Project: IEEE P802.15 Working Group for Wireless Personal Area Networks(WPANs)

Submission Title: OFDM PHY Merge Proposal for TG4m

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Re: All proposals presented in July 2012 and contributions for merge efforts for OFDM PHY

Abstract: This contribution presents a merge proposal for the TG4m OFDM with the efforts from all OFDM proposers . The scope of this work does not include narrow band OFDM , which will be presented by another group.

Purpose: Final baseline document in OFDM area to 802.15m

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INTRODUCTION

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- Goal of this work
  - To specify key components and their parametric values for TG4m OFDM PHY baseline proposal.
- In this document, key parameters and features for TVWS OFDM PHY baseline are identified
  - By merging four proposals so far presented.
  - The merged text draft was uploaded: 15-12-0xxx-00
- Proposals considered to prepare this document are:
  1. 15-12-0332-03-004m-etri-ofdm-phy-proposal-for-tg4m, ETRI OFDM proposal,
  2. 15-12-0336-02-004m-full-proposal-on-phy-and-mac-for-ieee-802-15-4m-by-nict, NICT proposal,
  3. 15-12-0338-00-004m-phy-proposal-for-tg4m, Silver Spring Networks PHY proposal, and
  4. 15-12-0340-01-004m-phy-proposal-for-the-ieee-802-15-4m-by-niigata-univ, Niigata University PHY proposal.

REQUIREMENTS FOR TVWS

- Operations in TVWS frequency bands under regulatory constraints:
  - Meet at least one, and as many as practical, TV White Space regulatory requirements.
- Data rate of typically 40Kbps to 2Mbps & optionally 10Mbps
- Optimal & power efficient device command & control applications
- Operating range of at least 1Km
- At least 1000 direct neighboring devices operated
- Opportunistic coexistence with primary users (TV broadcasting): not interfere with other primary users

15-12-0332-03-004m-etri-ofdm-phy-proposal-for-tg4m

SUMMARY OF MERGED OFDM PROPOSAL

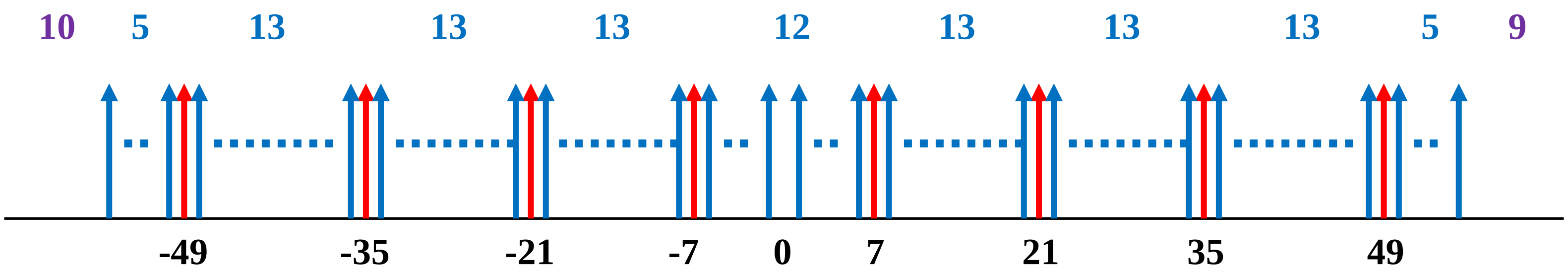
KEY PARAMETERS AND DATA RATES

Description	Mandatory mode	Optional mode (4 times overclock mode)
Nominal bandwidth (kHz)	1064.5	4258
Channel spacing (kHz)	1250	4*1250
Subcarrier spacing (kHz)	1250/128	4*1250/128
DFT Size	128	128
Number of pilot tones	8	8
Number of data tones	100	100
BPSK ½ rate	390.625: MCS0 Mode	1562.5: MCS3 Mode
QPSK ½ rate	781.250: MCS1 Mode	3125: MCS4 Mode
16-QAM ½ rate	1562.5: MCS2 Mode	6250: MCS5 Mode

* Baseline for narrowband OFDM PHY for 400kHz bandwidth is being prepared and will be presented by another group led by Harada San (NICT).

PILOT AND NULL TONE PATTERN

- 128 IFFT: (**100 data** + **8 pilot** + **19 guard** + **1 DC**) tones



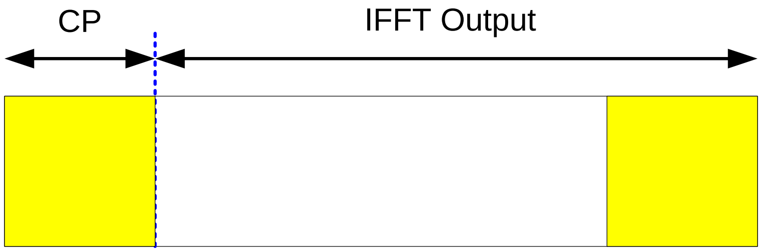
  - The data carried on the pilot tones shall be determined by a pseudo-noise sequence PN9 with the seed "111111111".

Mapping from PN9 sequence to pilot BPSK symbols

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

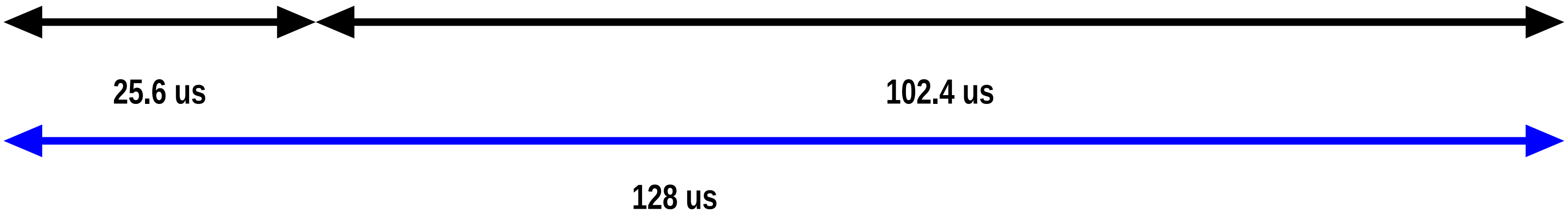
OFDM SYMBOL STRUCTURE

- Cyclic prefix (CP)
  - 1/4 of the base symbol



- Structure of OFDM Symbol
  - Except for STF and LTF

CP	Base symbol
$C_{96} \sim C_{127}$	$C_0 \sim C_{127}$



OFDM PPDU FORMAT

Number of OFDM symbols					
Variable (1 – 4)	2	1	Variable	6 bit	Variable
STF	LTF	PHR	PSDU	TAIL	PAD
SHR		PHY Header	PHY payload		

$\sqrt{2}j$

STF OF OFDM PPDU (1)

- Frequency domain STF

Tone #	**-64** **-48** **-40** **-38**
Value	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{-\sqrt{2}-\sqrt{2}j}$ 0 0
Tone #	**-37** **-32** **-24** **-16** **-14**
Value	0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{-\sqrt{2}-\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{-\sqrt{2}-\sqrt{2}j}$ 0 0
Tone #	**-13** **-8** **0** **8** **14**
Value	0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 $\boxed{-\sqrt{2}-\sqrt{2}j}$ 0 0 0 0 0 0
Tone #	**15** **16** **24** **32** **39**
Value	0 $\boxed{-\sqrt{2}-\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0
Tone #	**40** **48** **63**
Value	$\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 $\boxed{\sqrt{2}+\sqrt{2}j}$ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

$\sqrt{2}j$

STF OF OFDM PPDU (2)

- Time domain STF generation
  - Given a sequence of 128 samples f(n), indexed by n=0, ..., 127, the discrete Fourier transform (DFT) is defined as F(k), where k=0, ..., 127:

$$F(k) = \frac{1}{\sqrt{128}} \sum_{n=0}^{127} f(n) e^{-j2\pi kn/128}$$

  - The sequence f(n) can be calculated from F(k) using the inverse discrete Fourier transform (IDFT), where the k values numbered from 0 to 63 correspond to tones numbered from 0 to 63 and the k values numbered from 64 to 127 correspond to tones numbered from -64 to -1, respectively:

$$f(n) = \frac{1}{\sqrt{128}} \sum_{k=0}^{127} F(k) e^{j2\pi nk/128}$$

  - The time domain STF is obtained as follows:

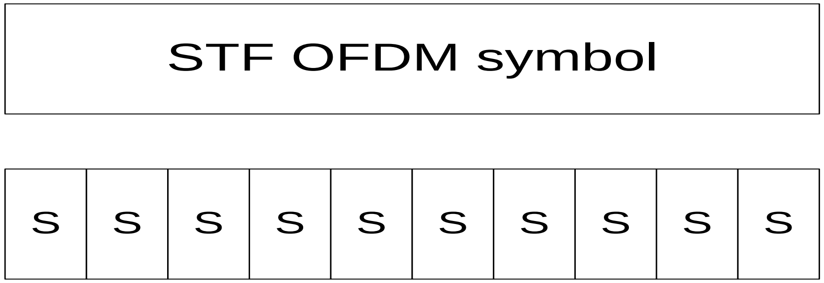
$$STF_{time} = IDFT(STF_{freq})$$

  - The CP is then prepended to the OFDM symbol.

STF OF OFDM PPDU (3)

- Time domain STF repetition
  - The STF is repeated eight times per STF symbol and the CP is also 1/4 symbol. Therefore, there are **10 repetitions of 1/8 STF symbol in each STF OFDM symbol**. The number of STF OFDM symbols varies from 1 to 4.

Each "s" represents one time-domain repetition of a subsequence of TVWS-OFDM.



- STF power boosting
  - Power boosting shall be applied to the STF OFDM symbols in order to aid preamble detection, The boost should be a multiplication by TBD.

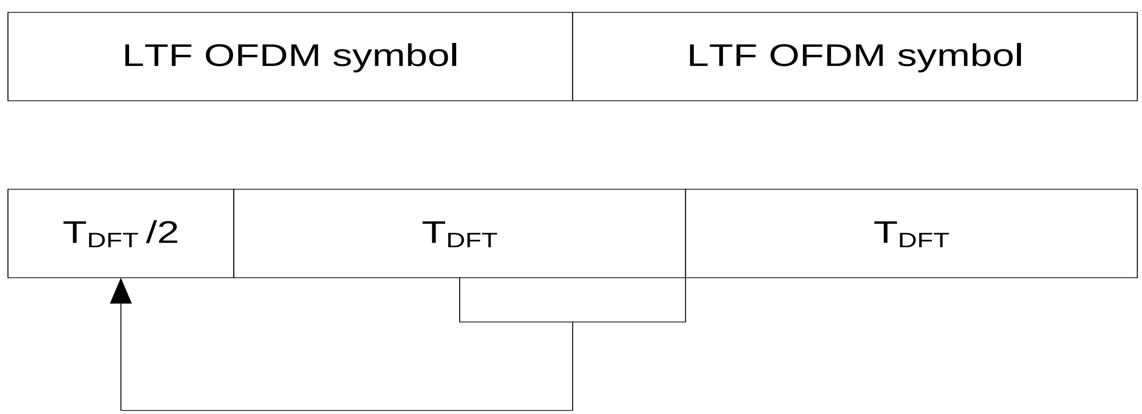
LTF OF OFDM PPDU

- Frequency domain LTF: TBD

- Time domain LTF generation
  - The time domain LTF is obtained as follows:

    $$LTF_{time} = IDFT(LTF_{freq})$$

  - A 1/2 symbol CP is prepended to two consecutive copies of the base symbol.
    - T_{DFT} is the duration of the base symbol.



PHY HEADER FIELDS (PHR) (1)

Bit string index	0-5	6-7	8-18	19-27	28-43	44-49
Bit mapping	R_5-R_0	RA_1-RA_0	L_{10}-L_0	S_8-S_0	H_{15}-H_0	T_5-T_0
Field name	Reserved	Rate	Frame Length	Scrambling seed	HCS	Tail

- The PHR occupies one OFDM symbol.
- The PHR shall be transmitted using the lowest supported modulation and coding scheme (MCS) level, MCS0 mode.
- It is sent directly to the convolutional encoder without being scrambled.

- Rate field (RA_1-RA_0):
  - Data rate of the payload
  - 00: MCS0 or MCS3, 01: MCS1 or MCS4, 10: MCS2 or MCS5
- Scrambler Seed field (S_8–S_0):
  - The scrambling seed used to scramble the PHY payload (PSDU) of that packet

PHY HEADER FIELDS (PHR) (2)

- Frame Length field (L_{10}–L_0):
  - Total number of octets contained in the PSDU (prior to FEC encoding)
- Header Check Sequence (HCS) field (H_{15}-H_0)
  - 16-bit CRC taken over the PHY header (PHR) fields.
  - The HCS shall be computed using the first 28 bits of the PHR.
  - The HCS shall be calculated using the polynomial, $G_{16}(x)=x^{16}+x^{12}+x^5+1$.
- Tail bit field (T_5-T_0)
  - Consists of all zeros
  - For Viterbi decoder flushing
- Reserved field (R_5-R_0)
  - Set to zero upon transmission
  - Shall be ignored upon reception.

TAIL BIT FIELD (TAIL)

- Tail bit field (T_5–T_0)
  - 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 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.

PAD BIT FIELD (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.
- 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 PHR):

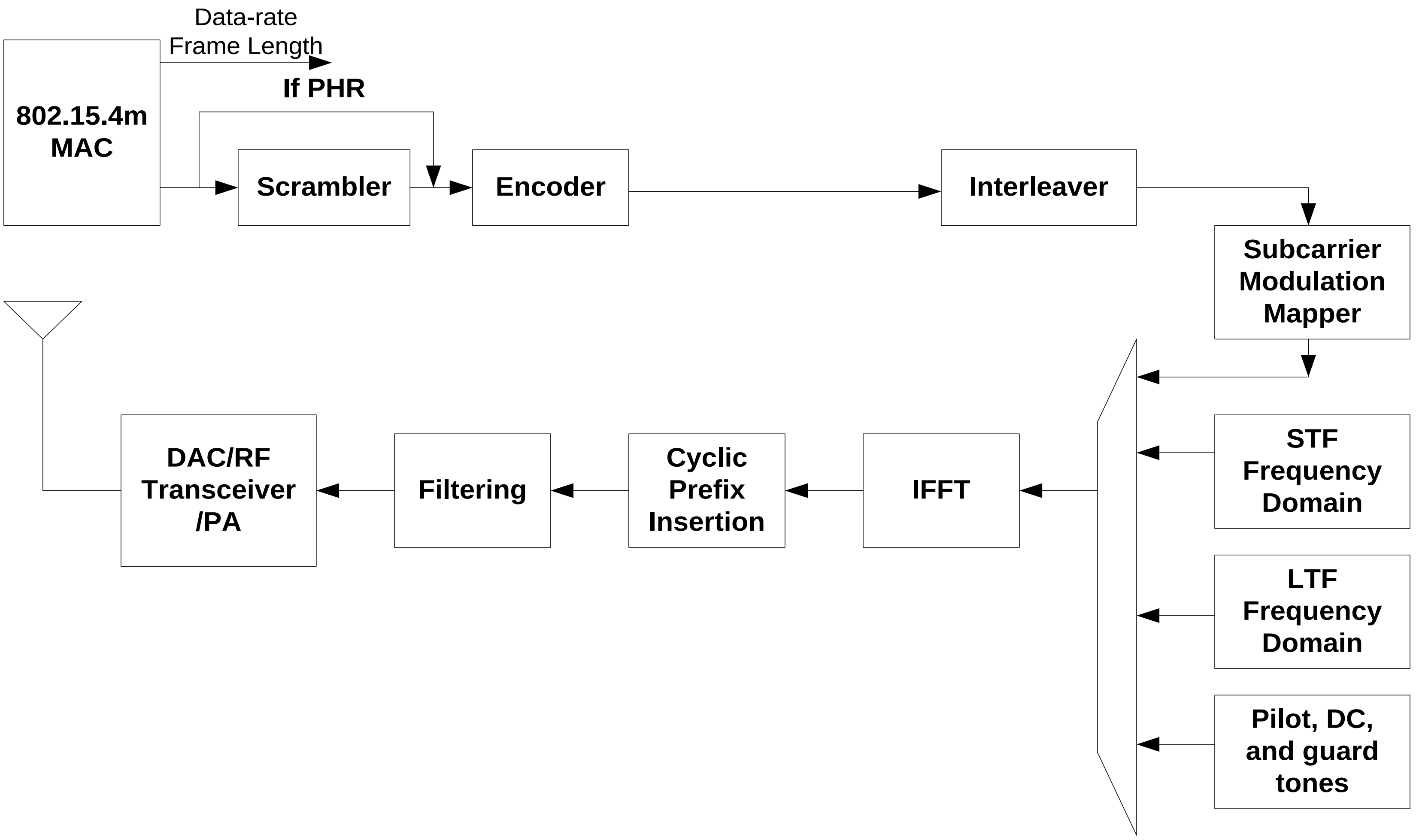
  N_{SYM} = ceiling [(8 x LENGTH + 6)/ N_{dbps}] *

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

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

* The function ceiling() returns the smallest integer value greater than or equal to its argument value.

REFERENCE MODULATOR DIAGRAM



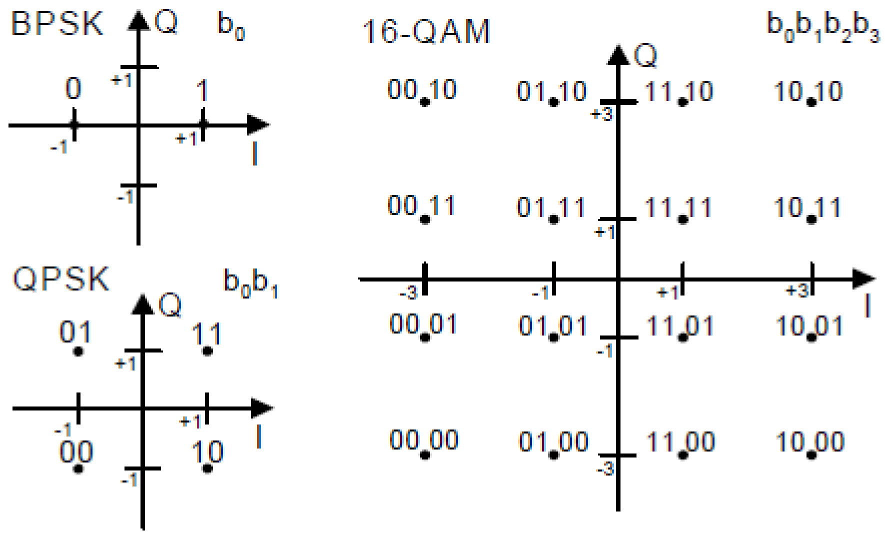
BIT-TO-SYMBOL MAPPING

- Bit-to-symbol mapping for BPSK, QPSK, and 16-QAM

The output values, d, are formed by multiplying the resulting (I + jQ) value by a normalization factor KMOD:

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

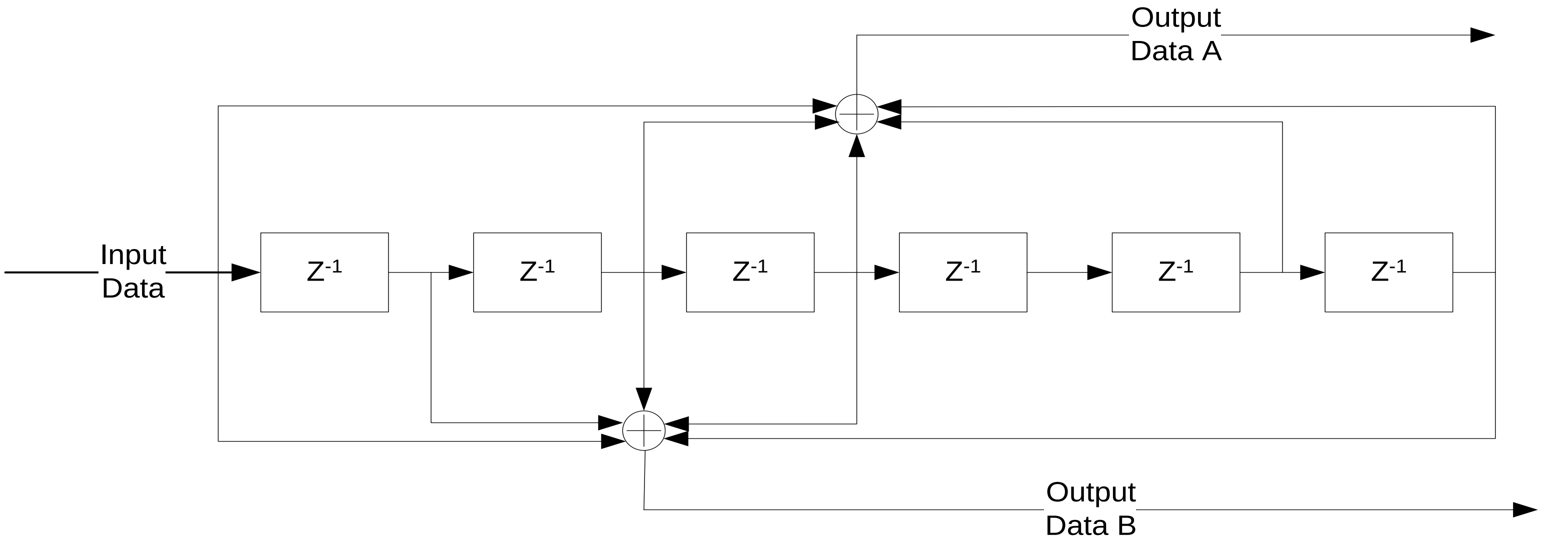
The normalization factor, K_{MOD}, depends on the base modulation mode, The purpose of the normalization factor is to achieve the same average power for all mappings.



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

FORWARD ERROR CORRECTION (FEC)

- The DATA field shall be coded with a convolutional encoder of coding rate R = 1/2.
- The convolutional encoder shall use the generator polynomials expressed in octal representation, $g_0=133_g$ and , $g_1=171_g$.



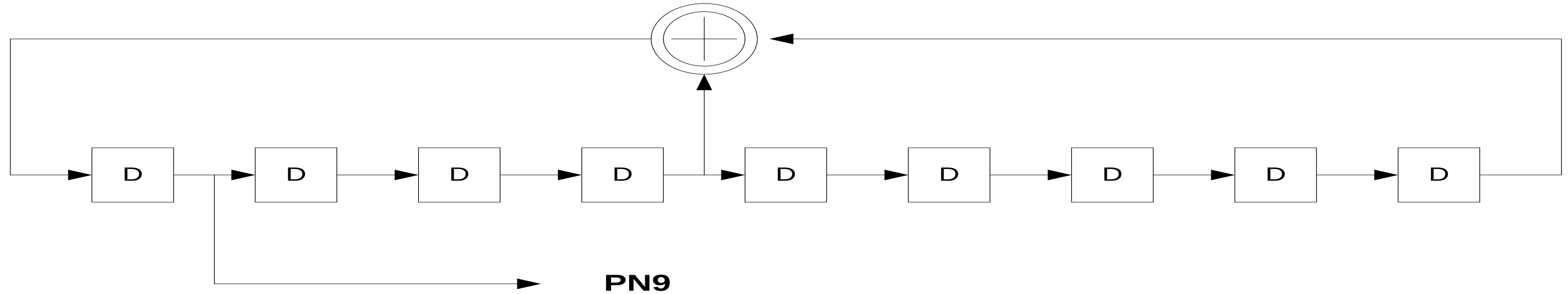
Convolutional Encoder: Rate ½, constraint length K=7
Octal generator polynomials [133, 171]

SCRAMBLER

- The input to the scrambler is the data bits followed by tail bits and then pad bits.
- The scrambler uses a PN9 sequence.
  - The PN9 scrambler is initialized by the scrambling seed specified by 9 bits in the PHR.
  - The PN9 generator shall be reinitialized to the seed after each packet (either transmit or receive).
  - 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.



PULSE SHAPING

- 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

CONCLUSION

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- For the baseline of TVWS OFDM PHY for 15.4m standard,
  - All four proposals so far presented are considered for merging.
  - All features and parameters which should be specified in the standard are identified through proposal merging work.

- As the result of this work,
  - The text draft of the merged OFDM PHY proposal was prepared and uploaded: 15-12-0xxx-00.
  - This text document will be utilized as a baseline for drafting 15.4m standard in this area.