**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 | November 16, 2022 |
| 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)] |
| 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](#_Toc119526967)

[2. UWB Data Communications 3](#_Toc119526968)

[Preamble sequence (SYNC field) 3](#_Toc119526969)

[SFD field 3](#_Toc119526970)

[PHR field for HRP-ERDEV in enhanced HPRF (EHPRF) mode 3](#_Toc119526971)

[Modulation 4](#_Toc119526972)

[FEC (Advanced coding) 4](#_Toc119526973)

[HRP-ERDEV modulation in EHPRF mode 6](#_Toc119526974)

[15.3.4.2 Modulation at 249.6 MHz PRF 7](#_Toc119526975)

[15.3.4.3 Modulation at 124.8 MHz PRF 8](#_Toc119526976)

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 potentially new preamble sequence(s), higher and lower data rates, LDPC coding schemes, as well as PHR changes.

1. UWB Data Communications

## Preamble sequence (SYNC field)

It may be necessary to design a new sync sequence, to distinguish this new generation UWB standard from IEEE 802.15.4z.

The preamble sequence needs to be designed with good auto-correlation and cross-correlation properties. In addition, the new preamble sequence shall have low correlation with the existing UWB preamble sequence to avoid IEEE 802.15.4z devices from inadvertently receiving and decoding new frames as false alarms. The preamble sequences are TBD.

The number of preamble symbol repetition for SYNC field, denoted by *phyHrpUwbPsr*, is negotiated at the higher layers. If receiver specifies a single value, the transmitted sync repetition field does not change from one packet to another.

In enhanced HPRF (EHPRF) mode, 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, and 96.

## SFD field

There should be no changes in the SFD field from those already 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: HRP-ERDEV HPRF PHR and dynamic PHR. In the HRP-ERDEV HPRF configuration, the PHR shall use the format in Figure 15-6a, and the PHR shall use the same symbol structure as PSDU. The selection of modulation and the resultant bit rates for the PHR and PSDU are still TBD**.**

The PHR shall have the following content:

Data rate, PHY payload length, LDPC indication, Sensing indication, 2 Reserved bits, and CRC.

The Data rate field indicates the data rate of the received PHY payload field.

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 LDPC indication field signals whether LDPC encoding is enabled. It shall be set to 1 when LDPC is enabled and zero otherwise.

The Sensing indication field signals whether this packet is to be used for sensing and may indicate whether a sensing waveform occurs after the PHY payload.

The 2 Reserved bits are set to 0 by default.

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

## 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 1 – 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 1 – 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 1 illustrates examples (for a subblock size of 8 **×** 8) of cyclic-permutation matrices *Pi*.

|  |
| --- |
| Figure 1 |

Table 2 - 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 1. Vacant entries of the table denote null (zero) submatrices.

Table 2 - 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 |

The matrices for block lengths 1296 and 1944 are TBD.

**LDPC PPDU encoding process**

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

1. Compute the integer number of LDPC codewords to be transmitted, NCW, and the length of the codewords to be used from Table 3 – PPDU encoding parameters and the payload bit duration *Npld,* where *Npld, = 8* (PHY payload length**)** when the data rate is 1.95 and from Table 4 – PPDU encoding parameters for 7.8 Mbps and above when the rate is 7.8Mbps and above.

Table 3 – PPDU encoding parameters for 1.95 Mbps

|  |  |  |
| --- | --- | --- |
| Range of *Npld* | LDPC Codeword length LLDPC (bits) | Number of LDPC codewords (NCW) |
| 1296< *Npld* | 1944 | Ceil(*Npld* /972) |
| 968< *Npld* <= 1296 | 1296 | 2 |
| TBD1< *Npld* <=968 | 1944 | 1 |
| TBD2< *Npld* <= TBD1 | 1296 | 1 |
| *Npld* <= TBD2 | 648 | 1 |

Table 4 – PPDU encoding parameters for 7.8 Mbps and above

|  |  |  |
| --- | --- | --- |
| Range of *Npld* | LDPC Codeword length LLDPC (bits) | Number of LDPC codewords (NCW) |
| 1296< *Npld* | 1944 | Ceil(*Npld* /972) |
| 968< *Npld* <= 1296 | 1296 | 2 |
| TBD3< *Npld* <=968 | 1944 | 1 |
| TBD4*< Npld* <= TBD3 | 1296 | 1 |
| *Npld* <= TBD4 | 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 3 – PPDU encoding parameters and Table 4 – PPDU encoding parameters for 7.8 Mbps and above). 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 supports the K=7 BCC (non-RS) HPRF modes defined in Table 15-10a and defines three new modulation schemes in Section 15.3.4.2 and Section 15.3.4.3 and allows for LDPC coding in all 5 rates. The modulation parameters of these are summarized in Table 5. Note that the bit rate when LDPC is enabled is variable and depends on the payload duration.

Table 5

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| #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 |

Data rates that include 1.95, 7.8, 31.2, and 62.4 Mbps shall be supported. The support of 124.8 Mbps is optional.

#### Modulation at 249.6 MHz PRF

31.2Mbps modulation remains the same as 802.15.4z, except that K=7 convolutional encoder is the mandatory BCC mode and LDPC codes replace Reed-Solomon code.

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 2, where the vertical arrows indicate the pulse positions. When the PHR is configured in the HRP-ERDEV HPRF mode, the PHR shall use the format in Figure 15-6a, and the same modulation and symbol structure as the PSDU, as described in Figure 2.

When employing the K=7 convolutional encoder, the data modulation shown in Figure 2 shall apply to both PHR and PSDU.



Figure 2

In the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively. The g0(n) and g1(n) output of the K=7 convolutional encoder specified in 15.3.3.3 and the g0(n) and g1(n) output of the LDPC encoder shall be mapped onto the burst bit patterns specified in Table 6 and 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 6

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

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 3 where the vertical arrows indicate the pulse positions. When the PHR is configured in the HRP-ERDEV HPRF mode, the PHR shall use the format in Figure 15-6a, and the same modulation and symbol structure as the PSDU, as described in Figure 3.



Figure 3

In the case of LDPC encoding, g0(n) and g1(n) denote the even and odd bits, respectively. The g0(n) and g1(n) output of the K=7 convolutional encoder specified in 15.3.3.3 and the g0(n) and g1(n) output of the LDPC encoder 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).

#### Modulation at 124.8 MHz PRF

7.8Mbps modulation remains the same as 802.15.4z, except that K=7 convolutional encoder is the mandatory BCC mode and LDPC codes replace Reed-Solomon code.

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 4, where the vertical double arrows indicate the active pulse positions. When the PHR is configured in the HRP-ERDEV HPRF mode, the PHR shall use the format in Figure 15-6a, and the same modulation and symbol structure as the PSDU, as described in Figure 4. When employing the K=7 convolutional encoder, the data modulation shown in Figure 4 shall apply to both PHR and PSDU. When employing the optional LDPC encoding with 1.95 Mbps, the PHR data rate is TBD. When employing the optional LDPC encoding with 7.8 Mbps, the PHR data rate is TBD.



Figure 4