**3GPP TSG RAN-WG1 Meeting #117 R1-24xxxxx**

**Fukuoka, Japan, May 20-24, 2024**

**Source: Moderator (Huawei)**

**Title:****Feature Lead Summary #1 for 9.4.2.1: “Ambient IoT – General aspects of physical layer design”**

**Document for:** **Discussion and decision**

**Agenda item: 9.4.2.1**

# Introduction

According to the chair’s agenda, this feature lead summary will cover discussions on:

* Waveform ([R2D](#_R2D_waveform_[ACTIVE]); [D2R](#_D2R_waveform_[ACTIVE]))
* Modulation ([R2D](#_R2D_modulation_[ACTIVE]); [D2R](#_D2R_modulation_[ACTIVE]))
* Coding
  + Line coding ([R2D](#_R2D_line_coding); [D2R](#_D2R_line_coding)), channel coding / repetition ([R2D](#_R2D_FEC_/); [D2R](#_D2R_FEC_/))
  + CRC (jointly [for R2D and D2R](#_CRC))
* Multiple access ([R2D](#_R2D_multiple_access); [D2R](#_D2R_multiple_access))
* Time-domain definitions ([R2D](#_R2D_numerology); [D2R](#_D2R_numerology_[INACTIVE]))
* Bandwidth ([R2D](#_R2D_bandwidths_[ACTIVE]); [D2R](#_D2R_bandwidths_[ACTIVE]))

Proposal X.Y(z) is in Section X.Y, where (z) a Roman numeral I, II, III, IV, V, …, is the version of that proposal.

Proposals for online sessions will be added to Section 5 ([link](#_Proposals_for_online_1)).

Decisions are authoritatively in the chair notes, and may be copied into Section 6 ([link](#_Summary)) from time to time.

Previous meetings’ decisions are in Annex A ([link](#_Annex_A_–)).

## Versions

FLS #1: R1-24…

# R2D

## R2D waveform [ACTIVE]

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| Agreement RAN1#116  A-IoT DL study includes an OFDM-based waveform from A-IoT R2D (reader-to-device) perspective.   * Depending on what modulation(s) are decided to be studied:   + Study whether/how to handle CP at transmitter/device/design * Study other characteristics of the OFDM waveform, e.g.:   + CP-OFDM   + DFT-s-OFDM   + Etc.   + The type of OFDM waveform is transparent to A-IoT device.   Other waveforms from DL transmitter’s perspective can be proposed, and further discussion will consider whether or not they are included in the study. |

### CP handling

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| Agreement RAN1#116bis  For R2D CP handling for OFDM based OOK waveform:   * For potential down-selection, study among the following candidate methods   + Method Type 1: Removal of CP at device without specified transmit-side     - FFS: How device determines the CP location     - FFS: Impact on feasibility of device SFO     - FFS: relation to M, if any   + Method Type 2: Ensure the CP insertion of OFDM-based waveform will not introduce false rising/falling edge between the last OOK chip in OFDM symbol (*n*-1) and the first OOK chip in OFDM symbol *n*.     - FFS: Whether/how to arrange that OOK chips have equal length after CP insertion     - FFS: relation to M, if any     - FFS: Detail of relationship to line code codewords     - FFS: Impact on feasibility of device SFO   + [Other method types are not precluded] * Study of the methods should include e.g.:   + CP impact on R2D timing acquisition, and decoding & performance of PRDCH   + Reader and device implementation complexities   + Interference between R2D and NR DL/UL if in the same NR band   + Spectrum efficiency |

Companies have expanded a little on the detail of the methods that might fit into Method Type 1 and Method Type 2, so FL here attempts to group the sub-cases further. This is with a view to prioritizing or selecting among them after further discussions on feasibility and pros/cons, etc., in terms of the aspects identified in the previous agreement.

**Proposal 2.1.1a(I): For potential down-selection of the design for Method Type 1, study the following regarding CP location determination for Method Type 1:**

* **Alt 1: CP location related information is known by device before starting decoding**
  + **Alt 1-1: CP length of each OFDM symbol is known by device**
  + **Alt 1-2: Device does not distinguish exact CP length among different OFDM symbols**
* **Alt 2: CP location related information is not known by device before starting decoding**
* **Companies are encouraged to clarify the CP removal method used and implementation aspects for the device**
* **Evaluations are encouraged to be performed for a small value of M, e.g. 4 and a large value of M, e.g. 24.**

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| **Company** | **Views** |
| EURECOM | It is unclear to us why we need to down-select between Alt 1 and Alt 2. Knowledge of CP at the receiver can be implementation-specific. Some designs may work without others estimate CP from a known signal, e.g. preamble. |
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**Proposal 2.1.1b(I): For potential down-selection of the design for Method Type 2, study the following options regarding subcarrier orthogonality:**

* **Alt 1: Method Type 2 retains subcarrier orthogonality (i.e. CP copied from the end of an OFDM symbol)**
* **Alt 1-1: The first OOK chip and the last OOK chip in an OFDM symbol are the same**
* **Alt 1-2: Ensure the transition edge of a line-code codeword occurs at the CP boundary**
* **Other potential methods are not precluded**
* **Alt 2: Method Type 2 does not retain subcarrier orthogonality**
* **E.g., CP is copied from the beginning of an OFDM symbol**
* **Evaluations are encouraged to be performed for a small value of *M*, e.g. *M* = 4 and a large value of *M*, e.g. *M* = 24.**

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| **Company** | **Views** |
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### Waveform(s)

Although it is possible that the R2D waveform generation may be not specified, it will have in e.g. RAN4 certain time domain characteristics that ensure it is ‘good’. For evaluation purposes in RAN1, it seems we need to agree on how we will model the generation. Hence FL suggests as follows for DFT-s-OFDM:

Note that the below is an attempt to harmonize understanding of signal generation among companies for evaluation purposes. It does not imply any specification of the reader’s signal generation.

**Proposal 2.1.2a(I): For R2D evaluation purposes, the R2D waveform for DFT-s-OFDM is generated as follows:**

1. **The time domain OOK signal is the M chips of one OFDM symbol.**
2. **A chip is potentially up-sampled to L samples, L = N’/M.**
   * **Companies to report L.**
3. **An N’-points DFT (e.g. N’=128) is performed to obtain the frequency domain signal.**
   * **Companies to report N’. N’ modulo M = 0.**
4. **The frequency domain signal FFT-shifted to be centered on DC, and the central X elements are mapped to the X subcarriers of Btx,R2D;**
5. **Zero padding is added on both sides of the obtained X-length frequency signal to create a total N’-length frequency domain signal.**
6. **FFT-shift is reversed. An N’-points IDFT is performed to obtain the time domain signal.**
7. **CP samples are added according to the definition in TS 38.211 section 5.3.1, i.e. .**

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| **Company** | **Views** |
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For CP-OFDM generation, there are no specific proposals available. Proponents may wish to provide them, or we can focus on DFT-s-OFDM from now on.

**Proposal 2.1.2b(I): For R2D evaluation purposes, the R2D waveform for CP-OFDM is generated as: FFS details.**

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| **Company** | **Views** |
| EURECOM | For the CP-OFDM, we may follow the LP-WUS generation. |
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## R2D modulation [ACTIVE]

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| Agreement RAN1#116  A-IoT DL study includes OOK from DL transmitter’s perspective.   * For an OFDM waveform, assume OOK-1 for single-chip per OFDM symbol transmission, and OOK-4 for *M*­-chip per OFDM symbol transmission, starting from definitions in TR 38.869.   + FFS value(s) of *M*.   + FFS: Any changes needed from the definitions in TR 38.869.   + FFS: Exact definition of chip * If other DL waveforms are included, further elaboration of the transmitter’s OOK generation would be needed. |

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| Agreement  For R2D study OFDM-based waveform with subcarrier spacing of 15 kHz, *B*tx,R2D is ≤ [12] PRBs and is down-selected among:   * Alt 1: Including 180 kHz, 360 kHz, and FFS other values * Alt 2: Integer multiple(s) of 180 kHz (FFS: what integer(s)) * Alt 3: Integer multiple(s) of the subcarrier spacing (FFS: what integer(s)) |

### *M* values

It is already agreed that when *M*=1, we use OOK-1. Thus values for *M*>1 apply to OOK-4. There are comments that we should know something about data rate before deciding M, but since the two go together this does not seem to be a strict precondition.

Note that in UHF RFID, Tari ≥ 6.25 μs (for two chips) equating to a data rate approx. 107 kbps with PIE encoding.

**Proposal 2.2.1a(I): For 15 kHz SCS for double sideband modulation:**

* **Support the following pairs of {*M*, *B*tx,R2D}**
* **Support the data rates implied by the corresponding line code(s), if selected in other agreements**
* **FFS: In case CP handling alters the number of chips per OFDM symbol, whether values M’ *=* M ± 1 (M>1) are also supported**
* **NOTE: Single sideband modulation will be separately discussed (if agreed)**

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| ***M*** | **Btx,R2D # of PRBs** | **kilochips/s** | **kbps Manchester encoded** | **kbps PIE encoded with example of 0:1 = 2-chip:4-chip encoding** |
| **1** | 1 | 14 | 7 | 4.67 |
| **2** | 1 | 28 | 14 | 9.33 |
| **4** | 1 | 56 | 28 | 18.67 |
| **6** | 1 | 84 | 42 | 28 |
| **8** | 2 | 112 | 56 | 37.33 |
| **12** | 2 | 168 | 84 | 56 |
| **16** | 3 | 224 | 112 | 74.67 |
| **24** | 4 | 336 | 168 | 112 |
| **32** | 6 | 448 | 224 | 149.33 |

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| **Company** | **Views – especially:**   1. **Any entries your company objects?** 2. **Any other** **{*M*, *B*tx,R2D} your company thinks essential to support?** |
| EURECOM | We are generally fine with this kind of table. However, some combinations, e.g. M=6, 1 PRB, will result in very short chips and are hence extremely sensitive to timing errors and multi-path propagation. |
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### Single / double sideband modulation

The proposals in the papers seem to offer M values for a 2SB modulation. There is not information yet for single sideband. Hence, FL suggests we begin design for 2SB and, if companies can provide details for 1SB, it can be also considered, since this characteristic of the R2D transmission is transparent to the device.

**Proposal 2.2.2a(I): Double sideband modulation is the first assumption for design.**

* **Single sideband modulation can be further studied, e.g. by providing detail values of {*M*, *B*tx,R2D} association, and waveform generation method.**

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| **Company** | **Views** |
| EURECOM | OK |
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## R2D line coding [ACTIVE]

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| **Agreement** RAN1#116  For R2D, line codes studied are: Manchester encoding and pulse-interval encoding (PIE).   * FFS: Mapping(s) from bit(s) to line-code codewords * FFS: Time domain definition of e.g., chips and relation to OFDM symbols, resource allocation unit, etc. |

Removing the parts of the RAN1#116bis proposal that are now handled elsewhere; and FL noting from papers: the general convention for Manchester line coding; and that PIE, if used, is primarily motivated by having a longer high voltage duration, we have:

**Proposal 2.3a(I): The study assumes the following codewords:**

* **For Manchester encoding:** 
  + **bit 0→chips{01}, bit 1→chips{10}**
* **For PIE:**
  + **bit 0→chips{10}, bit 1→chips{1110}.**
* **Note: The SI intends to further down-select between Manchester encoding and PIE.**

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| **Company** | **Views** |
| EURECOM | Concerning Manchester Coding, there is a significant SNR gain if multiple bits are encoded jointly. For instance, M=4, bits{00}🡪chips{0001}, bits{01}🡪chips{0010}, bits{10}🡪chips{0100} and bits{11}🡪chips{1000} will result in a single ON chip per OFDM symbol where all transmit power is concentrated, hence a 3dB SNR gain compared to encoding the 2 bits separately resulting in 2 ON chips.  Therefore, we suggest to add multi-bit Manchester Encoding to the proposal. |
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The general level of support seems to be for Manchester encoding to be preferred, since the availability of energy from RF to the level of several tens of seconds of charging time is not provided by the PIE codewords.

**Proposal 2.3b(I): Use Manchester line coding for R2D.**

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| **Company** | **Views** |
| EURECOM | If the R2D data transmission is NOT used for energy harvesting, i.e. to power the receiver circuit like in passive RFID tags, then Manchester coding is preferred over PIE. |
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## R2D FEC / repetition [ACTIVE]

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| **Agreement** RAN1#116  Regarding FEC, R2D with no forward error-correction code (FEC) is studied as baseline.   * Evaluations would be by comparison to this baseline |

In RAN1#116bis, there was concern on the necessity of repetition in the physical layer for R2D, and no agreement was reach either way. In this meeting, most companies do not mention a need to support it, whatever the definition(s), but a couple of companies raise it. It may be better to come back to this if a coverage shortage is found in 9.4.1.1 evaluations.

(D2R repetition is discussed in Section 3.4).

**Proposal 2.4a(I): R2D transmissions are assumed to not use repetitions as baseline.**

* **Note: Repetitions can be discussed if justified based on the coverage evaluation results.**

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| **Company** | **Views** |
| EURECOM | Coverage extension techniques will likely be required. So better not agree on anything for moment. |
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FL does not currently see sufficient support for detailed further study of other FECs for R2D, and since the coverage evaluation results may not show any need, does not develop a proposal at this time.

## R2D and D2R CRC [VOID]

**See Section 4.**

## R2D multiple access [ACTIVE]

Given the agreements on slotted-ALOHA, and the nature of discussions in Changsha, FL thinks we should simply accept that TDMA is supported, and move to its details. It seems in this agenda item,

**Conclusion 2.6a(I): Due to the agreements in RAN1 and RAN2 related to support of slotted-ALOHA, time-domain multiple access of R2D transmissions is already supported.**

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| **Company** | **Views – FL does not see a way to reasonably deny this conclusion!** |
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In terms of specific details of TDMA, it seems there is little raised in papers as needing further effort in this agenda item, since it will follow naturally as a consequence of timing relationship definitions, system access procedure, etc. Nonetheless, there is one general level constraint proposed as follows.

**Proposal 2.6b(I): Study whether it is necessary to define a guard time between successive transmissions in the time domain to account for device SFO**

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| **Company** | **Views – including if this should be considered under another agenda item** |
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There are a few discussions about whether FDMA is needed or feasible in a harmonized design, but the overall view of RAN1 is directly clear. Hence FL requests views.

**Proposal 2.6c(I): Regarding potential FDMA for R2D:**

* **Alt 1: Do not study for Rel-19.**
* **Alt 2: List aspects that require study for feasibility / benefits / necessity analysis, for all devices**

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| **Company** | **Views**  **If your company prefers Alt 2, appreciated if you can list some relevant aspects** |
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## R2D time-domain definitions

### Subcarrier spacing(s) [INACTIVE]

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| Agreement  R2D study includes subcarrier spacing of 15 kHz, from the reader perspective, for OFDM-based waveform.   * Inclusion in the study of subcarrier spacing of 30 kHz is FFS. |

There is little further discussion of 30 kHz SCS, so FL defers bringing a further proposal relating to it.

### Time unit(s) [ACTIVE]

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| Agreement RAN1#116bis |

Deriving from the previous FL proposals, there are proposals to establish that the transmitter perspective, i.e. for specification purposes, should define a basic time unit that is equal to what is used in NR, i.e. *Tc*. Perhaps it only has applicability to evaluation purposes for knowing how to generate a R2D waveform commonly in simulators. Hence, see Section 2.1.2 instead.

In the previous meeting, FL attempted to define chips by reference to the line code they represented. A number of companies this time have suggested that instead it is more convenient to refer to the unit of baseband (OOK) modulation.

FL agrees, and thinks we need two stages in the definition. First, what does a chip represent?; second, what is a chip’s duration?

FL anticipates there may be question on what is a modulated symbol in the below proposal. The answer is that it’s that part of the output OFDM waveform which results from the various transform steps that are performed on one line code chip.

**Proposal 2.7.2a(I): In R2D, the smallest time unit of resource allocation is a line-code chip**

* **A line-code chip corresponds to one modulated symbol, e.g. according to agreed OOK modulation.**
* **Line-code chip duration = (1/M) × OFDM symbol duration, FFS: without or with CP duration.**

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| **Company** | **Views** |
| EURECOM | This looks agreeable to us. However, what does coding have to do with the definition? The chip duration is (1/M) x OFDM duration, which depends only on the OOK modulation parameter M. Hence, we propose to remove “line-code” in the definition. Moreover, the chip duration should be defined WITHOUT CP duration. |
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## R2D bandwidths [ACTIVE]

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| **Agreement** RAN1#116  At least the following bandwidths for R2D are defined for the purpose of the study:   * Transmission bandwidth, *B*tx,R2D from a Reader perspective: The frequency resources used for transmitting R2D * Occupied bandwidth, *B*occ,R2D from a Reader perspective: The frequency resources used for transmitting R2D, and potential guard band * Bocc,R2D ≥ *B*tx,R2D   + FFS: Further constraint(s) e.g. Bocc,R2D = *B*tx,R2D.   + Possible values of each bandwidth are FFS |
| Agreement  For R2D study OFDM-based waveform with subcarrier spacing of 15 kHz, *B*tx,R2D is ≤ [12] PRBs and is down-selected among:   * Alt 1: Including 180 kHz, 360 kHz, and FFS other values * Alt 2: Integer multiple(s) of 180 kHz (FFS: what integer(s)) * Alt 3: Integer multiple(s) of the subcarrier spacing (FFS: what integer(s)) |

For *B*tx, R2D, see section 2.2.1.

For *B*occ,R2D, or potential *B*sys,R2D, existence would depend on FDMA discussions, hence FL defers making proposal(s) here for the time being.

# D2R

## D2R waveform [ACTIVE]

In this agenda item, most companies think this should apply to device 2b, i.e. internally-generated carrier wave, and several say that it should be the same as the externally-generated carrier wave in agenda 9.4.2.4. Hence FL pauses this until further progress in 9.4.2.4.

**Proposal 3.1a(I): The D2R waveform(s) is/are such that they can be used by all devices 1/2a/2b.**

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| **Company** | **Views** |
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## D2R modulation [ACTIVE]

### Modulation scheme(s)

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| Agreement  Study for all devices the following for D2R baseband modulation, for potential down-selection:   * OOK * Binary PSK * Binary FSK   + Strive to identify one variant of Binary FSK to study further |

In this agenda item, most companies talk about OOK and BPSK. Some companies propose to prioritize OOK and a few companies propose to prioritize BPSK including study phase shaping. For BFSK, some companies mentioned different BFSK in their papers while similar number of companies propose to deprioritize or not study BFSK.

Companies are hence invited to give their views on the variants and, if they wish to, which one they think should be studied further (or otherwise to indicate no further study). Thus, FL proposes the following:

**Proposal 3.2.1(I):**

* **OOK and Binary PSK are the basic D2R modulation for all devices.**
  + **FFS: Whether/how pulse shaping of Binary PSK and impact to devices**
* **Strive to identify one variant of Binary FSK for all devices among the followings**
  + **Variant 1: Frequency offset being a function of symbol rate**
  + **Variant 2: MSK**
  + **Variant 3: GFSK**
  + **Variant 4: GMSK**
  + **Variant 5: Deprioritize/not study further**

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| **Company** | **Views** |
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### Single / double sideband

It seems companies have identified that 1SB modulation cannot be supported by the hardware available in all devices, and hence think that 2SB should be supported. It is not clear whether 1SB can be incorporated into a harmonized design at this stage, and FL suspects it may cause complications in other proposals such as small frequency-shifting by line-code or square wave. For the sake of minimizing cases, and harmonizing the design, FL suggests we take 2SB at this stage.

**Proposal 3.2.2a(I): 2SB modulation is supported.**

* **FFS if 1SB can be supported by all, or any, devices, taking account of other issue such as how to achieve small frequency shift.**

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| **Company** | **Views** |
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## D2R line coding [ACTIVE]

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| **Agreement**  For D2R, study: Manchester encoding, FM0 encoding, Miller encoding, no line coding.   * FFS: Mapping(s) from bit(s) to line-code codewords * FFS: How to achieve small frequency shift in baseband and/or FDM(A) among devices * Aspects to study include:   + Spectrum shape   + Complexity   + Power consumption   + BER, BLER   + Resilience to SFO   + If there is any relation to CFO |

It seems there is sufficient commonality to define the basic codewords for the D2R line codes, and this is done in Proposal 3.3a, which is some kind of reference set of codewords, to be used in a next step, Proposal 3.3b for small frequency-shift.

There is the related proposal in Section 3.7 which defines the further detail of time duration.

**Proposal 3.3a(I): The study assumes the following codewords corresponding to an information bit 0 or bit 1, before considering potential small frequency-shifting:**

* **For Manchester encoding:** 
  + **bit 0→chips{01}, bit 1→chips{10}**
* **For FM0:**
  + **If the immediately previous chip is 1, bit 0 → chips {01}, otherwise bit 0 → chips {10}.**
  + **If the immediately previous chip is 1, bit 1 → chips {00}, otherwise bit 1 → chips {11}.**
* **For Miller:**
  + **According to Figure 6-12 of UHF RFID standard.**

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| **Company** | **Views** |
| EURECOM | Concerning Manchester Coding, there is a significant SNR gain if multiple bits are encoded jointly. For instance, M=4, bits{00}🡪chips{0001}, bits{01}🡪chips{0010}, bits{10}🡪chips{0100} and bits{11}🡪chips{1000} will result in a single ON chip per OFDM symbol where all transmit power is concentrated, hence a 3dB SNR gain compared to encoding the 2 bits separately resulting in 2 ON chips.  Therefore, we suggest to add multi-bit Manchester Encoding to the proposal. |
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**Proposal 3.3b(I): For Manchester and Miller line codes, small frequency-shifts are produced using repetition of the codewords within the same time duration corresponding to an information bit.**

* **Details FFS**

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| **Company** | **Views** |
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**Proposal 3.3c(I): The study does not further consider FM0 line encoding.**

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| **Company** | **Views** |
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The following is FL’s effort to describe the square-wave generation based proposal at similar level of detail as using line codes, to achieve equivalent functions, that being FL’s understanding of the idea. Proponents are welcome to correct the proposal in their responses.

**Proposal 3.3d(I): The study of ‘no line code’ assumes that an information bit is XOR’d with a square wave having a frequency such that a desired small frequency shift, equivalent to one achievable using a line code in Proposal 3.3a + 3.3b, is achieved.**

* **Details FFS**

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| **Company** | **Views** |
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## D2R FEC / repetition [ACTIVE]

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| **Agreement RAN1#116bis**  A-IoT D2R study of FEC includes at least convolutional codes.   * Comparisons are encouraged to compare to the case of no FEC * FFS details of convolutional codes, such as polynomial(s), shift-register termination, etc. * FFS if other FEC candidates/methods will be studied.   **Agreement RAN1#116bis**  Study D2R transmission in the physical layer using repetition  Note: Discussions regarding higher-layer repetitions are up to RAN2 |

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| **Agreement RAN1#116bis**  **From 9.4.2.3:**  For PDRCH generation at the device, at least following blocks are studied as the baseline:   * CRC bits are appended if there is non-zero length CRC   + Note: CRC details discussed in agenda item 9.4.2.1 * Coding   + Exact coding methods within the coding block, e.g. with/without line coding and/or FEC discussed under agenda 9.4.2.1   + Note: If no line coding is used, there may be an additional block (e.g. square wave generator) before/after modulation block * Modulation * Note: Other blocks could be added if agreed     PDRCH generation |

### Repetition

The agreement in RAN1#116bis left “repetition” undefined, and companies have kindly provided various definitions. FL collects them there, so we can have a common basis of further discussion. There is a following proposal to choose among them.

**Proposal 3.4.1a(I): Define for study purposes repetition types as follows:**

* **Block level or PDRCH-level: The whole block of bits received from higher layers is repeated Rblock times before other physical-layer processing**
* **Bit level: Each bit after CRC attachment (if used) is repeated Rbit times**
  + **NOTE: Equivalent to line-code codeword level repetition**
* **FEC codeword level: Each set of bits in a codeword after FEC encoding is repeated Rfec times**
  + **NOTE: For a rate 1/R convolutional code, a codeword is R consecutive coded bits**
* **Chip level: Each chip after line coding is repeated Rchip times**
  + **NOTE: Equivalent to extending the duration of each chip by Rchip times**

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| **Company** | **Views** |
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Based on the papers, FL understands that according to above definitions, chip-level is the same as having longer chips or lower M value, hence does not seem to be necessary to include as a repetition method. There is only one company proposing FEC codeword level repetition. Hence the following proposal:

**Proposal 3.4.1b(I): The study supports at least block-level and bit-level repetition for D2R.**

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| **Company** | **Views** |
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### FEC

For convolutional code, companies describe that the length of the shift register and the code rate interact for performance and device encoding complexity. There are suggestions to re-use directly the LTE convolutional code, or to consider shortening its constraint length, i.e. the shift register length. Since complexity is also affected by how many shift registers are involved, i.e. the code-rate, that point is also discussed.

**Proposal 3.4.2a(I): For convolutional codes, the LTE convolutional code polynomials are the baseline. Other designs can be studied subject to:**

* **Constraint length of each shift register is not longer than in LTE, i.e. constraint length K ≤ 7.**
* **Code rate is not higher than in LTE, i.e. code-rate R ≤ 1/3.**
* **FFS other details, e.g. shift-register initialization/termination.**

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| **Company** | **Views** |
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For “FFS if other FEC candidates/methods will be studied”, there are not enough proposals to justify bringing a specific proposal for others at this time.

## D2R CRC [VOID]

Section 4.1 will take R2D and D2R CRCs together.

## D2R multiple access [ACTIVE]

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| Agreement  Study time-domain multiple access of D2R transmissions. Further details, including pros/cons, are FFS.  Agreement  Study frequency-domain multiple access of D2R transmissions, at least by utilizing a small frequency-shift in baseband. Further details, including pros/cons, are FFS.  Agreement  Whether code-domain multiple access is feasible and necessary for D2R transmissions for all devices is FFS. |

To understand the pros and cons of frequency-domain multiple access and code-domain multiple access for D2R transmissions, FL collects the technical aspects to be considered from papers.

**Proposal 3.6a(I): For frequency-domain multiple access of D2R transmissions, study at least the following aspects:**

* **Maximum supported small frequency shift**
  + **Note: The detailed design of small frequency shifting is discussed in Section 3.3.**
* **The impact of SFO**
* **The impact of harmonics in the backscattered signal**
* **The potential gain of D2R transmission efficiency by FDMA comparing to only TDMA**

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| **Company** | **Views** |
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**Proposal 3.6b(I): For considering feasibility and necessity of code-domain multiple access of D2R transmissions for all devices, study at least the following aspects:**

* **How CDMA is used for D2R transmissions carrying information in the same time-frequency resource**
* **The impact of SFO**
* **The impact of timing offset between devices** 
  + **Note: The timing offset can be caused by the different processing time and sampling frequency offset between devices.**
* **The number of codes with required correlation properties in a set**
  + **Note: The corresponding code length should also be reported.**
* **The potential gain of D2R transmission efficiency by CDMA comparing to only TDMA**

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| **Company** | **Views** |
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## D2R time-domain definitions [ACTIVE]

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| **Agreement RAN1#116bis**  **From 9.4.2.3:**  For PDRCH generation at the device, at least following blocks are studied as the baseline:   * CRC bits are appended if there is non-zero length CRC   + Note: CRC details discussed in agenda item 9.4.2.1 * Coding   + Exact coding methods within the coding block, e.g. with/without line coding and/or FEC discussed under agenda 9.4.2.1   + Note: If no line coding is used, there may be an additional block (e.g. square wave generator) before/after modulation block * Modulation * Note: Other blocks could be added if agreed     PDRCH generation |

As with R2D, we should define what is a chip, and try to be independent of each type of line code, based on the submitted papers. In D2R, the chip duration has a relationship with the possibility of a small frequency shift, by methods within Manchester and Miller linecodes. FL would like to take that discussion in section 3.3 and in this proposal produce a generally-applicable definition.

Hence, in option 1 below, FL believe it is likely to be necessary to come back in a second stage to define what the calculation is exactly, depending on which line code.

**Proposal 3.7a(I): In D2R, the smallest time unit of resource allocation is a (line code) chip**

* **A (line code) chip corresponds to one modulated symbol**
* **(Line-code) chip duration is:**
  + **Option 1: Calculated according to the transmission bandwidth and amount of a small frequency shift.**
    - **FFS: The detailed bandwidth, e.g., double sideband transmission bandwidth, or, BLF.**
    - **FFS: Exact calculation details according to line code design, e.g.**
  + **Option 2: One of a pre-defined set of pulse time durations.**

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| **Company** | **Views** |
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## D2R bandwidths [ACTIVE]

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| Agreement  The following bandwidths for D2R are defined for the purpose of the study:   * Transmission bandwidth, *B*tx,D2R: The frequency resources scheduled by a reader for a D2R transmission from one device.   + FFS in agenda 9.4.2.3: how frequency resources scheduled by a reader are determined * Occupied bandwidth, *B*occ,D2R: The transmission bandwidth plus the potential associated intra A-IoT guard-bands totalling *B*guard,D2R   + Note: this guard band is not for coexistence with NR/LTE * If/how to define guard band for coexistence between A-IoT D2R and NR/LTE is up to RAN4. * Bocc,D2R >= *B*tx,D2R   + Possible values of each bandwidth are FFS |

### Bandwidth sizes

For bandwidth sizes in D2R, it would be possible to face complications if we try to define their values wrt potential multi-single tone CW, due to the gap between the multiple tones. Hence, based on how FL understands the papers, the suggestion is to define them wrt to just one single tone. This should then be general across whether the tones are used by multiple CW nodes for multiple devices (somehow), or apply to one device.

**Proposal 3.8.1a(I): For *B*occ,D2R of the D2R transmission associated with one/each single-tone of a carrier wave, it can be:**

* **Alt 1: An integer number of PRBs**
* **Alt 2: An integer multiple of SCS**

**NOTE: Carrier wave is internal or external to device as appropriate.**

**Proposal 3.8.1b(I) For Btx,D2R of the D2R transmissions associated with one/each single-tone of a carrier wave, it can be:**

* **Alt 1: An integer number of PRBs**
* **Alt 2: An integer multiple of SCS**

**NOTE: Carrier wave is internal or external to device as appropriate.**

**Proposal 3.8.1c(I): For Bguard,D2R, companies are invited to propose values which:**

* **Would be necessary due to SFO value X**
* **Would support narrowband filtering by e.g. IF band-pass filter or BB low-pass filter with negligible performance impact at the D2R receiver**

**Note: For Device 1 and 2a, Bguard,D2R corresponds to the unmodulated single-tone carrier-wave.**

**Note: The required frequency gap between the tones in the multiple unmodulated single-tone carrier-wave is studied in 9.4.2.4.**

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| **Company** | **Views on Proposals 3.8.1a, b, c** |
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# R2D and D2R

## CRC [ACTIVE]

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| **Agreement** RAN1#116  R2D study assumes use of CRC. FFS which CRC generator polynomial(s) are assumed, and if any cases are included with no CRC.   * FFS: Association, if any, between down-selected CRC(s) and message size, considering at least false-alarm rate target |
| **Agreement** RAN1#116  D2R study assumes use of CRC. FFS which CRC generator polynomial(s) are assumed, and if any cases are included with no CRC.   * FFS: Association, if any, between down-selected CRC(s) and message size, considering at least false-alarm rate target |

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| Agreement RAN1#116BIS  Study   * baseline: using 6 bits and 16 bits CRC with polynomials from TS 38.212, or no CRC, for PRDCH * baseline: using 6 bits and 16 bits CRC with polynomials from TS 38.212, or no CRC, for PDRCH * FFS: details when different CRC lengths or no CRC may be used * FFS: other 6 bits and 16 bits CRC with different polynomials than from TS 38.212 |

For the details when different CRC lengths or no CRC may be used, some companies discussed about the design aspects. Proposals seem to be to support no CRC for short messages to save the CRC overhead while some proposed no CRC is used for message with high importance to improve the robustness of the system and others to use separate CRCs for payload and control information carried by PRDCH or PDRCH.

**Proposal 4.1a(I): For PRDCH/PDRCH transmissions with CRC, the used CRC length depends on the number of bits Z before CRC, i.e. CRC-6 for Z<=X bits, while CRC-16 for Z > X bits**

* **Option 1: X = 16**
* **Option 2: X = 24**

**Note: This does not preclude PRDCH/PDRCH transmissions also without CRC.**

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| **Company** | **Views, including value of X** |
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For the study of potentially not having CRC in some cases, there are two cases: that either it is for the smallest messages, or for some certain ‘less critical’ transmissions. However, there are not many details in papers, so FL requests more specific inputs.

FL notes that the message(s)/channel(s) case will depend on the detail design of system access procedure messages, which belong primarily to RAN2, so would keep this at high-level in RAN1 for the time being at least.

**Proposal 4.1b(I): For further study of possibly using no CRC in some cases:**

* **Companies to identify potentially applicable maximum number of bits Z=Y < X**
* **Companies to identify potentially applicable message(s)/channel type(s)**

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| **Company** | **Views** |
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For whether to use CRCs other than those in TS 38.212, there is only one proposal to do so (ZTE). Hence FL would wait to see other companies adopting this direction before attempting to agree on moving away from the baseline.

# Proposals for online sessions

# Summary

# References

1. R1-2403842 General aspects of physical layer design for Ambient IoT Ericsson
2. R1-2403860 Discussion on physical layer design for Rel-19 Ambient IoT devices FUTUREWEI
3. R1-2403881 Discussion on general aspects of physical layer design for Ambient IoT TCL
4. R1-2403888 General aspects of physical layer design for Ambient IoT Nokia
5. R1-2403954 On general aspects of physical layer design for Ambient IoT Huawei, HiSilicon
6. R1-2404005 Discussion on Physical Layer Design for Ambient-IoT EURECOM
7. R1-2404028 Discussion on general aspects of physical layer design for Ambient IoT Spreadtrum Communications
8. R1-2404117 Considerations on general aspects of Ambient IoT Samsung
9. R1-2404179 Discussion on General Aspects of Physical Layer Design vivo
10. R1-2404286 On general physical layer design aspects for AIoT Apple
11. R1-2404345 On General Physical Layer Design Considerations for Ambient IoT (internet of things) Applications Lekha Wireless Solutions
12. R1-2404403 Discussion on general aspects of physical layer design CATT
13. R1-2404429 Discussion on general aspects of physical layer design for Ambient IoT China Telecom
14. R1-2404458 Discussion on general aspects of A-IoT physical layer design CMCC
15. R1-2404502 General aspects of physical layer design for Ambient IoT Sony
16. R1-2404556 Discussion on general aspects of physical layer design for Ambient IoT ZTE, Sanechips
17. R1-2404592 Consideration on general aspects of physical layer Fujitsu
18. R1-2404620 Discussion on physical layer design of Ambient IoT Xiaomi
19. R1-2404674 Discussion on general aspects of ambient IoT physical layer design NEC
20. R1-2404743 General aspects of physical layer design for Ambient IoT Panasonic
21. R1-2404775 Discussion on general aspects of physical layer design ETRI
22. R1-2404870 Discussion on general aspects of physical layer design of A-IoT communication OPPO
23. R1-2404890 General aspects of Ambient IoT physical layer design LG Electronics
24. R1-2404941 Discussion on the physical layer design aspects for Ambient IoT devices Lenovo
25. R1-2404959 Discussion on general aspects of physical layer design for Ambient IoT InterDigital, Inc.
26. R1-2404962 Discussion on general aspects of physical layer design Sharp
27. R1-2405044 Study on general aspects of physical layer design for Ambient IoT NTT DOCOMO, INC.
28. R1-2405078 General aspects of physical layer design MediaTek Inc.
29. R1-2405124 Discussions on general aspects of physical layer design for Ambient IoT Ruijie Networks Co. Ltd
30. R1-2405157 General aspects of physical layer design Qualcomm Incorporated
31. R1-2405216 Discussion on physical layer design for Ambient IoT Comba
32. R1-2405224 General aspects of physical layer design for Ambient IoT ITL
33. R1-2405242 Discussion on General aspects of physical layer design CEWiT
34. R1-2405269 Ambient IoT – General aspects of physical layer design, performance for uplink modulation Wiliot Ltd.
35. R1-2405298 Discussion on General aspects of physical layer design for AIoT IIT Kanpur, Indian Institute of Tech (M)

# Annex A – Previous Decisions

## RAN1#116, Athens, February 2024

Agreement

A-IoT DL study includes an OFDM-based waveform from A-IoT R2D (reader-to-device) perspective.

* Depending on what modulation(s) are decided to be studied:
  + Study whether/how to handle CP at transmitter/device/design
* Study other characteristics of the OFDM waveform, e.g.:
  + CP-OFDM
  + DFT-s-OFDM
  + Etc.
  + The type of OFDM waveform is transparent to A-IoT device.

Other waveforms from DL transmitter’s perspective can be proposed, and further discussion will consider whether or not they are included in the study.

Agreement

A-IoT DL study includes OOK from DL transmitter’s perspective.

* For an OFDM waveform, assume OOK-1 for single-chip per OFDM symbol transmission, and OOK-4 for *M*­-chip per OFDM symbol transmission, starting from definitions in TR 38.869.
  + FFS value(s) of *M*.
  + FFS: Any changes needed from the definitions in TR 38.869.
  + FFS: Exact definition of chip
* If other DL waveforms are included, further elaboration of the transmitter’s OOK generation would be needed.

**Agreement**

For R2D, line codes studied are: Manchester encoding and pulse-interval encoding (PIE).

* FFS: Mapping(s) from bit(s) to line-code codewords
* FFS: Time domain definition of e.g., chips and relation to OFDM symbols, resource allocation unit, etc.

**Agreement**

Regarding FEC, R2D with no forward error-correction code (FEC) is studied as baseline.

* Evaluations would be by comparison to this baseline

**Agreement**

**R2D study assumes use of CRC. FFS which CRC generator polynomial(s) are assumed, and if any cases are included with no CRC.**

* **FFS: Association, if any, between down-selected CRC(s) and message size, considering at least false-alarm rate target**

**Agreement**

**D2R study assumes use of CRC. FFS which CRC generator polynomial(s) are assumed, and if any cases are included with no CRC.**

* **FFS: Association, if any, between down-selected CRC(s) and message size, considering at least false-alarm rate target**

**Agreement**

At least the following bandwidths for R2D are defined for the purpose of the study:

* Transmission bandwidth, *B*tx,R2D from a Reader perspective: The frequency resources used for transmitting R2D
* Occupied bandwidth, *B*occ,R2D from a Reader perspective: The frequency resources used for transmitting R2D, and potential guard band
* Bocc,R2D ≥ *B*tx,R2D
  + FFS: Further constraint(s) e.g. Bocc,R2D = *B*tx,R2D.
  + Possible values of each bandwidth are FFS

## RAN1#116bis, Changsha, April 2024

Agreement

Study time-domain multiple access of D2R transmissions. Further details, including pros/cons, are FFS.

Agreement

Study frequency-domain multiple access of D2R transmissions, at least by utilizing a small frequency-shift in baseband. Further details, including pros/cons, are FFS.

Agreement

Whether code-domain multiple access is feasible and necessary for D2R transmissions for all devices is FFS.

Agreement

The following bandwidths for D2R are defined for the purpose of the study:

* Transmission bandwidth, *B*tx,D2R: The frequency resources scheduled by a reader for a D2R transmission from one device.
  + FFS in agenda 9.4.2.3: how frequency resources scheduled by a reader are determined
* Occupied bandwidth, *B*occ,D2R: The transmission bandwidth plus the potential associated intra A-IoT guard-bands totalling *B*guard,D2R
  + Note: this guard band is not for coexistence with NR/LTE
* If/how to define guard band for coexistence between A-IoT D2R and NR/LTE is up to RAN4.
* Bocc,D2R >= *B*tx,D2R
  + Possible values of each bandwidth are FFS

Agreement

For D2R, study: Manchester encoding, FM0 encoding, Miller encoding, no line coding.

* FFS: Mapping(s) from bit(s) to line-code codewords
* FFS: How to achieve small frequency shift in baseband and/or FDM(A) among devices
* Aspects to study include:
  + Spectrum shape
  + Complexity
  + Power consumption
  + BER, BLER
  + Resilience to SFO
  + If there is any relation to CFO

Agreement

A-IoT D2R study of FEC includes at least convolutional codes.

* Comparisons are encouraged to compare to the case of no FEC
* FFS details of convolutional codes, such as polynomial(s), shift-register termination, etc.
* FFS if other FEC candidates/methods will be studied.

Agreement

Study

* baseline: using 6 bits and 16 bits CRC with polynomials from TS 38.212, or no CRC, for PRDCH
* baseline: using 6 bits and 16 bits CRC with polynomials from TS 38.212, or no CRC, for PDRCH
* FFS: details when different CRC lengths or no CRC may be used
* FFS: other 6 bits and 16 bits CRC with different polynomials than from TS 38.212

Agreement

Study D2R transmission in the physical layer using repetition

* Note: Discussions regarding higher-layer repetitions are up to RAN2.

**R1-2403678** Feature Lead Summary#3 for 9.4.2.1: “Ambient IoT – General aspects of physical layer design” Moderator (Huawei)

Agreement

R2D study includes subcarrier spacing of 15 kHz, from the reader perspective, for OFDM-based waveform.

* Inclusion in the study of subcarrier spacing of 30 kHz is FFS.

Agreement

For R2D study OFDM-based waveform with subcarrier spacing of 15 kHz, *B*tx,R2D is ≤ [12] PRBs and is down-selected among:

* Alt 1: Including 180 kHz, 360 kHz, and FFS other values
* Alt 2: Integer multiple(s) of 180 kHz (FFS: what integer(s))
* Alt 3: Integer multiple(s) of the subcarrier spacing (FFS: what integer(s))

Agreement

For R2D CP handling for OFDM based OOK waveform:

* For potential down-selection, study among the following candidate methods
  + Method Type 1: Removal of CP at device without specified transmit-side
    - FFS: How device determines the CP location
    - FFS: Impact on feasibility of device SFO
    - FFS: relation to M, if any
  + Method Type 2: Ensure the CP insertion of OFDM-based waveform will not introduce false rising/falling edge between the last OOK chip in OFDM symbol (*n*-1) and the first OOK chip in OFDM symbol *n*.
    - FFS: Whether/how to arrange that OOK chips have equal length after CP insertion
    - FFS: relation to M, if any
    - FFS: Detail of relationship to line code codewords
    - FFS: Impact on feasibility of device SFO
  + [Other method types are not precluded]
* Study of the methods should include e.g.:
  + CP impact on R2D timing acquisition, and decoding & performance of PRDCH
  + Reader and device implementation complexities
  + Interference between R2D and NR DL/UL if in the same NR band
  + Spectrum efficiency

Agreement

Study for all devices the following for D2R baseband modulation, for potential down-selection:

* OOK
* Binary PSK
* Binary FSK
  + Strive to identify one variant of Binary FSK to study further