IEEE 802.15  
Wireless Specialty Networks

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| IEEE P802.15.13  Text update for PM-PHY | | | | |
| Date: 2019-09-19 | | | | |
| Author: | | | | |
| Name | Affiliation | Address | Phone | Email |
| Kai Lennert Bober | Fraunhofer HHI |  |  | kai.lennert.bober@hhi.fraunhofer.de |

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 |

1. PM-PHY parameters
   1. PHY properties
      1. Base MCS

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

* + 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. | 1024 | octets |
| *aPhyTurnarountTime* | The maximum time required to switch the PHY from TX mode to RX mode or from RX mode to TX mode. | 10 | µs |
| *aPhyClockAccuracy* | The minimum accuracy of the PHY reference clock. | ± 20 | ppm |

1. Constant PHY PIB attributes
   1. PPDU format

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

1. 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).

* 1. Transmission
     1. Synchronization Header (SHR)
        1. 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 |

1. Parametrization of PM PHY preamble and header
   * + 1. 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 49.

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 from Table 49). The CE sequence is finally passed through a 2-PAM modulator.

* + 1. Physical Layer Header (PHR)
       1. PHY Header

The PHY header consists of the fields given in Table 46.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 2 octets | 1 bit | 6 bits | 1 bit | 1 octet |
| PSDU  Length | Short  CP | RS Num | **reserved** | MCS  ID |

1. Fields in the PHY header

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

**Short CP** indicates whether a short CP applies to the payload. CE and PHY Header are always using the long CP.

* If Short CP = 0 and NRS = 1, no RS is sent in the optional fields.
* If Short CP = 0 and NRS > 1, send NRS RS in the optional fields using the long CP.
* If Short CP = 1 and NRS = 1, send oneRS in the optional fields using the short CP.
* If Short CP = 1 and NRS > 1, send NRS RS in the optional fields using the short CP.

If OCR ID > 0 is used, repeat the RS Nseq / 64 times, where Nseq can be obtained from Table 49 for the given OCR ID.

**RS Num** specifies the number of MIMO RS trailing the PHY header. The sequence index for the specific RS to be used is incremented from 1 to NRS in steps of 1.

The **MCS ID** specifies the MCS used for the payload.

* + - 1. 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.

* + - 1. 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 RSs are orthogonal in the time domain and constructed as follows. For the ith data stream/transmitter, respectively, RS use the *i*th row of the NxN Hadamard matrix **H**K where N = 2K = 64 and K = 6.

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.

Depending on the OCR, the resulting sequence is repeated by Nseq / 64 where Nseq can be obtained from Table 49 for each OCR. A cyclic prefix is finally inserted, with length NCP from Table 49.[[1]](#footnote-1)

The MIMO RS are identified by their corresponding row number *i* on the MAC layer.

* + 1. Payload

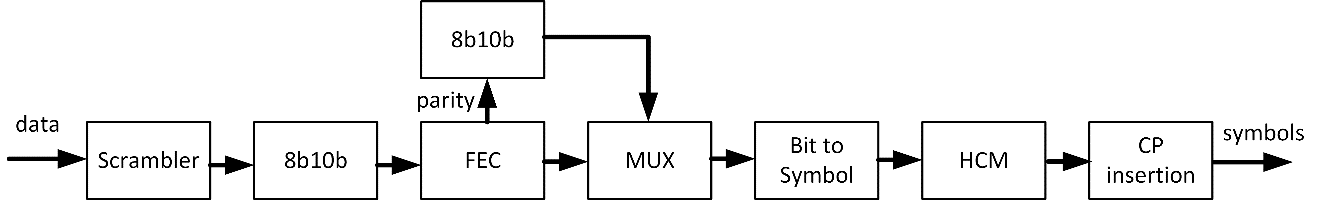
The payload contains the PSDU as received from the upper layer. For modulation and coding of the payload data, an MCS is used, identified through an MCS ID. The MCS ID is composed as depicted in Table 48.

|  |  |  |  |
| --- | --- | --- | --- |
| 1 octet | | | |
| 2 bits | 3 bits | 2 bits | 1 bits |
| PAM  Levels | OCR  ID | Encoding | reserved |

1. MCS ID scheme

MCSs are combinations of line coding, HCM and OCR. 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 (12.5 MHz) yields 9.6 Mbit/s while using RS(256,248) with 16-PAM, m=15 for HCM and n=0 (100 MHz) yields 363 Mbit/s.

* 1. Modulation and coding

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

1. Transmitter structure for the payload

Header or payload data 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) and the header encoding uses RS(36, 24).

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 (360 – 240 = 120 bits in case of header data and 2560-2480 = 80 bits in case of payload data) passes through 8B10B line encoder. Both parts are concatenated again in a multiplexer.

Subsequently, 2-PAM bit-to-symbol mapping is applied for the header. For payload data, 2-, 4-, 8- or 16-PAM may be used in combination with HCM. 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.

* + 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.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| OCR ID | Opt. clock rate / MHz | Opt. clockcycle / ns | Nseq / optical clock cycles | NCP / optical clock cycles | Channel estimation sequence  (Annex D) |
| 0 | 12.5 | 80 | 64 | 2 | A64 |
| 1 | 25 | 40 | 128 | 4 | A128 |
| 2 | 50 | 20 | 256 | 8 | A256 |
| 3 | 100 | 10 | 512 | 16 | A512 |
| 4 | 200 | 5 | 1024 | 32 | A1024 |

1. OCRs for the PM-PHY
   * 1. 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]

* + 1. 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.

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.

* + 1. 8b10b Line Encoder

Data bits are line coded in 8b10b coding in combination with 2-PAM when 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.

* + 1. 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.

* + 1. 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

1. HCM encoder

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

1. HCM decoder

As shown in Figure 72, 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

( 2 )

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.

* + 1. 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, the PHY header and MIMO RS shall always have a CP length of 1280 ns. The payload CP length is indicated in the PHR.

* + 1. Spatial Precoder

The spatial precoder formalizes the usage of multiple OFEs for transmission. A spatial precoding per PPDU defines the set of OFEs over which a given PPDU is transmitted and is prescribed for each PPDU by the MAC layer.

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)