IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)	
Title	TVWS-NB-OFDM Merged Proposal to TG4m	
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Re:	Submission in response to TG4m CFP for PHY amendment to IEEE 802.15.4	
Abstract	Text for the TVWS-NB-OFDM merged proposal to TG4m	
Purpose	TVWS-NB-OFDM merged proposal submission	
Notice		
Release		

20.2 TVWS-OFDM

20.3 TVWS-NB-OFDM PHY Specification

The TVWS narrow band orthogonal frequency division multiplexing (TVWS-NB-OFDM) PHY supports data rates ranging from 156 kb/s to 1638 kb/s. The subcarrier spacing is constant and is equal to 125/126 kHz. The mandatory symbol rate is 9.620 ksymbol/s, which corresponds to 1039.5 µs per symbol. This symbol is composed of a 1/32 duration cyclic prefix (31.5 µs) and a base symbol (1008 µs). Optional cyclic prefix, whose duration is 1/16 (63.0 µs) or 1/8 (126.0 µs), is supported for larger multipath delay. Channel aggregation is also optionally supported for data rate enhancement to attain over 18 Mbps.

20.3.1 PPDU format for TVWS-NB-OFDM PHY

The TVWS-NB-OFDM PPDU shall be formatted as illustrated in Figure 117. 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.

Definitions are provided in the frequency domain for the Short Training field (STF) in 20.3.1.1 and for the Long Training field (LTF) in 20.3.1.2. In each case, a normative set of operations is specified to transform the frequency domain fields to the time domain and to insert prescribed repetitions or cyclic prefixes of these time domain sequences.

							Variable length
SHR						PHR	PPDU
STF	STF	STF	STF	LTF	LTF		

Figure 117 PPDU format

20.3.1.1 Short Training field (STF)

Subclauses 20.3.1.1.1 through 20.3.1.1.4 describe the STF.

20.3.1.1.1 Time domain STF generation

The short training field sequence is generated based on Zadoff Chu Sequence with length N=96. H is a prime number H=19, k=0, 1, …, N-1. The short training field sequence S(k) in time domain can be calculated as below:

S(k)=(exp(j*H*π*k^2/N));

20.3.1.1.2 Time domain STF repetition

There are 4 repetitions of STF in the time domain as shown in the following Figure 118.

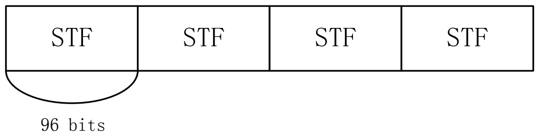

Figure 118 SFT format

Given a STF sequence, f(n), indexed by n=0, 1, 2, …, N_{ST}-1, where N_{ST} is Number of effective subcarriers It is the 4 repetition of S(k). It can be represented as

STF(n)=S(MOD(n, N)) for n=0, 1, …, 4*N-1

where N=96. MOD(n, N) is the modulo-N operation for any input n.

20.3.1.1.2 Frequency domain STF

The STF for the TVWS-NB-OFDM in frequency domain can be calculated from time domain STF sequence f(n) based on the discrete Fourier transform (DFT) and represented as F(m), where m=0, 1, …, N_{ST}-1.

$$F(m) = \frac{1}{\sqrt{N_{ST}}} \sum_{n=0}^{N_{ST}-1} f(n) e^{-j2\pi mn/(N_{ST}-1)}$$

where the k values numbered from 0 to N_{ST}/2-1 correspond to tones numbered from 0 to N_{ST}/2-1 and the k values numbered from N_{ST}/2 to N_{ST}-1 correspond to tones numbered from - N_{ST}/2 to -1, respectively.

Similarly, given frequency domain STF, the time domain STF can be generated as follows:

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

The CP is then prepended to the OFDM symbol.

20.3.1.1.4 STF normalization

The STF uses a lesser number of tones than the DATA field. Hence, normalization of the frequency domain STF is required to ensure that the STF power is the same as the rest of the packet. In order to have the same power as the DATA field, the normalization value is as follows:

$$\text{sqrt}(N_{active}/N_{stf})$$

where

Nactive is the number of used subcarriers in rest of the OFDM packet for the particular DFT option
Nstf is the number of subcarriers used in the STF.

20.3.1.2 Long Training filed (LTF)

Subclauses 20.3.1.2.1 through 20.3.1.2.4 describe the LTF.

20.3.1.2.1 Time domain LTF generation

Long Training Sequence is generated based on Zadoff Chu Sequence with length N=192. H is a prime number, H=53, k=0, 1, …, N-1. The long training field sequence L in time domain can be calculated as below:

$$L(k)=\exp(j*H*\pi*k^2/N)$$

20.3.1.2.2 Time domain LTF repetition

The LTF shall be repeated for 2 times in the time domain as shown in Figure 119.

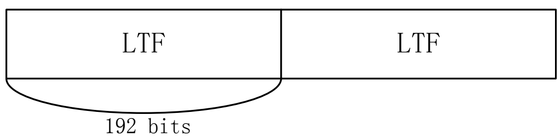

Figure 119 LTF format

Given a LTF sequence, f(n), indexed by n=0, 1, 2, …, N_{ST}-1. It is the 2 repetition of L(k). It can be represented as

$$f(n)=L(MOD(n, N)), \quad n=0, 1, \ldots, 2*N-1$$

where N=192. MOD(n, N) is the modulo-N operation for any input n.

20.3.1.2.3 Frequency domain LTF

The LTF for the TVWS-NB-OFDM in frequency domain can be calculated from time domain LTF sequence f(n) based on the discrete Fourier transform (DFT) and represented as F(m), where m=0, 1, …, N_{ST}-1.

$$F(m) = \frac{1}{\sqrt{N_{ST}}} \sum_{n=0}^{N_{ST}-1} f(n) e^{-j2\pi mn/(N_{ST}-1)}$$

where the k values numbered from 0 to $N_{ST}/2-1$ correspond to tones numbered from 0 to $N_{ST}/2-1$ and the k values numbered from $N_{ST}/2$ to $N_{ST}-1$ correspond to tones numbered from - $N_{ST}/2$ to -1, respectively.

Similarly, given frequency domain LTF, the time domain LTF can be generated as follows:

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

The CP is then prepended to the OFDM symbol.

20.3.1.2.4 LTF normalization

The LTF uses a lesser number of tones than the DATA field. Hence, normalization of the frequency domain LTF is required to ensure that the LTF power is the same as the rest of the packet. In order to have the same power as the DATA field, the normalization value is as follows:

sqrt(*Nactive/Nltf*)

where

Nactive is the number of used subcarriers in rest of the OFDM packet for the particular DFT option. *Nltf* is the number of subcarriers used in the LTF.

20.3.1.3 PHR

Table 1 shows PHR format, which is composed of 40 bits for controlling PHY.

Table 1 PHR format

Bit String Index	0-3	4-7	8-9	10-20	21-24	25	26-33	34-39
Bit Mapping	R_3-R_0	M_3-M_0	F_1-F_0	L_{10}-L_0	A_3-A_0	R	H_7-H_0	T_5-T_0
Field Name	Reserved	Modulation Type	FEC Type	Frame length	Channel aggregation	Reserved bit	HCS	Tail

20.3.1.4 PSDU field

TBD

20.3.2 System parameters for TVBS-NB-OFDM

Table 2 shows system parameters for TVBS-NB-OFDM.

Table 2 System parameters

	Mode #1	Mode #2
Nominal bandwidth	380.95 kHz	
Subcarrier spacing (ΔF)	0.99206 kHz (=125 kHz/126)	
Number of subcarriers, total (N_{ST})	384	
Number of pilot subcarriers per (N_{SP})	32	
Number of data subcarriers per (N_{SD})	352	
Effective symbol duration (T_{FFT})	1008 μs	
Guard interval duration (T_{GF})	1/32 (31.5 μs) as mandatory 1/16 (63.0 μs) as an option 1/8 (126.0 μs) as an option	
Symbol interval(T_{SYM})	1039.5 μs as a mandatory 1071.0 as an option 1134.0 as an option (T_{FFT}+T_{GF})	
STF duration (T_{SHR})	TBD	
LTF duration (T_{SHR})	TBD	

20.3.3 Modulation and coding parameters for TVBS-NB-OFDM

The modulation and coding schemes with supported data rates for TVBS-NB-OFDM and corresponding MCS-related parameters are shown in the Table 3.

Table 3 Supported data rates and modulation and coding related parameters

MCS Index	**Modulation**	**CC coding rate**	**Data Rate (Kbps)**	**CC Coded bits per subcarrier (N_{BPSC})**	**CC Coded bits per OFDM symbol (N_{CPBS})**	**RS encoded Data bits per OFDM symbol (N_{DBPS})**
MCS0	BPSK	1/2	156	1	352	176

MCS1	BPSK	3/4	234	1	352	264
MCS2	QPSK	1/2	312	2	704	352
MCS3	QPSK	3/4	468	2	704	528
MCS4	16-QAM	1/2	624	2	1408	704
MCS5	16-QAM	3/4	936	4	1408	1056
MCS6	64-QAM	2/3	1248	4	2112	1408
MCS7	64-QAM	3/4	1404	6	2112	1584
MCS8	64-QAM	7/8	1638	6	2112	1848

20.3.3.1 Reference modulator diagram

TBD.

20.3.3.2 Forward error correction (FEC)

Subclauses 20.3.3.2.1 through 20.3.3.2.3 describe outer encoding, inner encoding, and pad bit insertion.

20.3.3.2.1 Outer encoding

Reed Solomon (RS) encoding (204, 188) shall be used for outer encode. The RS encoding is applied with a RS (255, 239) coder as a shorten code. 51 byte 00 HEX shall be subsequently to 188 byte input data before encoding, and 51 byte data shall be removed after encoding. A root of the primitive polynomial for the RS encoder is

$p(x) = 1 + x^2 + x^3 + x^4 + x^8$.

Polynomial generator g(x) shall be following equation.

$G(x) = (x - \lambda^0)\,(x - \lambda^1)\,(x - \lambda^2)\,(x - \lambda^3)\ldots(x - \lambda^{15})$,

where λ is 02Hex.

20.3.3.2.2 Inner encoding

A recursive and systematic convolutional encoder of coding rate R = 1/2, 2/3, 3/4, 7/8 encodes the RS encoded data bits, 6 tail bits, and pad bits. The convolutional encoder shall use the generator polynomials g_1 = 171 and g_1 = 133, of rate R = 1/2, with feedback connection of g_0 as shown in Figure 114.

Puncturing enables higher data rate by omitting some of the encoded bits in the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy “zero” metric into the convolutional decoder on the receive side in place of the omitted bits. The puncturing patterns are illustrated in Figure 121.

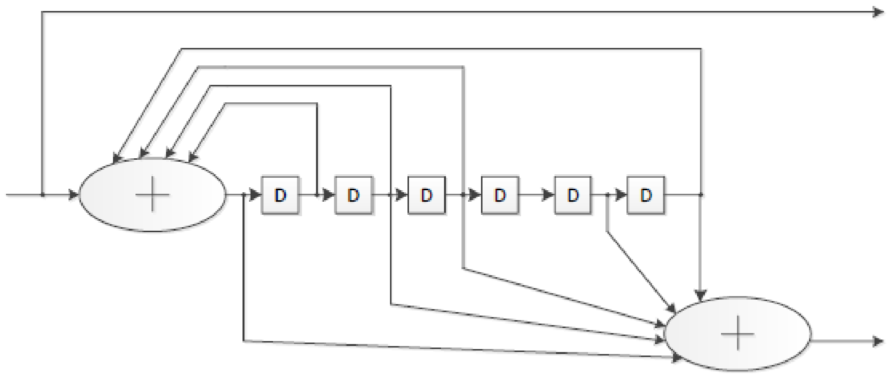

Figure 120. Recursive and systematic convolution encoder

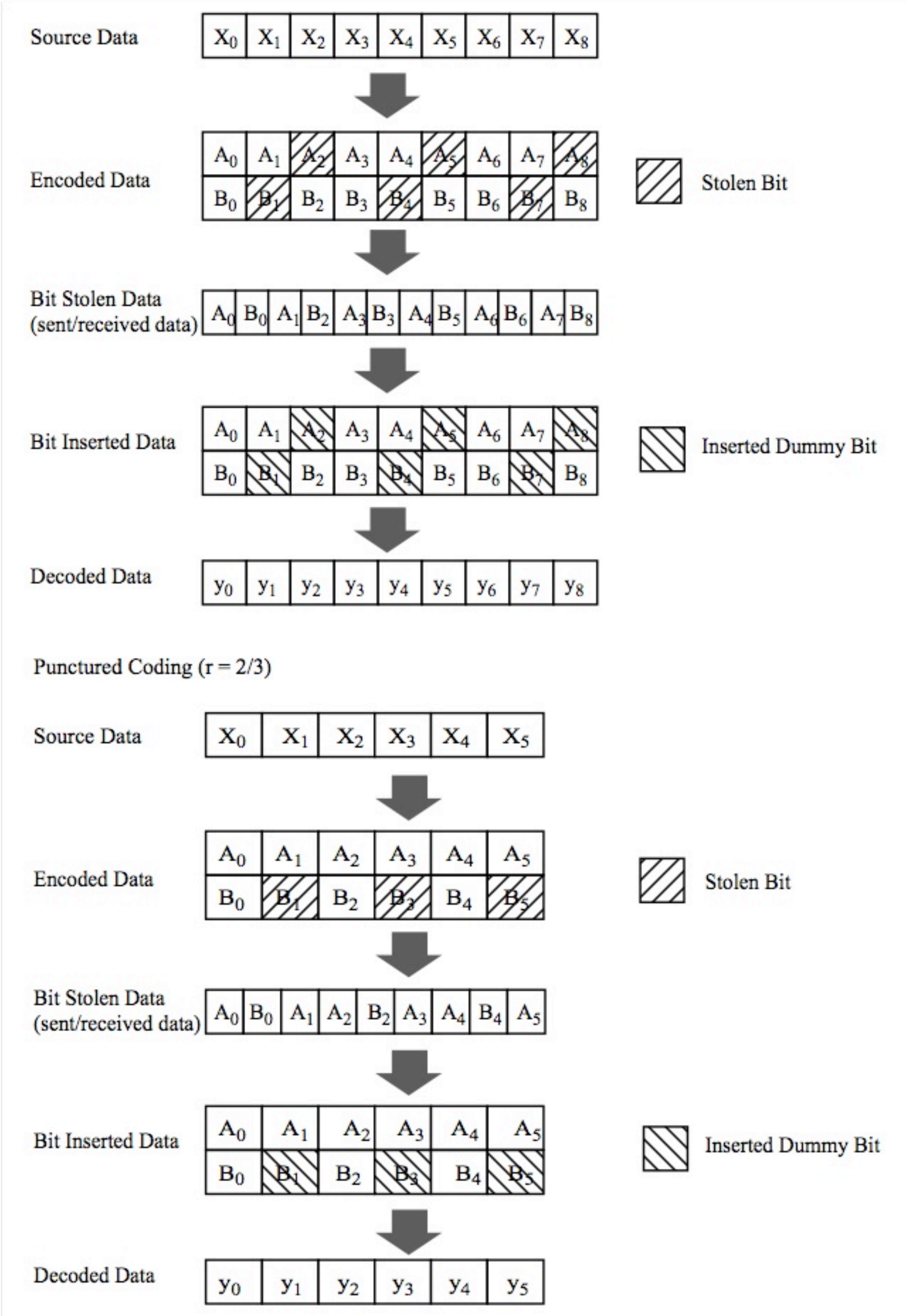

Figure 121. Puncturing pattern

20.3.3.2.3 Pad bit Insertion

TBD

20.3.3.3 Bit interleaving and mapping

20.3.3.3.1 Bit interleaving

All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of encode bits in a single OFDM symbol, N_{CBPS}. The interleaver is defined by a two-step permutation.

The first permutation is defined by the rule $i = (N_{CBPS}/44)\ (k \bmod 44) + \text{floor}(k/44)\quad k = 0,1,\ldots, N_{CBPS} - 1$

Here, k shall be the index of the coded bit before the first permutation; i shall be the index after the first and before the second permutation, and j shall be the index after the second permutation, just prior to mapping. The function floor (.) denotes the largest integer not exceeding the parameter. The second permutation is defined by the rule

$$j = s \cdot \text{floor}(i/s) + (i + N_{CBPS} - \text{floor}(44 \cdot i/ N_{CBPS})) \bmod s \qquad i = 0,1,\ldots N_{CBPS} - 1$$

The value of s is determined by the number of coded bits per subcarrier, N_{BPSC}, according to

$$s = \max(N_{BPSC}/2,1)$$

The deinterleaver, which performs the inverse relation, is also defined by two corresponding permutations.

20.3.3.3.2 Subcarrier Mapping

The OFDM subcarriers shall be modulated by using BPSK, QPSK, 16-QAM, or 64-QAM modulation. The encoded and interleaved binary serial input data has $\mathbf{N_{BPSC}}$ bits per symbol and mapped onto I- and Q-channel data. The conversion shall be performed according to Gray-coded constellation mappings, illustrated in Figure 122, with the input bit, b0, being the earliest in the stream. The output values, d, are formed by multiplying the resulting (I+jQ) value by a normalization factor K_{MOD}, as described in the following Equation:

$$d = (\mathrm{I} + j\mathrm{Q}) \times \mathrm{K}_{MOD}$$

The normalization factor, K_{MOD}, depends on the base modulation mode, as prescribed in the following table.

Table 4 Modulation-dependent normalization factor K_{MOD}

Modulation	**K_{MOD}**
BPSK	1
QPSK	$1/\sqrt{2}$
16-QAM	$1/\sqrt{10}$
64-QAM	$1/\sqrt{42}$

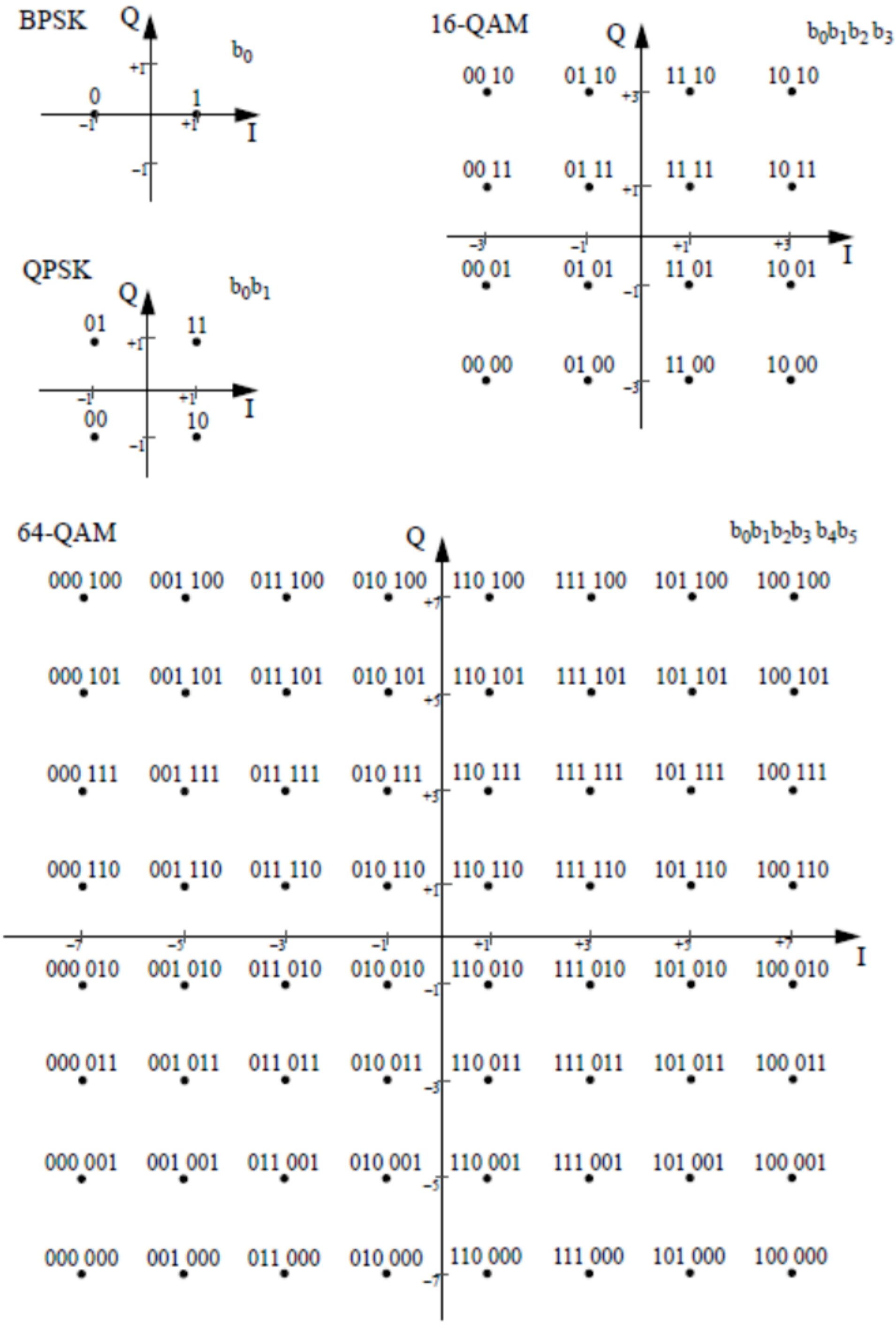

Fig. 122. BPSK, QPSK, 16-QAM, and 64-QAM constellation mapping

20.3.3.4 Frequency Interleaving

The frequency interleaving follows the following rule. The index of input bit before interleaving and J(k) represents the index of output bit after interleaving shall be represented as:

J=Z(i) k

= 0,1,..., 352– 1

where Z=[63 14 12 286 337 221 227 93 57 47 121 176 299 173 236 54 165 188 126 83 6 46 174 259 136 183 142 274 127 265 287 89 234 62 250 311 180 156 58 124 209 15 228 101 312 206 80 185 186 329 78 116 278 113 21 200 179 144 153 216 205 140 235 193 310 184 82 130 257 315 102 44 98 325 143 158 91 215 103 30 304 262 32 23 53 306 302 294 178 117 297 86 197 192 115 59 199 17 168 146 120 246 114 296 194 233 18 109 284 247 65 238 190 129 303 321 240 336 40 348 352 74 159 277 244 100 39 288 4 331 154 316 118 290 214 211 150 338 340 152 242 322 218 31 335 162 323 50 177 13 347 61 29 230 266 289 226 60 182 171 320 342 87 252 134 345 110 45 269 258 324 56 318 122 261 276 191 20 64 19 249 10 241 212 151 231 333 232 72 256 351 84 88 155 219 139 270 349 131 161 279 217 237 309 224 255 26 99 301 202 138 220 37 326 125 67 170 22 36 108 51 107 334 327 263 253 272 264 137 1 207 160 123 189 7 285 97 27 201 198 187 346 341 350 104 85 229 213 3 68 319 2 75 343 167 195 34 69 268 112 119 141 196 106 203 292 260 24 172 66 282 25 166 9 95 223 332 35 239 267 90 81 254 164 281 248 5 291 280 55 79 181 73 317 283 132 208 344 307 222 133 8 149 300 169 225 49 48 314 76 105 71 148 41 111 70 147 38 175 42 33 305 308 313 16 273 135 243 204 210 163 298 328 11 94 43 251 157 339 293 145 295 330 128 271 77 96 92 245 275 28 52].

Figure 123 shows the distribution of interleaving for input bits before interleaving against output bits after interleaving.

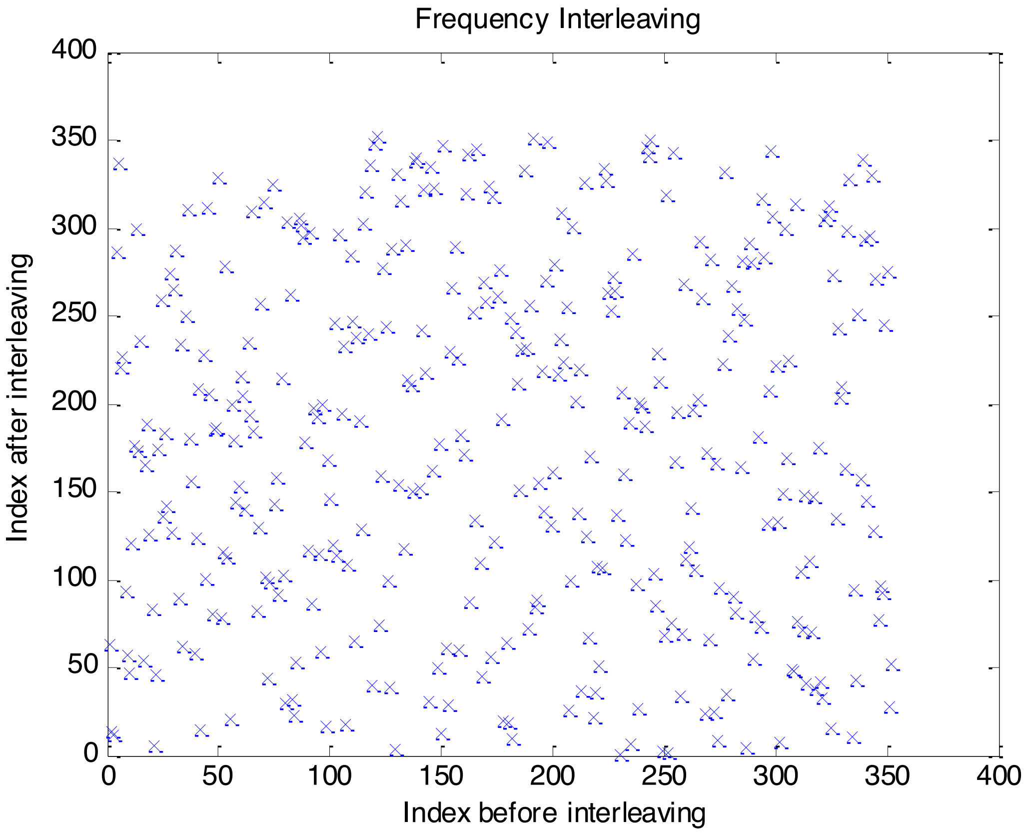

Figure 123 Illustration of frequency interleaving mapping.

20.3.3.6 Pilot tones/null tones

Figure 124 shows the pilot symbol pattern of TVWS-NB-OFDM. The pilot symbol is inserted into a frame once every 12 carriers in the frequency direction, and once every 4 symbols in the symbol direction, as shown in the figure.

Frequency

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	…	…	…	383
0	Pilot												Pilot		…	…	…	
1				Pilot											…	…	…	

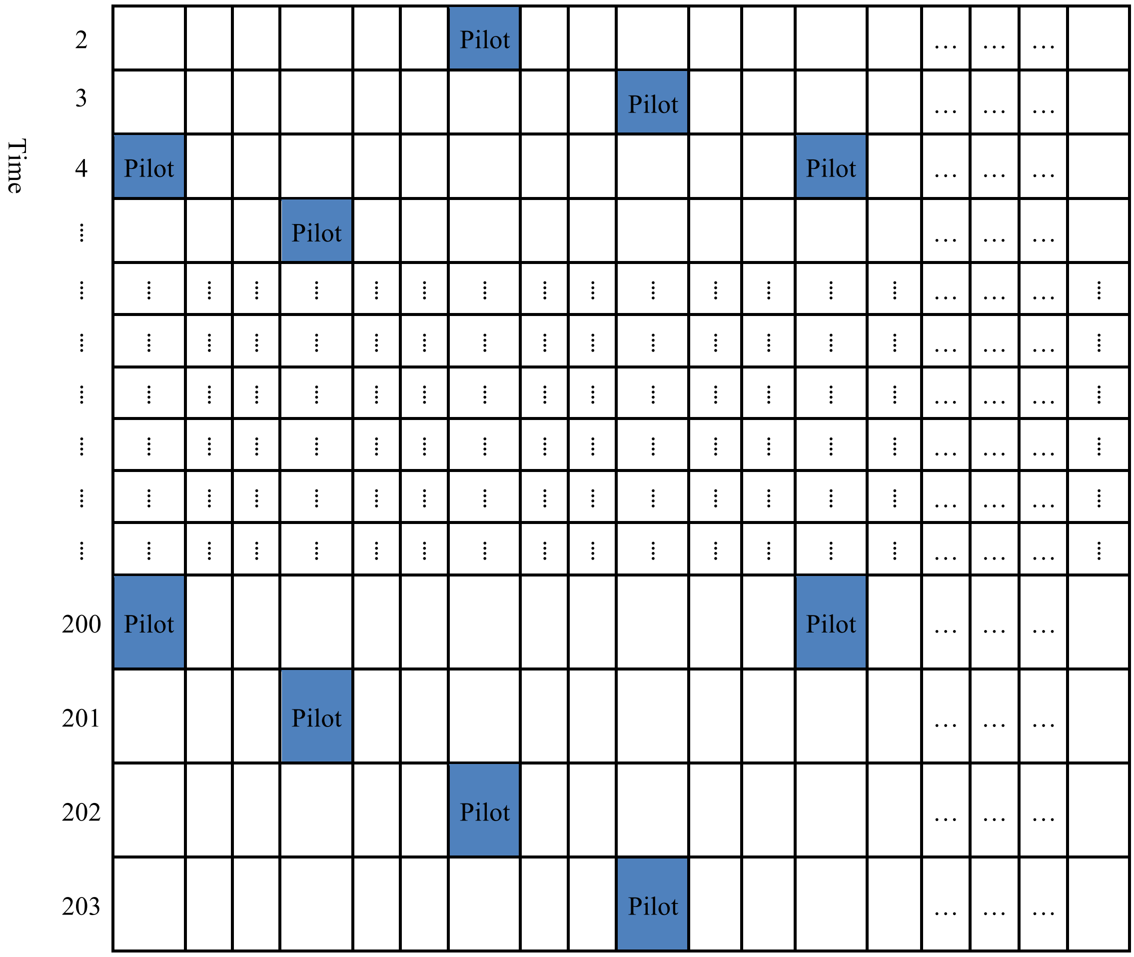

Figure 124 Pattern of pilot subcarriers allocated in OFDM symbol.

20.3.3.5 Cyclic prefix

A cyclic prefix shall be prepended to each OFDM symbol. By default, the duration of the cyclic prefix (31.5µs) shall be 1/32 of the OFDM symbol (1008µs). Optionally, the cyclic prefix of duration 63µs which is 1/16 of the OFDM symbol, or the cyclic prefix of duration 126µs which is 1/8 of the OFDM symbol or can be selected.

20.3.4 Channel aggregation

Table 5 shows channel aggregation parameters. For several regional supports, Modes 1 or 2, i.e, either of bandwidths, 6 MHz or 8 MHz, shall be supported. According to the channel bandwidth, maximal aggregated channel depends on the available channel bandwidth.

Table 5 Channel aggregation parameters

Maximal bandwidth on channel aggregation use	6 MHz	8 MHz
Number of maximal aggregated channels	11	16
Channel spacing	400 kHz	
Guard band for each side of channel	800 Hz	

20.3.5 TVWS-NB-OFDM PHY RF requirement

20.3.5.1 Operating frequency range

The TVWS-NB-OFDM PHY operates in the following bands:

TBD

20.3.5.2 Transmit power spectral density (PSD) mask

The TVWS-NB -OFDM transmit PSD mask shall conform with local regulations.

20.3.5.3 Pulse shaping

TBD