use different overlaid OFDM sequence for different cells to minimize inter-cell interference. [2] [4] analyze that, ZC sequences generated by the same root but difference cyclic shifts may not reduce inter-cell interference, since the timing difference between different cells may be larger than the minimum cyclic shift which results in strong interference, while different root helps because the aperiodic cross-correlation between sequences with different root can be kept small even with large timing difference among cells.

[8] thinks it can be up to gNB implementation to configure same or different sets of sequences for different cells.

FL suggests to agree different roots for different cells. Regarding different roots for a cell, it depends on Question 3.2-1 & 3.2-2 and number of overlaid OFDM sequences per OON ON chip, thus FL suggests it FFS.

**[H][FL1] Proposal 3.2-4:** Different overlaid OFDM sequences based on different roots are used for different cells.

|  |  |  |
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| Company | Y/N | Comments |
|  |  |  |

Regarding the configuration signaling, [2][4][8] propose it to be configurable by the network to have more flexibility. [3][5][19] prefer a pre-defined rule. [3] prefers the overlaid ZC sequences is enumerated in increasing order of first increasing cyclic shift of a root ZC sequence and then in increasing order of the root index. [5][19] prefers to use similar rule to derive the root as NR PRACH.

FL suggests to discuss the detailed configuration signaling after progress of question 3.2-1 and 3.2-2.

### How to carry information by OFDM sequences

1. In case of overlaid OFDM sequence not carrying information, RAN1 made following agreement

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| AgreementIn case of overlaid OFDM sequence not carrying information: * Option 1: Single overlaid sequence is on each OOK ‘ON’ symbol.
* Note 1: multiple overlaid OFDM sequences are specified.
* Note 2: gNB can configure different overlaid OFDM sequence(s) for different cells.
 |

[4] discusses which single sequence can be configured by gNB, e.g., the sequence is one of the candidate overlaid OFDM sequence discussed for the case of overlaid OFDM sequence carrying information. Considering detailed design for multiple overlaid OFDM sequence is still under discussion, FL suggests to go back to this issue after progress of section 3.2.1.

[6] suggests to clarify, the single overlaid sequence is configured by gNB as a known sequence to the UE. According to FL’s understanding, since single sequence is configured per above agreement, it is already clear that the sequence is known to the UE.

1. In case of overlaid OFDM sequence carrying information, RAN1 made following agreement

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| --- |
|  AgreementUpdate the existing agreement as shown below:In case of overlaid OFDM sequence carrying information, support option 2: * Option 2: One sequence is selected from multiple candidates overlaid OFDM sequences on each OOK ‘ON’ symbol, and OFDM-based LP-WUR obtain LP-WUS information at least by overlaid OFDM sequence(s). Consider the following two sub-options for potential down-selection.
	+ ~~Option 2-1: The overlaid OFDM sequence(s) carry part of information bits of LP-WUS. OFDM-based LP-WUR can obtain the whole information bits by OFDM sequence(s) and location of the OFDM sequence(s)/OOK ‘ON’ 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)
		- FFS the how the information bits are carried by the overlaid OFDM sequence(s)

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

Regarding the FFS point, how the information bits are carried by the overlaid OFDM sequence(s), companies discuss two issues.

**Issue 1: information bits order carried by the overlaid OFDM sequence**

* Option 1: in ascending order [2][10] [13][16] [25]
* Option 2: in descending order [4][10][25]
* Option 3: A pre-defined order determined by the number of OOK symbols which may be received and combined with overlaid OFDM sequences [18] [23] [24] [27]

The motivation for option 2/3 is to support earlier termination for reception. It is understood by companies that, if the bit carried by OOK symbols is not original information bit, Option 2 and option 3 cannot help earlier termination. If the bit carried by OOK symbols is original information bit, option 2 and option 3 can enable earlier termination. Some examples for the latter case are provided.

FL suggests to come back after progress of section 3.3, which discusses whether the carried by OOK symbols is original information bit.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Manchester symbol (two chips)** | **0** | **1** | **2** | **3** | **4** | **5** |
| **Original information bit** | b1 | b2 | b3 | b4 | b5 | b6 |
| **Overlaid sequences****carrying 2-bits (mapping order option 1)** | b1b2 | b3b4 | b5 b6 |  |  |  |
|  | OFDM detector receives 3 OOK ON chips for option 1 |
| **Overlaid sequences****carrying 2-bits (mapping order Option 2)** | b6b5 | b4 b3 | b2b1 |  |  |  |
|  | OFDM detector receives 2 OOK ON chips for option 2 |
| **Overlaid sequences****carrying 2-bits (mapping order Option 3)** | b3b4 | b5 b6 | b1b2 |  |  |  |
|  | OFDM detector receives 2 OOK ON chips for option 3 |

**Issue 2: Whether the overlaid OFDM sequence in one OOK ON chip should carry all information for a LP-WUS [5] [6][9] [17].**

Companies discuss following options,

* option 1: overlaid OFDM sequences in one OOK ON chip carries partial information bits so that a UE receivers overlaid OFDM sequences in multiple OOK ON chips to receive the whole information bits [2] [6][9], [5] prefers option 1 for M=4.
* option 2: overlaid OFDM sequences in one OOK ON chip carries all information bits. prefers to support at least option 1. [5] for M=1/M=2.

In FL’s understanding, it is also relevant to the supported maximum number of overlaid OFDM sequences. Companies supporting number of candidate sequences per OOK ON chip less than 32 naturally support option 1, assuming maximum up to 32 subgroups supported.

**Others**

[9] discusses whether the information bits carried by overlaid OFDM sequence is codepoint or bitmap indication. [9] proposes the overlay sequences based on bitmap scheme for both RRC idle/inactive and RRC connected mode, for easier sequence detection by OFDM detector, without trying several MOs for sequence detection.

However, based on FL’s understanding, the agreement to use codepoint for RRC idle/inactive state is applicable to both OOK and overlaid OFDM sequence. Bitmap for RRC connected mode can be discussed under section 3.5.

|  |
| --- |
| AgreementFor RRC idle/inactive state, support the following option for at least indicating subgroup information using LP-WUS:* Option 2: A LP-WUS indicates a codepoint value corresponding to one or more subgroup(s) from N subgroups for part of, one or more POs
	+ UE monitoring one or more MOs (up to X MOs) for the same beam within an LO is supported
		- Value of X is larger than 1. FFS on additional details of X.
 |

* 1. The schemes for OOK to meet target requirements for LP-WUS

RAN1 made following agreement.

|  |
| --- |
| AgreementDown-select among the following alternatives for LP-WUS information for OOK to meet target requirements: * adding CRC
* channel coding other than Manchester coding, including rate matching if any
* mapped to a binary sequence/codeword, include truncation if any
* repetition, including rate matching if any
* Note: combination of options above is not precluded
* Note: combination of Manchester coding with above is assumed

FFS how LP-WUS is transmitted within a MO/MOs |

For candidate alternatives for LP-WUS information for OOK to meet target requirements, company views are summarized as below:

* Option 1: Adding CRC, supported by [2] [3] [7][9] [12] [13] [15] [19] [23][26]

CRC can be used to control FAR from noise and from other codepoints/bit value. FAR performance depends on number of CRC bits which can be independent of SNR.

Companies support CRC for bitmap, but have different views on the necessity of CRC for codepoint. [2][8] think no need of CRC for codepoint. [7][3] think CRC is still needed to control FAR.

[2][12] discusses CRC length, and factors impacting CRC length, e.g., size of information bits, probability of transmitting a LP-WUS, e.g., no larger than 6 bits CRC would be sufficient for RRC connected mode.

[9] proposes appending a known bits to the information bits instead of CRC to improve detection performance.

* Option 2: channel coding other than Manchester coding, including rate matching if any, supported by [2] [8][9] [15][18][26] [27]

[2][8][9] provides simulation results comparing channel coding and repetition, showing channel coding outperforms repetition.

[2][8] propose to reuse NR RM coding with rate matching, which can flexibly map different information bits lengths L (e.g., at least L= 4 for 16 codepoints, L=5 for 32 codepoints) to flexible number of available OFDM symbols in a LP-WUS MO. [27] mention 16-bit RM codeword.

* Option 3: mapped to a binary sequence/codeword, include truncation if any, supported by [5] [6][13] [16][21]

[6] considers Hadamard sequence, [5] considers Walsh sequence and [21] considers Kasami sequences, Gold sequences, or m-sequences with good correlation properties.

* Option 4: repetition, including rate matching if any, supported by [2] [3] [4] [5] [7] [8] [11] [17][20] [23] [24]

Companies discuss different repetition schemes, including bit level repetition, OFDM symbol level repetition and block level repetition.

* Bit level repetition: [3] [4] [17]
* OFDM symbol level repetition: [4]
* Block-level repetition: [2][4][8][11][17]

**Table 2 Analysis for option 2-1 and option 2-2 provided by companies**

|  |  |
| --- | --- |
|  | Benefit for corresponding option  |
| Option 1: Adding CRC | * + Robust to FAR from noise and other codepoint/bit value, independent of SNR.
	+ More scalable for various payload than mapping to pre-defined sequence
	+ Less standard effort, because of no sequence design
	+ Lower complexity at receiver side, because both demodulation per OOK bit can be applied, while options relying on sequence detection leads to higher complexity.
 |
| Option 2: Using channel coding, e.g., RM coding, including rate matching if any | * + Better MDR detection performance than the case without channel coding, similar performance as mapping to binary sequence.
	+ Robust to FAR from noise and other codepoint/bit value, even without CRC, if proper threshold is set.
	+ More flexible resource occupancy thus lower overhead than mapping to pre-defined sequence
	+ More scalable for various payload than mapping to pre-defined sequence
	+ Less standard effort, because of no sequence design
 |
| Option 3: Mapping to binary sequence/codeword, including truncation if any | * + Better detection performance than the case without channel coding, if proper threshold is set.
	+ Common design for LP-WUS and LP-SS
 |
| Option 4: Repetition, including rate matching if any | * + Time diversity gain by block-level repetition
	+ Simple for both standard impact and receiver
	+ Easy to combine with other options, e.g., option 1 and/or option 3 to further improve performance
	+ Potential early termination
 |

Performance evaluation comparing different options are summarized as below:

|  |  |
| --- | --- |
|  | Performance |
| Option 1 vs option 2 | [8] shows better performance of codepoint + RM coding, compared with codepoint +CRC |
| Option 2 vs option 3 | [2] shows similar performance for Hadamard sequence and RM coding with sequence length 2^n, but better performance for RM coding than Hadamard sequence when LP-WUS length is not 2^n, i.e., degradation is observed for Hadamard sequence with truncation. |
| Option 2 vs option 4 | [8] shows better performance for RM coding with rate matching, compared with repetition, |
| Option 3 vs option 1 | [5] shows better performance of one or two-stage Walsh sequence than 10bits+6 bit CRC with same overhead.  |

* Other options not captured in previous agreement：
* Spatial diversity with time domain repetition: [4]
* Frequency domain diversity (frequency hopping) with time domain repetition: [3] [4]
* Time domain spreading: [4]

Based on analysis from [6], both option 2 and option 3 essentially belongs to coding problem, to maximize hamming distance between different codepoints. In that sense, one of option 2 and option 3 would be sufficient. Considering option 2 RM coding with rate matching can be more scalable for various payload than mapping to option 3 pre-defined sequence, FL suggests to go with option 2.

Considering necessity of CRC is different for codepoint and bitmap, separate proposals are provided as below.

**[H][FL1] Proposal 3.3-1: For LP-WUS information carried by OOK, support following alternatives for codepoint to meet FAR and MDR performance.**

* **RM coding with rate matching**
* **block-level repetition**
* **Combination of above alternatives**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

**[M][FL1] Proposal 3.3-2: For LP-WUS information carried by OOK, support following alternatives for bitmap (if supported) to meet FAR and MDR performance:**

* **RM coding with rata matching and block-level repetition**
* **CRC and block-level repetition**

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

* 1. The schemes for overlaid OFDM sequence to meet target requirements for LP-WUS

According to evaluation of overlaid OFDM sequences by companies, e.g., [2][8], it is observed single transmission cannot meet performance requirement at SNR=-3dB. Several options are discussed by companies to improve OFDM detector performance, including

* Option 1: repetition [2][4][6] [7] [8][9] [12] [16] [25][27]
	+ [2][4][6] [7] [8][9] [12][25][27] consider block-level repetition
	+ [16] considers repetitions within each OFDM symbol, i.e., candidates overlaid OFDM sequences on two OOK ‘ON’ symbols within one OFDM symbol are repeated, for M=4

If repetition is supported, one follow-up design aspect is, how UE can know the duration of OOK symbols to be detected, depending on the number of repetitions, which may or may not occupy all OFDM symbols for a LP-WUS carrying OOK symbols.

* Option 2: overlaid OFDM sequence carries encoded bits rather than original information bit [9] [18]

[9] think additional robustness can be obtained by employing block decoding original bits, if the overlaid sequence carries encoded bit stream rather using the original information bits. [2][7][12] think the overlaid sequence should carry original information bits, because good correlation property of overlaid OFDM sequence can provide sufficient protection.

**[M][FL1] Proposal 3.4-1:** Support at least repetition for overlaid OFDM sequence to meet target requirements.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

**[M][FL1] Question 3.4-1:** If repetition for overlaid OFDM sequence is supported, do you think the number of actual repetitions should be explicitly configured by gNB, or can be detected by UE implementation?

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

**[M][FL1] Proposal 3.4-2:** The overlaid OFDM sequence carriers the original information bits, without coding or CRC.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

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

RAN1 agreed to down-select between bitmap and codepoint for RRC connected mode.

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

In RAN1 #119 meeting, FL tried to list all possible sub-options for bitmap and codepoint.

|  |
| --- |
| **RAN1 #119****For future meetings:**Companies are encouraged to consider the following for future discussions Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, * Option 1: A bitmap with each bit corresponding to [one or more] UEs
	+ 1A No CRC
		- Per bit coding, e.g., one bit is mapped to one of **2** codeword/sequences
		- The maximum number of codewords targeting per bit position in the bitmap for a UE is **1**
		- FFS coded bit length
		- Single MO
	+ 1B No CRC
		- Bitmap-level coding, e.g., one bitmap of L bits is mapped to one of **2L** codeword/sequences
		- The maximum number of codewords/sequences targeting for a UE is **2L-1**
		- Single MO
	+ 1C With CRC
		- FFS CRC length
		- Single MO
* Option 2: A codepoint value corresponding to [one or more] UEs
	+ 2A only 1-1 mapping from codepoint to UE
		- The maximum number of codepoints targeting per MO for a UE is 1
		- FFS the maximum number of MOs to be detected by a UE
	+ 2B 1-to-1, 1-to-all mapping from codepoint to UEs
		- The maximum number of codepoints targeting per MO for a UE is up to 2
		- FFS the maximum number of MOs to be detected by a UE
	+ 2C 1-to-X mapping from codepoint to UEs,
		- The maximum number of codepoints targeting per MO for a UE is up to
		- FFS the maximum number of MOs to be detected by a UE

Note: L is the number of UEs associated monitoring the same WUS |

Companies discuss bitmap and codepoint. Some companies show preference generally on bitmap or codepoint, some companies show preference on each sub-option. Based on input from companies, company views are summarized as below.

* Option 1: [2] [3] [6][9][10] [11] [12] [13][17] [19] [25] [26]
	+ Option 1A: [6][13]
	+ Option 1B: [11]
	+ Option 1C: [2][9][13][19]
* Option 2: [4] [5] [6][7][8] [16] [19] [20] [21][23]
	+ Option 2A: [6]
	+ Option 2B:[7][8][16] [19] [20]
	+ Option 2C: 1-to-X mapping, [21][23]

**Table 3 Argument for option 1 and option 2 provided by companies**

|  |  |
| --- | --- |
|  | Reasons to support corresponding options provided by companies  |
| Option 1 | 1. Lower overhead compared with codepoint, with same target coverage, especially when traffic arrival probability is medium to high.
2. Smaller number of MOs than codepoint, e.g., 1 vs more than 10 MOs
3. Easier resource management than codepoint, due to smaller maximum number of LP-WUS to be transmitted per cycle, especially for TDD
4. Better power saving gain due to lower FAR (false wake up rate)
5. Simple and straightforward design
6. Simple for UE reception, by monitoring single MO.
 |
| Option 2 | 1. Lower overhead compared with bitmap, when traffic arrival rate is below a threshold, e.g., lower than 30%, and/or the number of UEs associated with a LP-WUS is below a threshold, e.g., less than 8.
2. Flexible link adaptation for each UE.
3. Unified Codepoint for both RRC idle/inactive and connected mode.
4. Lower complexity and less power consumption, due to earlier termination of LP-WUS detection
5. Lower FAR, if the codepoint is long enough.
6. Better MDR performance [4].
 |

Besides the above arguments in table 3, some companies provide evaluation results.

* **Overhead comparison**

When number of UEs per group=8, and traffic probability≥10%, bitmap has smaller overhead than codepoint with one-to-all mapping, w/ and w/o link adaption, targeting SNR matching PDCCH AL=1, 2 and 4 [2].

When number of UEs per group =8, and traffic probability <30%, or number of UEs per group=16 and traffic probability <40%, or number of UEs per group=32 and traffic probability <45%, targeting SNR matching Msg 3 PUSCH coverage, assuming single MO, bitmap has larger overhead than codepoint. Otherwise, bitmap has smaller overhead than codepoint [4].

When number of UEs per group <8, and traffic probability =40%, bitmap has larger overhead than codepoint, assuming single MO [8], otherwise, bitmap has smaller overhead than codepoint.

When number of UEs per group=8, and traffic probability>15%, bitmap has smaller overhead than codepoint with one-to-one mapping. When number of UEs per group=16 or 32, and traffic probability>10%, bitmap has smaller overhead than codepoint with one-to-one mapping. [9].

When number of UEs per group=8, and traffic probability > 5%, codepoint is worse than bitmap [11].

* **False wake-up rate comparison**

Assuming one-to-one and one-to-all codepoint mapping, if maximum MO is 4, showing up to 11% false wake up probability caused by codepoint [2], while FAR for bitmap is always no larger than 1%.

Assuming one-to-one and one-to-all codepoint mapping, if maximum MO is 2, UE traffic probability is 10% ~ 20%, FAR is up to 11.84% for 8 UE case, up to 48.16% for 16 UE case, and 77% for 32 UE case. And if maximum MO is 4, UE traffic probability is 10% ~ 20%, FAR is up to 13.14% for 16 UE case, and 61.7% for 32 UE case. The FAR is always later than bitmap with CRC and/or channel coding [9].

* **Number of MOs required for codepoint:**

Assuming one-to-one and one-to-all codepoint mapping, the number of MOs is 3~6 with UE traffic probability of 10% ~ 50% to meet 1% FAR caused by codepoint [2].

* **Link level performance comparison**

MDR Performance of codepoint is better than bitmap + CRC, with false wake-up rate =1% assuming single MO [4][5].

MDR Performance is similar for 1-1 mapping from codepoint to UE with single MO for a UE and bitmap with 8-bit CRC, with same false wake-up rate and same resource assuming 8 UEs per group, and bitmap without CRC outperforms these two cases [6].

Companies’ preference on bitmap and codepoint are almost half-half. For each option, the sub-option supported by majority is selected for bitmap and codepoint respectively.

**[H][FL1] Proposal 3.4-1:** Regarding the LP-WUS information to trigger PDCCH monitoring of RRC connected UEs, down-selection from the following:

- Option 1-C: bit map with CRC. Repetition can be applied to improve coverage.

- Option 2-B: codepoint, with one-to-one and one-to-all mapping. RM coding with rate matching and/or repetition can be applied to improve coverage.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |

1. LP-SS
	1. M value for LP-SS

### Supported M values for LP-SS

[8] proposes to confirm the working assumption on the M value for LP-SS and M value does not depend on the SCS, with the reason: To have more flexibility for LP-SS transmission the value of M for OOK-4 should not depend on the SCS in FR1, thus M={2,4} should be supported for both 15 kHz and 30 kHz SCS.

Further, considering it has been agreed that OOK-1 is considered as specific case of OOK-4 with M=1. FL suggests to confirm the working assumption with the following updates in red:

**[M][FL1] Proposal 4.1-1:** Confirm the working assumption:

**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~~
	+ Value of M doesn’t depend on SCS
* The SCS of a CP-OFDM symbol used for LP-SS generation is the same as that used for LP-WUS generation
* Note1: OOK-1 is considered as specific case of OOK-4 with M=1.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

###  Same or different M value for LP-WUS and LP-SS

|  |
| --- |
| **RAN1#119 Agreement**For the M value for LP-WUS and LP-SS, down-select one alternative from the following in RAN1#120:* Alt1: The M values for LP-WUS and LP-SS are always same.
* Alt2: The M values for LP-WUS and LP-SS can be configured to be same or different. M value for LP-WUS cannot be larger than that of LP-SS.
* Alt3: The M values for LP-WUS and LP-SS can be configured to be same or different.
 |

Companies view are summarized as below:

* Alt 1: supported by [5] [8] [17] [20][21][23] with the following reason:
	+ the sync performance of LP-SS is not related to the M value but only depends on the sampling rate of 15.36 MHz
* Alt 2: supported by [2][4] [9] [10][11][13] [18] with the following reason:
	+ With same time resource, larger M provides better synchronization time accuracy
	+ Using same M value for both LP-WUS and LP-SS may not be efficient as the requirement for timing offset itself will be the accuracy of estimation.
* Alt 3: supported by [3] [7] [12] [17] [19], [8] if UE supports all M values {1,2,4}, with the following reason:
	+ As long as synchronization accuracy is satisfied, Alt 3 can enable gNB the flexibility to control the time domain resources occupied by LP-WUS and LP-SS.

Based on the analysis in section 5.2, it seems that the sync accuracy required by LP-WUS with larger M value can’t be satisfied by the LP-SS with smaller M value without additional sync. Therefore, FL suggests the following:

**[M][FL1] Proposal 4.1-2:** For the M value for LP-WUS and LP-SS, support:

* Alt2: The M values for LP-WUS and LP-SS can be configured to be same or different. M value for LP-WUS cannot be larger than that of LP-SS.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

* 1. Binary sequence design for LP-SS

### Summary on cross-checking results

[2] [3] [4] [6] [9] [11] [16][18] provide cross-checking results for the sequences collected in R1-2410939. Some companies provide cross-checking results for certain M and L value, while some others provide to all collected M and L values. For each set of M and L, the cross-checked sync accuracy values by companies as well as the sync accuracy from the proposed company are averaged by removing the maximum value and the minimum value. In [6], it provides only single sync accuracy value to a set of 4 sequences and thus, the single sync accuracy is applied to all the four sequences when perform average operation. In [3], it provides two sets of cross-checking results based on detection scheme of mismatch and unipolar, respectively. The averaged sync accuracy values for each combination of M and L are summarized in the excel. For easier catch up, logic index is used to represent the same sequence but proposed by different companies with different sequence index.

The sequences can be ranked according to averaged sync accuracy, and the performance gap among the adjacent ones may be marginal, which could be deemed as the same accuracy by considering simulation error as well as different simulation assumptions among companies. Besides the sync accuracy, low cross-correlation shall be also considered when select 4 sequences. Therefore, instead of directly picking up the top four sequences within the ranked list, it would be better to leave some margin by considering simulation error, and the sequences within the margin can be considered as the same sync accuracy and then, 4 sequences can be selected by further considering the cross-correlation.

In the following, for illustration, a margin of two samples (7.68MHz sampling rate, sample length of 0.13 us) is used to filter out the sequences, if the number of sequences within the margin of 2 samples is smaller than 4, the margin can be extended to count in 4 sequences. The actual margin to be used can be further discussed among the group.

Among these sequences filtered out by the sync margin, cross-correlation can be further checked. Considering that the 4 sequences from the same company are carefully selected for low cross-correlation, it would be helpful to save workload if a set of 4 sequences are selected from the same company for certain M and L. Otherwise, if the 4 sequences are selected from different companies, the cross-correlation may not be guarantted and the cross-correlation shall be checked for all potential combinations of any 4 sequences within the margin.

**[H][FL1] Question 4.2-1:** For certain M and L, do you support to select 4 LP-SS binary sequences by the following?

* For sync accuracy, a margin of [2] samples to the best one is assumed, within which the sequences are considered as having the same accuracy.
* Within the sync margin, a set of 4 sequences from the same company is selected.
* If multiple sets of 4 sequences satisfying above are available, the set with the smallest averaged cross-correlation value is selected.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

* M=1, L=4

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 4 | 3.43  | 2 vivo86 CATT207 docomo304 OPPO335 Ericsson383 Apple |
| 2 | 4.25  | 3 vivo74 Panasonic87 CATT302 OPPO334 Ericsson382 Apple |
| 5 | 4.97 | 1 vivo75 Panasonic88 CATT206 docomo333 Ericsson381 Apple |
| 6 | 8.64 | 76 Panasonic205 docomo |
| 1 | 8.84  | 73 Panasonic301 OPPO |
| 3 | 8.99 | 4 vivo85 CATT303 OPPO336 Ericsson384 Apple |

* M=1, L=6

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 6 | 2.645 | 306 OPPO8 vivo117 ZTE Corporation, Sanechips123 ZTE Corporation, Sanechips387 Apple |
| 4 | 2.840 | 7 vivo118 ZTE Corporation, Sanechips124 ZTE Corporation, Sanechips305 OPPO388 Apple |
| 7 | 3.309 | 5 vivo120 ZTE Corporation, Sanechips121 ZTE Corporation, Sanechips337 Ericsson385 Apple |
| 1 | 3.369 | 386 Apple6 vivo119 ZTE Corporation, Sanechips122 ZTE Corporation, Sanechips340 Ericsson |

* M=1, L=8

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 10 | 2.835  | 10 vivo92 CATT126 ZTE Corporation, Sanechips130 ZTE Corporation, Sanechips263 Qualcomm295 Samsung310 OPPO389 Apple |
| 12 | 2.914 | 11 vivo264 Qualcomm296 Samsung127 ZTE Corporation, Sanechips131 ZTE Corporation, Sanechips311 OPPO390 Apple344 Ericsson |
| 8 | 3.035  | 12 vivo128 ZTE Corporation, Sanechips132 ZTE Corporation, Sanechips262 Qualcomm294 Samsung309 OPPO |
| 1 | 3.176  | 125 ZTE Corporation, Sanechips129 ZTE Corporation, Sanechips261 Qualcomm293 Samsung |

* M=2, L=8

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 7 | 1.582 | 93 CATT133 ZTE Corporation, Sanechips139 ZTE Corporation, Sanechips141 ZTE Corporation, Sanechips145 ZTE Corporation, Sanechips237 LGE267 Qualcomm13 vivo |
| 12 | 1.584 | 347 Ericsson14 vivo134 ZTE Corporation, Sanechips143 ZTE Corporation, Sanechips147 ZTE Corporation, Sanechips80 Panasonic |
| 16 | 1.641  | Apple |
| 5 | 1.651 | 16 vivo135 ZTE Corporation, Sanechips266 Qualcomm395 Apple |
| 14 | 1.685 | 36 Nokia96 CATT136 ZTE Corporation, Sanechips238 LGE299 Samsung393 Apple |
| 6 | 1.699 | 348 Ericsson |
| 3 | 1.730 | 265 Qualcomm15 vivo |
| 11 | 1.741 | 35 Nokia79 Panasonic95 CATT240 LGE268 Qualcomm |
| 16 | 1.760 | 137 ZTE Corporation, Sanechips142 ZTE Corporation, Sanechips146 ZTE Corporation, Sanechips300 Samsung |
| 9 | 1.821 | 315 OPPO |

* M=2, L=12

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 14 | 1.054 | 149 ZTE Corporation, Sanechips160 ZTE Corporation, Sanechips164 ZTE Corporation, Sanechips |
| 5 | 1.098 | 20 vivo151 ZTE Corporation, Sanechips156 ZTE Corporation, Sanechips157 ZTE Corporation, Sanechips161 ZTE Corporation, Sanechips |
| 7 | 1.103 | 18 vivo150 ZTE Corporation, Sanechips158 ZTE Corporation, Sanechips162 ZTE Corporation, Sanechips |
| 17 | 1.153 | 39 Nokia |
| 8 | 1.236 | 399 Apple |
| 4 | 1.271 | 152 ZTE Corporation, Sanechips351 Ericsson |
| 18 | 1.300 | 153 ZTE Corporation, Sanechips159 ZTE Corporation, Sanechips163 ZTE Corporation, Sanechips |
| 12 | 1.318 | 17 vivo |

M=2, L=16 ：

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 4 | 0.886 | 165 ZTE Corporation, Sanechips354 Ericsson |
| 26 | 0.892 | 168 ZTE Corporation, Sanechips175 ZTE Corporation, Sanechips179 ZTE Corporation, Sanechips355 Ericsson |
| 38 | 0.902 | 23 vivo |
| 36 | 0.920 | 99 CATT170 ZTE Corporation, Sanechips |
| 7 | 0.922 | 253 Huawei |
| 39 | 0.924 | 100 CATT292 MTK |
| 22 | 0.932  | 21 vivo |
| 12 | 0.948  | 291 MTK |
| 9 | 0.950  | 167 ZTE Corporation, Sanechips |
| 5 | 0.954  | 166 ZTE Corporation, Sanechips |
| 34 | 0.969  | 272 Qualcomm |
| 28 | 0.971 | 256 Huawei271 Qualcomm |
| 25 | 0.972  | 22 vivo |
| 11 | 0.973  | 97 CATT |
| 13 | 0.981  | 98 CATT |
| 20 | 0.991  | 269 Qualcomm |
| 39 | 0.992  | 292 MTK |
| 10 | 0.996  | 171 ZTE Corporation, Sanechips |
| 36 | 1.003 | 174 ZTE Corporation, Sanechips178 ZTE Corporation, Sanechips |
| 24 | 1.005 | 24 vivo270 Qualcomm |
| 27 | 1.010 | 173 ZTE Corporation, Sanechips177 ZTE Corporation, Sanechips |
| 29 | 1.015 | 176 ZTE Corporation, Sanechips180 ZTE Corporation, Sanechips |
| 33 | 1.036  | 289 MTK  |
| 8 | 1.046  | 254 Huawei  |
| 2 | 1.046  | 255 Huawei |
| 6 | 1.047  | 290 MTK  |
| 41 | 1.056  | 172 ZTE Corporation, Sanechips |
| 3 | 1.062  | 244 LGE |
| 40 | 1.070  | 404 Apple |
| 23 | 1.102  | 242 LGE |
| 30 | 1.106  | 403 Apple |
| 37 | 1.117  | 241 LGE |
| 42 | 1.147  | 356 Ericsson169 ZTE Corporation, Sanechips |

* M=4, L=16

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 27 | 0.871 | 25 vivo |
| 28 | 0.885 | 184 ZTE Corporation, Sanechips190 ZTE Corporation, Sanechips194 ZTE Corporation, Sanechips407 Apple |
| 33 | 0.890 | 183 ZTE Corporation, Sanechips189 ZTE Corporation, Sanechips193 ZTE Corporation, Sanechips |
| 48 | 0.897 | 192 ZTE Corporation, Sanechips196 ZTE Corporation, Sanechips |
| 41 | 0.935 | 27 vivo |
| 30 | 0.940  | 188 ZTE Corporation, Sanechips |
| 12 | 0.944  | 181 ZTE Corporation, Sanechips |
| 35 | 0.944  | 187 ZTE Corporation, Sanechips |
| 39 | 0.960  | 408 Apple |
| 40 | 0.976 | 185 ZTE Corporation, Sanechips191 ZTE Corporation, Sanechips195 ZTE Corporation, Sanechips |
| 47 | 0.985  | 182 ZTE Corporation, Sanechips |
| 38 | 0.985  | 108 CATT |
| 27 | 1.002  | 28 vivo |
| 15 | 1.011  | 105 CATT |
| 36 | 1.013  | 107 CATT |
| 34 | 1.016  | 82 Panasonic |
| 43 | 1.034  | 186 ZTE Corporation, Sanechips |
| 9 | 1.048  | 26 vivo |
| 16 | 1.048  | 106 CATT |
| 29 | 1.067  | 276 Qualcomm |
| 32 | 1.103  | 405 Apple |

* + unbalanced ‘0’ and ‘1’ within each OFDM symbol:

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 1 | 0.871  | 287MTK |
| 22 | 0.894  | 61 Futurewei |
| 18 | 0.910  | 64 Futurewei |
| 20 | 0.937  | 63 Futurewei |
| 21 | 0.957  | 62 Futurewei |
| 46 | 1.026  | 50 Futurewei |
| 5 | 1.040  | 286 MTK |
| 19 | 1.040  | 285 MTK |
| 23 | 1.040  | 288 MTK |
| 31 | 1.053  | 51 Futurewei |

* M=4, L=32
	+ balanced ‘0’ and ‘1’ within each OFDM symbol:

|  |  |  |
| --- | --- | --- |
| 36 | 0.614  | 197 ZTE Corporation, Sanechips |
| 13 | 0.621  | 258 Huawei |
| 42 | 0.626  | 29 vivo |
| 33 | 0.628  | 32 vivo |
| 17 | 0.633  | 109 CATT |
| 37 | 0.656  | 200 ZTE Corporation, Sanechips |
| 41 | 0.658  | 30 vivo |
| 5 | 0.666  | 198 ZTE Corporation, Sanechips |
| 35 | 0.666  | 199 ZTE Corporation, Sanechips |
| 52 | 0.668  | 203 ZTE Corporation, Sanechips |
| 45 | 0.668  | 201 ZTE Corporation, Sanechips |
| 10 | 0.670  | 260 Huawei |
| 44 | 0.673  | 202 ZTE Corporation, Sanechips |
| 43 | 0.673  | 204 ZTE Corporation, Sanechips |
| 34 | 0.684  | 110 CATT |
| 38 | 0.685  | 111 CATT |
| 39 | 0.687  | 112 CATT |
| 40 | 0.702  | 245 LGE |
| 11 | 0.708  | 257 Huawei |
| 8 | 0.708  | 259 Huawei |
| 29 | 0.734  | 247 LGE |
| 16 | 0.742  | 246 LGE |

|  |  |  |
| --- | --- | --- |
| 14 | 0.784  | 279 Qualcomm |
| 31 | 0.794  | 280 Qualcomm |
| 46 | 0.796  | 364 Ericsson |
| 9 | 0.798  | 248 LGE |
| 28 | 0.804  | 31 vivo |
| 7 | 0.820  | 277 Qualcomm |

* + unbalanced ‘0’ and ‘1’ within each OFDM symbol:

|  |  |  |
| --- | --- | --- |
| logic sequence index | Average sync accuracy (Exclude the max and min values) (us) | sequence index + company |
| 2 | 0.563  | 281 MTK |
| 22 | 0.651  | 68 Futurewei |
| 1 | 0.651  | 282 MTK |
| 24 | 0.651  | 65 Futurewei |
| 23 | 0.651  | 67 Futurewei |
| 3 | 0.651  | 283 MTK |
| 4 | 0.651  | 284 MTK |
| 20 | 0.694  | 66 Futurewei |
| 19 | 0.716  | 72 Futurewei |

### The sequence lengths for LP-SS

|  |
| --- |
| **Agreement**For the length L of LP-SS binary sequence, limit the selection to the following:* M=1, L= {4, 6, 8}
* M=2, L= {8, 12, 16}
* M=4, L= {16, 32}
 |

The supported number of sequence lengths for each M provided by companies are summarized as below

* [2] supports L=8,8,32 for M=1,2,4
* [4]:
	+ M=1, L= 8
	+ M=2, L= 16
	+ M=4, L= 32
* [5] [17]: 4,8,16 for M=1,2,4
* [7] supports three LP-SS lengths, but not bundled with M value
* [8] supports 2 LP-SS lengths for each M, L= {4,6} for M=1 and L= {8,12} for M=2
* [9] supports L=8,16 for M=2, M=4
* [11] supports L=8,16 for M=2 and L=16,32 for M=4

Considering, the LP-SS length depends on the discussion on time error tolerance vs total timing error due to residual timing error by LP-SS and residual frequency error. This part can be further discussed until progress in section 5.2.

### The number of ‘0’ and ‘1’ within each OFDM symbol of the LP-SS sequence

For M=1, the number of ‘1’s and the number of ‘1’s are same or different within the binary sequence.

* [2][3][4][7] [9] support the same number with the following reason :
	+ Improving LP-RSRP/LP-RSRQ calculation accuracy;
	+ Ensuring the AGC performance;

Based on the discussion above, FL suggests the following :

**[M][FL1] Proposal 4.2-1:** For LP-SS binary sequences, support the same number of 1(s) and 0(s) within the binary sequence for M=1.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

For M >1, the number of ‘1’s within one OFDM symbol is same or different for different OFDM symbols

* [2][3][7] [4] [9] support the same number with the following reason :
	+ the same power level of OOK symbol in each OFDM symbol can be kept to ensure sequence correlation performance
	+ avoid transmit power saving waste
	+ the resulting power variations degrade both timing and RSRP estimation performance.
* [16] [18][25] provide binary sequence with different number ’1’s for different OFDM

Based on the discussion above, FL suggests the following :

**[M][FL1] Proposal 4.2-2:** For LP-SS binary sequences, support the same number of 1(s) across OFDM symbols for M>1.

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

For M>1, balanced or unbalanced ‘0’ and ‘1’ within each OFDM symbol

 [2] [4] [3] [9] propose to support balanced 0 & 1 within each OFDM symbol:

* Improving LP-RSRP/LP-RSRQ calculation accuracy;
* Ensuring the AGC performance;

[4][7] analyzes the unbalanced 0&1 has the following drawbacks:

* it contains consecutive OOK OFF symbols, which impacts the detectable range of frequency error
* higher power level of OOK ON symbol for LP-SS than that for LP-WUS, AGC can be impacted One company
* it becomes harder for the receiver to set the proper range for ADC operation

 [11] [18] support low density sequence with unbalanced 0&1 within each OFDM symbol since it provides the following advantages:

* Better sync accuracy due to power pooling

Based on the discussion above, FL suggests the following:

**[H][FL1] Proposal 4.2-3:** For LP-SS binary sequences, support the same number of 0(s) and 1(s) within each OFDM symbol for M>1

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. LP-SS with overlaid OFDM sequences

|  |
| --- |
| **Agreement**Support overlaid OFDM sequence(s) for LP-SS:* LP-SS reuses the overlaid OFDM sequence(s) specified for LP-WUS. The design on overlaid OFDM sequence(s) specified for LP-WUS doesn’t target for sync and RRM measurement performance based on overlaid OFDM sequence for LP-SS.
* Whether to transmit LP-SS by using a specified overlaid OFDM sequence is configurable.
	+ Applicable at least for OOK-1 and FFS for OOK-4
* From RAN1 perspective, it is not intended to introduce new RAN4 requirements specific to overlaid sequences
 |

### OOK-4: Whether to transmit LP-SS by using a specified overlaid OFDM sequence is configurable

Regarding whether to transmit LP-SS by using a specified overlaid OFDM sequence is configurable, whether it is applicable to OOK-4 is still FFS.

Don’t support configurable by [4][10][14][20] with the following reason:

* it is impossible to share the resource of LP-SS with legacy NR UEs. In this case, it is always beneficial to let UE know the transmitted overlaid sequence, while it does no harm to gNB

Based on the above, FL suggests the following

**[H][FL1] Proposal 4.3-1:** Update the agreements in RAN1 #118bis as below

**Agreement**

Support overlaid OFDM sequence(s) for LP-SS:

* LP-SS reuses the overlaid OFDM sequence(s) specified for LP-WUS. The design on overlaid OFDM sequence(s) specified for LP-WUS doesn’t target for sync and RRM measurement performance based on overlaid OFDM sequence for LP-SS.
* Whether to transmit LP-SS by using a specified overlaid OFDM sequence is configurable.
	+ Applicable ~~at least~~ for OOK-1 ~~and FFS for OOK-4~~
* From RAN1 perspective, it is not intended to introduce new RAN4 requirements specific to overlaid sequences

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

### How to specify OOK waveform if overlaid OFDM sequence is not configured

Since transmitting LP-SS by using a specified overlaid OFDM sequence is configurable, how to specify OOK waveform if overlaid OFDM sequence is not configured shall be considered. [2] provides two approaches:

* Approach 1: the input of DFT is simply specified by a vitual sequence with constant envelope to guarantee the OOK detection performance.

It’s up to gNB to generate any sequence with constant envelop, e.g., CSI-RS sequence (bipolar Gold sequence) or PDCCH (QPSK modulation).

* Approach 2: the input of DFT is unspecified in RAN1, and it is left to RAN4 requirements to guarantee the OOK detection performance.

It’s up to gNB to generate any sequence as long as it meets RAN4 requirements.

**[M][FL1] Question 4.3-1:** What’s your consideration on how to specify OOK waveform if overlaid OFDM sequence is not configured?

|  |  |
| --- | --- |
| **Company** | **Comments** |
|  |  |
|  |  |

### How LP-SS reuses the overlaid OFDM sequence(s) specified for LP-WUS

In RAN1#118bis meeting, it has been agreed that LP-SS reuses the overlaid OFDM sequence(s) specified for LP-WUS. Regarding how to reuse such specified overlaid OFDM sequence(s), [4] proposes using different roots of ZC sequences on different OOK "on" symbols can improve receiving performance. FL notices that in RAN1#118bis meeting, it has been agreed that for the case of overlaid OFDM sequence not carrying information, the solution of using different overlaid sequences across different OOK "on" symbols is precluded and single overlaid sequence on each OOK ‘ON’ symbol has been agreed. It seems that the same design principle can apply to the overlaid OFDM sequence for LP-SS.

**[M][FL1] Question 4.3-2:** Do you support using different roots of ZC sequences on different OOK "on" symbols for LP-SS?

|  |  |
| --- | --- |
| **Company** | **Comments** |
|  |  |
|  |  |

Further, to reduce UE complexity, [6] proposes to maintain the same overlaid sequence length for LP-SS and LP-WUS when they have different M values, e.g., when the M value for LP-SS is larger than that for LP-WUS, length of the overlaid sequence is determined by M for LP-SS. From FL’s understanding, the existing agreement doesn’t restrict that the length of the overlaid sequence used by LP-SS shall be the same with the one used by LP-WUS. What’s your consideration on the overlaid OFDM sequence length for LP-SS and LP-WUS when they have different M values?

**[M][FL1] Question 4.3-3:** What’s your consideration on the overlaid OFDM sequence length for LP-SS and LP-WUS when they have different M values?

Option 1: Same overlaid OFDM sequence length for LP-SS and LP-WUS

Option 2: Different overlaid OFDM sequence lengths corresponding to its respective M value

|  |  |  |
| --- | --- | --- |
| **Company** | **Option** | **Comments** |
|  |  |  |
|  |  |  |

1. Necessity of additional synchronization signal
	1. Summary on companies’ views

|  |
| --- |
| **Agreement**Regarding whether to support additional sync signal to LP-SS, down-selection from the following: * Option 1A: No additional sync signal, LP-SS periodicity =320ms
	+ Additionally support at least one of [80ms,160ms]
		- FFS: whether different values can be applicable for different M values
* Option 1B: No additional sync signal, LP-SS periodicity =320ms
	+ No additional support of other periodicities
* Option 2: With additional sync signal, LP-SS periodicity =320ms
	+ FFS additionally support other LP-SS periodicities
	+ FFS details on additional sync signal
	+ FFS additional sync signal is configurable and/or conditionally present
 |

Companies’ views are summarized as below:

* Option 1A supported by [2] [4] [7] [16] [18]:
	+ [4][7]: additionally support 160ms
	+ [2][16]: additionally support 80ms for at least M=4, 160ms for at least M=1,320ms is sufficient for M=2
	+ [16]: additionally support 80ms,160ms
	+ [18]: only support under the condition target residual time error is updated as T=0.5 μs and the residual frequency error is ≤ 5 ppm, additionally support160ms
	+ [7]: it can be up to UE implementation for how to receive LP-WUS successfully under the given LP-SS periodicity, e.g., via sliding window detection
* Option 1B supported by [8][9][11]:
	+ [8]: for OOK-1
	+ [9]: with codeword detection of LP-WUS, it can avoid introducing additional overhead/signal design at the NW.
* Option 2 supported by [5] [6] [8] [12] [13] [15] [18]:
	+ [8]: for OOK-4 with M=2,4
	1. Time error tolerance vs Total timing error due to residual timing error by LP-SS and residual frequency error
* In this section, total timing error is calculated based on the maximum residual timing error with in the margin in terms of sync accuracy from the averaged cross-checking results in section 4.2.1.
	+ M=1

|  |  |
| --- | --- |
| **LP-SS periodicity**  | **Fr=5 ppm** |
| **320 ms** | L=4, Tr=8.6 us | L=6, Tr=3.4 us  | L=8, Tr=3.2 us  |
| 10.2 us | 5 us | 4.8 us |

* + M=2

|  |  |
| --- | --- |
| **LP-SS periodicity**  | **Fr=5 ppm** |
| **320 ms** | L=8, Tr=1.8 us | L=12, Tr=1.3 us  | L=16, Tr=1.1 us  |
| 3.2 us | 2.9 us | 2.7 us |

* + M=4

|  |  |
| --- | --- |
| **LP-SS periodicity**  | **Fr=5 ppm** |
| **320 ms** | L=16, Tr=1.1 us(balanced 0 and 1 within an OFDM symbol) | L=16, Tr=1.0 us(unbalanced 0 and 1 within an OFDM symbol) | L=32, Tr=0.8 us(balanced 0 and 1 within an OFDM symbol) | L=32, Tr=0.7 us(unbalanced 0 and 1 within an OFDM symbol) |
| 2.7 us | 2.6 us | 2.4 us | 2.2 us |
| **160ms** | 1.9us | 1.8us | 1.6us | 1.5us |
| **80ms** | 1.1us | 1.0us | 0.8us | 0.7us |

* When compare the total time error above with the time error tolerance in TR 38.869, i.e., 5,3,1 us for M=1,2,4, it seems that LP-SS of 320 ms is sufficient for M=1, 2 with length below, when 5ppm residual frequency error is assumed, and if 10 ppm residual frequency error is assumed, 160ms shall be additionally supported.
	+ M=1, L=6, 8
	+ M=2, L=12,16
* While for M=4, for 5ppm residual frequency error, it seems that 80ms shall be additionally supported to meet the time error tolerance 1 us, and both the length of 16 and 32 work.

Based on the analysis above, considering up to 10ppm residual frequency error, FL suggests the following:

**[M][FL1] Proposal 5.2-1:** Regarding whether to support additional sync signal to LP-SS, support the following for LP-WUS with M=1 and M=2:

* Option 1A: No additional sync signal, LP-SS periodicity =320ms
	+ Additionally support at least one of 160ms
* FFS: LP-WUS with M=4

|  |  |  |
| --- | --- | --- |
| **Company** | **Y/N** | **Comments** |
|  |  |  |
|  |  |  |

* The time error tolerance considered by companies:

|  |  |
| --- | --- |
|  | Time error tolerance |
| M=1 | M=2 | M=4 |
| TR 38.869(SNR degradation <= 2dB) | 5us | 3us | 1us |
| [4] | 8us | 4us | 2us |
| [8](SNR degradation <1dB) | 6us | 2us | 1us |

* Total timing error derived by companies
	+ [8]: periodicity of 320ms, Fr=5 or 10 ppm, LP-SS length of 4 or 6 OFDM symbols for M=1,2,4

|  |  |  |
| --- | --- | --- |
| **LP-SS periodicity and duration** | **Fr=5 ppm for OOK-WUR** | **Fr=10 ppm for OOK-WUR** |
| **320 ms, 4 OFDM symbols** | Tr=2.8 us [OOK-1] | Tr=1.5 us [OOK4, M=2] | Tr=1.4 us [OOK4, M=4] | Tr=2.8 us [OOK-1] | Tr=1.5 us [OOK4, M=2] | Tr=1.4 us [OOK4, M=4] |
| 4.4 us | 3.1 us | 3 us | 6 us | 4.7 us | 4.6 us |
| **320 ms, 6 OFDM symbols** | Tr=2.2 us [OOK-1] | Tr=1.1 us [OOK4, M=2] | Tr=1 us [OOK4, M=4] | Tr=2.2 us [OOK-1] | Tr=1.1 us [OOK4, M=2] | Tr=1 us [OOK4, M=4] |
| 3.8 us | 2.7 us | 2.6 us | 5.4 us | 4.3 us | 4.2 us |

* + [2]: periodicity of 320,160, 80ms, Fr=5 ppm, LP-SS length of {6,8},{4,6,8},{4,8} OFDM symbols for M=1,2,4, respectively

|  |  |  |  |
| --- | --- | --- | --- |
|  | * + Tr=4.3 and 3.5us and based on evaluation in section 5
 | * + Tr=1.04, 0.78 and 0.52us based on evaluation in section 5
 | * + Tr=0.78 and 0.52 us based on evaluation in section 5
 |
| * + Time error tolerance in TR 38.869
 | * + 5 (OOK-1)
 | * + 3 (OOK4, M=2)
 | * + 1(OOK4, M=4)
 |
| * + LP-SS periodicity 320 ms
 | * + 5.9us, 5.1us
 | * + 2.6us, 2.4us, 2.1us
 | * + 2.4us, 2.1us,
 |
| * + LP-SS periodicity 160 ms
 | * + 5.1us, 4.3us
 | 1.84us, 1.58us, 1.32us | * + 1.6us, 1.3us,
 |
| * + LP-SS periodicity 80 ms
 | * + 4.7us, 3.9us
 | * + 1.44us, 1.18us, 0.92us
 | * + 1.2us, 0.9us
 |
| Note 1: Fe=5ppm is assumed. Note 2: As evaluated in section 5, * For M=1, assuming no power pooling across OFDM symbols. LP-SS length = 6 bits to achieve Tr=4.3us, LP-SS length = 8 bits to achieve Tr=3.5us.
* For M=2, LP-SS length = 8 bits to achieve Tr=1.04us, LP-SS length = 12 bits to achieve Tr =0.78us and LP-SS length = 16 bits to achieve Tr =0.52us.
* For M=4 & 30kHz SCS, LP-SS length =16 to achieve Tr=0.78us, and LP-SS length = 32 bits to achieve Tr=0.52us.
 |

* + ZTE: periodicity of 320,160, 80ms, Fr=5 or 10 ppm or 20ppm, LP-SS length of 4 or 6 OFDM symbols for M=1,2,4

|  |  |  |  |
| --- | --- | --- | --- |
|  | Residual frequency error=20ppm | Residual frequency error=10ppm  | Residual frequency error=5ppm |
| LP-SS periodicity(ms) | Worst time drift before LP-WUS detection, T,(us) | LP-SS TO estimation accuracy, $∆T$,(us) | Total TO before LP-WUS detection,(us) | Worst time drift before LP-WUS detection, T,(us) | LP-SS TO estimation accuracy, $∆T$,(us) | Total TO before LP-WUS detection,(us) | Worst time drift before LP-WUS detection, T,(us) | LP-SS TO estimation accuracy, $∆T$,(us) | Total TO before LP-WUS detection,(us) |
| 80 | 1.6 | 5 | 6.6 | 0.8 | 5 | 5.8 | 0.4 | 5 | 5.4 |
| 2 | 3.6 | 2 | 2.8 | 2 | 2.4 |
| 1 | 2.6 | 1 | 1.8 | 1 | 1.4 |
| 160 | 3.2 | 5 | 8.2 | 1.6 | 5 | 6.6 | 0.8 | 5 | 5.8 |
| 2 | 5.2 | 2 | 3.6 | 2 | 2.8 |
| 1 | 4.2 | 1 | 2.6 | 1 | 1.8 |
| 320 | 6.4 | 5 | 11.4 | 3.2 | 5 | 8.2 | 1.6 | 5 | 6.6 |
| 2 | 8.4 | 2 | 5.2 | 2 | 3.6 |
| 1 | 7.4 | 1 | 4.2 | 1 | 2.6 |
| Note1: The residual frequency error is assumed after frequency error correction by RTC calibration. |

* 1. Overhead comparison
* Overhead of LP-SS only vs LP-SS and additional sync compared by companies are summarized as below:

According to the table, FL observes overhead results depend on the following aspects:

* + The length of LP-SS
	+ The length of additional sync signal
	+ Subgroup paging rate
	+ Number of Pos within one I-DRX cycle

Under different assumptions, which scheme provides less overhead is different.

Before going through the overhead comparison details, it’s more important to figure out whether the sync accuracy provided by LP-SS only without additional sync signal can satisfy the time error tolerance with certain periodicities in 5.2. Then the overhead comparison can be further discussed.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Lenth: LP-SS only(OFDM symbol) | Length: {LP-SS, additional sync}(OFDM symbol) | Subgroup paging rate | Overhead comparison |
| 160ms LP-SS <320ms LP-SS+ additional sync | 80ms LP-SS <320ms LP-SS+ additional sync | 160ms LP-SS <640ms LP-SS+ additional sync | 80ms LP-SS <640ms LP-SS+ additional sync | note |
| [2] | 8 for M=1&4; 4 for M=2; | {6,4} for M=1;{4,4} for M=2,4 | Set1:3.47%, set2: 1.26% | Yes for M=1 | Yes for M=4 with 1.26% subgroup paging rate | N/A | N/A | 32,64 |
| [3] | 8 | {8,4} | 0.1% per UE paging rate |  |  |  |  |  |
| [4] | 8 | {8,8}{8,4} | 3% | yes | N/A | yes | NA | 64POs |
| [8] | 6 | {6,4} | 0.01%,0.1%,0.4%,1% per UE paging rate | Yes for 1% per UE paging rate, no for others | no | N/A | N/A | 32POs  |

[2]:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Options | LP-SS periodicity T and LP-SS length | Additional sync signal length  | Overhead for sync  | Overhead ratio of additional aperiodic sync signal/(LP-WUS without additional aperiodic sync signal) |
| M=1 | Option 1A | 320msLength 8 | N/A | 0.18% | N/A |
| Option 1A | 160msLength 6 | N/A | 0.27% | N/A |
| Option 1A | 160msLength 8 | N/A | 0.36% | N/A |
| Option 2-1 | 320msLength 4 |  Length 6  | Set1: 1.25%Set2: 0.92% | Set1: 32%Set2: 37% |
| Option 2-2MOs within 160ms share one additional sync signal | 320msLength 4 |  Length 6  | Set1: 0.36%Set2: 0.35% | Set1: 9.2%Set2: 14.1% |
| M=2 | Option 1A | 320msLength 8 | N/A | 0.09% | N/A |
| Option 1A | 320msLength 12 | N/A | 0.14% | N/A |
| Option 1A | 320msLength 16 | N/A | 0.18% | N/A |
| Option 2-1 | 320msLength 8 | Length 8  | Set1: 0.87%Set2:0.64% | Set1: 22%Set2:26% |
| M=4 | Option 1A | 80msLength 32 | N/A | 0.71% | N/A |
| Option 2-1 | 320msLength 16 | Length 16 | Set1: 0.87%Set2: 0.64% | Set1: 22%Set2:26% |
| Option 2-2MOs with 40ms shared one additional sync signal | 320msLength 16 | Length 16 | Set1: 0.51%Set2: 0.44% | Set1: 13%Set2:18% |
| Note: UE settings as provided in appendix 9.4 (also same as the setting in [3]) is reused for additional sync signal overhead calculation. |

* + [4]:

|  |  |
| --- | --- |
| Total overhead (OFDM symbols) | periodicity of LP-SS  |
| 160 ms | 320 ms | 640 ms | 1280 ms |
| no preamble | 256 | 128 | 64 | 32 |
| with preamble= 8 OFDM symbols # of LP-WUS per 1.28s | 30 | 1232 (=30\*4\*8+256) | 1104 (=30\*4\*8+128) | 1024 (=30\*4\*8+64) | 992 (=30\*4\*8+32) |
| 50 | 1856 | 1728 | 1664 | 1632 |
| 100 | 3456 | 3328 | 3264 | 3232 |
| with preamble= 4 OFDM symbols # of LP-WUS per 1.28s | 30 | 736 | 608 | 544 | 512 |
| 50 | 1056 | 928 | 864 | 832 |
| 100 | 1856 | 1728 | 1664 | 1632 |

[8]:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 0.01% per UE paging rate | 0.1% per UE paging rate | 0.4% per UE paging rate | 1% per UE paging rate |
| Preamble overhead | **0.02** | **0.2** | **0.7** | **1.7** |
| LP-SS overhead (320 ms periodicity) | **1** | **1** | **1** | **1** |
| LP-SS overhead (160 ms periodicity) | **2** | **2** | **2** | **2** |
| LP-SS overhead (80 ms periodicity) | **4** | **4** | **4** | **4** |
| Preamble+LP-SS (320 ms periodicity) | **1.02** | **1.2** | **1.7** | **2.7** |
| **Note: according to the SI (TR 38.869), the following per-UE paging rates can be considered:** RE, REF= 1%, 0.1%, 0.01% or 0.001% and YREF = 1.28s**Note: for 0.4%** per UE paging rate, the PO group paging rate is over 10%.**Note: 4-symbol preamble and 6-symbol LP-SS are assumed.** |

Companies’ views

FW:

Proposal 1: Support Option 1A (No additional sync signal with LP-SS periodicity ∈{160,320}ms) if the 90% target residual time error is updated as T=0.5 μs for OOK-1 and OOK-4/M=2 waveforms and the residual frequency error is ≤ 5 ppm. Otherwise, support Option 2.

[4]

1. ***For LP-SS periodicity and preamble, support Option 1A, i.e., additionally support 160ms and does not support preamble.***

[2]

**Proposal 16: Support option 1A with LP-SS periodicty of 80ms for at least M=4, 160ms for at least M=1, and 320ms or smaller periodicity for M=2, without addtional sync signal.**

[8]: with 320ms, preamble is not necessary for OOK-1, but needed for OOK-4 (M=2, 4)

Proposal 29 Regarding additional synchronization signal (i.e., preamble), among options identified in RAN1#119, Option 1B should be supported at least for OOK-1. For OOK-4 (M>1), Option 2 can be considered further.

[9]

[16]: Considering timing error requirement for M=4, support option 1A: No additional sync signal, LP-SS periodicity =320ms, and additional 80ms periodicity

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

[6][12][15][5][13][8][3][6][5][13][12][21][23][25][28][7] support additional synchronization signal with the following reason:

* Considering both overhead and timing accuracy, using the preamble is preferred over more frequent LP-SS transmission [8]
* With preamble, LP-WUS waveform and LP-SS periodicity can be flexible by the NW configuration [3]
* reduce periodicity of periodic LP-SS transmission and reduce system overhead [6]

In addition to timing acquisition, AGC stabilization, or channel/interference estimation can be supported by the additional synchronization signal.

[2][16][4][9][2][16] don’t support additional synchronization signal with the following reason:

* Introducing preamble in addition to periodic LP-SS will increase the resource overhead[2] [4]
* LP-WUS codeword itself can be used for sync and it can obtain similar time synchronization performance as LP-SS [9]
1. References
2. RP-234056, New WID: Low-power wake-up signal and receiver for NR (LP-WUS/WUR).
3. R1-2500357, Discussion on LP-WUS and LP-SS design, vivo
4. R1-2500131, Discussion on LP-WUS design, ZTE Corporation, Sanechips
5. R1-2500073, Signal Design of LP-WUS and LP-SS, Huawei, HiSilicon
6. R1-2500231, Design of LP-WUS and LP-SS, CATT
7. R1-2501163, LP-WUS and LP-SS Design, Qualcomm Incorporated
8. R1-2500857, Discussion on LP-WUS and LP-SS design, Samsung
9. R1-2501254, LP-WUS and LP-SS design, Ericsson
10. R1-2500573, LP-WUS and LP-SS design, Nokia
11. R1-2500788, LP-WUS and LP-SS design, Apple
12. R1-2501023, LP-WUS and LP-SS Design, MediaTek Inc.
13. R1-2500739, Discussion on LP-WUS and LP-SS design, Xiaomi
14. R1-2500294, Discussion on LP-WUS and LP-SS design, CMCC
15. R1-2500496, Discussion on LP-WUS and LP-SS Design, EURECOM
16. R1-2500176, Discussion on LP-WUS and LP-SS design, Spreadtrum , UNISOC
17. R1-2500437, Signal design for LP-WUS and LP-SS, OPPO
18. R1-2500491, Discussion on the LP-WUS and LP-SS design, Panasonic
19. R1-2500048, Discussion on LP-WUS and LP-SS Design, FUTUREWEI
20. R1-2501113, Discussion on LP-WUS and LP-SS design, Honor
21. R1-2500530, Discussion on LP-WUS and LP-SS design, InterDigital, Inc.
22. R1-2500656, LP-WUS and LP-SS design, Sony
23. R1-2500063, Discussion on LP-WUS and LP-SS Design, TCL
24. R1-2500956, Discussion on LP-WUS and LP-SS design, LG Electronics
25. R1-2500602, Discussion on LP-WUS and LP-SS design, NEC
26. R1-2501209, Discussion on LP-WUS and LP-SS design, NTT DOCOMO, INC
27. R1-2501096, Discussion on LP-WUS and LP-SS design, Sharp
28. R1-2501294, On LP-WUS and LP-SS design, Nordic Semiconductor ASA
29. R1-2501100, Discussion on LP-WUS and LP-SS design, Lenovo