IEEE 802.15  
Wireless Specialty Networks

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE P802.15.13  Text update for PM-PHY | | | | |
| Date: 2019-09-17 | | | | |
| Author: | | | | |
| Name | Affiliation | Address | Phone | Email |
| Kai Lennert Bober | Fraunhofer HHI |  |  | kai.lennert.bober@hhi.fraunhofer.de |
| Volker Jungnickel | Fraunhofer HHI |  |  | volker.jungnickel@hhi.fraunhofer.de |
| Xu Wang | VLNComm Inc |  |  | wang@vlncomm.com |
| Sang-Kyu Lim | ETRI |  |  |  |

Abstract

# This document contains proposed text changes for the PM-PHY.

1. PM-PHY specifications

The Pulsed Modulation (PM) PHY enables moderate data rates from 1 Mbit/s to some 100 Mbit/s. The main approach is to achieve high data rates by using a high optical clock rate (OCR) while keeping spectral efficiency low. This approach offers enhanced reach in applications where power efficiency is an issue, e.g. for uplink and Internet of Things (IoT).

* 1. **General information**

Binary Pulse-Amplitude Modulation (2-PAM) with 8B10B line coding and variable optical clock rate or M-ary PAM with Hadamard-Coded Modulation (HCM) are used, together with Reed-Solomon (RS) forward error correction (FEC).

The PM PHY includes means to adapt the data rate of the link to varying channel conditions by i) varying the OCR, ii) varying the modulation alphabet size M for PAM and iii) the number of codes used in HCM.

Table 43 provides an overview over the different parameters of the PM-PHY.

|  |  |
| --- | --- |
| **Parameter** | **Options** |
| Line and  Hadamard  coding | 8b10b  HCM(1-3, 4)  HCM(1-7, 8)  HCM(1-15, 16) |
| Header FEC | RS(36,24) |
| Payload FEC | RS(256,248) |
| OCR / MHz | 12.5  25  50  100  200 |
| PAM level | 2  4  8  16 |
| CP Duration | 160 ns  1280 ns |

**PM-PHY parameters**

**PHY properties**

* + 1. **Multi-OFE pilots**

[Describe here the numbering of MIMO pilots to be corresponding to the MAC layer IDs]

* + 1. **Base MCS**

The base MCS for the PM-PHY shall be MCS 1.

**PHY constants**

Table 44 lists the constant PHY PIB attributes for the PM-PHY.

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Description** | **Value** | **Unit** |
| *aPhyMaxPsduSize* | The maximum supported PSDU size. This attribute is PHY-specific. | 65535 | octets |
| *aPhyTurnarountTime* | The maximum time required to switch the PHY from TX mode to RX mode or from RX mode to TX mode. |  | µs |
| *aPhyClockAccuracy* |  |  |  |

**Constant PHY PIB attributes**

**PPDU format**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Preamble | Channel  Estimation | PHY  Header | HCS | MIMO  RS | PSDU |
| **SHR** | | **PHR** | | | **PHY Payload** |

**PPDU format for Pulsed Modulation PHY**

The PM PHY uses the PPDU format shown in Figure 70. It consists of a synchronization header (SHR), physical layer header (PHR) and PHY payload (PSDU).

**Transmission**

**Synchronization Header (SHR)**

**Preamble**

The preamble enables both, cross- and autocorrelation with an appropriate window size [B24 – B27].

For the preamble, the base sequence **A**N, a specific pseudo-noise sequence of length N is used, see Annex D). **A**N is repeated six times yielding a total sequence length of 6\*N. Each base sequence is multiplied with positive or negative sign as given below which is known to create a sharper peak after autocorrelation, compared to a double sequence of the same total length [B27].

The total preamble reads [**A**N **A**NAN **A**NANAN] where x=1-x for elements of the sequence. The preamble is finally passed through the 2-PAM Modulator.

|  |  |  |  |
| --- | --- | --- | --- |
| **Header**  **encoding** | **Payload**  **encoding** | **N (base sequence**  **length)** | **Preamble**  **length** |
| 8B10B | 8B10B | 8 | 48 |
| HCM(1,4) | HCM(1-3,4) | 16 | 96 |
| HCM(1,8) | HCM(1-7,8) | 32 | 192 |
| HCM(1,16) | HCM(1-15,16) | 64 | 394 |

**Parametrization of PM PHY preamble and header**

**Channel Estimation**

Channel estimation (CE) is needed for equalization and subsequent detection of header information and data. Although defined in the time domain, the CE sequence allows frequency-domain equalization and hence consists of a base sequence and a cyclic prefix (CP).

Measured in time units, the time durations of both, the base sequence Tseq and the cyclic prefix TCP, are maintained, independent of the OCR. By increasing OCR, the number of clock cycles for the sequence and for the CP, i.e. Nseq and NCP, respectively, increase proportionally, see Table 50.

As CE sequence, a specific pseudo-noise sequence **A**N given in Annex D is used having variable length N=2k (k=5 … 11), depending on the OCR so that N=Nseq (see ). The CE sequence is finally passed through a 2-PAM modulator.

**Physical Layer Header (PHR)**

**PHY Header**

The PHY header consists of the fields given in Table 45.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **2 octets** | **4 octets** | **2 octets** | **3 bits** | **3 bits** | **1 bit** | **1 bit** |
| PSDU  Length | MCS  Vector | RS  Configuration | Num  RS | RS  Division | CP  Length | reserved |

**Fields in the PHY header**

The **PSDU Length** scales from 0 up to *aPhyMaxPsduSize*.

The **MCS Vector** field consists of four MCS fields, whose structure is depicted in Table 47.

|  |  |  |
| --- | --- | --- |
| **2 bits** | **2 bits** | **? bits** |
| Modulation | Encoding | Code Index Vector |

**MCS field**

The code index vector IHCM is a binary vector of 16 bits indicating by a “1” at ith position that the ith HCM code is being used. Any combination of HCM codes can be assigned in this way.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** |  | **Values** |
| Stream 1 | 3-5 | [0] | reserved | Reserved |
| [3:1] | Modulation | 0:2-PAM  …  3:16-PAM  >3: reserved |
| [7:4] | NHCM | 0: 8B10B is used  1: NHCM=1  2: NHCM=2  …  15: NHCM=15 |
| [23:8] | code index vector IHCM | Bit0: always “0”  Bit1: 2nd code used  Bit3: 3rd code used  …  Bit15: 16th code used |
| Stream 2-4 | 6-8 | [31:8] | … | … |

**Descriptor for MCS**

When using MIMO, RS\_type defines the use of time- or frequency-domain reference signals (RS) in the optional field. NRS is the number of RS in the optional field. The sequence index for the specific RS to be used is assigned to each transmitter through the PHY SAP.

Relaying mode specifies the mode of relaying operation (amplify-and-forward, decode-and forward). Relay duplex mode specifies the duplex mode for relaying (time- or full duplex).

**HCS**

The header check sequence (HCS) uses CRC-16 as defined in Annex B. The HCS bits shall be processed in the transmitted order. The registers shall be initialized to all ones.

**MIMO-RS**

Optional fields contain reference symbols for multiple-input multiple-output (MIMO) channel estimation. For MIMO RS, repetitions, FEC, line coding and HCS do not apply. MIMO RS can be defined in time- and frequency domain. The use of time- or frequency-domain RS is configurable via the MAC SAP. At lower OCR, typically, time-domain RS are appropriate. At higher OCR, frequency-domain RS apply.

Time-domain (TD) RSs are orthogonal in the time domain and constructed as follows. For the ith data stream/transmitter, respectively, TD RS use the *i*th row of the NxN Hadamard matrix **H**K where N=Nseq=2K according to Table 42. The value of *i* is used to identify the specific transmitter and defined by the MAC via the PHY SAP. Matrix **H**K is obtained iteratively by incrementing k from k=1…K as

* **( 1 )**

The resulting sequence is scrambled symbol-wise by logical XOR operation with the base sequence **A**N after subtracting a constant value of 0.5 from **A**N. A cyclic prefix is finally inserted, with length NCP=Nseq/32.[[1]](#footnote-1)

**Payload**

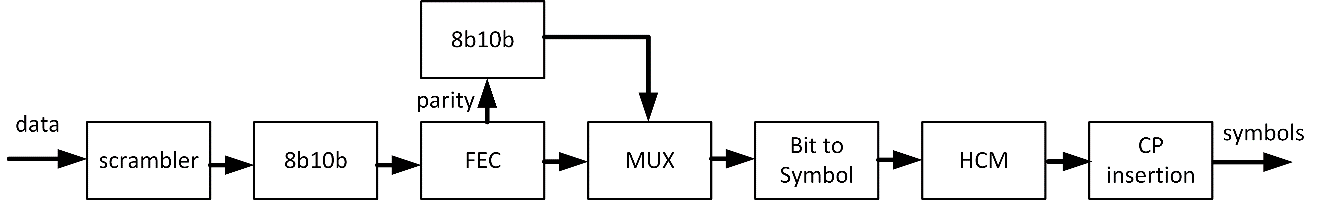
The payload contains the PSDU as received from the upper layer. For modulation and coding of the payload data, the following MCS are used:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **MCS ID** | **PAM Levels** | **OCR** | **Encoding** | **Data Rate** |
| 1 | 2 | 12.5 | 8b10b | tbd |
| 2 | 2 | 25 | 8b10b | tbd |
| 3 | 2 | 50 | 8b10b | tbd |
| 4 | 2 | 100 | 8b10b | tbd |
| 5 | 2 | 200 | 8b10b | tbd |
| 6 | 4 |  |  | tbd |
| 7 | 4 |  |  | tbd |
| … |  |  |  |  |

1. **MCS supported by the PM-PHY**

MCSs are combinations of line coding, FEC, HCM and OCR. In combination with , it is possible to obtain the data rate for each transmission mode. For instance, using RS(256,248) with 2-PAM, 8B10B and n=4 (6.25 MHz) yields 4.8 Mbit/s while using RS(256,248) with 16-PAM, m=15 for HCM and n=0 (100 MHz) yields 363 Mbit/s.

**Modulation and coding**

The generic transmitter structure is shown in Figure 71. For specific MCS, only a subset of the blocks are used.

**Transmitter structure for the payload**

A data block enters the transmitter and gets scrambled in order to randomize uncoordinated interference. If the MCS specifies 8B10B line coding, it is applied as the second step. For FEC, the payload uses RS(256, 248) code as defined below.

According to [B35, B36], a particular order of line and channel coding shown in Figure 71 achieves lowest error rates. After FEC, only the systematic part of the binary output code word (248 bits) is well balanced. For maintaining a constant average light output, also the redundant part of the binary code word (256-248=8 bits) passes through 8B10B line encoder. Both parts are concatenated again in a multiplexer.

Subsequently, the bits are passed through the bit-to-symbol mapper where 2-PAM is commonly used.

In combination with Hadamard Coded Modulation (HCM) other than the trivial mode HCM(1, 1), 8B10B line coding is not used while M-PAM with M≥2 can be used.

Finally, a spatial precoder transmits the PPDU over the set of OFEs, selected on the higher layers, thereby applying delay precoding on a per-OFE basis.

Header encoding uses RS(36, 24) as defined below. According to [B35, B36], a particular order of line and channel coding shown in Figure 71, achieves lowest error rate. After FEC, only the systematic part of the binary output code word (24 bits) is well balanced. For maintaining a constant average light output for the entire sequence, also the redundant part of the binary code word (36-24=12 bits) passes through 8B10B line encoder. Both parts are concatenated in a multiplexer and passed through the bit-to-symbol mapper for 2-PAM modulation. Finally, a spatial pre-coder selects what transmitters will sent out the header and how.

* + 1. **Optical clock rate**

The OCR defines the sample rate used for transmission of a PPDU. As the symbol duration of 5120 µs and CP duration are fixed in time, different numbers of bits apply for each of the possible OCRs.

Table 49 lists the supported OCRs and provides information on how different PHY parameters relate for each given OCR.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Opt. clock rate / MHz** | **Opt. clockcycle / ns** | **Nseq / optical clock cycles** | **NCP / optical clock cycles** | **Channel estimation sequence**  **(Annex D)** |
| 12.5 | 80 | 64 | 2 | A64 |
| 25 | 40 | 128 | 4 | A128 |
| 50 | 20 | 256 | 8 | A256 |
| 100 | 10 | 512 | 16 | A512 |
| 200 | 5 | 1024 | 32 | A1024 |

**OCRs for the PM-PHY**

**Scrambler**

Scrambling can be defined by the MAC sublayer through the PHY SAP. If used, scrambling is based on a pseudo-random binary sequence (PRBS) being characteristic for a given data stream.

[Needs specification]

**Reed-Solomon forward error correction**

Reed Solomon error coding is applied to the header and payload. For the header, a RS(36, 24) code is used, while the payload is protected by an RS(256, 248) code. For both codes, symbol widths of 10 bits apply, which is compatible with the output of the 8b10b encoder.

The resulting FEC input lengths of 240 bit for the header and 2480 bits for the payload might require the insertion of padding bits at the end of the data sequence. The padding shall consist of an alternating pattern of 0 and 1, starting with a 0.

For constructing both codes, the RS(36, 24) and RS(256, 248), the generator polynomial x10+x3+1 is used. Scaling factor is 1 and generator start equal to 0.

**8b10b Line Encoder**

Data bits are line coded in 8b10b coding in combination with 2-PAM and if HCM is disabled, i.e. HCM(1, 1) is used. For the 8B10B encoding, see ANSI/INCITS 373 and Annex F.

In case HCM with other than the trivial HCM(1, 1) mode is enabled, i.e. advanced HCM schemes HCM(1-3, 4), HCM(1-7, 8) or HCM(1-15, 16), 8b10b is deactivated and 1b1b is applied.

**Bit-to-symbol Mapper**

The bit-to-symbol mapper is using PAM with 2 to M levels. For 2 levels, each input bit is mapped in one symbol. The symbols are mapped to levels as {0, 1} to {0, 1}, respectively. With 4 levels, two consecutive bits are combined in a symbol. The symbols are mapped to levels as {00, 01, 10, 11} to {0, 1/3, 2/3, 1}, respectively. With arbitrary M, symbols map to signal levels as {0, 1/(M-1), 2/(M-1),...,1}. Gray mapping tables for M=2, 4, 8 and 16 are found in Annex E.

A constant value of 0.5 is always subtracted to make the mapper output DC free. Subsequently, the DC-free signal is modulated onto the bias signal. Setting the modulation amplitude and the bias signal of the LED is due to the analogue optical frontend.

**Hadamard Coded Modulation**

Hadamard Coded Modulation (HCM) is an extension of the bit-to-symbol mapper. Besides removing the need for line coding, HCM allows the use of M-PAM with variable M, despite the high-pass characteristics of the channel, together with a variable number of codes.

../../UVA%20-%20HCM%20(JSAC)/Main/HCM-TCOM/HCM-Transmitter.pdf

**HCM encoder**

**../../UVA%20-%20HCM%20(JSAC)/Main/HCM-TCOM/HCM-Receiver.pdf**

**HCM decoder**

As shown in Figure 73, HCM multiples a vector of *N* data symbols (where *N* is a power of two) with a Hadamard matrix, denoted as fast Walsh-Hadamard transform (FWHT). As described in [B31], the HCM signal *x =* [*x*0*, x*1*, ..., x*N-1]is generated from the data sequence

as

* **( 3 )**

where ***H***N is the Hadamard matrix of order *N* [B32], and is the complement of ***H***N. The complement of ***H*** is a binary matrix in which each element *h* of the matrix is replaced by 1-*h*. The components of *u* are assumed to be modulated using M-PAM. DC is removed by setting *u*0 = 0.

**Cyclic Prefix**

For frequency domain equalization (FDE), a cyclic prefix is applied to the header and payload bits of the PPDU. The CP length can take two values, 160 and 1280 ns.

The channel estimation part of the SHR and the header always have a CP length of 1280 ns. The payload CP length is indicated in the PHR.

**Spatial Precoder**

The spatial precoder is based on the architecture with multiple OFEs at the PHY layer, as depicted in Figure 5. A spatial precoding per PPDU defines the set of OFEs over which a given PPDU, resulting from a request over the PD-SAP, is transmitted.

In general, the spatial precoder is a matrix-vector operation *P∙x* operating symbol-wise when using time-domain RS and subcarrier-wise when using frequency-domain RS.

The transmitter multiplies the 1x1 stream of header information symbols *x* with the NERSx1 precoding vector *P* which contains ones for all active transmitters in a coordinated transmission cluster and zeros elsewhere.

All transmitters in the cluster broadcast the same header information (regional transmission). The master coordinator in the infrastructure network sends header information to all active transmitters in a coordinated transmission cluster. All transmitters send in a synchronous manner.

1. All sequences in **H**K are mutually orthogonal. The XOR operation with **A**N does not change the orthogonality of sequences but improves cross-correlation properties which is beneficial in case of multi-path [B28][B29]. Note that the sequence for the first stream or transmitter just contains **A**N. [↑](#footnote-ref-1)