**IEEE P802.15**

**Wireless Personal Area Networks**

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| Abstract | [Proposal for pulsed modulation PHY in 802.15.13]  |
| Purpose | [Inform TG13 about most recent work.] |
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1. **Pulsed Modulation PHY**

The Pulsed Modulation PHY enables moderate data rate from 1 Mbit/s up to few 100 Mbit/s. The main approach is to achieve higher data rates by increasing the optical clock rate but keeping spectral efficiency moderate. This is required e.g. in uplink scenarios where power efficiency is important and for many applications in the Internet of Things (IoT). PAM modulation with variable data rates is defined in Table 1. Controlled by higher layers, the PM PHY includes means to adapt the data rate to varying channel conditions i) by varying the optical clock rates and ii) by varying the modulation and coding scheme. In Table 1, only i) is considered.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Opt. clock rate /MHz** | **Opt. clockcycle/ns** | **Tseq/ns** | **TCP/ns** | **Nseq/optical clock cycles** | **NCP/optical clock cycles** | **MCS** | **Data rate/****Mbit/s** | **Channel estimation sequence (Appendix** |
| 3.125 | 320 | 5120 | 160  | 16 | 0  | 2-PAM8B10BRS(255,248) | 2.4 | A16 |
| 6.25 | 160 | 32 | 1  | 4.7 | A32 |
| 12.5 | 80 | 64 | 2  | 9.4 | A64 |
| 25 | 40 | 128 | 4  | 19 | A128 |
| 50 | 20 | 256 | 8  | 38 | A256 |
| 100 | 10 | 512 | 16  | 75 | A512 |
| 200 | 5 | 1024 | 32 | 150 | A1024 |

**Table 1 Numerology for Pulsed Modulation PHY**

* 1. **PPDU format**

Preamble

Channel estimation

SHR

PHY header

HCS

Optional Fields

PHR

PPDU

PHY payload

**Figure 1 PPDU format for Pulsed Modulation PHY**

The PM PHY uses the PPDU format shown in Figure 1. It consists of a synchronization header (SHR), physical layer header (PHR) and PHY payload (PPDU). Fields are specified in the following sub-clauses.

**1.2 Transmission**

**1.2.1 Synchronization Header (SHR)**

**1.2.1.1 Preamble**

The Preamble enables Schmidl-Cox autocorrelation [1-4] to achieve time synchronization using a correlation window size of 192. As a base sequence **A**64, a specific pseudo-noise sequence of length 64 is used, see Appendix 1).

In the preamble, the base sequence **A**64 is repeated six times yielding a total sequence length of 384. Each base sequence is multiplied with positive or negative sign as given below which is known to create a sharper peak after the autocorrelation, compared to a double word of the same total sequence length [4].

The total preamble reads **P**384 = [**A**64 **A**64 **-A**64 **A**64 **-A**64 **- A**64].

The preamble is finally passed through a 2-PAM Modulator.

**1.2.1.2 Channel estimation**

The channel estimation sequence enables block-wise frequency-domain equalization (FDE). The block consists of two parts, a base sequence and a cyclic prefix (CP). Measured in time units, the durations of both, the base sequence Tseq and the cyclic prefix TCP are maintained, independent of the optical clock rate. Also without using FDE, the CP is transmitted (with exception of optical clock rate below 6.25 MHz). Consistent block duration allows mixed operation of links with different optical clock rates in the same superframe. By increasing the optical clock rate, the number of optical clock cycles for the sequence and for the CP, i.e. Nseq and NCP, respectively, increase proportionally, see Table 1.

As channel estimation sequences, a specific pseudo-noise sequence **A**N given in Appendix 1) of length N=2k (k=5…11) is used, depending on the optical clock rate, so that N=Nseq (see Table 1**).**

The channel estimation sequence is finally passed through a 2-PAM Modulator.

**1.2.2 Physical Layer Header (PHR)**

**1.2.2.1 PHY header**

The PHY header has a fixed length and contains frame type (Probe or Data) and the length of the PSDU. The PHY header defines the fields given in Table 2.

|  |  |  |  |
| --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** | **Description** |
| FT | 0 | [7:0] | Frame type |
| PSDU\_length | 1-2 | [15:0] | Length of PSDU in optical clock cycles |

**Table 2 PHY header**

FT defines the frame types

FT=0 Data frame (used in MAC e.g. for Data, RTS, CTS, ACK, Feedback, Control, …)

FT=1 Probe frame

FT>1 Reserved

The PSDU length scales from 0 up to *aMaxPHYFrameSize.*

**1.2.2.2 HCS**

The HCS uses CRC-16 as defined in Annex C. The HCS bits shall be processed in the transmitter order. The registers shall be initialized to all ones.

**1.2.2.3 Optional fields**

Presence and structure of optional fields depend on the FT defined in the beginning of the PHY header. If **FT=0** (data frame), optional fields provide descriptors for the modulation and coding scheme (MCS) used, for implicit reference sequences (IRS) and the IRS themselves. IRS enable measurements of the effective channel matrix including the effect of the precoder for single stream or multiple streams transmitted in parallel. The effective channel matrix allows demodulation of data and higher layer control information.

|  |  |  |  |
| --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** | **Description** |
| MCS\_vector | 3-6 | [31:0] | Modulation and Coding Vector for PSDU |
| IRS\_type | 7 | [7:0] | Type of IRS |
| NIRS | 8 | [7:0] | Number of IRS |
| IRS | n. a. | n. a. | Block of IRS |

**Table 3 Optional fields for FT=0.**

The MCS\_vector defines the used modulation and coding schemes, being a number for single-stream transmission and a vector for spatial multiplexing with per-stream MCS adaptation. MCS adaptation is due to the MAC Layer. Definition of MCS needs 8 bits per stream, see Table 4.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** |  | **Values** |
| Stream 1 | 3 | [0] | Line coding | 0:8B10B, 1:HCM |
| [3:1] | Modulation | 0:2-PAM1:4-PAM2:8-PAM3:16-PAM>3: reserved |
| [7:4] | NHCM | 0: NHCM=01: NHCM=1…15: NHCM=15 |
| Stream 2-4 | 4-6 | [31:8] | … | … |

**Table 4: Descriptor for the MCS vector.**

IRS type defines the use of time- or frequency-domain IRS. Time-domain IRSs typically apply for transmission without FDE at lower optical clock rates. They are also sufficient for single-stream transmission. Frequency-domain IRSs enable transmission at higher optical clock rates using FDE and orthogonal transmission and detection of IRSs for multiple streams.

If **FT=1** (probe frame), optional fields provide a time reference, descriptors for explicit reference sequences (ERS) and the ERS themselves. ERS enable measurement of the direct channel matrix from individual transmitters to individual receivers. The most important role of a probe frame is the beacon sent at the beginning of a superframe.

|  |  |  |  |
| --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** | **Description** |
| Time\_stamp | 3-6 | [31:0] | Start of probe frame, 10 ns time resolution  |
| ERS\_type | 7 | [7:0] | Type of ERS |
| NERS | 8 | [7:0] | Number of ERS |
| ERS | n. a.  | n. a. | Block of ERS |

**Table 5 Optional fields for FT=1.**

ERS type defines the use of time- or frequency-domain ERS. Time-domain ERSs typically apply for transmission without FDE at lower optical clock rates and using a single or multiple transmitters. Frequency-domain ERS enable transmission at higher optical clock rates when using FDE and multiple transmitters multiple transmitters.

IRS and ERS are constructed following the same basic principles. As IRS and ERS are binary reference signals, no repetitions, no FEC and no line coding apply to them.

***1.2.2.3.1. Time-domain RS***

The time-domain RS for the ith data stream/transmitter in case of IRS/ERS, respectively, is constructed by bit-wise logical XOR operation of the base sequence **A**N given in the Appendix 1), where N=Nseq according to the numerology in Tabl*e* 1, and the ith row of the NxN Hadamard matrix **H**k obtained as follows



where N=2k. Note that the sequence in the first row of **H**k contains a sequence with all ones reproducing the base sequence for the first stream or transmitter. All pairs of sequences in **H**k are mutually orthogonal, using bit-wise multiplication and summation from j=1…N. The XOR operation with **A**N does not change orthogonality of sequences but improves auto- and cross-correlation properties which is beneficial in case of multi-path [5, 6].

***1.2.2.3.2. Frequency-domain RS***

The frequency-domain RS for the ith data stream or transmitter use the base sequence **A**N given in the Appendix 1), where N=Nseq according to the numerology in Table 1. Frequency-domain RSs are a set of NRS OFDM symbols [7]. A specific comb of subcarriers in the frequency domain identifies a particular stream or antenna. Comb spacing *Δ* is defined by higher layers taking the fundamental relation

*Δ≤Nseq/NCP*

into account. The definition of *Δ* is conveyed to the receiver in the variables ERS\_type and IRS\_type. There are

*Ncomb*=*Nseq / Δ*

non-zerosignals (tines) in the comb. The base sequence AN where *N=Ncomb* yield an appropriate definition of the signals on tines yielding low peak-to-average power ratio in the time domain.

For the first stream/transmitter, the comb starts at the first subcarrier following the DC subcarrier (being excluded from frequency-domain transmission in general). By using a single RS, up to Δ streams/transmitters could be identified. This is achieved by a cyclic shift of the comb by an integer number Nshift=0…Δ-1 of subcarriers, which makes RS oprtogonal in the frequency domain. However, higher layers shall reserve the shift Nshift = Δ-1 for noise estimation at the receiver. Hence, any subset of streams or transmitters that can be identified by a single RS is always smaller than Δ-1. When deploying more than Δ-1 streams or transmitters, one must add more RSs. Higher layers shall indicate this by variables Δ and NRS, where index RS means IRS and ERS, accordingly. In order to keep RSs for multiple subsets of streams/transmitters orthogonal to each other, M-th RS can be obtained by multication of the appropriate comb RS with the respective elements from the mth row of the MxM Hadamard matrix **H**k identifying the mth set of RSs. **H**k is obtained as follows

, k=1…M

where M = NRS is defined by higher layers but always as a power of 2.

**1.2.3. Header encoding and modulation**



**Figure 2 Transmitter Structure for the header.**

**1.2.3.1General**

The transmitter structure in Figure 2 is used for the header. Scrambling is only used in the coordinated topology to randomize uncoordinated interference. In other topologies, it is optional. For enhanced error protection, the header is repeated 3 times. Header encoding uses RS(36,24) code as defined below. Next, 8B10B line encoding applies to the header. Note that, for maintaining a constant average light output, both the systematic output of the FEC ( bits) and the redundant part (*k*-*n* bits) pass through the line encoder. 2-PAM modulation applies for the header using a bit-to-symbol mapper. Finally, a spatial precoder selects what transmitters will sent out the header and how.

**1.2.3.2 RS(36,24) code**

The description of RS(36,24) encoder is given in Appendix 2).

**1.2.3.3 Line Encoder**

In combination with 2-PAM and HCM(1,1), the line encoder uses 8B10B. Note that, for maintaining a constant average light output, both the systematic output bits of the FEC ( bits) and the redundant bits (*k*-*n* bits) should pass through the line encoder. For the 8B10B encoding, see ANSI/INCITS 373 and Appendix 3).

**1.2.3.4 Bit-to-Symbol Mapping**

Bit-to-symbol mapping for the header is based on 2-Pulse Amplitude Modulation (PAM). For 2 levels, each input bit is mapped on one symbol. The symbols are mapped to levels as {0, 1} to {0, 1}. A constant value of 0.5 is then subtracted to make the mapped output signal DC free. Setting the modulation amplitude and the bias of the LED is due to the analogue optical frontend.

**1.2.3. 5 Spatial Precoder for the Header**

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.

If FT=0 (data frame), mathematically, 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. In this way 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, what is out of scope for this standard.

If FT=1 (probe frame), mathematically, the transmitter multiplies the 1x1 scalar stream of header symbols ***x*** with the NERSx1 vector ***P*** which contains all ones. In this way all transmitters broadcast the same header information (global transmission). The master coordinator in the infrastructure network sends the header information to all transmitters. All transmitters send in a synchronous manner, what is out of scope for this standard.

**1.2.4 PHY payload**



**Figure 3 Transmitter Structure for the payload.**

**1.2.4.1 General**

The transmitter structure in Figure 3 applies to the payload, which besides data includes also RTS, CTS, ACK, Feedback and Control signals used at the MAC layer.

Scrambling is only used in the coordinated topology to randomize uncoordinated interference. In other topologies, it is optional. The payload uses RS(255,248) code with fixed code rate 248/255 for FEC. Line coding is then applied with 8B10B line code. For maintaining a constant average light output, both the systematic output of the FEC ( bits) and the redundant part (*k*-*n* bits) pass through the line encoder. 2-PAM is commonly used in the bit-to-symbol mapper. In combination with Hadamard Coded Modulation (HCM), M-PAM (M>2) may be used. By varying the parameter M for PAM and the number of used codes in HCM, the pulsed modulation PHY can adapt the data rate to varying optical channel conditions over a wide range. The value of M and the configuration of HCM(i,N) for the payload are conveyed via the MCS vector. A spatial precoder selects finally what transmitters will sent out the payload and how.

**1.2.4.2 Scrambler**

Scrambling is only used in the coordinated topology to ensure that uncoordinated interference is randomized. In other topologies, scrambling is optional. As scrambling is part of the data which identify different master coordinators, it is considered out of scope in this standard.

**1.2.4.3. RS(255,248) code**

The description of RS(255,248) encoder is given in Appendix 4).

**1.2.4.4 Line Encoder**

In combination with 2-PAM and HCM(1,1), the line encoder uses 8B10B. Note that, for maintaining a constant average light output, both the systematic output of the FEC ( bits) and the redundant part (*k*-*n* bits) should pass through the line encoder. For the 8B10B encoding, see ANSI/INCITS 373 and Appendix 3). In case HCM is used in other than the trivial HCM(1,1) mode, line coding is set to 1B1B, i.e. deactivated.

**1.2.4.5. Bit-to-Symbol Mapper**

The PAM mapper is using 2 up 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}. 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}. With arbitrary M, symbols map to levels . Gray mapping for arbitrary M-PAM is given in Appendix 5). A constant value of 0.5 is always subtracted to make the mapper output DC free. Setting the modulation amplitude and the bias signal of the LED is due to the analogue optical frontend.

**1.2.4.6. HCM**

Hadamard Coded Modulation (HCM) is an extension of the bit-to-symbol mapper and applied after PAM. HCM removes the need for line coding. As shown in **Figure 4**, HCM, multiples a vector of N data symbols (where is a power of two) with a Hadamard matrix, what is also denoted as fast Walsh-Hadamard transform (FWHT). As described in [8], the HCM signal is generated from the data sequence as

,

where is the binary Hadamard matrix of order [9], and is the complement of . The components of are assumed to be modulated using PAM.



**Figure 4 HCM encoder (left) and decoder (right)**

The DC part of HCM signals can be easily removed by setting the first component of () to zero and modulating only codewords of the Hadamard matrix with data symbols [8]. In this way, the average transmitted power is reduced by sending () instead of . Figure 5 shows an example of DC reduction. Reduced DC level counts per HCM symbol and its value can be different for each symbol. This idea makes transmitted signals orthogonal to DC bias at a overhead cost on data-rate.



**Figure 5 (a) A HCM signal, and (b) its corresponding DC reduced signal**

Table 5 lists overheads for different values of in comparison to 8B10 line encoding. Although higher values of N could enable even lower data rates, synchronization gets lost at these correspondingly low SNR levels. Then it is better to reduce the optical clock rate. As a consequence, HCM(NHCM,16) is used with variable number of codes transmitted in parallel NHCM=0…15.

|  |  |
| --- | --- |
| **HCM (N-1,**  | **Overhead [%]** |
| 2 | 50 |
| 4 | 25% |
| 8 | 12.5% |
| 16 | 6.25% |
| 32 | 3.2% |
| **8B10B** | 25% |

**Table 6 Over-head of HCM compared to 8B10B for different values of**

**1.2.4.7 Spatial Precoder for Payload**

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.

If FT=0 (data frame), mathematically, the transmitter multiplies the 1xNIRS vector of data symbols ***x***with the NERSxNIRS precoding matrix ***P.*** The master coordinator in the infrastructure network computes the required individual weight factors in the precoding matrix ***P***, splits the data into streams contained in vector ***x*** and passes streams to the used transmitters in a coordinated transmission cluster so that they can be send out in a synchronous manner, what is out of scope for this standard.

If FT=1 (probe frame), mathematically, the transmitter multiplies the 1x1 scalar stream of data symbols *x* with the NERS x 1 vector ***P*** which contains all ones. In this way all transmitters broadcast the same information. The master coordinator in the infrastructure network passes information to all transmitters so that it can be sent out in a synchronous manner, what is out of scope for this standard.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Modula-tion | Level/spectral efficiency [bit/s/Hz]  | FEC RS(n,k) | Line code | HCM | Optical Clock Rates/MHz | Data Rate/Mbps |
| PAM | 2 / 1 | (255, 248) for payload | 8B10B | (1,1) | 200/2N with N=0…7 | use Table 1 for HCM(1,1) and take into account ii) spectral efficiency for M-PAM i) overhead for HCM instead of 8B10B, see Table 5 |
| (36,24) for header |
| 2 / 1 | 1B1B | (0-15,16) |
| 4 / 2 |
| 8 / 3 |
| 16 / 4 |

**Table 7 Transmission modes using combinations of M-PAM and Line Coding or HCM**

**References**

[1] T. M. Schmidl, D. C. Cox, "Robust frequency and timing synchronization for OFDM", IEEE Transactions on Communications, 1997.

[2] H. Minn, V. K. Bhargava, K. B. Letaief, "A robust timing and frequency synchronization for OFDM systems," in IEEE Transactions on Wireless Communications, vol. 2, no. 4, pp. 822-839, July 2003.

[3] M. Schellmann, V. Jungnickel, C. von Helmolt, "On the value of spatial diversity for the synchronization in MIMO-OFDM systems," IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, Berlin, 2005, pp. 201-205.

[4] K. Goroshko, K. Manolakis, L. Grobe, V. Jungnickel, "Low-latency synchronization for OFDM-based visible light communication," 2015 IEEE International Conference on Communication Workshop (ICCW), London, 2015, pp. 1327-1332.

[5] V. Jungnickel, Yun-Shen Chang, V. Pohl, "Performance of MIMO Rake receivers in WCDMA systems," IEEE Wireless Communications and Networking Conference (IEEE Cat. No.04TH8733), 2004, pp. 2075-2080 Vol.4.

[6] V. Jungnickel, H. Chen, V. Pohl, "A MIMO RAKE receiver with enhanced interference cancellation," IEEE 61st Vehicular Technology Conference, 2005, pp. 3137-3141 Vol. 5.

[7] V. Jungnickel, K. Manolakis, L. Thiele, T. Wirth, T. Haustein, „Handover Sequences for Interference-Aware Transmission in Multicell MIMO Networks, “ *Proceedings International ITG Workshop on Smart Antennas – WSA 2009*, February 16–18, Berlin, Germany.

[8] M. Noshad, and M. Brandt-Pearce. "Hadamard-coded modulation for visible light communications." *IEEE Transactions on Communications* 64.3 (2016): 1167-1175.

[9] K. J. Horadam, Hadamard Matrices and Their Applications. Princeton University Press, 2006.

[10] <https://mentor.ieee.org/802.15/dcn/17/15-17-0598-00-0013-generic-mac-for-coordinated-topology.ppt>

**Appendix**

1. **Pseudo-noise sequences A**N

The following base sequences are the first from two mother sequences of length N=2k with k=1…11 usually used to form a set of Gold sequences. A ‘1’ is added to keep the sequence balanced.

**A**2 = [-1 1]

**A**4 = [-1 1 -1 1]

**A**8 = [-1 -1 1 -1 1 1 -1 1 ]

**A**16 = [-1 -1 -1 1 -1 1 -1 -1 1 1 -1 1 1 1 -1 1]

**A**32 = [ -1 -1 -1 -1 1 1-1 -1 1 -1 1 1 -1 1 1 1 1 -1 1 -1 1 -1 -1 -1 1 -1 -1 1 1 1 -1 1]

**A**64 = [ -1 -1 -1 -1 -1 1 -1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 1 1 -1 1 1 -1 -1 -1 1 1 1 -1 1 -1 -1 -1 -1 1 1 -1 1 -1 1 1 1 -1 -1 1 1 1 1 -1 1 1 1 1 1 -1 1]

**A**128 = [ -1 -1 -1 -1 -1 -1 1 1 1 -1 -1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1 -1 1 -1 -1 -1 -1 -1 1 -1 1 -1 1 -1 1 1 1 1 -1 1 -1 -1 1 -1 -1 -1 -1 1 1 -1 -1 -1 1 1 -1 1 -1 1 -1 -1 1 1 -1 -1 1 1 1 1 1 -1 -1 1 -1 -1 1 -1 1 -1 -1 -1 1 -1 1 1 1 -1 -1 1 1 -1 1 1 1 -1 1 1 1 1 1 1 -1 1 1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1 -1 1 1 1 1 -1 1]

**A**256 = [ -1 -1 -1 -1 -1 -1 -1 1 1 -1 1 1 1 1 -1 1 -1 1 1 -1 -1 -1 -1 -1 1 -1 1 -1 1 -1 1 -1 -1 -1 1 1 1 1 1 -1 -1 1 1 1 -1 1 -1 1 -1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 -1 -1 -1 -1 1 -1 -1 -1 -1 1 1 -1 -1 1 -1 -1 -1 1 -1 -1 -1 1 1 -1 1 -1 1 -1 1 1 -1 1 -1 1 1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 -1 -1 -1 1 1 1 -1 -1 1 -1 -1 1 1 1 1 -1 1 1 1 -1 1 -1 -1 -1 1 -1 1 -1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 -1 -1 1 1 1 1 -1 -1 1 -1 1 1 -1 -1 1 -1 1 -1 -1 1 -1 -1 1 -1 1 -1 1 1 1 1 1 -1 1 1 -1 -1 -1 1 -1 -1 1 1 -1 1 1 -1 1 1 -1 -1 1 1 1 1 1 1 -1 -1 -1 1 -1 1 1 -1 1 1 1 -1 -1 -1 1 1 1 -1 1 1 1 1 1 1 1 -1 1 -1 -1 1 1 1 -1 -1 -1 -1 1 -1 1 1 1 1 -1 1]

**A**512 = [ -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 1 -1 -1 -1 -1 1 -1 -1 -1 1 1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 -1 1 -1 -1 -1 -1 1 -1 1 1 1 1 -1 -1 -1 1 1 -1 -1 1 1 1 1 -1 1 1 -1 1 1 1 -1 1 -1 1 -1 -1 -1 1 -1 1 -1 -1 -1 -1 1 1 -1 1 1 -1 1 -1 -1 -1 1 1 -1 -1 -1 1 1 1 1 1 1 -1 -1 -1 1 -1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1 1 -1 1 1 -1 1 -1 1 1 1 1 1 1 -1 1 -1 1 -1 1 -1 1 -1 -1 -1 -1 -1 1 -1 1 -1 -1 1 -1 1 1 1 1 1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 -1 1 -1 1 -1 -1 1 1 1 1 1 -1 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 1 1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 -1 1 -1 -1 -1 1 1 1 -1 -1 1 -1 1 1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1 -1 -1 1 1 1 -1 -1 1 1 1 1 1 1 1 -1 -1 1 1 -1 -1 1 1 -1 1 -1 1 -1 -1 1 1 -1 1 1 -1 -1 -1 -1 -1 -1 1 -1 -1 1 -1 1 1 -1 1 1 -1 1 1 -1 -1 1 -1 -1 -1 -1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 -1 1 1 1 1 -1 1 -1 1 1 1 -1 1 1 -1 -1 -1 1 -1 -1 1 1 -1 1 -1 -1 -1 -1 1 -1 -1 1 1 1 1 -1 -1 1 -1 1 -1 1 -1 1 1 -1 -1 -1 1 1 -1 1 1 1 1 -1 -1 1 1 1 -1 1 1 1 1 -1 1 1 1 1 1 1 1 1 -1 1 1 1 -1 1 1 1 -1 -1 1 1 -1 1 1 1 -1 -1 -1 1 -1 1 -1 1 -1 -1 1 -1 -1 1 1 1 -1 -1 -1 1 1 1 -1 1 1 -1 1 -1 1 -1 1 1 1 -1 -1 1 -1 -1 1 1 -1 -1 -1 -1 -1 1 1 -1 -1 -1 -1 1 1 1 -1 1 -1 -1 1 -1 -1 -1 1 1 -1 1 -1 1 1 -1 1 1 1 1 1 -1 1 1 -1 -1 1 1 -1 -1 -1 1 -1 1 1 1 -1 -1 -1 -1 -1 1 -1 -1 -1 -1 1 1 1 1 1 -1 1]

**A**1024 = [-1 -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 -1 -1 -1 1 1 1 -1 1 1 -1 -1 -1 1 -1 -1 1 1 -1 1 -1 1 -1 -1 -1 1 -1 -1 -1 -1 1 -1 1 -1 1 1 1 -1 -1 -1 -1 1 -1 1 1 -1 1 -1 1 -1 1 1 1 1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 -1 -1 -1 1 -1 1 1 1 1 -1 -1 -1 1 -1 1 1 -1 1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 -1 -1 1 1 -1 -1 -1 -1 1 -1 1 -1 -1 1 1 1 -1 -1 1 1 -1 -1 -1 -1 -1 -1 1 1 -1 1 -1 1 -1 1 -1 1 1 -1 -1 1 1 -1 -1 1 1 -1 1 -1 1 1 -1 -1 -1 -1 -1 1 -1 1 1 -1 -1 -1 1 1 1 1 -1 1 1 1 -1 -1 1 -1 -1 1 1 -1 1 1 1 -1 1 -1 1 1 -1 -1 1 -1 -1 -1 -1 1 -1 -1 -1 1 -1 1 -1 1 -1 -1 -1 1 1 -1 -1 1 1 -1 -1 -1 1 -1 -1 -1 1 -1 -1 -1 1 1 -1 -1 -1 1 -1 1 -1 1 1 -1 -1 -1 1 -1 1 1 1 1 1 -1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 1 1 1 1 -1 -1 1 1 1 -1 1 1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 1 -1 1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 -1 1 -1 1 1 -1 -1 1 1 1 -1 1 -1 -1 1 1 1 1 1 1 -1 1 -1 1 1 -1 1 1 -1 1 -1 -1 -1 -1 -1 1 -1 -1 -1 -1 1 1 1 -1 -1 1 1 1 -1 -1 1 -1 -1 -1 1 -1 -1 1 1 1 1 -1 -1 -1 -1 1 1 -1 1 1 -1 -1 -1 1 1 -1 1 -1 -1 1 1 1 -1 1 1 1 1 -1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 1 -1 -1 -1 1 1 1 -1 -1 1 -1 1 -1 1 1 -1 1 -1 1 1 1 1 -1 1 1 1 1 -1 1 1 -1 1 -1 -1 1 -1 -1 -1 -1 -1 1 -1 1 -1 -1 -1 1 1 1 -1 1 -1 -1 -1 1 1 -1 1 1 1 1 -1 -1 -1 -1 -1 1 -1 -1 1 -1 1 -1 1 -1 1 1 1 -1 1 -1 -1 -1 -1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 -1 -1 -1 -1 1 1 1 1 1 -1 -1 -1 1 1 -1 1 1 -1 1 -1 1 -1 -1 1 1 -1 1 -1 -1 -1 -1 1 1 -1 1 -1 -1 -1 1 1 1 1 1 -1 1 -1 1 -1 -1 1 -1 -1 1 1 -1 -1 1 1 1 1 -1 -1 1 -1 1 -1 -1 1 -1 -1 -1 1 -1 1 1 1 -1 1 -1 1 -1 -1 -1 -1 -1 -1 1 -1 1 1 1 -1 -1 -1 1 1 -1 -1 1 -1 -1 -1 1 1 -1 1 -1 1 1 1 -1 -1 1 -1 1 1 1 1 1 1 -1 -1 1 1 -1 1 1 -1 1 1 1 -1 1 1 1 1 1 -1 1 1 -1 -1 1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1 1 -1 -1 1 1 1 1 -1 1 -1 -1 -1 1 -1 -1 1 -1 1 1 1 -1 -1 1 1 1 1 -1 1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 -1 -1 1 1 1 -1 -1 -1 -1 1 1 1 1 1 1 -1 -1 -1 1 -1 -1 1 -1 -1 1 1 1 -1 1 -1 1 1 1 -1 1 1 -1 -1 1 1 -1 1 1 1 1 1 -1 -1 1 -1 1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 1 1 -1 1 -1 1 -1 1 -1 -1 1 -1 1 1 1 1 -1 1 -1 1 1 1 1 1 1 1 -1 1 -1 -1 1 -1 -1 1 -1 -1 -1 -1 1 1 -1 -1 -1 -1 1 1 1 -1 1 1 1 -1 -1 -1 -1 -1 -1 1 -1 -1 1 1 1 -1 -1 -1 1 -1 1 -1 -1 1 -1 1 -1 1 1 1 1 -1 -1 1 1 -1 -1 1 -1 -1 1 1 1 1 1 -1 -1 1 1 1 1 1 1 1 1 -1 -1 1 -1 -1 1 -1 -1 1 -1 1 -1 -1 -1 1 -1 1 -1 -1 -1 -1 1 1 1 1 -1 1 -1 1 -1 1 1 -1 1 1 1 1 -1 1 -1 -1 1 1 -1 1 1 -1 -1 1 1 1 1 1 -1 1 1 1 -1 1 1 -1 1 1 1 1 1 1 -1 1 1 1 1 1 1 1 1 1 -1 1 1 -1 1 1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 -1 1 -1 -1 -1 -1 -1 1 1 -1 -1 1 1 1 -1 -1 -1 -1 -1 1 1 -1 1 1 1 -1 -1 -1 1 -1 -1 -1 -1 -1 -1 1 1 1 1 -1 -1 -1 1 1 1 1 1 1 1 -1 1 ]

1. **Generators of RS(36, 24)**

t.b.d.

1. **8B10B encoding**

t.b.d. See also <http://application-notes.digchip.com/056/56-39724.pdf>

1. **Generators of RS(255, 248)**

t.b.d.

**Beacon fields moved to MAC layer**

|  |  |  |  |
| --- | --- | --- | --- |
| **Field** | **Octet** | **Bits** | **Description** |
| OWPAN ID | 1 | [7:0] | OWPAN ID |
| SID | 2-3 | [15:0] | Source ID |
| DID | 4-5 | [15:0] | Destination ID |
| OWPAN name | 22-53 | [255:0] | Character-based ID of OWPAN |
| CAP duration after beacon | 13-16 | [31:0] | Duration of CAP in SF, 10 ns resolution |
| BPOS | 11-12 | [15:0] | Beacon slot in each frame, 10 ns resolution |