**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |
| --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | **Coherent PHY Layer proposal for 15.4ab TFD** |
| Date Submitted | March 15, 2023 |
| Source | Carlos Aldana, Chunyu Hu, Kangjin Yoon, Claudio da Silva, Jack Zou (Meta), Lei Huang, Bin Qian, Chenchen Liu, Wei Lin, Rani Keren (Huawei), Frank Leong, Riku Pirhonen, Wolfgang Küchler, Jianxuan Du (NXP Semiconductors), Xiliang Luo, Vinod Kristem (Apple), Bin Tian, Koorosh Akhavan, Pooria Pakrooh, Steve Shellhammer, Ehsan Hosseini (Qualcomm), Billy Verso, Jarek Niewczas, Carl Murray, Michael McLaughlin (Qorvo), Li-Hsiang Sun, ChaoChun Wang, James Yee, Thomas Pare, Yonggang Fang (Mediatek)] |
| Re: | Contribution to IEEE 802.15.4ab  |
| Abstract |  |
| Purpose | This submission proposes text for the IEEE Std 802.15.4ab specification framework document.  |
| Notice | This document does not represent the agreed views of the IEEE 802.15 Working Group or IEEE 802.15.4ab Task Group. It represents only the views of the participants listed in the “Source(s)” field above. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. |

Contents

[1. Introduction 3](#_Toc129704865)

[2. UWB Data Communications 3](#_Toc129704868)

[Preamble sequence (SYNC field) 3](#_Toc129704869)

[SFD field 3](#_Toc129704870)

[PHR field for HRP-ERDEV in enhanced HPRF (EHPRF) mode 4](#_Toc129704871)

[4z HPRF PHR mode 4](#_Toc129704872)

[Dynamic PHR mode 6](#_Toc129704873)

[Modulation 8](#_Toc129704874)

[FEC (Advanced coding) 8](#_Toc129704875)

[HRP-ERDEV modulation in EHPRF mode 11](#_Toc129704876)

[Modulation at 249.6 MHz PRF 12](#_Toc129704877)

[Modulation at 124.8 MHz PRF 16](#_Toc129704878)

[3. References 18](#_Toc129704961)

1. Introduction

As one of the key PAR objectives provided by TG4ab, next generation UWB should support high data-rate communications allowing at least 50 Mbit/s of throughput. In this document we address PHY aspects that help us achieve this and improve link budget. These aspects include higher and lower data rates, LDPC coding schemes with full parity bits, as well as PHR changes to accommodate improved PHY payload performance. There are 3 new PHY payload rates introduced: 1.95, 62.4, and 124.8 Mbps.

There will be 2 different types of PHR supported: Legacy 802.15.4z HPRF PHR with the new PHY rates as well as a dynamic PHR that reduces PHR duration adaptively, depending on PHR rates.

The dynamic PHR is composed of 2 parts: PHR1 and PHR2. PHR1 signals the PHY data rate as well as whether LDPC is enabled or not. PHR2, on the other hand, is transmitted at the same rate as the payload (if binary convolutional encoding (BCC) is enabled), or at half the rate of the payload (if low-density parity check (LDPC) codes is enabled). PHR2 signals the PHY payload length as well as an indication if this packet is to be used for ranging or sensing.

1. UWB Data Communications

## Preamble sequence (SYNC field)

The 802.15.4ab device shall support the length 91 codes specified in Table 15-7a with the parameters specified in Table 15-7b in IEEE 802.15.4z-2020. The *phyCurrentCode* attribute specifies the code to be used. The selected code sequence *C*i is spread to generate the preamble symbol Si.

When Dynamic PHR is used, the number of preamble symbol repetitions for the SYNC field, denoted by *phyHrpUwbPsr*, is negotiated at the higher layers via the mechanisms described in [5]. It shall remain fixed until re-negotiation occurs. In particular, the transmitter indicates the variable PSDU data rate range it intends to use. For example, it can indicate one of the following three options.

* + 1. PSDU data rate >= 7.8Mbps (either LDPC or BCC can be used)
		2. PSDU data rate >=  1.95Mbps + BCC  ( For >1.95Mbps, either LDPC or BCC can be used. For 1.95Mbps, only BCC is used)
		3. PSDU data rate >= 1.95 Mbps + LDPC (either BCC or LDPC can be used)

The receiver shall indicate the preamble symbol repetition(s) for that option. If one PSR value length is indicated for all PSDU data rates and encoding schemes, this PSR value shall be used for all the following PPDU transmissions. If multiple PSR values are indicated, the transmitter shall use a PSR value that is no less than the value indicated for the corresponding PSDU data rate and encoding scheme. The transmitter can re-negotiate the PSDU data rate range option to change different PSR value(s).

In enhanced HPRF (EHPRF) mode with dynamic PHR, the HRP-ERDEV shall support transmission and reception with PSR values of 32, 64, 128, and 256 with optional PSR values being 16, 24, 48, 96, and 192. If the transmitter cannot support sending a requested non-mandatory length, it shall use the next higher mandatory length.

In EHPRF mode with 4z HPRF PHR, the HRP-ERDEV shall support transmission and reception with PSR values of 32 and 64, with optional PSR values being 16, 24, 48, 96, 192, and 256. The use PSR with value of 128 as being mandatory or optional is TBD.

The number of preamble symbol repetition for SYNC field is specified by the *phyHrpUwbPsr* attribute, when this is zero the UwbPreambleSymbolRepetitions parameter of the MCPS-DATA.request determines the transmitted SYNC field length.

## SFD field

When Dynamic PHR is used, the SFD sequence, signalled by *phyHrpUwbSfdSelector*, is negotiated at the higher layers via the mechanisms described in [5] and is fixed for all the negotiated data rates, until re-negotiation occurs.

Other than this change, there are no further changes in the SFD field from those already defined in 802.15.4z-2020.

## PHR field for HRP-ERDEV in enhanced HPRF (EHPRF) mode

The PHR shall use the same convolutional code and modulation associated with HPRF mode as described in 15.3.4.The PHR supports two configurations: 4z HPRF PHR and dynamic PHR.

#### 4z HPRF PHR mode

When 4z HPRF PHR format is used to support the PSDU bit rates of 1.95 Mb/s, 62.4 Mb/s, and 124.8 Mb/s introduced in 4ab, the PHR shall be formatted as in 15.2.7.3 of 802.15.4z-2020. See also Figure 1-PHY header in 4z HPRF PHR mode below. Both the PHR and the PSDU use the same symbol structure as specified below. In addition, both PHR and PSDU shall be encoded with K=7 convolutional encoder with the generator polynomials (133,171), as shown in Figure 15-11a of 802.15.4z-2020. This encoder shall be initialized to all zero state before transmission of each PPDU and shall be returned to all zero state by separately appending six zero bits to both the PHR and the PSDU.



Figure 1-PHY header in 4z HPRF PHR mode

For the PSDU bit rate of 1.95 Mb/s, both PHR and PSDU shall use the symbol structure in Figure 2 with mean PRF at 124.8 MHz.



Figure 2-Data Symbol Structure at 124.8 MHz PRF for 1.95 Mb/s

For the PSDU bit rate of 62.4 Mb/s, both PHR and PSDU shall use the symbol structure in Figure 3 with mean PRF at 249.6 MHz.



Figure 3-Data Symbol Structure at 249.6 MHz PRF for 62.4 Mb/s

For the PSDU bit rate of 124.8 Mb/s, both PHR and PSDU shall use the symbol structure in Figure 4 with mean PRF at 249.6 MHz.



Figure 4-Data Symbol Structure at 249.6 MHz for 124.8 Mb/s

The following table provides a summary of all the supported data rates including the rates specified in 15.3.4 of 802.15.4z-2020 and the corresponding modulation for PHR and PSDU with the 4z HPRF PHR format. Note that only the PSDU data rates of 1.95, 62.4, and 124.8Mbps are in the scope of 4ab specification. Other rates have already been defined in 802.15.4z-2020.

Table 1 – Summary of Data Rates with 4z HPRF PHR

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| PSDU bit rate(Mb/s) | PSDU encoding | PHR bit rate(Mb/s) | PHR encoding | PSDU Symbol Structure | PHR Symbol Structure |
| 1.95(4ab) | K=7 CC  | 1.95 | K=7 CC | As in Figure 2  | As in Figure 2 |
| 6.8 | Reed-Solomon and K=3 CC | 3.9 | K=3 CC | As in Figure 15-11d in 802.15.4z-2020 | As in Figure 15-11e in 802.15.4z-2020 |
| 7.8 | K=7 CC | 7.8 | K=7 CC | As in Figure 15-11d in 802.15.4z-2020 | As in Figure 15-11d in 802.15.4z-2020 |
| 27.2 | Reed-Solomon and K=3 CC | 15.6 | K=3 CC | As in Figure 15-11b in 802.15.4z-2020 | As in Figure 15-11c in 802.15.4z-2020 |
| 31.2 | K=7 CC | 31.2 | K=7 CC | As in Figure 15-11b in 802.15.4z-2020 | As in Figure 15-11b in 802.15.4z-2020 |
| 62.4(4ab) | K=7 CC | 62.4 | K=7 CC | As in Figure 3 | As in Figure 3 |
| 124.8(4ab) | K=7 CC | 124.8 | K=7 CC  | As in Figure 4 | As in Figure 4 |

#### Dynamic PHR mode

In EHPRF mode with dynamic PHR, the PHR shall be composed of two parts: PHR1 and PHR2. PHR1 is encoded as below and PHR2 shall use the K=7 convolutional code.

##### PHR1

PHR1 encodes the data rate for the PSDU and whether the optional LDPC coding is being employed for the PSDU, as shown in Table 2. The content of PHR1 also determines the modulation rate of PHR2.

PHR1 consists of sixteen codes total, each 20 bits long. 10 of them are used in Table 2 and 6 are left as Reserved. The set has Hamming Distance >=13 for the first code, and lower Hamming Distance for the remaining codes [1]. The first Reserved entry has the biggest Hamming distance (HD=12) among all Reserved entries. All the other Reserved entries have Hamming Distance = 8. Note that the leftmost bit (as shown) is sent first.

Table 2

|  |  |  |
| --- | --- | --- |
| Data Rate (Mb/s) | LDPC (Yes/No) | Bit Sequence (20 bits) |
| 1.95 | Yes | 11111111111111111111 |
| 1.95 | No | 00000100110011001100 |
| 7.8 | Yes | 00000001100110011001 |
| 7.8  | No | 00000111000011110000 |
| 31.2 | Yes | 00000010010110100101 |
| 31.2 | No | 00000100001111000011 |
| 62.4 | Yes | 00000001011010010110 |
| 62.4 | No | 00000111111100000000 |
| 124.8 | Yes | 00000010101001010101 |
| 124.8 | No | 00000100110000110011 |
| Reserved | Reserved | 11111000000000000000 |
| Reserved | Reserved | 00000001100101100110 |
| Reserved | Reserved | 00000111000000001111 |
| Reserved | Reserved | 00000010010101011010 |
| Reserved | Reserved | 00000100001100111100 |
| Reserved | Reserved | 00000001011001101001 |

##### PHR1 modulation at 124.8 MHz PRF



Figure 5

Each PHR1 bit per symbol is sent in the format shown in Figure 5, with all 32 pulses carrying either 1 or 0, as before, with no additional coding, and scrambled by the time-varying spreading code sn as specified in Section 15.3.2 of IEEE 802.15.4z before being sent as pulses as per section 15.3.1 of IEEE 802.15.4z (i.e., zero is positive polarity and one is negative polarity). Each symbol has duration of 128 chips (~256.4ns) so that the duration of the 20-bit PHR1 is ~5.1282µs.

##### Gap between PHR1 and PHR2

There shall be a gap of silence between PHR1 and PHR2 consisting of 512 chips, for a total duration of ~1.0256 µs.

Note that the scrambling operation starts from PHR1, continues in PHR2 and the PSDU, but pauses during this gap of silence.

##### PHR2

PHR2 shall have the content as shown in Figure 6 – PHR 2 Content.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | B0 B1 | B2 B13                | B14 | B15                                B22 |
|  | Reserved | PHY Payload Length | Ranging/Sensing | CRC |
| Bits: | 2 | 12 | 1 | 8 |

Figure 6 – PHR 2 Content

The 2 Reserved bits are set to 0 by default.

The 12-bit PHY payload length field shall be an unsigned integer number that indicates the number of octets in the PSDU field and shall be passed to the modulator most significant bit first.

The Ranging/Sensing field shall be set to one if the current frame is either a sensing frame or an RFRAME and shall be set to zero otherwise.

The 8-bit CRC, already defined in 802.15, shall be given by x^8 + x^2 + x + 1.

When LDPC is enabled, the data rate of PHR2 is half of the PSDU data rate.

 When BCC is enabled, the data rate of PHR2 is the same as the PSDU data rate. The PHR2 data rate as a function of LDPC and PSDU data rate is shown in Table 3.

Table 3-PHR2 and PSDU data rates for EHPRF mode

|  |  |  |
| --- | --- | --- |
| **LDPC enabled** | **PHR2 bit rate (Mb/s)** | **PSDU bit rate (Mb/s)** |
| Yes | 0.975  | 1.95  |
| No | 1.95  | 1.95  |
| Yes | 3.9 | 7.8 |
| No | 7.8 | 7.8 |
| Yes | 15.6 | 31.2 |
| No | 31.2 | 31.2 |
| Yes | 31.2 | 62.4 |
| No | 62.4 | 62.4 |
| Yes | 62.4 | 124.8 |
| No | 124.8 | 124.8 |

## Modulation

#### FEC (Advanced coding)

The use of the K=7 convolutional encoder with the generator polynomials (133, 171), as defined in 15.3.3.3 is mandatory. The use of LDPC code is optional. 802.11n based LDPC code shall contain full parity bits. The supported coding rates, information block lengths, and codeword blocks lengths are described in Table 4 – LDPC Parameters.

The details on LDPC implementation are as follows:

The code shall not be punctured. The LDPC encoder is systematic, i.e., when k<=972, it encodes an information block, (i0, i1, …, ik-1) of size k into a codeword **c** of size 1x n, where n is one of 648, 1296, or 1944, c = (i0, i1, …, ik-1, p0, p1, …, p(n-k-1)), by adding n-k=n/2 parity bits obtained so that **H**\***c**T = **0**, where **H** is an (n/2) x n parity-check matrix. The selection of the codeword block length (n) is achieved via the LDPC PPDU encoding process below.

Table 4 – LDPC Parameters

|  |  |  |
| --- | --- | --- |
| Coding rate  | LDPC information block length (bits)  | LDPC codeword length (bits) |
| ½ | 972 | 1944 |
| ½ | 648 | 1296 |
| ½ | 324 | 648 |

**Parity-check matrices**

Each of the parity-check matrices is partitioned into square subblocks (submatrices) of size *Z* **×** *Z*. These submatrices are either cyclic-permutations of the identity matrix or null submatrices.

The cyclic-permutation matrix *Pi*is obtained from the *Z* **×** *Z* identity matrix by cyclically shifting the columns to the right by *i* elements. The matrix *P*0 is the *Z* **×** *Z* identity matrix. Figure 7 illustrates examples (for a subblock size of 8 **×** 8) of cyclic-permutation matrices *Pi*.

|  |
| --- |
| Figure 7 |

Table 5 - Matrix prototype for codeword block length n=648, subblock size is Z=27 bits displays the “matrix prototypes” of the parity-check matrices for a codeword block length *n*= 648 bits, with a subblock size *Z*= 27 bits. The integer i denotes the cyclic-permutation matrix Pi, as illustrated in Figure 7. Vacant entries of the table denote null (zero) submatrices.

Table 5 - Matrix prototype for codeword block length n=648, subblock size is Z=27 bits

|  |
| --- |
|  |
| 0 - - - 0 0 - - 0 - - 0 1 0 - - - - - - - - - -22 0 - - 17 - 0 0 12 - - - - 0 0 - - - - - - - - - 6 - 0 - 10 - - - 24 - 0 - - - 0 0 - - - - - - - - 2 - - 0 20 - - - 25 0 - - - - - 0 0 - - - - - - -23 - - - 3 - - - 0 - 9 11 - - - - 0 0 - - - - - -24 - 23 1 17 - 3 - 10 - - - - - - - - 0 0 - - - - -25 - - - 8 - - - 7 18 - - 0 - - - - - 0 0 - - - -13 24 - - 0 - 8 - 6 - - - - - - - - - - 0 0 - - - 7 20 - 16 22 10 - - 23 - - - - - - - - - - - 0 0 - -11 - - - 19 - - - 13 - 3 17 - - - - - - - - - 0 0 -25 - 8 - 23 18 - 14 9 - - - - - - - - - - - - - 0 0 3 - - - 16 - - 2 25 5 - - 1 - - - - - - - - - - 0 |

Table 6 defines the matrix prototypes of the parity-check matrices for a codeword block length *n*= 1296 bits, with a subblock size *Z*= 54 bits.

Table 6 Matrix prototype for codeword block length n=1296, subblock size is Z=54 bits

|  |
| --- |
| 40 - - - 22 - 49 23 43 - - - 1 0 - - - - - - - - - -50 1 - - 48 35 - - 13 - 30 - - 0 0 - - - - - - - - -39 50 - - 4 - 2 - - - - 49 - - 0 0 - - - - - - - -33 - - 38 37 - - 4 1 - - - - - - 0 0 - - - - - - -45 - - - 0 22 - - 20 42 - - - - - - 0 0 - - - - - -51 - - 48 35 - - - 44 - 18 - - - - - - 0 0 - - - - -47 11 - - - 17 - - 51 - - - 0 - - - - - 0 0 - - - - 5 - 25 - 6 - 45 - 13 40 - - - - - - - - - 0 0 - - -33 - - 34 24 - - - 23 - - 46 - - - - - - - - 0 0 - - 1 - 27 - 1 - - - 38 - 44 - - - - - - - - - - 0 0 - - 18 - - 23 - - 8 0 35 - - - - - - - - - - - - 0 049 - 17 - 30 - - - 34 - - 19 1 - - - - - - - - - - 0 |

Table 7 Matrix prototype for codeword block length n=1944, subblock size is Z=81 bits defines the matrix prototypes of the parity-check matrices for a codeword block length *n*= 1944 bits, with a subblock size *Z*= 81 bits.

Table 7 Matrix prototype for codeword block length n=1944, subblock size is Z=81 bits

|  |
| --- |
| 57 - - - 50 - 11 - 50 - 79 - 1 0 - - - - - - - - - - 3 - 28 - 0 - - - 55 7 - - - 0 0 - - - - - - - - -30 - - - 24 37 - - 56 14 - - - - 0 0 - - - - - - - -62 53 - - 53 - - 3 35 - - - - - - 0 0 - - - - - - -40 - - 20 66 - - 22 28 - - - - - - - 0 0 - - - - - - 0 - - - 8 - 42 - 50 - - 8 - - - - - 0 0 - - - - -69 79 79 - - - 56 - 52 - - - 0 - - - - - 0 0 - - - -65 - - - 38 57 - - 72 - 27 - - - - - - - - 0 0 - - -64 - - - 14 52 - - 30 - - 32 - - - - - - - - 0 0 - - - 45 - 70 0 - - - 77 9 - - - - - - - - - - - 0 0 - 2 56 - 57 35 - - - - - 12 - - - - - - - - - - - 0 024 - 61 - 60 - - 27 51 - - 16 1 - - - - - - - - - - 0 |

**LDPC PPDU encoding process**

To encode an LDPC PPDU, the following steps shall be performed in sequence:

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Compute the integer number of LDPC codewords to be transmitted, NCW, and the length of the codewords to be used from Table 8 – PPDU encoding parameters and the payload bit duration *Npld,* where *Npld, = 8* (PHY payload length**)**.

Table 8 – PPDU encoding parameters

|  |  |  |
| --- | --- | --- |
| Range of *Npld* | LDPC Codeword length LLDPC (bits) | Number of LDPC codewords (NCW) |
|  |  |  |
|  |  |  |
| 352< *Npld*  | 1944 | ceil (*Npld* /972)  |
| 168*< Npld* <= 352 | 1296 | 1 |
| *Npld* <= 168 | 648 | 1 |

or (still TBD)

|  |  |  |
| --- | --- | --- |
| Range of *Npld* | LDPC Codeword length LLDPC (bits) | Number of LDPC codewords (NCW) |
| 1296< *Npld* | 1944 | ceil (*Npld* /972) |
| 968< *Npld<=*1296 | 1296 | 2 |
| 352< *Npld<=*968 | 1944 | 1 |
| 168*< Npld* <= 352 | 1296 | 1 |
| *Npld* <= 168 | 648 | 1 |

b) Compute the number of shortening bits, , to be padded to the *Npld* data bits before encoding, as shown in Equation (1).

1. Nshrt = max (0, NCW\* LLDPC /2 – *Npld*)

When , shortening is not performed. (Note that  is inherently restricted to be non-negative due to the codeword length and count selection of Table 8 – PPDU encoding parameters). When , shortening bits shall be equally distributed over all  codewords with the first *Nshrt* mod *NCW* codewords shortened 1 bit more than the remaining codewords. Define . Then, when , the shortening is performed by setting information bits  to 0 in the first *Nshrt* mod *NCW* codewords and setting information bits  to 0 in the remaining codewords. For all values of , encode each of the  codewords using the LDPC encoding technique described above. When , the shortened bits shall be discarded after encoding.

c) Aggregate all codewords and parse as follows. The succession of LDPC codewords that result from the encoding process above shall be converted into a bitstream in sequential fashion. Within each codeword, bit *i*0 is transmitted first.

## HRP-ERDEV modulation in EHPRF mode

The HRP-ERDEV in its EHPRF mode with dynamic PHR, supports the K=7 BCC (non Reed-Solomon codes) HPRF modes defined in Table 15-10a in 802.15.4z, defines three new modulation schemes and allows for optional LDPC coding when dynamic PHR mode is enabled. The modulation parameters are summarized in Table 9. Note that the bit rate when LDPC is enabled is variable and depends on the payload duration.

Table 9

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| #Pulses per data Symbol | #Chips per data symbol | Peak PRF (MHz) | Mean PRF (MHz) | Data symbol duration (ns) | Data symbol rate (MHz) | Nominal Bit rate (Mb/s), BCC and LDPC | Mandatory/Optional(M/O) |
| 64 | 256 | 249.6 | 124.8 | 512.82 | 1.95 | 1.95 | M |
| 16 | 64 | 249.6 | 124.8 | 128.21 | 7.8 | 7.8 | M |
| 8 | 16 | 499.2 | 249.6 | 32.05 | 31.2 | 31.2 | M |
| 4 | 8 | 499.2 | 249.6 | 16.026 | 62.4 | 62.4 | M |
| 2 | 4 | 499.2 | 249.6 | 8.0128 | 124.8 | 124.8 | O |

The HRP-ERDEV in its EHPRF mode with 4z HPRF PHR, supports the HPRF modes defined in 15.3.4 of 802.15.4z-2020, defines three new modulation schemes using K= 7 BCC (non Reed-Solomon codes) with the modulation parameters summarized in Table 9a. Data rates that include 1.95 Mbps and 62.4 Mbps shall be supported. The support of 124.8 Mbps is optional.

Table 9a

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| #Pulses per data Symbol | #Chips per data symbol | Peak PRF (MHz) | Mean PRF (MHz) | Data symbol duration (ns) | Data symbol rate (MHz) | Nominal Bit rate (Mb/s), BCC | Mandatory/Optional(M/O) |
| 64 | 256 | 249.6 | 124.8 | 512.82 | 1.95 | 1.95 | M |
| 4 | 8 | 499.2 | 249.6 | 16.026 | 62.4 | 62.4 | M |
| 2 | 4 | 499.2 | 249.6 | 8.0128 | 124.8 | 124.8 | O |

#### Modulation at 249.6 MHz PRF

##### 31.2 Mbps

31.2 Mbps modulation remains the same as 802.15.4z, except for the coding. When BCC is enabled, the K=7 convolutional encoder is mandatory and when LDPC is enabled, the optional LDPC codes are applied instead of the K=7 convolutional codes.

When the PHR is configured in the 4z HPRF PHR mode, the data modulation shown in Figure 15-11b in 802.15.4z shall apply to both PHR and PSDU. The burst bit patterns shall be as specified in Table 15-10d in 802.15.4z.

When the PHR is configured in the dynamic PHR mode and BCC is enabled, the data modulation shown in Figure 15-11b in 802.15.4z shall apply to both PHR2 and PSDU. The burst bit patterns shall be as specified in Table 15-10d in 802.15.4z.





When the PHR is configured in the dynamic PHR mode and optional LDPC is enabled, the data modulation shown in Figure 15-11b in 802.15.4z shall apply to the PSDU and Figure 15-11c in 802.15.4z shall apply to PHR2. For the PSDU, the burst bit patterns shall be as specified in Table 15-10d in 802.15.4z and for PHR2, the burst bit pattern shall be mapped onto the burst bit patterns specified in Table 10. Note that the last 2 rows are different from what was done in 802.15.4z with Reed Solomon coding. Note that in the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively.



Table 10

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst | (PHR2 only) Third burst | (PHR2 only) Fourth burst |
| 0 | 0 | 0000 | 0000 | 0000 | 0000 |
| 1 | 0 | 1111 | 0000 | 1111 | 0000 |
| 0 | 1 | 0000 | 1111 | 0000 | 1111 |
| 1 | 1 | 1111 | 1111 | 1111 | 1111 |

##### 62.4 Mbps

62.4Mbps modulation has 4 pulses per coded bit separated into two groups of two sent at the peak 499.2 MHz chipping rate, each group followed by a 2 chip guard interval, as shown in Figure 3-Data Symbol Structure at 249.6 MHz PRF for 62.4 Mb/s, where the vertical arrows indicate the pulse positions.

When the PHR is configured in the 4z HPRF PHR mode, the PHR and PSDU shall use K=7 BCC, with the data modulation shown in Figure 3 applied to both PHR and PSDU. The burst bit patterns shall be as specified in Table 11. The bit patterns shall be scrambled by the time-varying spreading code *sn* as specified in 15.3.2 before being sent as pulses as per 15.3.1, (i.e., zero is positive polarity and one is negative polarity).

When the PHR is configured in the dynamic PHR mode and when employing the K=7 convolutional encoder, the data modulation shown in Figure 3-Data Symbol Structure at 249.6 MHz PRF for 62.4 Mb/s shall apply to both PHR and PSDU. When optional LDPC is enabled, the data modulation shown in Figure 3-Data Symbol Structure at 249.6 MHz PRF for 62.4 Mb/s shall apply to the PSDU and Figure 8 shall apply to PHR2.



Figure 8

For the PSDU, the burst bit patterns shall be as specified in Table 11 and for PHR2, the burst bit patterns shall be as specified in Table 12. Note that in the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively. The bit patterns shall be

Table 11

|  |  |  |  |
| --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst |
| 0 | 0 | 00 | 00 |
| 1 | 0 | 11 | 00 |
| 0 | 1 | 00 | 11 |
| 1 | 1 | 11 | 11 |

Table 12

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst | (PHR2 only) Third burst | (PHR2 only) Fourth burst |
| 0 | 0 | 00 | 00 | 00 | 00 |
| 1 | 0 | 11 | 00 | 11 | 00 |
| 0 | 1 | 00 | 11 | 00 | 11 |
| 1 | 1 | 11 | 11 | 11 | 11 |

##### 124.8 Mbps

124.8Mbps modulation has 2 pulses per coded bit separated into two groups of one sent at the peak 499.2 MHz chipping rate, each pulse followed by a 1 chip guard interval, as shown in Figure 4-Data Symbol Structure at 249.6 MHz for 124.8 Mb/s where the vertical arrows indicate the pulse positions.

When the PHR is configured in the 4z HPRF PHR mode, the PHR and PSDU shall use K=7 BCC, with the data modulation shown in Figure 4 applied to both PHR and PSDU. The burst bit patterns shall be as specified in Table 13. The bit patterns shall be scrambled by the time-varying spreading code *sn* as specified in 15.3.2 before being sent as pulses as per 15.3.1, (i.e., zero is positive polarity and one is negative polarity).

Table 13

|  |  |  |  |
| --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst |
| 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |

When the PHR is configured in the dynamic PHR mode and when employing the K=7 convolutional encoder, the data modulation shown in Figure 4-Data Symbol Structure at 249.6 MHz for 124.8 Mb/s shall apply to both PHR and PSDU. When optional LDPC is enabled, the data modulation shown in Figure 4-Data Symbol Structure at 249.6 MHz for 124.8 Mb/s shall apply to the PSDU and Figure 9 shall apply to PHR2.



Figure 9

For the PSDU, the burst bit patterns shall be as specified in Table 13 and for PHR2, the burst bit patterns shall be as specified in Table 14. Note that in the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively. The bit patterns shall be scrambled by the time-varying spreading code *sn* as specified in Section 15.3.2 in 802.15.4-2020 before being sent as pulses as per Section 15.3.1 in 802.15.4-2020, (i.e., zero is positive polarity and one is negative polarity).

Table 14

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst | (PHR2 only) Third burst | (PHR2 only) Fourth burst |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 |

#### Modulation at 124.8 MHz PRF

##### 1.95 Mbps

1.95Mbps has 64 pulses per coded bit separated into two groups of 32 sent at half the peak 499.2 MHz chipping rate, each group followed by a 64 chip guard interval, as shown in Figure 2, where the vertical double arrows indicate the active pulse positions.

When the PHR is configured in the 4z HPRF PHR mode, the PHR and PSDU shall use K=7 BCC, with the data modulation shown in Figure 2 applied to both PHR and PSDU. The burst bit patterns shall be as specified in Table 15. The bit patterns shall be scrambled by the time-varying spreading code *sn* as specified in 15.3.2 before being sent as pulses as per 15.3.1, (i.e., zero is positive polarity and one is negative polarity).

When the PHR is configured in the dynamic PHR mode and when employing the K=7 convolutional encoder, the data modulation shown in Figure 2 shall apply to both PHR2 and PSDU. When optional LDPC is enabled, the data modulation shown in Figure 2 shall apply to the PSDU and Figure 10 shall apply to PHR2. For the PSDU, the burst bit patterns shall be as specified in Table 15 and for PHR2, the burst bit patterns shall be as specified in Table 16. Note that in the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively. The bit patterns shall be scrambled by the time-varying spreading code *sn* as specified in 15.3.2 before being sent as pulses as per 15.3.1, (i.e., zero is positive polarity and one is negative polarity).

Table 15

|  |  |  |  |
| --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst |
| 0 | 0 | 00000000000000000000000000000000 | 00000000000000000000000000000000 |
| 1 | 0 | 11111111111111111111111111111111 | 00000000000000000000000000000000 |
| 0 | 1 | 00000000000000000000000000000000 | 11111111111111111111111111111111 |
| 1 | 1 | 11111111111111111111111111111111 | 11111111111111111111111111111111 |



Figure 10

Table 16

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst | (PHR2 only) Third burst | (PHR2 only) Fourth burst |
| 0 | 0 | 00000000000000000000000000000000 | 00000000000000000000000000000000 | 00000000000000000000000000000000 | 00000000000000000000000000000000 |
| 1 | 0 | 11111111111111111111111111111111 | 00000000000000000000000000000000 | 11111111111111111111111111111111 | 00000000000000000000000000000000 |
| 0 | 1 | 00000000000000000000000000000000 | 11111111111111111111111111111111 | 00000000000000000000000000000000 | 11111111111111111111111111111111 |
| 1 | 1 | 11111111111111111111111111111111 | 11111111111111111111111111111111 | 11111111111111111111111111111111 | 11111111111111111111111111111111 |

##### 7.8 Mbps

7.8 Mbps modulation remains the same as 802.15.4z, except for the coding. When BCC is enabled, the K=7 convolutional encoder is mandatory and when LDPC is enabled, the optional LDPC codes are applied instead of the K=7 convolutional codes.

When the PHR is configured in the 4z HPRF PHR mode, the data modulation shown in Figure 15-11d in 802.15.4z shall apply to both PHR and PSDU. The burst bit patterns shall be as specified in Table 15-10f in 802.15.4z.

When the PHR is configured in the dynamic PHR mode and when BCC is enabled, the data modulation shown in Figure 15-11d in 802.15.4z shall apply to both PHR2 and PSDU. The burst bit patterns shall be as specified in Table 15-10f in 802.15.4z.





When the PHR is configured in dynamic PHR mode and when optional LDPC is enabled, the data modulation shown in Figure 15-11d in 802.15.4z shall apply to the PSDU and Figure 15-11e in 802.15.4z shall apply to PHR2. For the PSDU, the burst bit patterns shall be as specified in Table 15-10f in 802.15.4z and for PHR2, the burst bit pattern shall be mapped onto the burst bit patterns specified in Table 17. Note that the last 2 rows are different from what was done in 802.15.4z with Reed Solomon coding. In the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively.



Table 17

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| g0(n) | g1(n) | First burst | Second burst | (PHR2 only) Third burst | (PHR2 only) Fourth burst |
| 0 | 0 | 00000000 | 00000000 | 00000000 | 00000000 |
| 1 | 0 | 11111111 | 00000000 | 11111111 | 00000000 |
| 0 | 1 | 00000000 | 11111111 | 00000000 | 11111111 |
| 1 | 1 | 11111111 | 11111111 | 11111111 | 11111111 |

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

1. References

[1] 15-22-0653-05-04ab: An updated PHY Header Proposal

[2] 15-23-0078-00-04ab: Further consensus on data communications topic

[3] 15-22-0517-00-04ab: New Data rates and coding

[4] 15-22-0274-00-04ab: High Data Rates and Coding

[5] 15-23-0069-02-04ab: Signalling data modes and SYNC length