IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	PHY Proposal to TG4m
Date Submitted	July 9th 2012
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Re:	Submission in response to TG4m CFP for PHY amendment to IEEE 802.15.4
Abstract	Text for a PHY proposal to TG4m
Purpose	Final proposal submission
Notice	
Release	

Insert after Clause 19 the following new clause (Clause 20):

20. TVWS PHYs

Two PHYs are specified: a FSK PHY (TVWS-FSK), as described in 20.1, and an orthogonal frequency division multiplexing PHY (TVWS-OFDM) as described in 20.2.

20.1 TVWS-FSK

20.1.1 PPDU format for TVWS-FSK

The TVWS-FSK PPDU shall support the format shown in Figure 112.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length *n*, numbered b_0 on the left and b_{n-1} on the right. When transmitted, they are processed b_0 first to b_{n-1} last, without regard to their content or structure.

All reserved fields shall be set to zero upon transmission and shall be ignored upon reception.

		Octets	
		2	**Variable**
Preamble	SFD	As defined in 20.1.1.3	PSDU
SHR		PHR	PHY payload

Figure 112—Format of the TVWS-FSK PPDU

20.1.1.1 Preamble field

The Preamble field shall contain *phyFSKPreambleLength* (as defined in 9.3) multiples of the 8-bit sequence “01010101”.

20.1.1.2 SFD

The SFD for filtered 2FSK shall be a sequence selected from the list of values shown in Table 131. Devices that do not support the FEC (see 20.1.2.4) shall support the SFD associated with uncoded (PHR + PSDU). Devices that support FEC (see 20.1.2.4) shall support both SFD values shown in Table 131.

Table 131—TVWS-FSK SFD values

SFD value for coded (PHR + PSDU)	SFD value for uncoded (PHR + PSDU)
TBD	TBD

20.1.1.3 PHR

The format of the PHR is shown in Figure 113. All multi-bit fields are unsigned integers and shall be processed MSB first.

Bit string index	0	1–4	5–15
Bit mapping	PC	B_3–B_0	L_{10}–L_0
Field name	Parity Check	Check-sum	Frame Length

Figure 113—Format of the PHR for TVWS-FSK

The Frame Length field (L_{10}–L_0) specifies the total number of octets contained in the PSDU (prior to FEC encoding, if enabled). The most significant bit (leftmost) shall be transmitted first.

The Checksum field (B_3–B_0) is the checksum for the BCH(15,11) code. The generator polynomial for the Bose Chaudhuri Hocquenghem (BCH) code is as follows:

$$G(x) = 1 + x + x^4 .$$

The BCH code is applied over the Frame Length sub-field.

The Parity Check (PC) field provides improved error detection. Its value is the modulo-2 addition of all bits in the PHR other than the Parity Check.

20.1.1.4 PSDU field

The PSDU field carries the data of the PPDU.

20.1.2 Modulation and Coding for TVWS-FSK

The modulation for the TVWS-FSK PHY is 2-level Filtered FSK. The Filtering method is as needed to meet regulatory requirements in the band of operation. Table 132 shows the modulation and channel parameters for the TVWS-FSK PHY.

Table 132—TVWS-FSK modulation and channel parameters[a]

Frequency band (MHz)	Parameter	Operating mode #1	Operating mode #2	Operating mode #3	Operating mode #4
All available TVWS bands	Data rate (kb/s)	50	100	200	300
	Modulation index	1.0	0.5	0.5	0.5
	Channel spacing (kHz)	100	200	400	600

[a]Data rates shown are over-the-air data rates (the data rate transmitted over the air regardless of whether the FEC is enabled).

20.1.2.1 Reference modulator diagram

The functional block diagram in Figure 114 is provided as a reference for specifying the TVWS-FSK data flow processing functions.

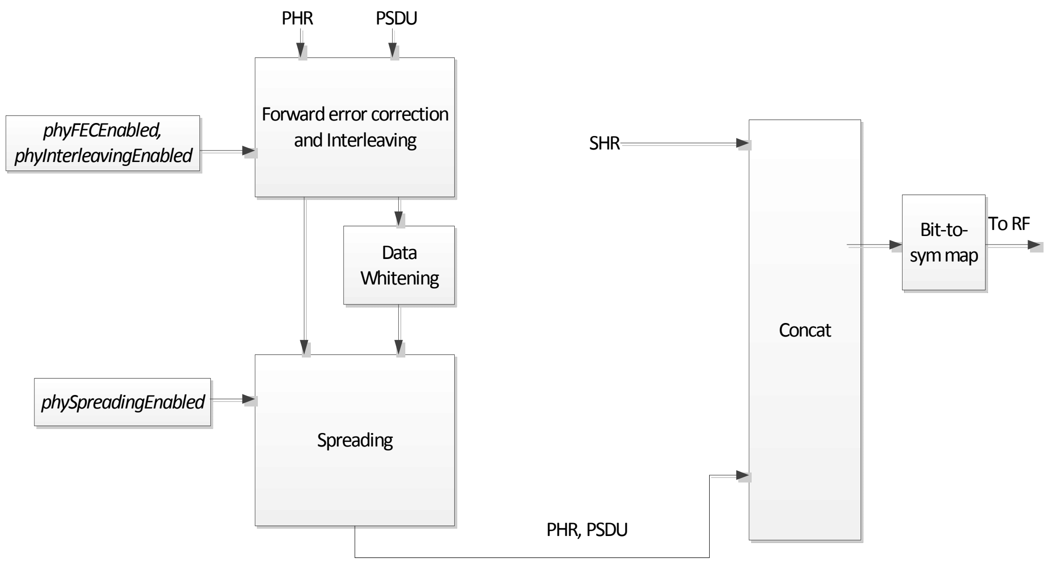


Figure 114—Reference modulator diagram

20.1.2.2 Bit-to-symbol mapping

The symbol encoding is shown in Table 133, where the frequency deviation, f_{dev}, is equal to (symbol rate x modulation index)/2. The symbol rate shall be the same for the entire PPDU.

Table 133—TVWS-FSK symbol encoding

Symbol (binary)	Frequency deviation
0	$-f_{dev}$
1	$+f_{dev}$

20.1.2.3 Modulation quality

The modulation quality shall be as given in 18.1.2.3 for 2-level modulation.

20.1.2.4 Forward error correction (FEC)

FEC support is optional. The use of FEC is controlled by the PIB attribute *phyFECEnabled*, as defined in 9.3. The FEC scheme shall be according to sub-clause 19.2.2.4 for the case when the PHR is 2-octet long.

20.1.2.5 Code-symbol interleaving

Interleaving support is optional. The use of interleaving is controlled by the PIB attribute *phyInterleavingEnabled*, as defined in 9.3. Interleaving shall be according to sub-clause 19.2.2.5 for the case when the PHR is 2-octet long.

20.1.2.6 Spreading

Spreading support is optional. The use of spreading is controlled by the PIB attribute *phySpreadingEnabled*, as defined in 9.3. The spreading method shall be as defined in 19.2.2.6.

20.1.3 Data whitening

Data whitening shall be supported. The data whitening algorithm shall be as defined in 18.1.3.

20.1.4 RF requirements for TVWS-FSK

20.1.4.1 Clock accuracy

The clock frequency and time accuracy shall be better than ±20 ppm.

20.1.4.2 Channel switch time

The channel switch time shall be as given in 18.1.5.4.

20.1.4.3 Receiver sensitivity

The receiver sensitivity shall be as given in 18.1.5.7.

20.1.4.4 Tx-to-Rx turnaround time

The TX-to-RX turnaround time shall be as given in 18.1.5.9.

20.1.4.5 Rx-to-Tx turnaround time

The RX-to-TX turnaround time shall be as given in 18.1.5.10.

20.2 TVWS-OFDM PHY

The TVWS-OFDM PHY supports data rates ranging from 50 kb/s to 1600 kb/s. The subcarrier spacing is constant and is equal to (10416 and 2/3) Hz (or 31250/3 Hz).

The symbol rate is (8 and 1/3) ksymbol/s, which corresponds $(4/5) \times (31250/3)$ or 120 μs per symbol. This symbol includes a quarter-duration cyclic prefix (CP; 24 μs) and a base symbol (96 μs).

This PHY includes four options, each one being characterized by the number of active tones during the PHR or PSDU. The total signal bandwidth for each option ranges from about 1 MHz down to <200 kHz.

While the standard does not specify the actual DFT size implemented in the system, the standard does support the following baseline DFT sizes: 128, 64, 32, and 16.

20.2.1 PPDU format for TVWS-OFDM

The TVWS-OFDM PPDU shall be formatted as illustrated in Figure 115.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length *n*, numbered b_0 on the left and b_{n-1} on the right. When transmitted, they are processed b_0 first to b_{n-1} last, without regard to their content or structure.

All reserved fields shall be set to zero upon transmission and shall be ignored upon reception.

The DATA field is composed of the PSDU, tail bits, and pad bits, as described in 20.2.3.

	Number of OFDM Symbols			
	Variable	**Variable**	**6 bits**	**Variable**
As defined in 20.2.1.1	As defined in 20.2.1.2	PSDU	TAIL	PAD
SHR	PHR	PHY payload		

Figure 115—Format of the TVWS-OFDM PPDU

20.2.1.1 SHR
20.2.1.2 PHR

The PHR consists of the Frame Length field and frame control bits. The PHR structure shall be formatted as illustrated in Figure 116. All multi-bit fields are unsigned integers and shall be processed MSB first.

The PHR shall be transmitted using the lowest data rate mode supported, as described in Table 134, for the option being used. It is sent to the convolutional encoder starting from the leftmost bit in Figure 116 to the rightmost bit.

The Mode field (M_1-M_0) specifies the data rate of the payload and is equal to the numerical value of the Mode, expressed in binary format. The list of data rates for each OFDM bandwidth option can be found in 20.2.2.

The Scrambler Seed field (S_1–S_0) specifies the scrambling seed, as described in 20.2.3.9.

Bit string index	0-2	3-4	5–6	7–17	18–41	42–47
Bit mapping	R_2–R_0	M_1–M_0	S_1–S_0	L_{10}–L_0	H_{23}–H_0	T_5–T_0
Field name	Reserved	Mode	Scrambler Seed	Frame Length	HCS	Tail

Figure 116—PHY header fields for TVWS-OFDM

The Frame Length field (L_{10}–L_0) specifies the total number of octets contained in the PSDU (prior to FEC encoding).

The Header Check Sequence (HCS) field (H_{23}–H_0) is a 24-bit CRC taken over the PHY header (PHR) fields.

The HCS shall be computed using the first 18 bits of the PHR. The HCS shall be calculated using the polynomial $G_{24}(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^7 + x^6 + x^5 + x^4 + x^3 + x + 1$.

The Tail bit field (T_5–T_0), which consists of all zeros, is for Viterbi decoder flushing, as described in 20.2.3.3.

20.2.1.3 PSDU field

The PSDU field carries the data of the PHY packet.

20.2.2 Data rates for TVWS-OFDM

There are four OFDM options, each with a different number of active tones. The various data rates are shown in Table 134. The nominal bandwidth is calculated by multiplying {the number of active tones + 1 for the DC tone} by {the subcarrier spacing}.

Table 134—Data Rates for TVWS-OFDM PHY

Parameter	OFDM Option 1	OFDM Option 2	OFDM Option 3	OFDM Option 4
Nominal bandwidth (kHz)	1094	552	281	156
Channel spacing (kHz)	1200	600	400	200
DFT size	128	64	32	16
Active tones	104	52	26	14
# Pilot tones	8	4	2	2
# Data tones	96	48	24	12
Mode 0 (kb/s) (BPSK rate 1/2)	400	200	100	50
Mode 1 (kb/s) (QPSK rate 1/2)	800	400	200	100
Mode 2 (kb/s) (16-QAM rate 1/2)	1600	800	400	200

20.2.3 Modulation and coding for TVWS-OFDM

20.2.3.1 Reference modulator diagram

20.2.3.2 Bit-to-symbol mapping

Figure 117 shows the bit-to-symbol mapping for BPSK, QPSK, and 16-QAM.

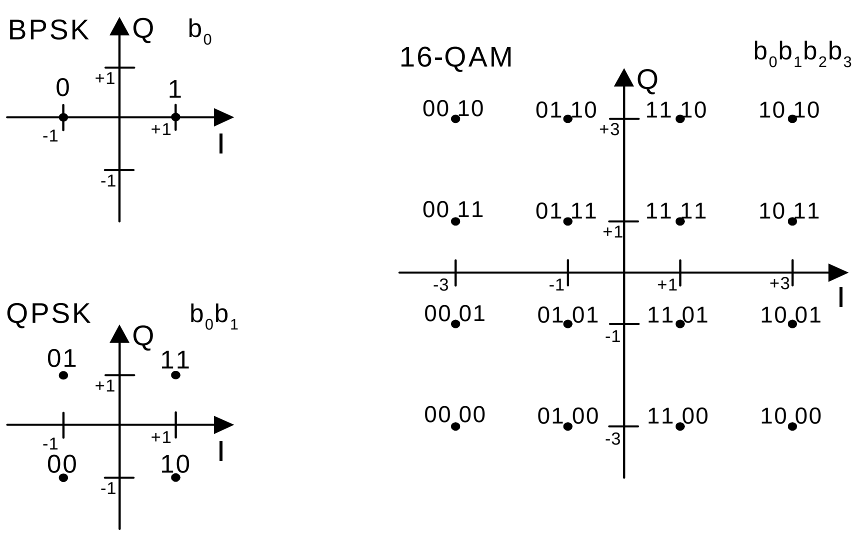


Figure 117—Bit-to-symbol mapping for TVWS-OFDM

The output values, *d*, are formed by multiplying the resulting $(I + jQ)$ value by a normalization factor K_{MOD}:

$$d = (I + jQ) \times K_{MOD}$$

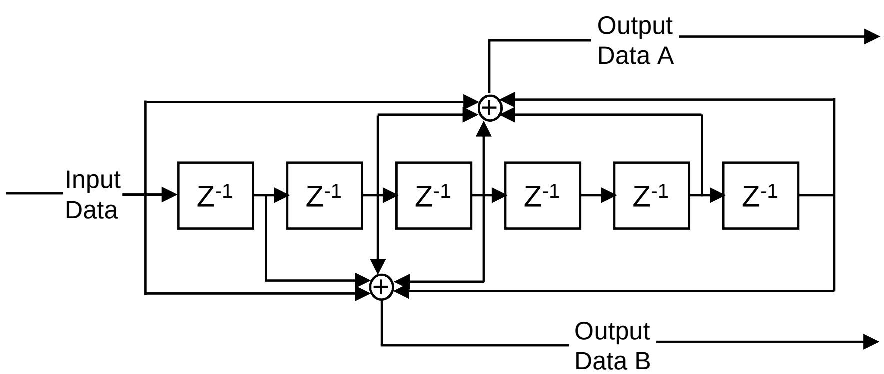
The normalization factor, K_{MOD}, depends on the base modulation mode, as described in Table 135. The purpose of the normalization factor is to achieve the same average power for all mappings.

Table 135—Modulation-dependent normalization factor K_{MOD}

Modulation	K_{MOD}
BPSK	1
QPSK	$1/(\sqrt{2})$
16-QAM	$1/(\sqrt{10})$

20.2.3.3 Forward error correction (FEC)

The DATA field shall be coded with a convolutional encoder of coding rate R = 1/2, corresponding to the desired data rate. The convolutional encoder shall use the generator polynomials expressed in octal representation, $g_0 = 133_8$ and $g_1 = 171_8$, of rate R = 1/2, as shown in Figure 118. The convolutional encoder shall be initialized to the all zeros state before encoding the PHR and then reset to the all zeros state before encoding the PSDU.



Convolutional Encoder: Rate ½, constraint length K=7
Octal generator polynomials [133 , 171]

Figure 118—Rate 1/2 convolutional encoder

20.2.3.4 Interleaver

20.2.3.5 Pilot tones / null tones

The number of pilot and null tones for each OFDM option are defined as shown in Table 136.

The DC tone is numbered as 0.

Table 136—Number of pilot and null tones for TVWS-OFDM PHY

	OFDM Option 1	OFDM Option 2	OFDM Option 3	OFDM Option 4
Active tones	104	52	26	14
# Pilot tones	8	4	2	2
# Data tones	96	48	24	12
#DC null tones	1	1	1	1

For Option 1, the subcarriers for pilot and data are numbered as –52 to 52 with the DC tone unused.

Table 137—Pilot tones for Option 1

Pilot set	–38	–26	–14	–2	10	22	34	46

For Option 2, the subcarriers for pilot and data are numbered as –26 to 26 with the DC tone unused.

Table 138—Pilot tones for Option 2

Pilot set	–14	–2	10	22

For Option 3, the subcarriers for pilot and data are numbered as –13 to 13 with the DC tone unused.

Table 139—Pilot tones for Option 3

Pilot set 1	–7	7

For Option 4, the subcarriers for pilot and data are numbered as –7 to 7 with the DC tone unused.

Table 140—Pilot tones for Option 4

Pilot set	–3	5

The data carried on the pilot tones shall be determined by a pseudo-noise sequence PN9 with the seed “111111111”. The first output bit is assigned to the pilot with the most negative index. Table 141 shows the mapping from PN9 bits to the pilot BPSK symbols for all OFDM options and modes. Index *n* starts after the SHR from zero and is increased by one every pilot subcarrier.

Table 141—Mapping from PN9 sequence to pilot BPSK symbols

Input bit ($PN9_n$)	BPSK symbol
0	$-1 + (0 \times j)$
1	$1 + (0 \times j)$

20.2.3.6 Cyclic prefix (CP)

A CP shall be prepended to each base symbol. The duration of the CP (24 µs) shall be 1/4 of the base symbol (96 µs). The CP is a replication of the last 24 µs of the base symbol. The CP is illustrated in Figure 119. In Figure 119, *N* is the number of samples in the base symbol, while *L* is the length of the CP that is added to the base symbol.

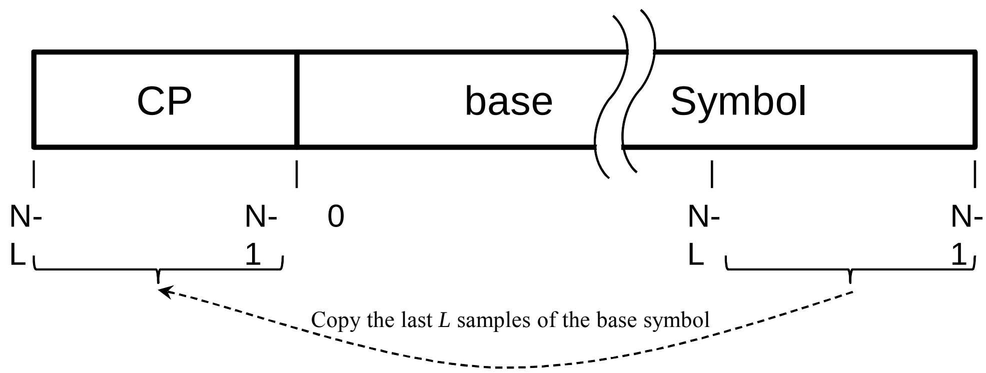


Figure 119—Cyclic prefix (CP)

20.2.3.7 PPDU Tail Bit field (TAIL)

The PPDU tail bit field shall be six bits of "0," which are required to return the convolutional encoder to the "zero state." This procedure reduces the error probability of the convolutional decoder, which relies on future bits when decoding and which may be not be available past the end of the message. The PPDU tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

20.2.3.8 Pad bits (PAD)

The length of the message is extended so that it becomes a multiple of N_{dbps}, the number of data bits per OFDM symbol. N_{dbps} for each Option and Mode combination is given in Table 142. The number of pad bits, N_{PAD}, are computed from the length, in octets, of the PSDU (LENGTH is equal to the content of the Frame Length field in Figure 116) as follows:

$$N_{SYM} = \text{ceiling}[(8 \times \text{LENGTH} + 6) / N_{dbps}]$$

$$N_{DATA} = N_{SYM} \times N_{dbps}$$

$$N_{PAD} = N_{DATA} - (8 \times \text{LENGTH} + 6) \quad (1)$$

The function ceiling() returns the smallest integer value greater than or equal to its argument value. The appended bits (i.e., pad bits) are set to “zeros” and are subsequently scrambled with the rest of the bits in the DATA field.

Table 142—Number of data bits per symbol

Mode/Option	Option 1	Option 2	Option 3	Option 4
Mode 0	48	24	12	6
Mode 1	96	48	24	12
Mode 2	192	96	48	24

20.2.3.9 Scrambler and scrambler seeds

The input to the scrambler is the data bits followed by tail bits and then pad bits. The scrambler uses a PN9 sequence that is shown in Figure 123. The PN9 scrambler is initialized by one of four seeds. The seed to be used for the scrambler is indicated by two bits in the PHR, as shown in Table 143. The leftmost value of the scrambling seed is placed into the leftmost delay element in Figure 123.

Table 143—Initial seeds to be used for PN9 scrambler

MSB scrambler[a]	LSB scrambler[a]	Scrambling seed
0	0	TBD
1	0	TBD
0	1	TBD
1	1	TBD

[a]See 20.2.1.2.

The scrambled bits are found using an XOR operation of each of the input bits with the PN9 sequence:

$$\text{bit}_n = (\text{input bit}_n)\ \text{XOR}\ (\text{PN9}_n)$$

After scrambling, the tail bits are reset to all zeros.

20.2.3.10 Pulse Shaping

Pulse shaping is applied at the transmitter. The pulse shaping method is as needed to meet regulatory requirements in the band of operation.

