Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Editorial changes to incorporate clause 8.3.2 and B.1.1.1 into 8.3.3 and 8.3.4.2.**
Date Submitted	**2002-05-14**
Source(s)	Brian Eidson & Nico van Waes (editors)
Re:	802.16-02/22
Abstract	Editorial changes to incorporate clause 8.3.2 and B.1.1.1 into 8.3.3 and 8.3.4.2. The changes, as marked in blue, are presuming deletion clause 8.3.2 and B.1.1.1. Doing this makes sense, as it makes the document more readable, while the communality, which was the initial intent of this joint clause, has been reasonably achieved.
Purpose	Incorporation of presented changes into 802.16a/D4
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8.3.3 WirelessMAN-SC2 PHY Layer

The WirelessMAN-SC2 PHY uses single carrier technology to extend WirelessMAN operation to the 2-11 GHz frequency bands (per clause 1.2.4) and NLOS propagation conditions. Elements within this PHY include:

- TDD and FDD support options.
- TDMA uplink.
- Time Division Multiplexed (TDM) DL.
- Block adaptive modulation and FEC coding for both UL and DL.
- Framing elements that enable improved equalization and channel estimation performance over NLOS and extended delay spread channels.
- Symbol-unit granularity in packet sizes.
- Concatenated FEC using Reed Solomon and Pragmatic TCM with optional interleaving.
- FEC option using Block Turbo Codes.
- No-FEC option using ARQ for error control.
- Alamouti transmit diversity option.
- Parameter settings and MAC/PHY messages that facilitate optional AAS implementations.

8.3.3.1 Transmit Processing

Figure 169 illustrates the steps involved in transmit processing. Source data shall first be randomized, and then FEC encoded and mapped to QAM symbols. The QAM symbols shall next be framed within a message burst, which typically introduces additional framing symbols. The burst symbols shall then multiplexed into a duplex frame, which may contain multiple bursts. The I and Q symbols components shall be injected into pulse shaping filters, quadrature modulated up to a carrier frequency, and amplified with power control so that the proper output power is transmitted.

Except where ~~explicitly~~ otherwise indicated, transmit processing is the same for both the UL and DL.

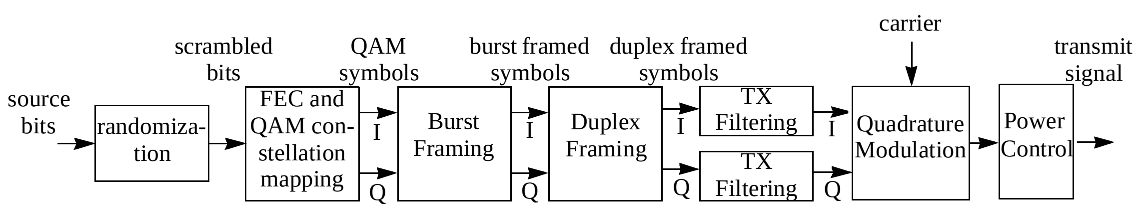

Figure 169—Transmit Processing

8.3.3.1.1 Source Bit Randomization

Source bits, i.e., the original information bits prior to FEC encoding, shall be randomized during transmissions.

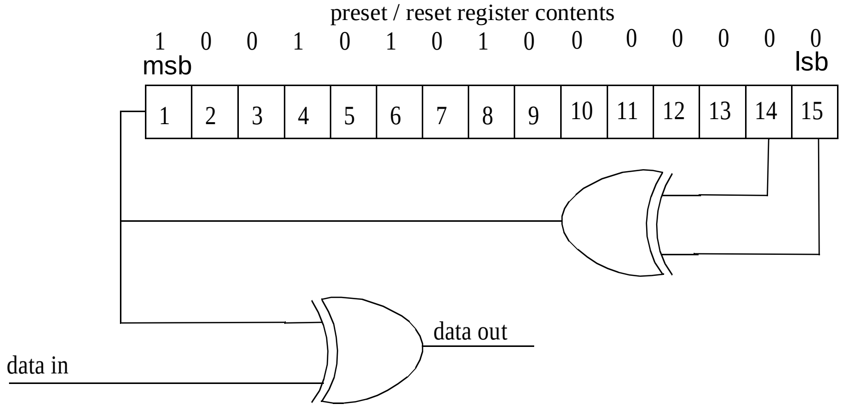

Figure 170—Randomizer for Energy Dispersal

As Figure 170 illustrates, source bit randomization shall be performed by modulo-2 addition (XORing) source (information) data with the output of Linear-Feedback Shift Register (LFSR) possessing characteristic polynomial $1 + X^{14} + X^{15}$. The LFSR shall be preset at the beginning of each burst to the value 100101010000000, and shall be clocked once per processed bit.

Note that only source bits are randomized. This includes source payloads, plus unencoded null (zero) bits that may be used to fill empty payload segments. Elements that are not a part of the source data, such as framing elements, pilot symbols, and parity bits generated by the FEC, shall not be randomized. Null (zero) bits used to complete a QAM symbol (when an allocation of does not fill an entire QAM symbol) shall also not be scrambled.

8.3.3.1.2 FEC

Broadcast messages shall use QPSK and the concatenated FEC of clause 8.3.3.1.2.1 with a rate 1/2 convolutional inner code. Adaptive modulation and the concatenated FEC of clause 8.3.3.1.2.1 shall be supported for non-broadcast messages. The support of BTC (clause 8.3.3.1.2.3) as FEC as well as omitting the FEC and relying solely on ARQ for error control (clause 8.3.3.1.2.2) is optional for non-broadcast messages.

8.3.3.1.2.1 Concatenated FEC

The concatenated FEC is based on the serial concatenation of a Reed-Solomon outer code and a rate-compatible TCM inner code. Byte interleaving between the outer and inner encoders is optional. Figure 171 illustrates the flow between blocks used by a concatenated FEC encoder.

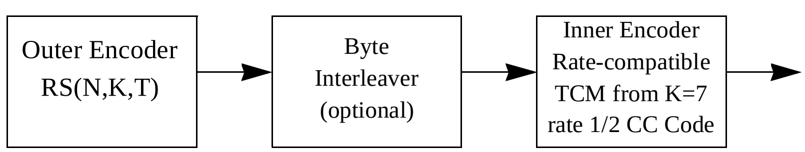

Figure 171—Concatenated FEC encoder blocks

8.3.3.1.2.1.1 Outer Code

The outer code consists of a Reed Solomon code.

This Reed-Solomon code shall be derived from a systematic RS (*N=255*, *K=239*, *T=8*) code using GF(2^8). The following polynomials are used for the systematic code:

Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots(x+\lambda^{2T-1}), \lambda = 02_{HEX}$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The bit/byte conversion shall be msb first.

This RS code may be shortened and punctured to enable variable block sizes and variable error-correction capability, where

- *N* number of overall bytes after encoding;
- *K*-number of data bytes before encoding;
- *T*- number of data bytes which can be corrected.

When a block is shortened to *K'* data bytes, the first *239-K'* bytes of the encoder block shall be zero. When a codeword is punctured to permit T' bytes to be corrected, only the first *2T'* of the total 16 codeword bytes shall be employed.

Support of shortening *K* of the base code to values smaller than 239 bytes while maintaining $R \equiv N - K = 16$ is mandatory. The capability to also puncture, such that $R \leq 16$, is optional, and is governed by the burst profile specification for *R*.

When a source allocation does not divide into an integer number of *K*-byte Reed-Solomon code words, the last (fractional) RS code word shall be shortened to a smaller *K* that accommodates the remainder bytes. All code words, including the shortened last codeword, shall use the *R* specified by the burst profile for the RS code words within that allocation.

8.3.3.1.2.1.2 [Optional] Block Interleaver

Support of interleaving between the inner and outer code is optional. Interleaving shall not be used in broadcast burst profiles. When interleaving is used, its usage and parameters shall be specified within a burst profile.

The interleaver changes the order of bytes from the Reed Solomon (RS) encoder output. A de-interleaver in the receiver restores the order of the bytes prior to RS decoding. The interleaver is a block interleaver, where a table is 'written', i.e., filled, a byte at a time row-wise (one row per RS code word) and 'read' a byte at a time column-wise. The number of rows, N_R, used by the interleaver is a burst parameter. So that bursts are not generated that exceed an intended receiver's capabilities, the largest N_R supported by a terminal is communicated during SS registration.

Operating parameters for an interleaver are summarized in Table 197.

Table 197—Operating parameters for block interleaver

Parameter	Description
C	Interleaver Width (number of columns), in bytes. Equivalent to the nominal Reed Solomon codeword length, N.
N_R	Maximum Interleaver Depth (number of rows), in bytes. Equals the maximum number of RS codewords that the block interleaver may store at any given time.
B	Nominal Interleaver Block Size, in bytes. B = C N_R.
P	RS-encoded Size of Packet, in bytes, to be interleaved.

When $P \le B$ and/or a RS codeword is shortened (so that not all of the columns within its row are filled), the interleaver shall be read column by column (taking a byte from each column), skipping empty elements within the table.

When $P > B$, data shall be parcelled into sub-blocks, and interleaving performed within each of the sub-blocks. The depth of these sub-blocks shall be chosen such that all sub-blocks have approximately the same depth (number of rows) using the following calculations:

Total RS codewords in packet: $T = \left\lceil \frac{P}{C} \right\rceil$

Number of sub-blocks: $S = \left\lceil \frac{P}{B} \right\rceil$

Interleaver depth of longest sub-blocks: $C_{max} = \left\lceil \frac{T}{S} \right\rceil$

Number of blocks with depth C_{max}: $Q_{C_{max}} = T - S(C_{max} - 1)$

Number of blocks with depth $C_{min} = C_{max} - 1$: $Q_{C_{min}} = S - Q_{C_{max}}$.

The first $Q_{C_{max}}$ sub-blocks within a packet shall use a (dynamic) interleaver depth C_{max}, and the remainder of the sub-blocks shall use an interleaver depth $C_{min} = C_{max} - 1$.

8.3.3.1.2.1.3 Inner Code

The inner code is a rate-compatible pragmatic TCM code [B31], [B32] derived from a rate 1/2 constraint length K=7, binary convolutional code.

The encoder for the rate 1/2 binary code shall use the following polynomials to generate its two code bit outputs, denoted X and Y:

$$\begin{aligned} G_1 &= 171_{OCT} \qquad For\ X \\ G_2 &= 133_{OCT} \qquad For\ Y \end{aligned} \tag{1}$$

A binary encoder that implements this rate 1/2 code is depicted in Figure 172.

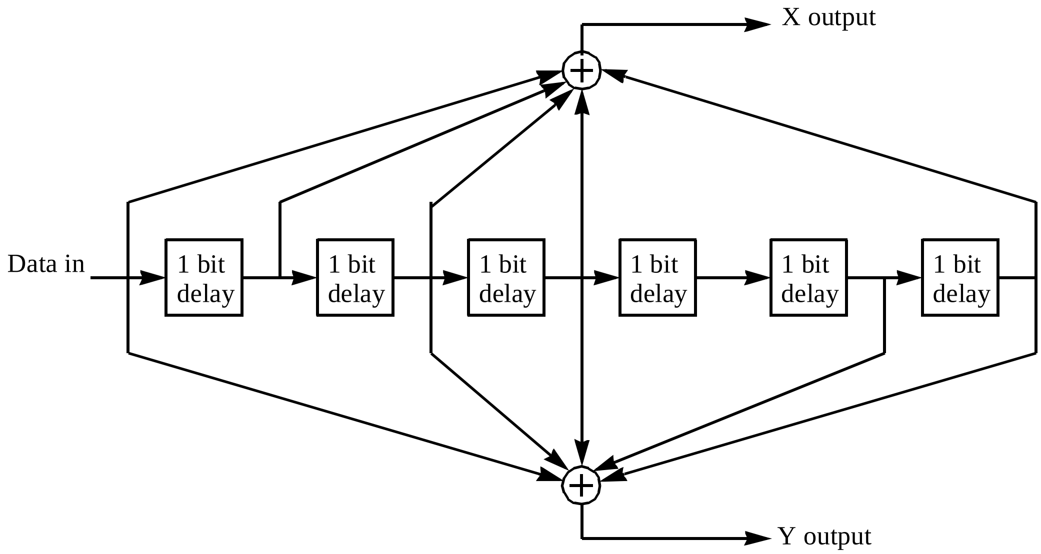

Figure 172—Binary rate 1/2 convolutional encoder

To generate binary code rates of 2/3, 3/4, 5/6, and 7/8, the rate 1/2 encoder outputs shall be punctured. The puncturing patterns and serialization order for the X and Y outputs are defined in Table 198. In the puncture patterns, a ‘1’ denotes a transmitted output bit and a ‘0’ denotes a non-transmitted (punctured) bit.

Table 198—Puncture patterns and serialization for convolution code

	Code Rates				
Rate	1/2	2/3	3/4	5/6	7/8
X Output Puncture Pattern	1	10	101	10101	1000101
Y Output Puncture Pattern	1	11	110	11010	1111010
Punctured XY Serialization	X_1Y_1	$X_1Y_1Y_2$	$X_1Y_1Y_2X_3$	$X_1Y_1Y_2X_3Y_4X_5$	$X_1Y_1Y_2Y_3Y_4X_5Y_6X_7$

The pragmatic TCM code is constructed from both non-systematic coded bits (that are taken from the outputs of the rate 1/2 binary convolutional encoder) and systematic uncoded bits (that are taken directly from the encoder input). The resulting coded bits are then mapped to symbol constellations. Supported modulations and code rates for UL and DL transmissions are listed in Table 199. The choice of a particular code rate and modulation is made via burst profile parameters.

As indicated in Table 199, clauses 8.3.3.1.2.1.3.1 through 8.3.3.1.2.1.3.7 specify pragmatic TCM encoder constructions. Clause 8.3.3.1.2.1.4 specifies the code bit to I-Q constellation maps associated with these TCM encoders, and clause 8.3.3.1.2.1.3.8 specifies inner code block termination.

Since the RS outer code generates byte-denominated records but the inner code generates symbol-denominated outputs, some combinations of RS record sizes and inner code rates may require the inner code to insert a fractional QAM symbol at the end of a data record. When such an event occurs, sufficient (unrandomized) zero-valued (null) bits shall be appended to the end of the inner encoder's input record to complete the final symbol. A receiver shall discard these null bits after inner decoding..

Table 199—Supported modulations and code rates

Modulation	Support (M=Mandatory, O=Optional)		Code Rates	Bits/symbol	Location of Encoder Description(s)
	UL	DL			
BPSK	O	O	1/2, 3/4	1/2, 3/4	8.3.3.1.2.1.3.1
QPSK	M	M	1/2, 2/3, 3/4, 5/6, 7/8	1, 4/3, 3/2, 5/3, 7/4	8.3.3.1.2.1.3.1
16-QAM	M	M	1/2, 3/4	2, 3	8.3.3.1.2.1.3.2, 8.3.3.1.2.1.3.3
64-QAM	O	M	2/3, 5/6	4, 5	8.3.3.1.2.1.3.4, 8.3.3.1.2.1.3.5
256-QAM	O	O	3/4, 7/8	6, 7	8.3.3.1.2.1.3.6, 8.3.3.1.2.1.3.7

8.3.3.1.2.1.3.1 Encoding for BPSK and QPSK Modulations, All Rates

For BPSK, the binary outputs of the punctured binary encoder shall be directly sent to the BPSK symbol mapper, using the multiplexed output sequence shown in the 'XY'-headed row of Table 198. For QPSK, the multiplexed output sequence in Table 198 is alternately assigned to the I and Q coordinate QPSK mappers, with the I coordinate receiving the first assignment. Figure 179 depicts ~~the~~ bits-to-symbol-constellation maps that shall be used for BPSK and QPSK.

8.3.3.1.2.1.3.2 Encoding for Rate ½ 16-QAM

Figure 173 illustrates the rate ½ pragmatic TCM encoder for 16-QAM. The baseline rate ½ binary convolutional encoder first generates a two-bit constellation index, b_3b_2, associated with the I symbol coordinate. Provided the next encoder input, it generates a two bit constellation index, b_1b_0, for the Q symbol coordinate. The I index generation shall precede the Q index generation. Note that this encoder should be interpreted as a rate 2/4 encoder, because it generates one four bit code symbol per two input bits. For this reason, input records of lengths divisible by two shall be fed to this encoder.

Figure 179 ~~of clause 8.3.2.5~~ depicts the bits-to-constellation map that shall be ~~is~~ applied to the rate 1/2 16-QAM encoder output. This is a Gray code map.

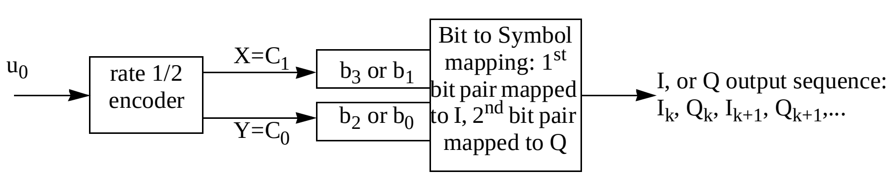

Figure 173—Pragmatic TCM encoder for rate ½ 16-QAM

8.3.3.1.2.1.3.3 Encoding for Rate 3/416-QAM

Figure 174 illustrates the rate 3/4 pragmatic TCM encoder for 16-QAM. This encoder uses the baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. With this structure, the encoder is capable of simultaneously generating 4 output bits per three input bits. The sequence of arrival for the $u_2u_1u_0$ input into the encoder is u_2 arrives first, u_1 second, u_0 last. During the encoding process, the encoder generates a two bit constellation index, b_3b_2, for the I symbol coordinate, and simultaneously generates another two bit constellation index, designated b_1b_0, for the Q symbol coordinate. Note that whole symbols must be transmitted, so input records of lengths divisible by three shall be fed to this encoder.

Figure 180 ~~of clause 8.3.3.1.2.1.4~~ depicts the bits-to-symbol-constellation map that shall be ~~is~~ applied to the rate 3/4 16-QAM encoder output. This is pragmatic TCM map.

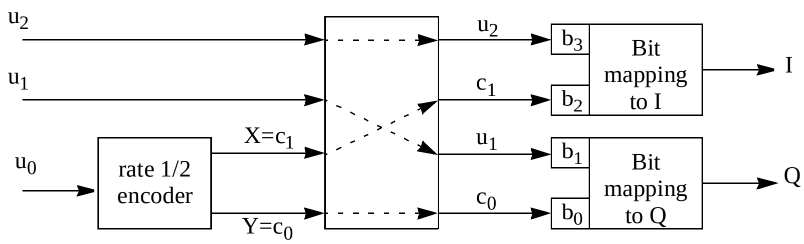

Figure 174—Pragmatic TCM encoder for rate 3/4 16-QAM

8.3.3.1.2.1.3.4 Encoding for Rate 2/3 64-QAM

Figure 175 illustrates the rate 2/3 pragmatic TCM encoder for 64-QAM. This encoder uses the baseline rate ½ binary convolutional encoder, along with one systematic bit that is passed directly from the encoder input to the encoder output. The sequence of arrival for the u_1u_0 input into the encoder is u_1 arrives first, u_0 last. The encoder (as a whole) then generates a three bit constellation index, $b_5b_4b_3$, which is associated with the I symbol coordinate. Provided another two-bit encoder input, the encoder generates another three bit constellation index, $b_2b_1b_0$, which is associated with the Q symbol coordinate. The I index generation should precede the Q index generation. Note that this encoder should be interpreted as a rate 4/6 encoder, because it generates one six bit code symbol per four input bits. For this reason, input records of lengths divisible by four shall be fed to this encoder.

Figure 180 ~~of clause 8.3.3.1.2.1.4~~ depicts the bits-to-symbol-constellation map that shall be ~~is~~ applied to the rate 2/3 64-QAM encoder output. This is a pragmatic TCM map.

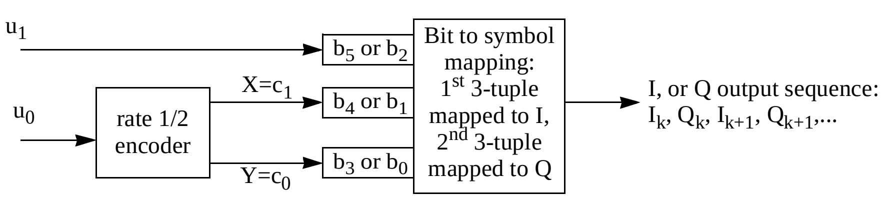

Figure 175—Pragmatic TCM encoder for rate 2/3 64-QAM

8.3.3.1.2.1.3.5 Encoding for Rate 5/6 64-QAM

Figure 176 illustrates the rate 5/6 pragmatic TCM encoder for 64-QAM. This encoder uses a rate ¾ punctured version of the rate baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The rate ¾ punctured code is generated from the baseline rate 1/2 code using the rate 3/4 puncture mask definition in Table 190 of clause 8.3.2.4.1.2. Puncture samples are sequenced c_3 first, c_2 second, c_1 third, and c_0 last. The sequence of arrival for the $u_4u_3u_2u_1u_0$ input into the encoder is u_4 arrives first, u_3 arrives second, u_2 arrives third, u_1 arrives next to last, and u_0 arrives last. During the encoding process, the pragmatic encoder generates a three bit constellation index, $b_5b_4b_3$, for the I symbol coordinate, and simultaneously generates another three bit constellation index, $b_2b_1b_0$, for the Q symbol coordinate. Note that whole symbols must be transmitted, so input records of lengths divisible by five shall be fed to this encoder.

Figure 180 ~~of clause 8.3.3.1.2.1.4~~ depicts the bits-to-symbol-constellation map that shall be ~~is~~ applied to the rate 5/6 64-QAM encoder output. This is a pragmatic TCM map.

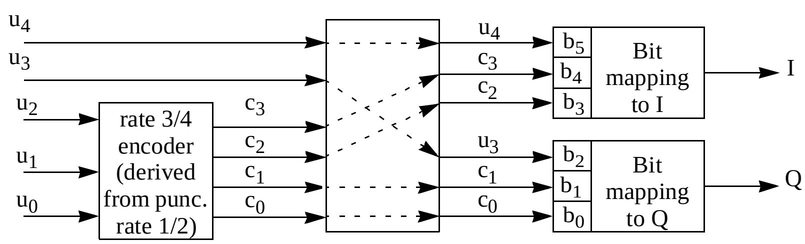

Figure 176—Pragmatic TCM encoder for rate 5/6 64-QAM

8.3.3.1.2.1.3.6 Encoding for Rate 3/4 256-QAM

Figure 177 illustrates the rate 3/4 pragmatic TCM encoder for 256-QAM. This encoder uses the baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The sequence of arrival for the $u_2u_1u_0$ input into the encoder is u_2 arrives first, u_1 next, u_0 last. Note that the encoder (as a whole) first generates a four bit constellation index, $b_7b_6b_5b_4$, which is associated with the I symbol coordinate. Provided another four bit encoder input, it generates a four bit constellation index, $b_3b_2b_1b_0$, which is associated with the Q symbol coordinate. The I index generation should precede the Q index generation. Note that this encoder should be interpreted as a rate 6/8 encoder, because it generates one eight bit code symbol per six input bits. For this reason, input records of lengths divisible by six shall be fed to this encoder.

Figure 181 ~~of clause 8.3.3.1.2.1.4~~ depicts the bits-to-symbol-constellation map that shall be ~~is~~ applied to the rate 3/4 256-QAM encoder output. This is a pragmatic TCM map.

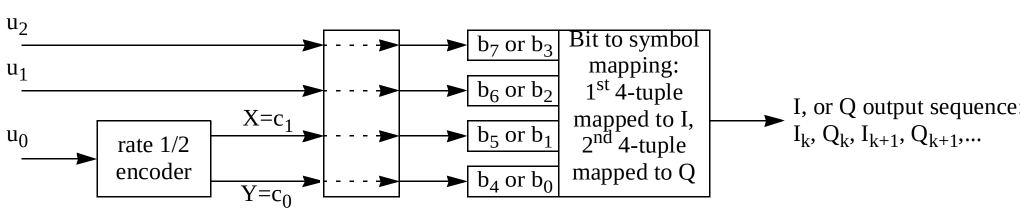

Figure 177—Optional pragmatic TCM encoder for rate ¾ 256-QAM

8.3.3.1.2.1.3.7 Encoding for Rate 7/8 256-QAM

Figure 178 illustrates the rate 7/8 pragmatic TCM encoder for 256-QAM. This encoder uses a rate ¾ punctured version of the rate baseline rate ½ binary convolutional encoder, along with two systematic bits that are passed directly from the encoder input to the encoder output. The rate ¾ punctured code is generated from the baseline rate 1/2 code using the rate 3/4 puncture mask definition in Table 190 of clause 8.3.2.4.1.2.

Puncture samples are sequenced c_3 first, c_2 second, c_1 third, and c_0 last. The sequence of arrival for the $u_6u_5u_4u_3u_2u_1u_0$ input into the encoder (as a whole) is u_6 arrives first, u_5 arrives second, u_4 arrives third, u_3 arrives fourth, u_2 arrives fifth, u_1 arrives next to last, and u_0 arrives last. During the encoding process, the encoder generates a four bit constellation index, $b_7b_6b_5b_4$, for the I symbol coordinate, and simultaneously generates another four bit constellation index, $b_3b_2b_1b_0$, for the Q symbol coordinate. Note that whole 256-QAM symbols should be transmitted, so input records of lengths divisible by seven shall be fed to this encoder.

Figure 181 ~~of clause 8.3.3.1.2.1.4~~ depicts the bits-to-symbol-constellation map that shall be ~~is~~ applied to the rate 7/8 256-QAM encoder output. This is a pragmatic TCM map.

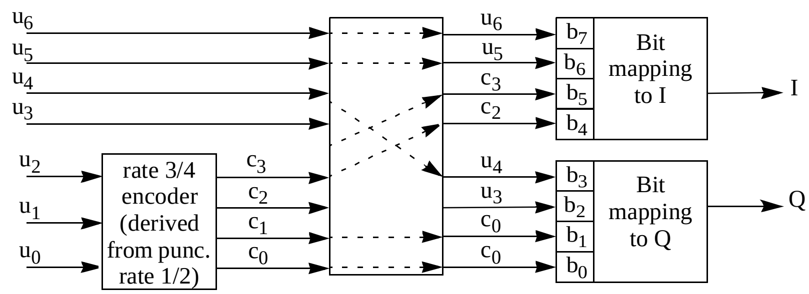

Figure 178—Optional pragmatic TCM encoder for rate 7/8 256-QAM

8.3.3.1.2.1.3.8 Inner Code Termination

Inner code blocks are to be zero-state terminated in transitions between adaptive modulation (and FEC) types, at the ends of bursts, or as instructed by the MAC and frame control.

When using zero state termination, the baseline rate ½ convolutional encoder shall be initialized with its registers in the all-zeros state. Inner encoding shall begin from this state, by accepting bit inputs. To terminate the inner code (and return the encoder to the all-zeros state) at the end of a code block, at least 6 zero inputs shall be fed into the baseline rate ½ binary convolutional encoder so that its register memory is flushed, i.e., its state memory is driven to zero. Once the first flushing zero bit is introduced into the convolutional encoder memory, all input bits, including the systematic input bits that are parallel to the binary convolutional encoder inputs, shall have zero value.

Table 200 specifies the exact number of systematic and non-systematic bits that shall be used to flush a pragmatic TCM encoder. It also tabulates the number of symbols consumed in the code termination process.

Table 200—Flushing bit requirements for inner code termination

Modulation	Code Rate	Number of Flushing Bits			Number of Consumed Symbols
		Non-systematic	Systematic	Total	
BPSK	1/2	6	0	6	12
	3/4	6	0	6	8
QPSK	1/2	6	0	6	6
	2/3	7	0	7	5
	3/4	6	0	6	4
	5/6	6	0	6	4
	7/8	7	0	7	4
16-QAM	1/2	6	0	6	3
	3/4	6	12	18	6
64-QAM	2/3	6	6	12	3
	5/6	6	4	10	2
256-QAM	3/4	6	12	18	3
	7/8	6	8	14	2

8.3.3.1.2.1.4 Constellation Mapping

For the concatenated FEC, code bits shall be mapped to I and Q symbol coordinates using either a pragmatic TCM or Gray code symbol map, depending on the code rate and modulation scheme. All BPSK and QPSK code rates and rate 1/2 16-QAM shall use the Gray coded constellation maps depicted in Figure 179. Rate 3/4 16-QAM and all code rates for 64-QAM shall use the pragmatic TCM constellation map depicted in Figure 180. All code rates for 256-QAM shall use the pragmatic TCM constellation map depicted in Figure 181.

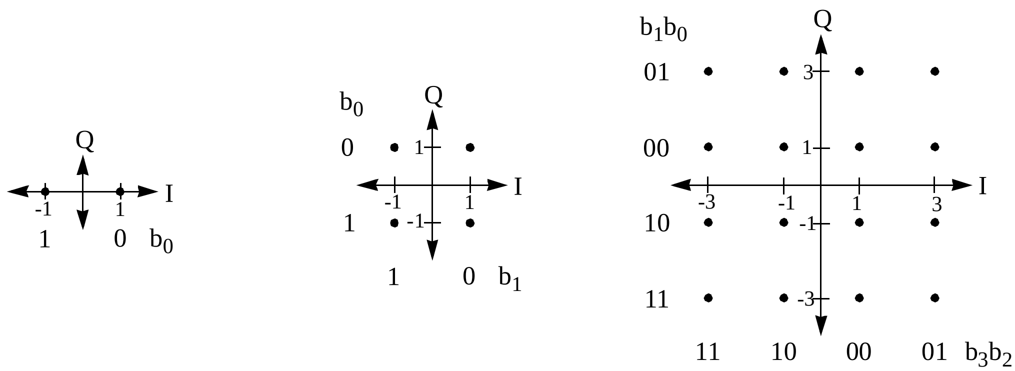

Figure 179—Gray maps for BPSK, QPSK and 16-QAM constellations

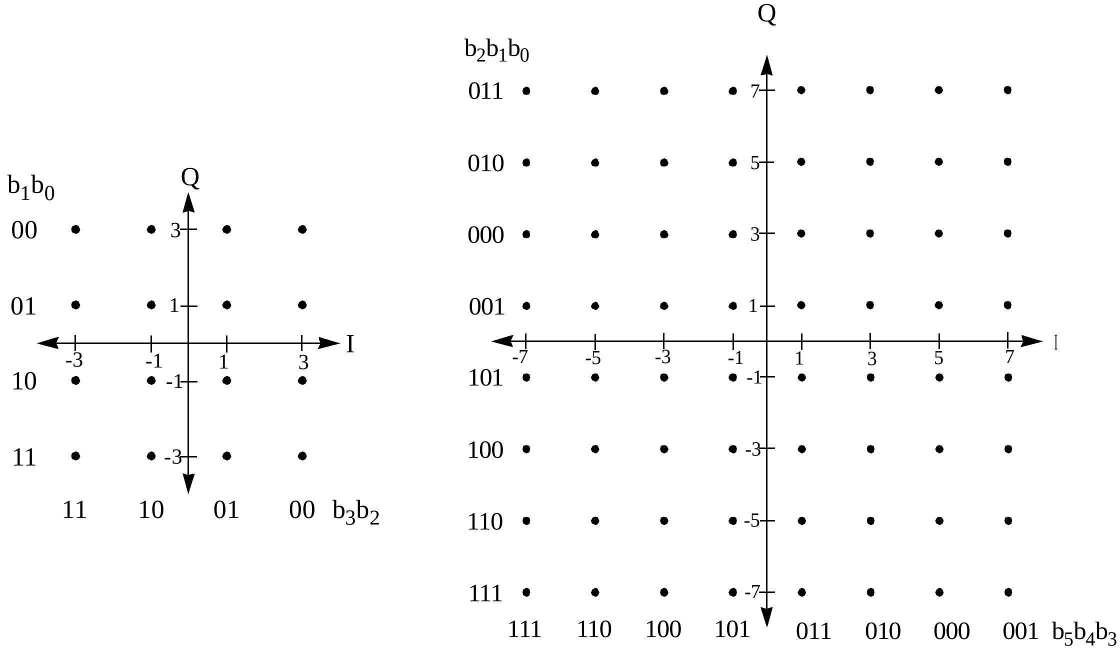

Figure 180—Pragmatic maps for 16-QAM and 64-QAM constellations

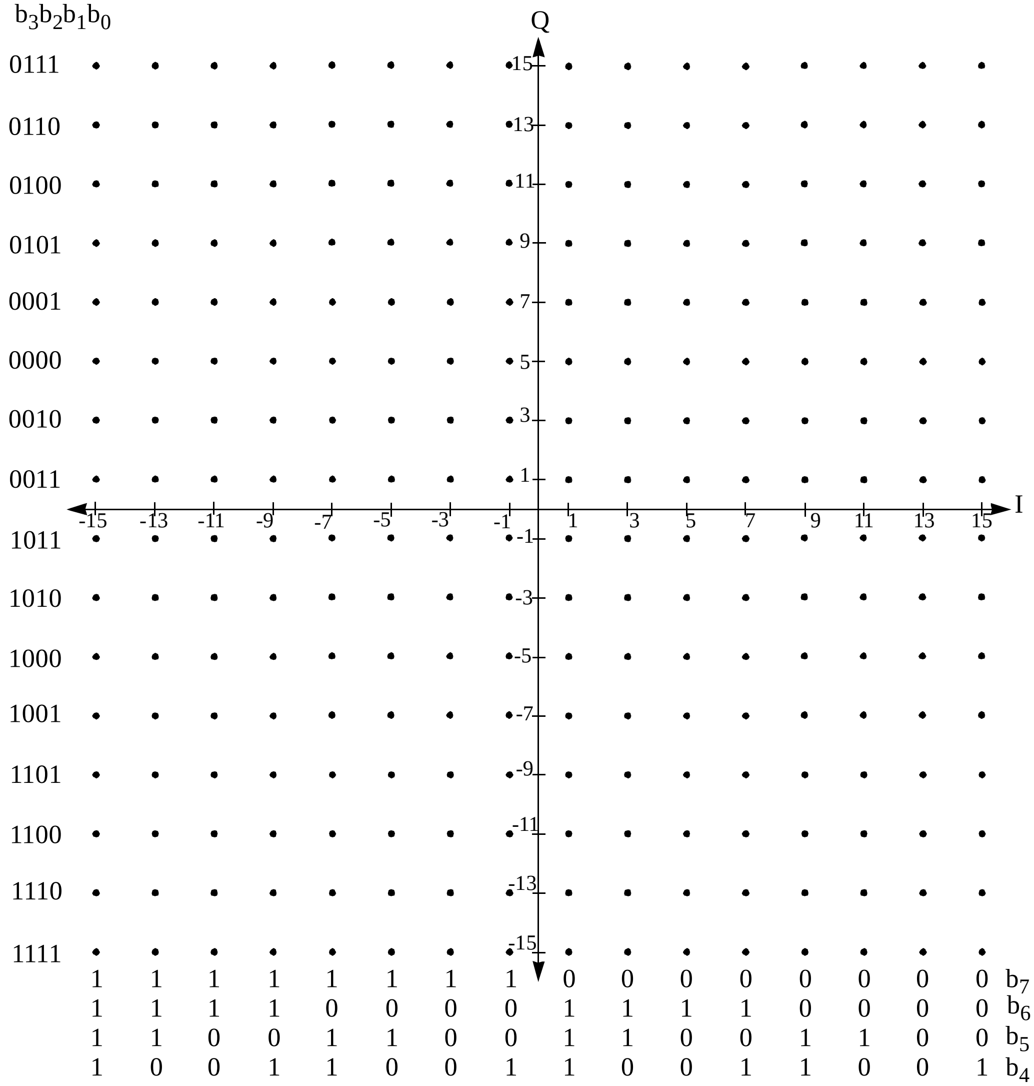

Figure 181—Pragmatic map for 256-QAM constellation

To obtain unity average power of transmitted sequences, I and Q coordinates of constellation points are multiplied by the appropriate factor for *c* listed in Table 201.

Table 201—Unity average power normalization factors

Modulation scheme	Normalization Constant for Unity Average Power
QPSK	$c = 1/\sqrt{2}$
16 QAM	$c = 1/\sqrt{10}$
64 QAM	$c = 1/\sqrt{42}$
256 QAM	$c = 1/\sqrt{170}$

8.3.3.1.2.2 No FEC

In the No FEC option, scrambled source data shall be mapped directly to a QAM symbol constellation, using the appropriate Gray coding map. These maps are found in Figure 179 (for BPSK, QPSK, 16-QAM), Figure 182 (for 64-QAM), and Figure 183 (for 256-QAM). Support of no-FEC operation for QPSK is mandatory, but is optional for all other QAM. This no-FEC mode is particularly useful for radio receiver performance testing.

In the event that the source record size in bytes does not divide into an integral number of QAM symbols, sufficient unscrambled zero-valued (null) bits shall be appended to the end of the data record to complete the last symbol. These null bits shall be discarded at the receiver.

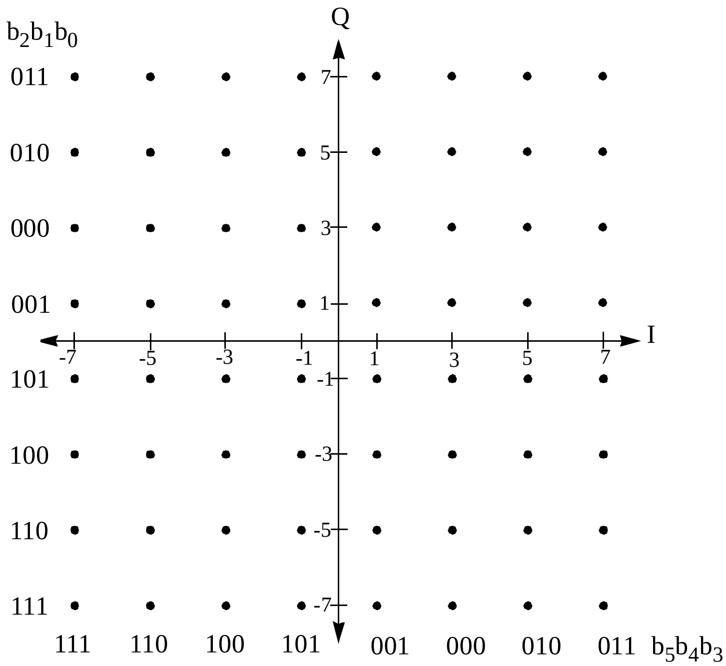

Figure 182—Gray map for 64-QAM constellation

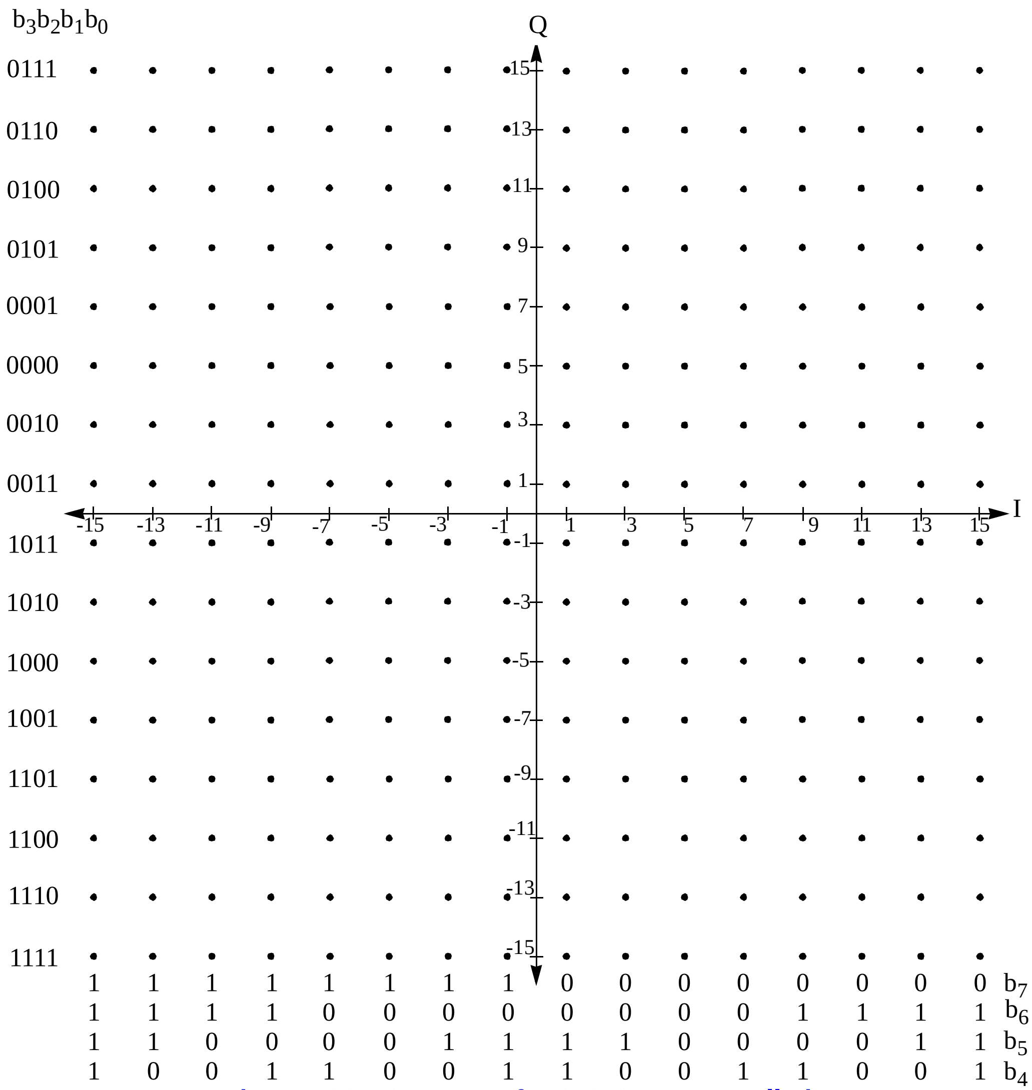

Figure 183—Gray map for 256-QAM constellation

8.3.3.1.2.3 Block Turbo Code

Support of the Block Turbo Code FEC is optional.

A BTC is formed from the product of two component codes, each of which is a binary extended Hamming code or single parity check code, and taken from the set of codes listed in Table 202. Table 203 specifies the generator polynomials for the Hamming codes; to form an extended Hamming code from the base Hamming code, an overall even parity check bit is added at the end of each Hamming code word.

Table 202—BTC component codes

Component code (n,k)	Code type
(64,57)	Extended Hamming Code
(32,26)	Extended Hamming Code
(16,11)	Extended Hamming Code
(8,4)	Extended Hamming Code
(64,63)	Parity Check Code
(32,31)	Parity Check Code
(16,15)	Parity Check Code
(8,7)	Parity Check Code
(4,3)	Parity Check Code

-

Table 203—Hamming code generator polynomials

n’	k’	Generator polynomial
7	4	X^3+X^1+1
15	11	X^4+X^1+1
31	26	X^5+X^2+1
63	57	X^6+X+1

A BTC is encoded by writing data row by row into the two dimensional matrix form illustrated in Figure 184. The k_x information bits in each row are encoded into n_x bits by using the component block (n_x, k_x) code specified for the respective ‘row’ component code. After encoding the rows, the columns are encoded using a block (n_y, k_y) code, where the check bits of the row codes are also encoded. Data bit ordering for the composite BTC matrix is: the left-most bit in the first row is the lsb, the next bit in the first row is the next-to-lsb, and the last data bit in the last data row is the msb.

An encoded BTC block shall be read out of matrix (for transmission) as a serial bit stream, starting with the lsb and ending with the msb. This bit stream shall sent to a symbol mapper which uses a Gray maps depicted in Figure 179 for BPSK and QPSK, and the pragmatic maps depicted in Figure 180 and Figure 181 for 16-QAM, 64-QAM and 256-QAM.

The overall block size of a product code is $n = n_x \times n_y$, the total number of information bits $k = k_x \times k_y$ and the code rate is $R = R_x \times R_y$, where $R_i = k_i / n_i$, i=x, y. To match an arbitrary required packet size, BTCs may be shortened by removing symbols from the BTC array. Rows, columns or parts thereof can be removed until the appropriate size is reached. Three steps are involved in the shortening of product codes:

Step 1: Remove I_x rows and I_y columns from the 2-dimensional code. This is equivalent to shortening the constituent codes that make up the product code.

Step 2: Remove B individual bits from the first row of the 2-dimensional code starting with the lsb.

Step 3: Use if the product code specified from steps 1 and 2 has a non-integral number of data bytes. In this case, the Q left over lsb bits are zero filled by the encoder. After decoding at the receive end, the decoder shall strip off these unused bits and only the specified data payload is passed to the next higher level in the physical layer. The same general method is used for shortening the last code word in a message where the available data bytes do not fill the available data bytes in a code block.

These three processes of code shortening are illustrated in Figure 184. The left-hand side of the figure illustrates a non-shortened BTC, whereas the right-hand side illustrates a shortened BTC. The new coded block length of the code is $(n_x\text{-}I_x)(n_y\text{-}I_y)\text{-}B$. The corresponding information length is given as $(k_x\text{-}I_x)(k_y\text{-}I_y)\text{-}B\text{-}Q$. Consequently, the code rate is given by:

$$R = \frac{(k_x - I_x)(k_y - I_y) - B - Q}{(n_x - I_x)(n_y - I_y) - B} \quad (2)$$

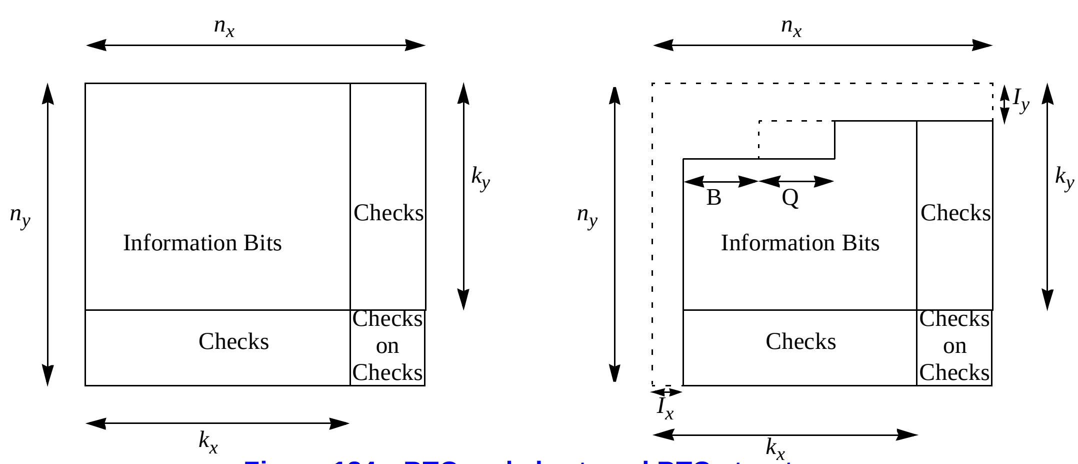

Figure 184—BTC and shortened BTC structures

8.3.3.1.3 Burst Framing

Both DL and UL data shall be formatted into bursts that use the Framed Burst format. The DL shall support the most general case of TDM bursts, while the UL shall support TDMA bursts.

TDMA burst and continuous DL operational modes are subclasses of the TDM burst DL mode of operation, and should be realizable using equipment designed for general TDM operation. The coordination of UL and DL bursts used to implement a TDD or FDD system is specified in 8.3.3.1.4.

8.3.3.1.3.1 Fundamental Burst Framing Elements

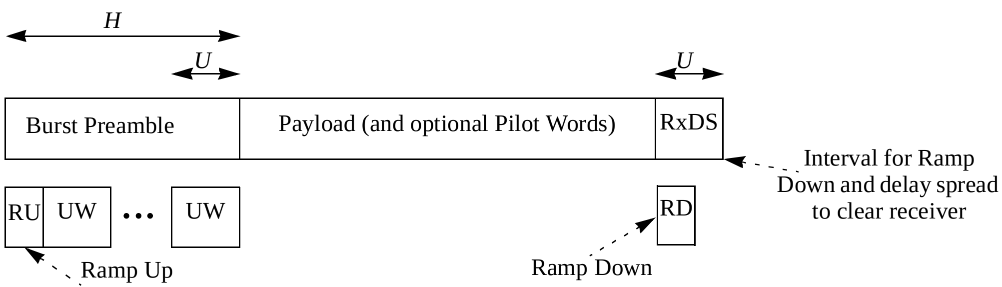

Figure 185—Fundamental burst framing elements

As Figure 185 illustrates, a burst consists of three fundamental framing elements: a Burst Preamble that includes ramp-up~~down~~; a Payload; and an RxDS interval that includes ramp-down.

8.3.3.1.3.1.1 Burst Preamble

A Burst Preamble shall consist of a ramp up region followed by a preamble body. Burst profile parameters shall specify R_r, the length of the ramp up region in symbols, and m, the number of Unique Words composing the preamble body. The burst profile shall also specify U, the number of symbols in a Unique Word.

8.3.3.1.3.1.1.1 Unique Word Content in the Burst Preamble

A Burst Preamble shall be constructed from the last R symbols of a Unique Word followed by an integer multiple $m \geq 0$ of Unique Words, each Unique Word being U symbols in length. Figure 186 illustrates this requirement.

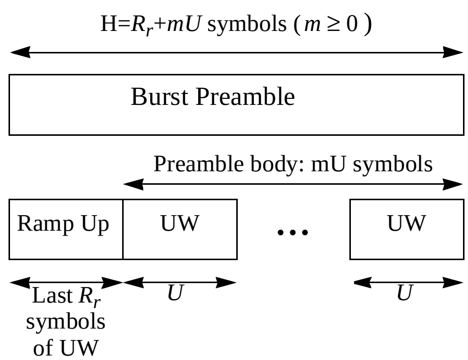

Figure 186—Burst preamble composition

8.3.3.1.3.1.1.2 Ramp Up

For $_r = 0$, a ramp up element within the Burst Preamble shall not be created.

For $_r > 0$, a ramp up element shall be created. When creating a ramp up element, the transmit filter memory shall be initialized with zero-valued (null) symbols. R_r ramp up symbols shall then be sequentially fed into the transmit filter input stream. The transient preceding the first ramp up symbol shall be suppressed at the transmit filter output until the symbol period of the first ramp up symbol. A ramped power buildup shall then be achieved by superimposing a multiplicative raised cosine half-window of duration R_r symbols upon the samples leaving the transmit filter.

8.3.3.1.3.1.2 Burst Payload

The Burst Payload block depicted in Figure 185 contains payload data. The Burst Payload block may also contain periodically inserted Pilot Words, if the burst profile specifies their inclusion. The capability to demodulate payloads of arbitrary length and symbol-unit granularity is mandatory. The capability to insert Pilot Words at the transmitter and remove them at the receiver is also mandatory.

8.3.3.1.3.1.2.1 MAC Frame Control and Adaptive Modulation Sequencing

A DL burst may contain time division multiplexed messages that are adaptively modulated for the intended message recipients. When a MAC frame control message is to be transmitted within a DL burst, it shall always appear first, and shall use QPSK. Subsequent messages within the burst shall be sequenced in decreasing order of modulation robustness, beginning with the most robust modulation that is supported at the transmitter. The capability to transition between modulation types on any symbol boundary within a burst shall be supported. FEC blocks shall be terminated at every such transition.

One exception to the modulation sequencing rule is null payload fill, which shall always appear as the final message in a burst, and shall be transmitted using QPSK.

An UL burst contains a single message, and uses a single modulation format within a burst. However, different bursts may have different modulation formats. Additional description of MAC / PHY support for adaptive modulation and coding is provided in clause 6.2.7.

8.3.3.1.3.1.3 Null Payload Fill

When additional payload data is necessary to fill the end of a burst frame, e.g., when a continuous DL does not have enough data fill a MAC frame, null payload fill may be inserted. The capability to insert null payload fill at a transmitter and discard it at a receiver is mandatory.

Null payload fill shall use the null fill data type. A MAC Frame control (MAP) message treats the null fill data type as an adaptive modulation type, and therefore shall indicate when and for how long this data type shall be transmitted within a burst. Null payload fill data shall also be subject to pilot word patterning within a burst.

The null fill data type is defined as zero-valued source bits that are randomized (clause 8.3.3.1.1) and mapped directly to QPSK symbols using the Gray code map in Figure 179. The randomizer shall run (without reset) through both the preceding burst payload and the null payload fill, but null payload fill shall not covered (in the MAC) by a CRC code. During null payload fill transmission, a transmitter's output power may be reduced.

8.3.3.1.3.1.4 Pilot Words

A Pilot Word is a contiguous sequence of symbols composed of an integer $n \geq 0$ multiple of Unique Words, which may periodically pattern a burst. As Figure 187 illustrates, the period of a Pilot Word, F (in symbols), is defined to include the length, P, of the Pilot Word. Both F and n are parameters specified within a burst profile. The setting $n = 0$ indicates that no Pilot words shall be patterned within a burst.

When Pilot Words are patterned within a burst, F for that burst shall be constant, and the first symbol of the first Pilot Word shall commence $F-P+1$ symbols into the burst. As Figure 187 illustrates, Pilot Word patterning shall cease when $F-P$ or less payload data symbols remain in the burst.

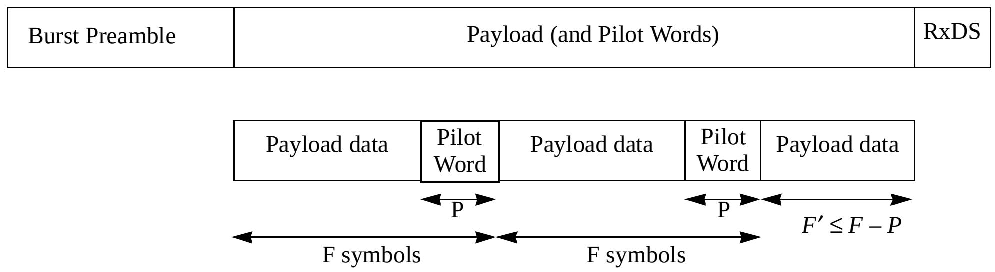

Figure 187—Pilot Word patterning within a burst

8.3.3.1.3.1.5 Receiver Delay Spread Clearing Region (RxDS)

The receiver delay spread clearing interval (RxDS) illustrated in Figure 185 is a quiet period during which the transmitter ramps down, and the receiver collects delay-spread versions of symbols at the end of the burst. The capability to insert theis RxDS region at the transmitter is mandatory. The length of the RxDS region shall always the length of a Unique Word, unless it is suppressed (i.e., set to length zero). One instance where the RxDS is automatically suppressed is when bursts are concatenated.

8.3.3.1.3.1.5.1 Ramp Down

If the RxDS region is nonzero in length, a transmitter shall ramp down during this RxDS region by inserting zero inputs into the transmit filter memory following the last intended data symbol, and allowing the natural response of the filter to drive the filter output to zero.

8.3.3.1.3.2 Unique Word

8.3.3.1.3.2.1 Selection

The length, *U*, in symbols of a Unique Word (UW) is a burst profile parameter. For best performance, *U* should be at least as long as the intended channel's span of significant delay spread.

8.3.3.1.3.2.2 Definition

Unique Words are derived from Frank-Zadoff [B22] or Chu [B23] sequences, and possess CAZAC (Constant Amplitude Zero [periodic] Auto-Correlation) properties. A burst profile specifies a Unique Word from the options listed in Table 204. The sequence length U = 64 shall be supported and considered a default setting. U = 16 shall also be supported for symbol rates below 1.25 Msymb/s, and U = 256 shall also be supported for symbol rates above 20 Msymb/s. The other optional sequence lengths listed in Table 204 may be useful for longer or shorter delay spread channels.

Table 204—UW lengths, types, and support

Length, U (symbols)	Sequence Type	Support Status
0	---	Optional
8	Chu	Optional
16	Frank-Zadoff	Optional (Mandatory below 1.25 Msymb/s)
32	Chu	Optional
64	Frank-Zadoff	Mandatory (default)
128	Chu	Optional
256	Frank-Zadoff	Optional (Mandatory above 20 Msymb/s)
512	Chu	Optional

The integer n-indexed I and Q components of a length U, $0 \le n < U$, Unique Word sequence shall be generated from

$$\begin{aligned} I[n] &= \cos(\theta[n]) \\ Q[n] &= \sin(\theta[n]) \end{aligned} \quad (3)$$

where $\theta[n] = \theta_{chu}[n]$ when generating a Chu sequence, and $\theta[n] = \theta_{frank}[n]$ when generating a Frank-Zadoff sequence. For a Chu sequence,

$$\theta_{chu}[n] = \frac{\pi n^2}{U}; \quad (4)$$

~~and,~~ for a Frank-Zadoff sequence,

$$\begin{aligned} \theta_{frank}[n = p + q\sqrt{U}] &= \frac{2\pi pq}{\sqrt{U}} \\ p &= 0, 1, \ldots, \sqrt{U} - 1 \\ q &= 0, 1, \ldots, \sqrt{U} - 1 \end{aligned} \quad (5)$$

The length U = 16, 64, and 256 Unique Word sequences are composed of symbols from QPSK, 8-PSK, and 16-PSK alphabets, respectively. However, the length U = 8, 32, 128, and 512 sequences are derived from polyphase symbol alphabets that may require additional care in a hardware implementation. The error vector magnitude (EVM) for Unique Word symbols in a transmitter implementation should conform with the general requirements stated in clause 8.3.3.4.1.5.

8.3.3.1.4 Duplex Framing

Clause 8.3.3.1.4.1 specifies FDD operation, while clause 8.3.3.1.4.2 specifies TDD operation. Support of at least one of these two duplexing modes is mandatory.

8.3.3.1.4.1 FDD

Frequency Division Duplexing (FDD) segregates the UL and DL on different-frequency carriers: BSs transmit at the DL carrier frequency, while SSs transmit at the UL carrier frequency.

A SS in a FDD system shall be capable of operation over a burst DL and UL. Moreover, given appropriate parameterization of a burst DL, a SS shall also be capable of continuous DL operation.

8.3.3.1.4.1.1 FDD with Burst DL

An example FDD system with burst-TDM DL is illustrated in Figure 188. As Figure 188 illustrates, DL and UL sub-frames shall coincide in length, and shall repeat at regular (MAC-defined) constant intervals.

8.3.3.1.4.1.1.1 DL

A DL burst shall not exceed the length of a DL sub-frame, but it need not fill the entire DL frame. Also, although not illustrated in Figure 188, the capability to support several DL bursts within a DL sub-frame is mandatory.

The first burst in each DL sub-frame shall commence with a Burst Preamble (BP), and shall be directly followed by a Frame Control Header (FCH), which is a broadcast message which governs the operation of DL and UL frames. Only the first burst in a DL sub-frame shall be required to possess the FCH.

A FCH shall use the Concatenated FEC with rate 1/2 inner code and QPSK, and shall not use byte-interleaving. The first X_{FCH} symbols of the FCH shall contain MAC data that can be used to determine the allocation extent of data containing the next DL frame's entire FCH. These X_{FCH} symbols shall be encapsulated within a 8-byte correcting RS codeword and a convolutional code that terminates at the X_{FCH} symbol point. X_{FCH} ~~and~~ is a software system configuration parameter that is downloaded from the SS MAC during SS initialization. ~~Neither~~ It shall not change within a system installation, unless a software update is provided to all current and future users of the system.

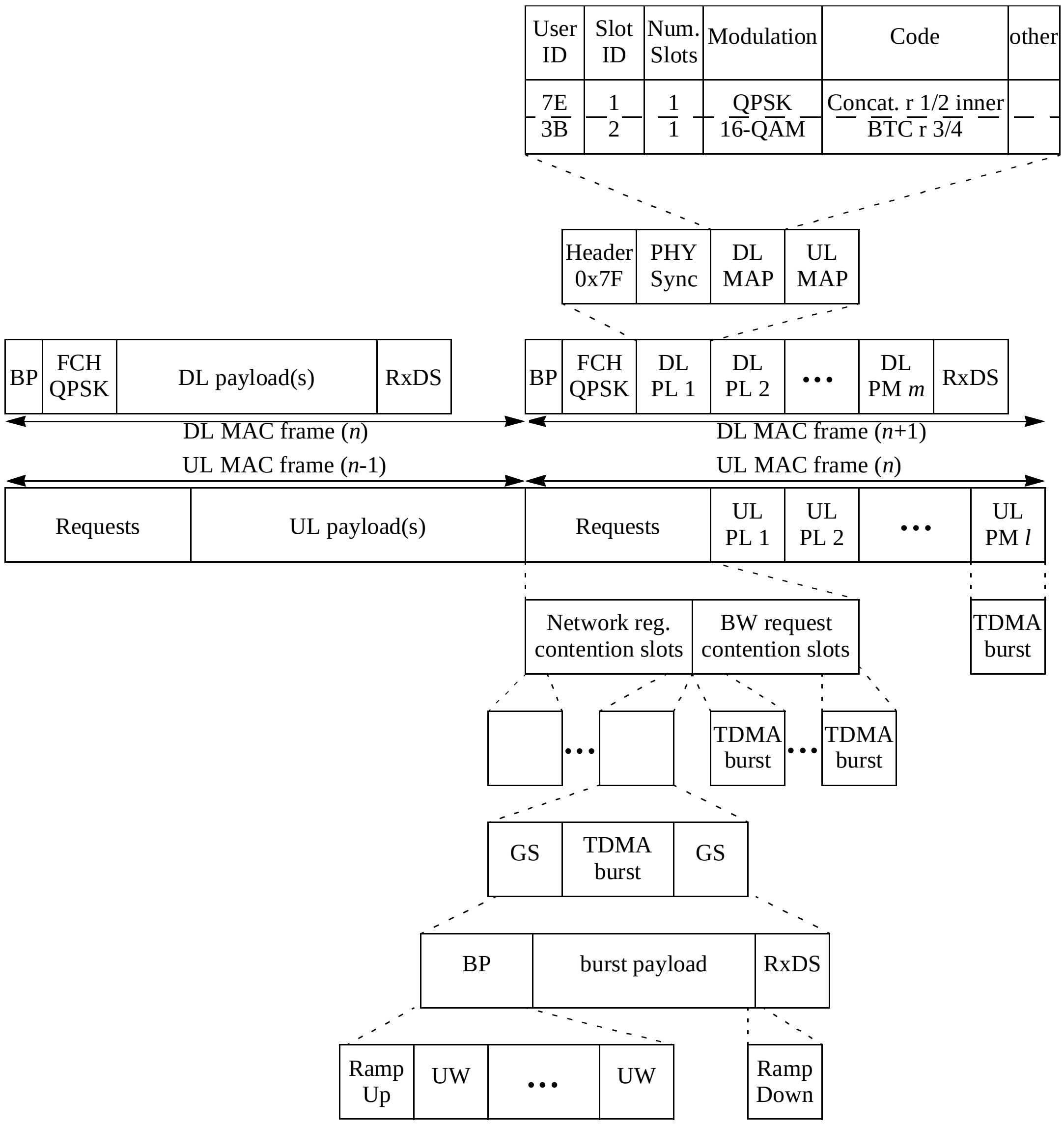

Figure 188—Example of FDD with burst TDM DL

The portion of the FCH following the first X_{FCH} symbols may be aggregated with data from an adjacent payload message if the payload data shares the same burst profile as the FCH. As the breakout illustration in the middle of Figure 188 illustrates, the FCH is composed of several fields. These include a fixed Header sequence; a PHY Sync that serves as a global time stamp to synchronize network time between the UL and DL duplexes; a DL MAP that contains the sizes and burst profile indices of the next MAC frame's multiplexed DL messages (including the next frame's FCH); and a UL MAP that contains the sizes and burst profiles of UL grants and request slots at some time in the future. Note that the first X_{FCH} symbols contain data up through the length of the first burst profile in the DL MAP.

Time division multiplexed DL payload data may follow the FCH. A DL burst concludes with an RxDS to allow delay spread to clear the receiver. In the event that a DL MAC frame is entirely filled with data, bursts may be concatenated and the RxDS suppressed. In other words, an RxDS of zero length shall be used, so that no ramp down occurs, and the Preamble of the next MAC frame may immediately commence. The preamble of that next MAC frame shall then use a ramp up parameter R_r ~~R~~ of zero, so that no ramp up occurs.

When more than one bursts ~~are~~ is to be transmitted within a single DL MAC sub-frame, the DL-MAP of the first payload in the follow-up burst shall have a burst profile with its DL Burst Transition Gap (DL-BTG) entry enabled. The DL-BTG is a burst profile parameter. When enabled, the DL-BTG also indicates the length of the gap between bursts. The DL-BTG includes the RxDS terminating such a burst, and thus, when enabled, shall be specified to be at least as long as the RxDS.

8.3.3.1.4.1.1.2 UL

An UL sub-frame contains three categories of bursts:

- Network Registration Contention Slots that are transmitted in contention slots reserved for station registration;
- BW Request Contention Slots that are transmitted in contention slots reserved for response to multicast and broadcast polls for bandwidth needs;
- Grants of BW that are specifically allocated to individual SSs.

As Figure 188 illustrates, UL bursts are TDMA, and shall be constructed from a Burst Preamble (BP), including ramp up; a Burst Payload; and a receiver delay spread clear interval (RxDS) ~~region~~, including ramp down. SS Transition Gaps (SSTGs) separate the burst transmissions of the various SSs using the UL. A SSTG specification includes the length of the RxDS, along with any additional guard symbols that may be inserted between UL bursts to reflect reference time uncertainties.

As shown in the UL sub-frame of Figure 188, the Network Registration and BW Request Contention Slots shall always be grouped contiguously as Request Slots. To insure interoperability, these request slots shall use UL burst profiles that all BSs and SSs can support. All UL bursts excluding network registration slots shall use a SSTG (between bursts) that is specified as a UCD channel descriptor parameter. Since larger time uncertainties may be experienced on the network registration slots, a special Network Registration SSTG channel descriptor parameter shall be associated with the network registration slots. The Network Registration SSTG specification includes both the length of the RxDS and additional guard symbols. The additional guard symbols used by the Network Registration SSTG are designated by ‘GS’ in Figure 188.

The UL-MAP in the DL FCH governs the location, burst size, and burst profiles for exclusive BW grants to SSs. Burst profile selection may be based on the effects of distance, interference and environmental factors on transmission from the SS.

8.3.3.1.4.1.2 Generating a Continuous DL from a Burst DL

A continuous DL may be derived from a burst DL by null payload filling the end of a burst, to insure that it spans an entire DL frame. By so doing, a burst DL is forced to suppress both the RxDS and ramp up burst elements, because burst DLs are mandated suppress these elements when a DL MAC frame is full. To insert null payload fill, the last entry in the DL MAP of an FCH shall specify the burst profile for the null fill data type. Clause 8.3.3.1.3.1.3 contains details on the null payload fill data type.

8.3.3.1.4.1.3 FDD Channel Descriptor Field Definitions

This clause identifies channel descriptor formats for a system using a FDD downlink.

8.3.3.1.4.1.3.1 DL Channel Descriptor Parameters

Each Downlink Channel Descriptor (DCD) message channel descriptor shall include the following TLV encodings:

Downlink_Burst_Profile

BS EIRP
Frame Duration Code
DCD Channel ID

8.3.3.1.4.1.3.2 DL Burst Descriptor Parameters

Each DCD message burst descriptor shall include the following TLV encodings:

Modulation Type
Reed Solomon Information Bytes (K)
Reed Solomon Parity Bytes (R)
BTC Row Code Type
BTC Column Code Type
BTC Interleaving Type
DIUC Mandatory Exit Threshold
DIUC Minimum Entry Threshold
Preamble Length
CC-specific Parameters
Unique Word Length
Pilot Word Parameters
Transmit Diversity Type
Block Interleaver Depth
DL Burst Transition Gap
Alamouti Parameters

8.3.3.1.4.1.3.3 UL Channel Descriptor Parameters

Each Uplink Channel Descriptor (UCD) message channel descriptor shall include the following TLV encodings:

Uplink_Burst_Profile
Symbol Rate
Frequency
SS Transition Gap
Roll-Off Factor
Contention-Based Reservation Timeout
Channel Width
Network Registration SSTG

8.3.3.1.4.1.3.4 UL Burst Descriptor Parameters

Each UCD message burst descriptor shall include the following TLV encodings:

Modulation Type
Preamble Length
RS Information Bytes (K)
RS Parity Bytes (R)
BTC Row Code Type
BTC Column Code Type
BTC Interleaving Type
Block Interleaver Depth

CC-specific Parameters
Preamble Parameters
Unique Word Length
Pilot Word Parameters
Transmit Diversity Type
Alamouti Parameters

8.3.3.1.4.2 TDD

TDD multiplexes the UL and DL on the same carrier, over different time intervals within the same MAC frame.

Figure 189 illustrates TDD operation with a single-burst TDM downlink. In TDD, the DL and UL alternate between occupying a shared MAC frame, with the DL sub-frame preceding the uplink sub-frame. The size of shared MAC frame shall be constant; however, the DL and UL sub-frame sizes within the shared MAC frame shall vary according to allocations directed by the UL-MAP and DL-MAP. Although Figure 189 illustrates a single TDM burst per DL sub-frame, the capability to accommodate several TDM bursts is mandatory, with the first burst in the DL duplex sub-frame containing the Frame Control Header.

When more than one bursts are to be transmitted within a single DL MAC sub-frame, the DL-MAP of the first payload in the follow-up burst shall have a burst profile with its DL Burst Transition Gap (DL-BTG) entry enabled. The DL-BTG is a burst profile parameter. When enabled, the DL-BTG also indicates the length of the gap between bursts. The DL-BTG includes the RxDS terminating such a burst, and thus, when enabled, shall be specified to be at least as long as the RxDS.

Most framing elements within TDD are found in FDD and perform the same functions; therefore, for descriptions of these elements, consult clause 8.3.3.1.4.1.1. The only frame element in TDD not found in FDD is the Tx/Rx Transition Gap (TTG), which separates the downlink sub-frame from the uplink sub-frame. The length of the TTG is a DCD channel profile parameter.

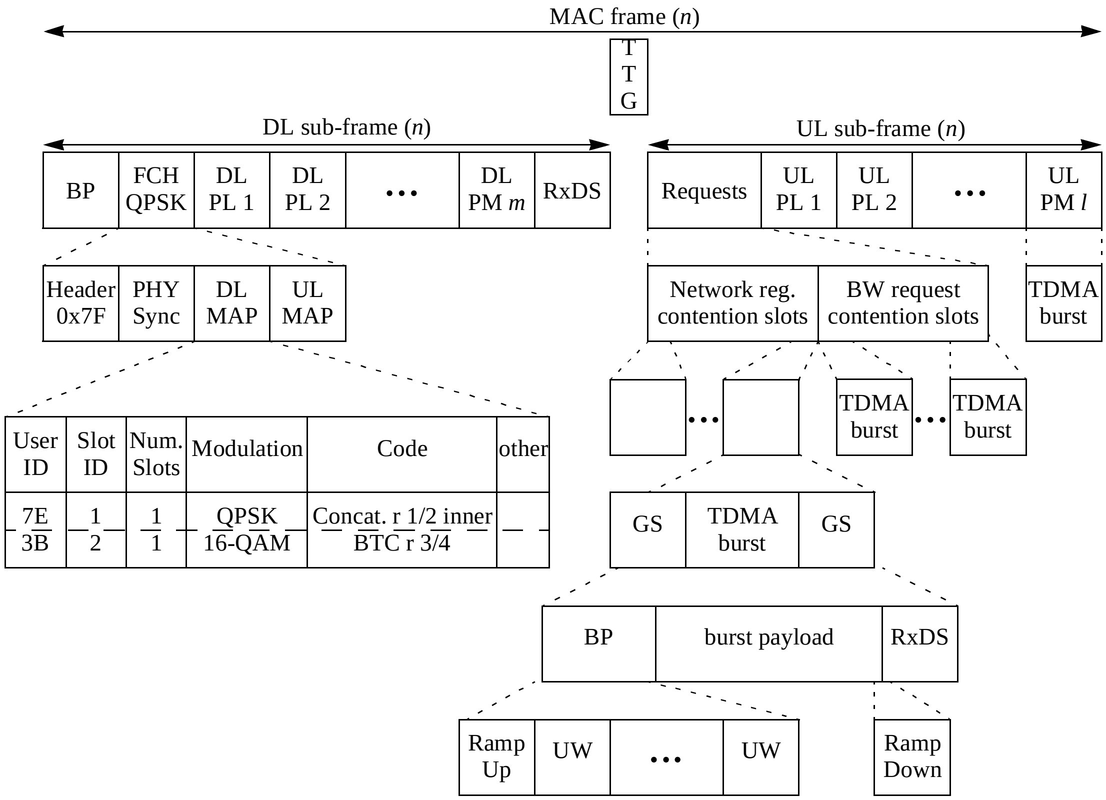

Figure 189—Example of TDD with single-burst TDM DL sub-frame

8.3.3.1.4.2.1 TDD Channel Descriptor Field Definitions

This clause identifies channel descriptor formats for a system using a TDD downlink.

8.3.3.1.4.2.1.1 DL Channel Descriptor Parameters

Each Downlink Channel Descriptor (DCD) message channel descriptor shall include the following TLV encodings:

Downlink_Burst_Profile
BS EIRP
Frame Duration Code
DCD Channel ID
TTG

8.3.3.1.4.2.1.2 DL Burst Descriptor Parameters

Each DCD message burst descriptor shall include the following TLV encodings:

Modulation Type
Reed Solomon Information Bytes (K)
Reed Solomon Parity Bytes (R)
BTC Row Code Type
BTC Column Code Type

BTC Interleaving Type
DIUC Mandatory Exit Threshold
DIUC Minimum Entry Threshold
Preamble Length
CC-specific Parameters
Unique Word Length
Pilot Word Parameters
Transmit Diversity Type
Block Interleaver Depth
DL Burst Transition Gap
Alamouti Parameters

8.3.3.1.4.2.1.3 UL Channel Descriptor Parameters

Each Uplink Channel Descriptor (UCD) message channel descriptor shall include the following TLV encodings:

Uplink_Burst_Profile
Symbol Rate
Frequency
SS Transition Gap
Roll-Off Factor
Contention-Based Reservation Timeout
Channel Width
Network Registration SSTG

8.3.3.1.4.2.1.4 UL Burst Descriptor Parameters

See clause 8.3.3.1.4.1.3.4.

~~Each UCD message burst descriptor shall include the following TLV encodings:~~

~~Modulation Type~~
~~Preamble Length~~
~~RS Information Bytes (K)~~
~~RS Parity Bytes (R)~~
~~BTC Row Code Type~~
~~BTC Column Code Type~~
~~BTC Interleaving Type~~
~~Block Interleaver Depth~~
~~CC-specific Parameters~~
~~Preamble Parameters~~
~~Unique Word Length~~
~~Pilot Word Parameters~~
~~Transmit Diversity Type~~
~~Alamouti Parameters~~

8.3.3.1.4.3 Burst Profiles for Standard Bursts

In order to inter-operate with any base station, a SS must be capable of

decoding DL bursts containing a Frame Control Header; and
sending Request messages over a contention channel in a format that the BS is seeking.

8.3.3.1.4.3.1 DL Bursts Containing a Frame Control Header

A compliant SS shall be capable of demodulating a Frame Control Header with the parameters listed in Table 205 and Table 206; a compliant BS shall be capable of transmitting FCHs using one of these sets.

Table 205—DCD channel profile setting for Broadcast FCH message

DCD Channel Profile Parameter	Default Setting	Alternatives that shall supported by auto-detection or SW initialization
Roll-off factor	0.25	---

Table 206—DCD burst profile settings for DL burst containing for Broadcast FCH

DCD Burst Profile Parameter	Default Setting	Alternatives that shall supported by auto-detection or SW download parameterization
Modulation Type (FCH payload only)	QPSK, Concatenated FEC without block interleaving	---
Inner (CC) Code Rate (FCH payload only)	1/2	---
RS Parameters	base $K = 239$ bytes; K variable via shortening with fixed $R = N - K = 16$ bytes	---
Preamble Length	length = $m\,U + R_r$ symbs; $m = 3$ repeated UWs; $R_r = 4$ ramp symbs	$2 \le m < 11$; $0 \le R \le \frac{U}{2} \le 60$ in increments of 4 symbs
Unique Word Length	$U = 64$ symbs	$U = 16, 256$ (optional for some symb rates)
Pilot Word Parameters	$n = 0$ repeated UWs; $F = 256$ symb interval	n=1,2; F= 256 (when $U \neq 256$), $F = 1024$
Transmit Diversity Type	None	---

8.3.3.1.4.3.2 Bursts on Request Slots

A compliant SS shall be capable of formatting a Request over a Network Registration Slot or BW Request using all combinations of the channel and burst settings listed in Table 207 and Table 208. A compliant BS shall designate at least one of these combinations as the expected format in its UL MAPs for these slots.

Table 207—UCD channel profile settings for UL Request Contention Slots

UCD Channel Profile Parameter	Default Setting	Alternatives that shall be supported by a SS transmitter
Roll-off factor	0.25	---
SS Transition Gap Length	0 symbs + RxDS (UW) length	0-50 symbs + RxDS (UW) length
Network Registration SSTG	30 symbs + RxDS (UW) length	0-500 symbs + RxDS length

Table 208—UCD burst profile settings for UL Contention Slots

UCD Burst Profile Parameter	Default Setting	Alternatives that shall be supported by a SS transmitter
Modulation Type	QPSK, Concatenated FEC without block interleaving	---
Inner Code Rate	1/2	---
RS Parameters	base $K = 239$ bytes; K variable via shortening with fixed $R = N - K = 16$ bytes	---
Preamble Length	length = $mU + R_r$ symbs; $m = 3$ repeated UWs; $R_r = 4$ ramp symbs	$2 \le m < 11$; $0 \le R \le \frac{U}{2} \le 60$ in increments of *4* symbs
Unique Word Length	$U = 64$ symbs	$U = 16, 256$ (optional for some symb rates)
Pilot Word Parameters	$n = 0$ repeated UWs $F = 256$ symb interval	$n = 1,2$; $F = 256$ (when $U \ne 256$), $F = 1024$
Transmit Diversity Type	None	---

8.3.3.1.4.4 Burst Profiles for non-Broadcast and non-Contention Messages

Burst profiles for non-broadcast and non-contention messages are adaptive (and potentially negotiable). Such burst profiles are specified by the MAC management encodings of clause 11.1.

8.3.3.1.4.5 PHY-Specific Frame Control Header Definitions

8.3.3.1.4.5.1 DL Information

8.3.3.1.4.5.1.1 PHY Synchronization Field

Table 209 provides the format of the PHY Synchronization Field of the Frame Control message described in 6.2.2.3.2.

Table 209—SC2 PHY synchronization field

Syntax	Size	Notes
PHY_synchronization_field() {		
Frame duration code()	8 bits	
Frame number	24 bits	
Allocation_Start_Time	32 bits	
}		

Frame duration code()- See clause 8.3.3.1.4.5.1.2 and Table 210.

Frame number- The Frame number. Is incremented by 1 each frame and eventually wraps around to zero.

Allocation_Start_Time- Effective start time of the downlink allocation defined by the DL-MAP in units of mini-slots. This start time is relative to the start of the frame in which the DL-MAP message is transmitted.

8.3.3.1.4.5.1.2 Frame duration codes

Table 210 indicates the various frame durations that are allowed. The actual frame time used by the DL can be determined by the periodicity of the frame start preambles.

Table 210—Frame duration codes

Code(N)	Nominal frame duration (T_F ms)
0-6	*N/2+2*
7-11	*N-1*
12-255	Reserved

A frame is an integer multiple of minislots long, with the multiple being chosen such that the resulting actual duration is as close as possible to a nominal frame duration listed in Table 210. For TTD systems, the TTG shall be no less than 5 μs in duration.

When using Alamouti STC Encoding, the frame shall contain (in addition to all other requirements) an even number of dual blocks. This requirement shall also be taken into account when choosing an actual frame duration.

8.3.3.1.4.5.1.3 Number of Information Elements

The number of downlink IE that may appear in a single MAP message is 255. The field occupies 8 bits.

8.3.3.1.4.5.1.4 Information Element Format

The information elements of Table 212 are used in DL-MAP messages. The format for these DL-MAP messages is specified in Table 211.

Table 211—SC2 DL-MAP information element format

Syntax	Size	Notes
DL-MAP_Information_Element() {		
DIUC	4 bits	
Offset	12 bits	
}		

DIUC: Downlink Interval Usage Code (see Table 91 in clause 8.2.5.1.2.5)

Offset: Offset (in units of mini-slots) to the start of the data burst from the mini-slot boundary specified by the downlink Allocation_Start_Time.

Table 212—SC2 Downlink Interval Usage Codes

IE Name	DIUC	Minislot Offset
Reserved	0	Reserved
Data Grant 1	1	Starting offset of data grant 1 burst type
Data Grant 2	2	Starting offset of data grant 1 burst type
Data Grant 3	3	Starting offset of data grant 1 burst type
Data Grant 4	4	Starting offset of data grant 1 burst type
Data Grant 5	5	Starting offset of data grant 1 burst type
Data Grant 6	6	Starting offset of data grant 1 burst type
Data Grant 7	7	Starting offset of data grant 1 burst type
Data Grant 8	8	Starting offset of data grant 1 burst type
Data Grant 9	9	Starting offset of data grant 1 burst type
Data Grant 10	10	Starting offset of data grant 1 burst type
Data Grant 11	11	Starting offset of data grant 1 burst type
Data Grant 12	12	Starting offset of data grant 1 burst type
Gap	13	Start offset of an unallocated frame interval
Null	14	Ending offset of the previous grant. Used to bound the length of the last actual interval allocation.
Expansion	15	Number of additional 32-bit words in the preceding IE.

8.3.3.1.4.5.2 UL Information

8.3.3.1.4.5.2.1 Number of Information Elements

The number of uplink information elements that may appear in a single map message is 255. The field occupies 8 bits.

8.3.3.1.4.5.2.2 Information Element Format

The information elements of Table 214 are used in UL-MAP messages. The format for these UL-MAP messages is specified in Table 213.

Table 213—SC2 UL-MAP information element format

Syntax	Size	Notes
UL-MAP_Information_Element() {		
CID	16 bits	
UIUC	4 bits	
Offset	12 bits	
}		

Connection Identifier (CID)- Represents the assignment of the IE to a unicast, multicast, or broadcast address. When specifically addressed to allocate a bandwidth grant, the CID may be either the Basic CID of the SS or a Traffic CID for one of the connections of the S.S

Uplink Interval Usage Code (UIUC)- A four-bit code used to define the type of uplink access and the burst type associated with that access. A Burst Descriptor shall be included in an UCD message for each Uplink Interval Usage Code that is to be used in the UL-MAP. The UIUC shall be one of the values defined in Table 108 of clause 8.2.6.1.2.

Offset- Indicates the start time, in units of mini-slots, of the burst relative to the Allocation Start Time given in the UL-MAP message. Consequently, the first IE will have an offset of 0. The end of the last allocated burst is indicated by allocating a NULL burst (CID = 0 and UIUC = 14) with zero duration. The time instants indicated by offsets are the transmission times of the first symbol of the burst including preamble.

.

Table 214—SC2 UL-MAP information elements

IE Name	UIUC	CID	Mini-slot Offset
Reserved	0	NA	Reserved for future use
Request	1	any	Starting offset of REQ region
Initial Maintenance	2	broadcast	Starting offset of MAINT region (used in Initial Ranging)
Station Maintenance	3	unicast	Starting offset of MAINT region (used in Periodic Ranging)
Data Grant Burst Type 1	4	unicast	Starting offset of Data Grant Burst Type 1 assignment
Data Grant Burst Type 2	5	unicast	Starting offset of Data Grant Burst Type 2 assignment
Data Grant Burst Type 3	6	unicast	Starting offset of Data Grant Burst Type 3 assignment
Data Grant Burst Type 4	7	unicast	Starting offset of Data Grant Burst Type 4 assignment
Data Grant Burst Type 5	8	unicast	Starting offset of Data Grant Burst Type 5 assignment
Data Grant Burst Type 6	9	unicast	Starting offset of Data Grant Burst Type 6 assignment
Null IE	10	zero	Ending offset of the previous grant. Used to bound the length of the last actual interval allocation.
Empty	11	zero	Used to schedule gaps in transmission
Reserved	12-14	any	Reserved
Expansion	15	expanded UIUC	# of additional 32-bit words in this Information Element

Alamouti Parameters

8.3.3.1.5 Baseband Pulse Shaping

Prior to modulation, I and Q signals shall be filtered by square-root raised cosine. A roll-off factor of $\alpha = 0.25$ shall be supported; 0.15 and 0.18 are optional, but defined settings. The ideal square-root cosine is defined in the frequency domain by the transfer function

$$H(f) = \begin{cases} 1 & |f| < f_N(1-\alpha) \\ \sqrt{\frac{1}{2} + \frac{1}{2}\sin\left(\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right)} & f_N(1-\alpha) \le |f| \le f_N(1+\alpha) \\ 0 & |f| \ge f_N(1+\alpha) \end{cases}$$

where

$$f_N = \frac{1}{2T_S} = \frac{R_S}{2},$$

f_N is the Nyquist frequency, T_s is the modulation symbol duration, and R_s is the symbol rate.

8.3.3.1.6 Quadrature modulation

Define the quadrature modulated transmit waveform $s(t)$ as

$$s(t) = I(t)\cos(2\pi f_c t) - Q(t)\sin(2\pi f_c t)$$

where $I(t)$ and $Q(t)$ are the filtered baseband signals of the I and Q symbols and f_c is the carrier frequency.

8.3.3.1.7 Power control

Power control shall be supported on the UL, using both initial calibration and periodic adjustment procedures, and without loss of data. To support this, a BS shall be capable of making accurate power measurements of a received signal burst, nominally using the specifications for measurements found in clause 8.3.3.2.2. This measurement can then be compared against a reference level, and the resulting error fed back to a SS in a calibration message from the MAC.

Although its exact implementation is not specified, the power control algorithm shall be designed to respond power fluctuations at rates of no more than TBD dB/second and depths of at least TBD dB. Clause 8.3.3.4.1.6 provides recommendations on overall power control range, stepsize, and absolute accuracy in an implementation.

A power control algorithm shall also account for the interaction of the RF power amplifier with different burst profiles. For example, when changing from the QAM modulation of one burst profile to another, amplifier back-off margins shall be maintained to prevent peak clipping and violation of emissions masks and/or excessive transmitter EVM.

8.3.3.2 Channel quality measurements

8.3.3.2.1 Introduction

RSSI, CINR, and uncoded BER signal quality measurements and associated statistics can aid in such processes as BS selection/assignment and burst adaptive profile selection. As channel behavior is time-variant, both mean and standard deviation statistics for RSSI and CINR are defined, while only a mean statistic for uncoded BER is defined.

The process by which RSSI measurements are taken does not necessarily require receiver demodulation lock; for this reason, RSSI measurements offer reasonably reliable channel strength assessments even at low signal levels. On the other hand, although CINR measurements require receiver lock, they provide information on the actual operating condition of the receiver, including interference and noise levels, and signal strength. CINR measurements also tend to have much more resolution than BER measurements in assessing channel quality, especially at high CINRs.

8.3.3.2.2 RSSI mean and standard deviation

When collection of RSSI measurements is mandated by the BS, a SS shall obtain an RSSI measurement from the data associated with MAC MAP messages. From a succession of RSSI measurements, the SS shall derive and update estimates of the mean and the standard deviation of the RSSI, and report them when solicited via RNG-REQ messages.

Mean and standard deviation statistics shall be reported in units of dBm. To prepare such reports, statistics shall be quantized in 1 dB increments, ranging from a maximum of -60 dBm (encoded 0x3F) to a minimum of -123 dBm (encoded 0x00). Values outside this range shall be assigned the closest extreme value within the scale.

The method used to estimate the RSSI of a single message is left to individual implementation, but the relative accuracy of a single signal strength measurement, taken from a single message, shall be +/- 2 dB, with an absolute accuracy of +/- 4 dB. This shall be the case over the entire range of input RSSIs. In addition, the range over which these single-message measurements are measured should extend 3 dB on each side beyond the –60 dBm to -123 dBm limits for the final averaged statistics that are reported.

The (linear) mean RSSI statistics (in mW), derived from a multiplicity of single messages, shall be updated using

$$\hat{\mu}_{RSSI}[k] = \begin{cases} R[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{RSSI}[k-1] + \alpha R[k] & k > 0 \end{cases} \quad \text{mW}$$

where k is the time index for the message (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.), $R[k]$ is the RSSI in mW measured during message k, and α is an averaging parameter specified by the BS. The mean estimate in dBm shall then be derived from

$$\hat{\mu}_{RSSI\ dBm}[k] = 10\log(\hat{\mu}_{RSSI}[k]) \quad \text{dBm}.$$

To solve for the standard deviation in dB, the expectation-squared statistic shall be updated using

$$\hat{x}^2_{RSSI}[k] = \begin{cases} |R[0]|^2 & k = 0 \\ (1-\alpha)\hat{x}^2_{RSSI}[k-1] + \alpha|R[k]|^2 & k > 0 \end{cases}$$

and the result applied to

$$\hat{\sigma}_{RSSI\ dB} = 5\log(|\hat{x}^2_{RSSI}[k] - (\hat{\mu}_{RSSI}[k])^2|) \quad \text{dB}.$$

8.3.3.2.3 CINR mean and standard deviation

When Carrier-to-Interference-and-Noise-Ratio (CINR) measurements are mandated by the BS, a SS shall obtain a CINR measurement from the data associated with MAC MAP messages. From a succession of these measurements, the SS shall derive and update estimates of the mean and the standard deviation of the CINR, and report them when solicited via RNG-REQ messages

Mean and standard deviation statistics for CINR shall be reported in units of dB. To prepare such reports, statistics shall be quantized in 1 dB increments, ranging from a minimum of -10 dB (encoded 0x00) to a maximum of 53 dB (encoded 0x3F). Values outside this range shall be assigned the closest extreme value within the scale.

The method used to estimate the CINR of a single message is left to individual implementation, but the relative and absolute accuracy of a CINR measurement derived from a single message shall be +/-1 dB and +/-2 dB, respectively, for all input CINRs above 0 dB. In addition, the range over which these single-packet measurements are measured should extend 3 dB on each side beyond the –10 dB to 53 dB limits for the final reported, averaged statistics.

One possible method to estimate the CINR of a single message is by normalizing the mean-squared residual error of detected data symbols (and/or pilot symbols) by the average signal power using

$$CINR[k] = \frac{A[k]}{E[k]},$$

where $CINR[k]$ is the (linear) CINR for message k, $r[k, n]$ is received symbol n within message k; $s[k, n]$ the corresponding detected or pilot symbol corresponding to received symbol n;

$$A[k] = \sum_{n=0}^{N-1} |s[k, n]|^2$$

is the average signal power, which is normally kept constant within a message by action of AGC; and

$$E[k] = \sum_{n=0}^{N-1} |r[k, n] - s[k, n]|^2.$$

The mean CINR statistic (in dB) shall be derived from a multiplicity of single messages using

$$\hat{\mu}_{CINR\ dB}[k] = 10\log(\hat{\mu}_{CINR}[k]),$$

where

$$\hat{\mu}_{CINR}[k] = \begin{cases} CINR[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{CINR}[k-1] + \alpha CINR[k] & k > 0 \end{cases}$$

k is the time index for the message (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.); $CINR[k]$ is a linear measurement of CINR (derived by any mechanism which delivers the prescribed accuracy) for message k; and α is an averaging parameter specified by the BS.

To solve for the standard deviation, the expectation-squared statistic shall be updated using

$$\hat{x}^2_{CINR}[k] = \begin{cases} |CINR[0]|^2 & k = 0 \\ (1-\alpha)\hat{x}^2_{CINR}[k-1] + \alpha|CINR[k]|^2 & k > 0 \end{cases}$$

and the result applied to

$$\hat{\sigma}_{CINR\ dB} = 5\log(|\hat{x}^2_{CINR}[k] - (\hat{\mu}_{CINR}[k])^2|) \quad \text{dB}.$$

8.3.3.2.4 Uncoded mean BER

When uncoded BER measurements are mandated by the BS, a SS shall obtain an uncoded BER measurement from the data associated with MAC MAP messages. From a succession of these measurements, the SS shall derive and update an estimate of the mean of the uncoded BER. The SS shall then be capable of reporting this mean BER estimate via RNG-REQ messages.

The mean statistic shall be reported in integer-quantized $10\log_{10}$(BER) units, spanning from –3 (BER=5e-1 in linear terms) to –66 (BER=2.5e-7 in linear terms). Values that exceed the extremes of –3 and –66 shall be encoded using the codes for the extreme values. These results shall be encoded into 6-bit words such that 0x00 represents -66 and 0x3F represents -3.

The uncoded BER of a single message shall be derived XORing an uncoded bit stream with a reference bit stream, and recording the number of dissimilar bit locations as well of the length of the bit stream. The BER is then calculated from the ratio of the number of bit errors to the total number of bits in the message to form the BER measurement, $BER[k]$, for message k.

The bit decisions for the uncoded bit stream are derived by directly slicing the incoming symbol stream, without passing the data to the FEC for decoding. The bit decisions for the reference stream are derived by obtaining bit decisions from the FEC output (or the output of sub-element within the FEC, such as the inner code decoder) and re-encoding these bit decisions.

The mean BER statistic shall then be updated using

$$\hat{\mu}_{BER}[k] = \begin{cases} BER[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{BER}[k-1] + \alpha BER[k] & k > 0 \end{cases}$$

where k is the time for message k (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.); and α is an averaging parameter supplied by the BS as a system parameter.

The logarithmic form used for BER reports shall be computed using

$$\hat{\mu}_{BER\ dB}[k] = 10\log(\hat{\mu}_{BER}[k]) \quad \text{dB}.$$

8.3.3.3 Antenna Diversity Systems

Diversity techniques are likely to find application in some broadband wireless installations. Receive diversity does not require special considerations on the part of the air interface or framing. With two-way delay transmit diversity, where two transmit antennas are used and the output of the second antenna is delayed with respect to the first, the considerations are minor. Namely, both receiver equalization and framing must be adequate to accommodate the extra delay spread introduced in the system due to the delayed output of the second transmitter.

However, framing considerations arise when the Alamouti transmit diversity scheme [B30] is to be used. Clause 8.3.3.3.1 describes the Alamouti transmit diversity scheme for the SC2 PHY and specifies framing that shall be used in its implementation.

8.3.3.3.1 Alamouti Transmit Diversity

Implementation of Alamouti transmit diversity is optional.

The Alamouti transmit diversity scheme logically pairs blocks of data separated by delay spread guard intervals. These paired blocks are jointly processed at both the transmitter and receiver. The technique to be described is particularly amenable to a frequency domain equalizer implementation.

8.3.3.3.1.1 Paired Block Transmit Processing

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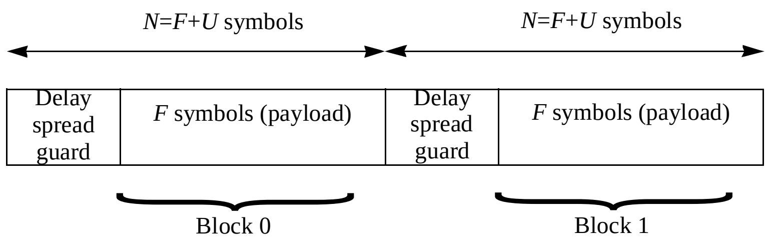

Figure 190—Paired blocks used in Alamouti transmit diversity combining

Figure 190 illustrates block pairing that shall be used by the Alamouti transmit diversity scheme. Let $\{s_0[n]\}$ and $\{s_1[n]\}$ represent two sequences, each of length F symbols ($0 \le n < F$), that are desired to be delivered to a receiver using the Alamouti transmit diversity scheme. Table 215 indicates the block multiplexing structure that a two antenna transmitter shall use to transmit the two sequences over the paired blocks illustrated in Figure 190. As Table 215 indicates, Transmit Antenna 0 shall transmit its data sequences in order, with no modifications. However, Transmit Antenna 1 must not only reverse the order in which its blocks are transmitted, but must also conjugate the transmitted complex symbols and must also time-reverse---cyclically about zero, modulo-*F*---the sequence of data symbols within each block. Clause 8.3.3.3.1.4 provides details on the composition of the delay spread guard intervals between the blocks illustrated in Figure 190.

Table 215—Multiplexing arrangement for block Alamouti processing

TX Antenna	Block 0	Block 1
0	$\{s_0[n]\}$	$\{s_1[n]\}$
1	$\{-s_1^*[(F-n)mod(F))]\}$	$\{s_0^*[(F-n)mod(F))]\}$

8.3.3.3.1.2 Paired Block Receive Processing

If $S_0(e^{j\omega})$, $S_1(e^{j\omega})$, $H_0(e^{j\omega})$, $H_1(e^{j\omega})$, $N_0(e^{j\omega})$, and $N_1(e^{j\omega})$ represent the Discrete-time Fourier transforms, respectively, of the symbol sequences $\{s_0[n]\}$ and $\{s_1[n]\}$, channel impulse responses (for the channels associated with each transmitter antenna) $\{h_0[n]\}$ and $\{h_1[n]\}$, and additive noise sequences (associated with each block) $\{n_0[n]\}$ and $\{n_1[n]\}$, the received signals associated with each block, interpreted in the frequency domain, are:

$$R_0(e^{j\omega}) = H_0(e^{j\omega})S_0(e^{j\omega}) - H_1(e^{j\omega})S_1^*(e^{j\omega}) + N_0(e^{j\omega}) \quad (6)$$

$$R_1(e^{j\omega}) = H_0(e^{j\omega})S_1(e^{j\omega}) + H_1(e^{j\omega})S_0^*(e^{j\omega}) + N_1(e^{j\omega}) \quad (7)$$

Assuming that the channel responses $H_0(e^{j\omega})$ and $H_1(e^{j\omega})$ are known, one shall use the frequency domain combining scheme

$$C_0(e^{j\omega}) = H_0^*(e^{j\omega})R_0(e^{j\omega}) + H_1(e^{j\omega})R_1^*(e^{j\omega}) \quad (8)$$

$$C_1(e^{j\omega}) = -H_1(e^{j\omega})R_0^*(e^{j\omega}) + H_0^*(e^{j\omega})R_1(e^{j\omega}) \quad (9)$$

to obtain the combiner outputs

$$C_0(e^{j\omega}) = (\left|H_0(e^{j\omega})\right|^2 + \left|H_1(e^{j\omega})\right|^2)S_0(e^{j\omega}) + H_0^*(e^{j\omega})N_0(e^{j\omega}) + H_1(e^{j\omega})N_1^*(e^{j\omega}) \quad (10)$$

$$C_1(e^{j\omega}) = (\left|H_0(e^{j\omega})\right|^2 + \left|H_1(e^{j\omega})\right|^2)S_1(e^{j\omega}) - H_1(e^{j\omega})N_0^*(e^{j\omega}) + H_0^*(e^{j\omega})N_1(e^{j\omega}) \quad (11)$$

The combiner outputs of Eq. 10 and Eq. 11 can then be independently equalized using frequency domain equalizer techniques (see [B21], for an example) to obtain estimates for $\{s_0[n]\}$ and $\{s_1[n]\}$.

8.3.3.3.1.3 Channel Estimation Using Pilot Symbols

The channel responses used by the equalizer(s) can be estimated using data received during pilot symbol intervals. Under the assumption that pilot symbols are the same in the 0 and 1 blocks, i.e., $S_0^{pilot}(e^{j\omega}) = S_1^{pilot}(e^{j\omega}) = S_{pilot}(e^{j\omega})$, the sum and differences of Eq. 6 and Eq. 5 can be multiplied by $S_{pilot}^*(e^{j\omega})$ to yield (ignoring noise terms):

$$S_{pilot}^*(e^{j\omega})(R_0^{pilot}(e^{j\omega}) + R_1^{pilot}(e^{j\omega})) = 2\left|S_{pilot}e^{j\omega}\right|^2 H_0(e^{j\omega}) \quad (12)$$

$$S_{pilot}(e^{j\omega})(R_1^{pilot}(e^{j\omega}) - R_0^{pilot}(e^{j\omega})) = 2\left|S_{pilot}e^{j\omega}\right|^2 H_1(e^{j\omega}) \quad (13)$$

The channel estimation task simply involves dividing the left hand sides of Eq. 11 and 12 by a constant independent of frequency, since pilot symbols are derived from the Unique Words of clause 8.3.3.1.3.2, and these Unique Words have a constant frequency domain magnitude, *i.e.*, $\left|S_{pilot}(e^{j\omega})\right|^2 = \left|S_{UW}(e^{j\omega})\right|^2 = C$.

8.3.3.3.1.4 Paired Block Profiles

Figure 191 and Figure 192 illustrate two defined frame (burst) profiles for Alamouti transmit diversity signaling.

Figure 191 illustrates the baseline framing structure for Alamouti transmit multiplexing. This is cyclic-prefix-based frame structure, with U-symbol cyclic prefixes, and F-symbol repetitions chosen to facilitate efficient FFT-based processing at the receiver. Note that although the cyclic prefix is not composed of Unique Words, the length, U, must be the same as the Unique Word length being used by the burst profile. Observe that the payload portions of Figure 191 reflect the Alamouti antenna multiplexing format described in Table 215 for Transmit Antennas 0 and 1. Note that a UW may be inserted within Payloads 0 and 1 to facilitate the use of frequency domain equalizers with time-domain decision feedback taps.

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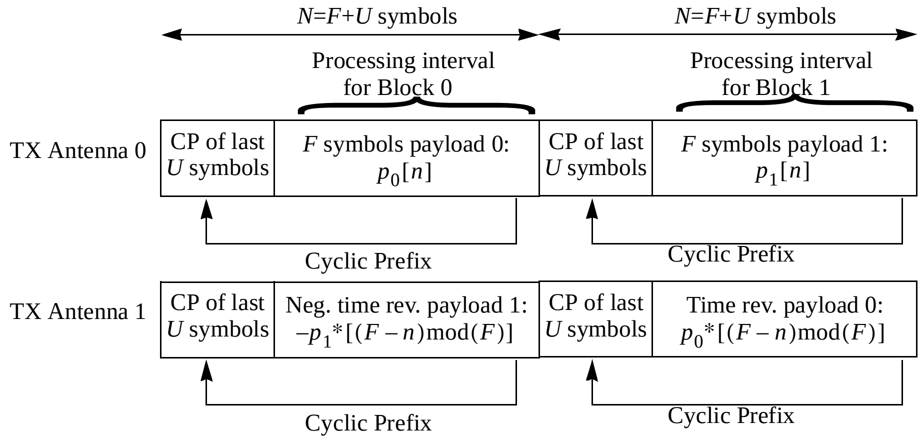

Figure 191—Cyclic prefix-based Alamouti framing

Figure 192 illustrates another burst profile which explicitly uses Unique Words, rather than a repetition of the payload data, to generate cyclic prefixes.

F, the length of an Alamouti block, is a burst profile parameter. The choice of the burst profile for the paired blocks, i.e., the scheme illustrated in Figure 191 or the scheme illustrated in Figure 192, is also a burst profile parameter.

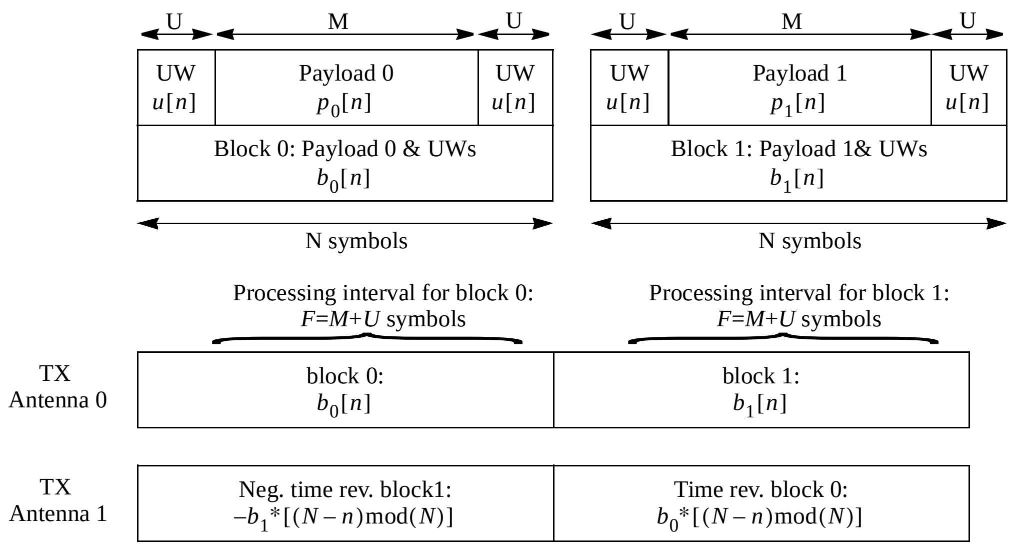

Figure 192—Alamouti framing using UWs as cyclic prefixes

8.3.3.3.1.5 Alamouti Burst Elements

An Alamouti Burst shall consist of a preamble, followed by a payload, which may consist of multiple pairs of Alamouti blocks.

Unlike conventional bursts, a ~~length-U~~ RxDS element shall not appear at the conclusion of an Alamouti burst.

8.3.3.3.1.5.1 Burst Preamble

Figure 193 illustrates the burst frame preamble that shall be used for bursts using Alamouti transmit diversity encoding. The number of UW blocks composing an Alamouti burst preamble is a burst profile parameter, through reuse of the general burst profile encoding for the number of UWs in a Preamble. However, since two channels must be estimated, the total number of UWs used to construct an Alamouti burst preamble shall be twice the number specified in the burst profile encoding.

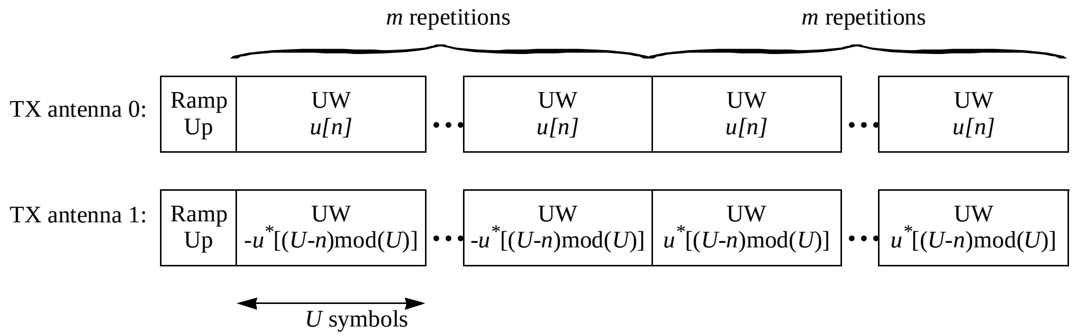

Figure 193—Alamouti frame preamble

Note that this preamble structure may also be inserted within a transmission as a group of contiguous Pilot Words, to assist in channel estimation and updating within a burst. In such an instance, this contiguous pilot symbol structure is considered external to the paired Alamouti payload data blocks illustrated in Figure 191, although the pilots may appear after every L^{th} paired payload block, where L is an integer greater than or equal to 1.

8.3.3.3.1.5.1.1 Ramp Up

Ramp-up shall use the same procedure described in clause 8.3.4.1.3.1.1.2, with the exception that the ramp up symbols for each transmit antenna are duplicates of the last R_r symbols of the first length-U data element in the Preamble. Note that this implies that first transmit antennas derives its ramp up symbols from a standard Unique word sequence $\{u[n]\}$, while second transmit antenna derives its ramp up symbols from the sequence $\{-u^*[(U-n)mod(U)]\}$.

8.3.3.3.1.5.2 Payload Data

Payload data within an Alamouti-encoded burst shall be formatted into block pairs, with each block pair possessing one of the block pair profiles described in 8.3.3.3.1.4. If not enough data is available to fill the last block pair, then the payload must be filled with null payload fill, as specified in clause 8.3.4.1.3.1.3. Except for the payload fill, modulations are sequenced in terms of decreasing modulation robustness on the Tx Ant 0 channel.

8.3.3.3.1.5.2.1 Pilot Words

The preamble structure of Figure 193, minus the ramp-up symbols, may also be inserted within a transmission as a group of contiguous Pilot Words, to assist in channel estimation and updating within a burst. In such an instance, this contiguous pilot symbol structure is considered external to the paired Alamouti payload data blocks illustrated in Figure 191, although the pilots may appear after every K^{th} paired payload block, where K is an integer greater than or equal to 1. The pilot word repetition interval, and the number of UWs composing a pilot word is a burst profile parameter.

8.3.3.3.1.5.3 Ramp Down

Ramp down follows the end of a burst. A transmitter shall ramp down by inserting zero symbol inputs into the transmit filter memory following the last intended data symbol, and windowing the resulting, transmit-filtered output waveform with a multiplicative raised cosine window that diminishes to zero in R_r symbols. The (Alamouti burst) ramp-down interval, R_r, shall be the same as the ramp-up interval.

8.3.3.3.2 Interoperability with Non-Alamouti-encoded Bursts

For interoperability reasons, Alamouti-encoded data and conventionally-encoded data shall not be time division multiplexed within the same burst. Instead, the Alamouti data shall be encapsulated within its own burst, and possess its own preamble.

All bursts with different Alamouti pair block sizes, *F*, shall also be segregated, although they may share the same preamble.

On a mixed DL containing both Alamouti-encoded bursts and conventional bursts, the FCH shall be transmitted at the beginning of the DL MAC sub-frame using conventional encoding. If the DL transmits primarily Alamouti-encoded data, then a FCH (describing frame control details for Alamouti-encoded data) may be Alamouti encoded and transmitted---if all SSs support the Alamouti block size *F* used for this FCH data.

8.3.3.4 Minimum Performance Recommendations

8.3.3.4.1 System Requirements

8.3.3.4.1.1 Channel Frequency Accuracy

RF channel frequency accuracy for a SS should be within +/-15 parts per million (ppm) of the selected RF carrier over a temperature range of –40 to +65 degrees C operational and up to 5 years from the date of manufacture of the equipment manufacture.

A BS can generally support the use of highly stable ovenized and/or disciplined oscillators with minimal overall system cost impact. For this reason, the frequency accuracy for a BS shall be within +/-4 ppm of the selected RF carrier over an operational temperature range of –40 to +65 degrees C, up to 10 years from the date of equipment manufacture.

8.3.3.4.1.2 Carrier Phase Noise

A BS transmitter should exceed an integrated double sideband carrier phase noise of 1.1 degrees RMS from 10 kHz to 2 MHz, while an SS transmitter should exceed 2.3 degrees RMS from 10 kHz to 2 MHz. These values should be suitable to meet the detection requirements for the respective highest mandatory modulation indices for the DL (64-QAM) and UL (16-QAM).

8.3.3.4.1.3 Symbol Rate

Carrier frequency stability, analog filter responses, the roll-off factor of a root-raised-cosine (RRC) filter, as well as spectral mask requirements are considerations when selecting an operating symbol rate. Table 216 provides sample recommendations on nominal symbol rates for several RF channel bandwidths, when

QPSK signaling is used. In this example, assumptions include frequency stabilities of 15 ppm in the SS and 4 ppm in the BS, as well as a roll-off factor for the RRC filter of 0.25,

Table 216—Nominal symbol rates for a sample system using QPSK and a roll-off factor of 0.25.

Channel Bandwidth (MHz)	Nominal Symbol Rate (Msymb/s)
25	19.84
20	15.84
14	11.04
10	7.84
7	5.44
6	4.64
5	3.84
3.5	2.64
3	2.24
1.75	1.24
1.5	1.04

8.3.3.4.1.4 Symbol Timing Jitter

The minimum-to-maximum difference of symbol timing over a 2 second period should be less than 2% of the nominal symbol period. This jitter specification should be maintained over an operational temperature range of –40 to +65 degrees C.

8.3.3.4.1.5 Transmitter Minimum SNR and EVM

A transmitted signal should have an SNR of no less than 40 dB at the transmit antenna feed point. The transmitter EVM should be no greater than 3.1%, assuming 64-QAM.

8.3.3.4.1.6 Transmitter Power Level Control

A SS transmitter should provide 50 dB of power level control with a tolerance of +/-3 dB and step size of 1 dB. A BS transmitter should provide 20 dB of power level control with a tolerance of +/-3 dB and stepsize of 1 dB.

8.3.3.4.1.7 Ramp up/down Requirements

During ramp up and ramp down of burst power, transmit output power should be within +/- 3 dB of the desired average power within 5 µs. Transients due to the transmit filter impulse response should be factored into settling time calculations.

8.3.3.4.1.8 Spurious Emissions during burst On/Off transients

A transmitter shall control spurious emissions to conform with applicable regulatory requirements. This includes prior to and during ramp up, during and following ramp down, and before and after a burst in a TDM/TDMA scheme.

8.3.3.4.1.9 Out of Band Spurious Emissions

Out of band spurious emissions shall conform with applicable local regulatory spectral masks and bandwidths described in clause 8.3.1.

8.3.3.4.1.10 Receiver Sensitivity

Recommendations on the threshold sensitivity value for a receiver, referenced to the receiver input, are as follows. These figures are intended to represent uncoded 10^{-6} BER performance, with no framing or coding overhead included.

$$\eta_{QPSK} = -93.4 + 10*\log(BW)$$

$$\eta_{16\text{-}QAM} = -86.6 + 10*\log(BW)$$

$$\eta_{64\text{-}QAM} = -80.4 + 10*\log(BW)$$

These figures were computed using the formula: -114 + 10*log(BW) + SNR_{req} + NF, where

BW - Bandwidth in MHz (.125 to 28 MHz);
SNR_{req} - Required SNR for 10^{-6} BER and no FEC coding
NF - Noise figure of the radio (conservatively, 7 dB assumed)
the constant -114 dBm = 10 log(k*T / 1 mW) + 10 log(1 MHz)
k = Boltzmann's Constant (1.3807 x 10^{-23})
T = Temperature in Kelvin (290 K).

SNR_{req} values (for uncoded signals at 10^{-6} BER) used in computing these values were:

QPSK: 13.6 dB
16 QAM: 20.4 dB
64 QAM: 26.6 dB.

8.3.3.4.1.11 Receiver Maximum Input Signal

A BS should be capable of receiving a maximum on-channel operational signal of –40 dBm and should tolerate a maximum input signal of 0 dBm without damage to circuitry. A SS should be capable of receiving a maximum on-channel operational signal of –20 dBm and should tolerate a maximum input signal of 0 dBm without damage to circuitry.

8.3.4 WirelessMAN-OFDM and WirelessMAN-OFDMA PHY Layer

8.3.4.1 Introduction

The WirelessMAN-OFDM and WirelessMAN-OFDMA ([B27], [B28]) PHYs, both based on OFDM modulation, are designed for operation in the 2-11 GHz frequency bands per clause 1.2.4.

Clauses 8.3.4.1 and 8.3.4.2 define common characteristics of these two PHYs, while clause 8.3.4.3 provides details specific to the OFDM PHY and clauses 8.3.4.4 and 8.3.4.5 provide details specific to the OFDMA PHY. Clause 8.3.4.6 contains PHY features specifically designed for 5 GHz license-exempt operation.

~~This clause is informative only.~~

~~The PHY specified in this clause is based on OFDM (Orthogonal Frequency Division Multiplex) modulation. Depending on the selected mode, it can support Time Division Multiple Access (TDMA) as well as Orthogonal Frequency Division Multiple Access (OFDMA) [B27], [B28]. This flexibility ensures that the system can be optimized both for short burst type of applications, as well as more streaming type oriented applications and provides a seamless development migration path from various existing OFDM-based standards.~~

~~The PHYs in this clause are designed for operation in 2-11 GHz frequency bands. The PHY features in clause 8.3.4.6 have been designed specifically for 5 GHz license-exempt operation.~~

8.3.4.1.1 Generic OFDM Symbol description

The OFDM symbol duration, or the related carrier spacing in frequency, is a major design parameter of an OFDM system. The symbol duration is composed of the FFT interval and of the Cyclic Prefix (CP) (see clause 8.3.4.1.2).

The number of carriers utilized, N_{used}, is usually only about 83% of the FFT bins (see 8.3.4.1.3). For implementation reasons, this number is chosen to be about 83% of the nearest power of 2. This choice involves implementation aspects of anti-aliasing filters. Note that the choice of FFT size is an artificial implementation parameter. For example a modulation of less than 256 carriers can be implemented either with a FFT of size 256, or with a FFT of size 512 at double sampling rate. We will stick with the convention, in which OFDM modes are denoted by the "FFT size" which is the smallest power of two above the number of carriers.

8.3.4.1.2 Time domain description.

Inverse-Fourier-transforming creates the OFDM waveform; this time duration is referred to as the useful symbol time T_b. A copy of the last samples is inserted before the useful symbol time, and is called the Cyclic Prefix (CP); its duration T_g is denoted as a fraction of the useful symbol time. The two together are referred to as the symbol time T_s. Figure 194 illustrates this structure.

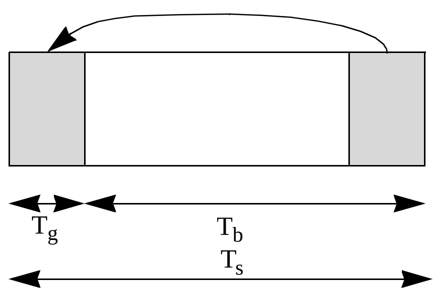

Figure 194—OFDM Symbol time structure

A cyclic extension of T_g µs is used to collect multipath, while maintaining the orthogonality of the tones. The transmitter energy increases with the length of the guard time while the receiver energy remains the same (the cyclic extension is discarded), so there is a $10\log(1 - T_g/(T_b + T_g))/\log(10)$ dB loss in SNR. Using a cyclic extension, the samples required for performing the FFT at the receiver can be taken anywhere over the length of the extended symbol. This provides multipath immunity as well as a tolerance for symbol time synchronization errors.

On initialization, a SS should search all possible values of CP until it finds the CP being used by the BS. Once a specific CP duration has been selected by the BS for operation on the DL, it should not be changed. Changing the CP would force all the SSs to resynchronize to the BS.

The CP overhead fraction can be reduced by using larger FFT intervals (i.e. a larger FFT size). Larger FFT intervals do however, among other things, adversely affect the sensitivity of the system to phase noise of the oscillators. To facilitate a choice in this trade-off, the designed PHY provides for various FFT sizes.

8.3.4.1.3 Frequency Domain Description

The frequency domain description includes the basic structure of an OFDM symbol.

An OFDM symbol is made up from carriers, the number of which of determines the FFT size used. There are several carrier types:

- Data carriers - for data transmission
- Pilot carriers - for various estimation purposes
- Null carriers - no transmission at all, for guard bands and DC carrier.

Figure 195 illustrates such a scheme:

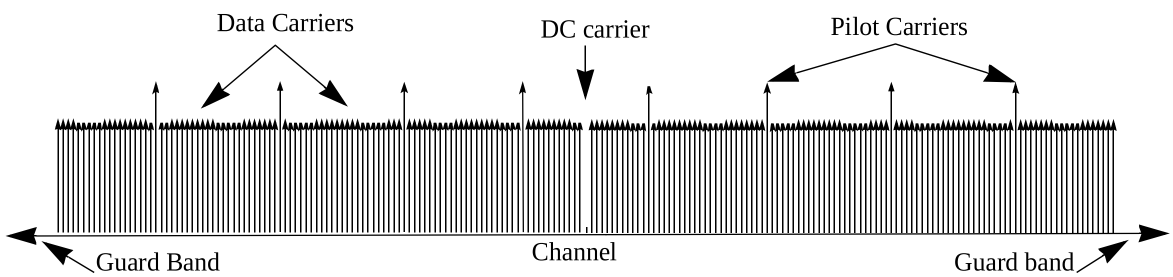

Figure 195—OFDM frequency description (256-FFT example)

The purpose of the guard bands is to enable the signal to naturally decay and create the FFT "brick Wall" shaping.

In the OFDMA mode, only part of all active carriers may be used by the transmitter, the different carriers of which may be intended for different (groups of) receivers. A set of carriers intended for one (group of) receiver(s) is termed a subchannel. The carriers forming one subchannel may, but need not be adjacent. The concept is shown in Figure 196.

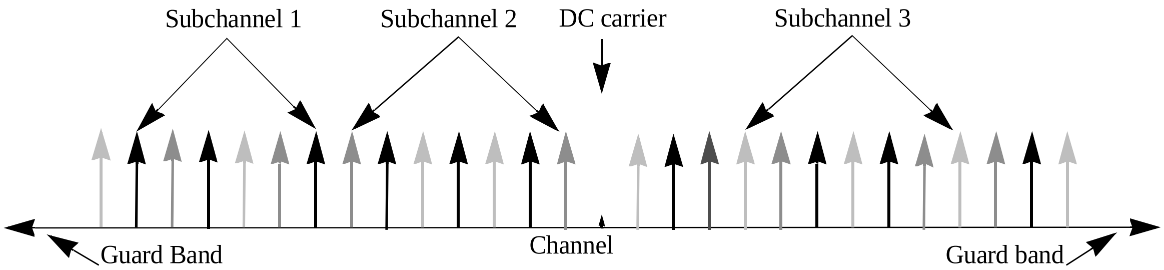

Figure 196—OFDMA frequency description (3 channel schematic example)

The symbol is divided into logical subchannels to support scalability, multiple access, and advanced antenna array processing capabilities. The subchannel structure will depend on the purpose for the subchannelization. For wideband processing, the mapping is based upon a special permutation code, which distributes consecutive symbols across the available bandwidth.

The number of carriers in the OFDMA mappings assigned to each subchannel is independent of the FFT size. For example doubling the FFT size hence results in twice the number of subchannels.

8.3.4.2 Common characteristics

This clause describes elements common to the OFDM and OFDMA PHY layers specifications.

8.3.4.2.1 OFDM Symbol Parameters

8.3.4.2.1.1 Primitive Parameters

Four primitive parameters characterize the OFDM symbol:

BW. This is the nominal channel bandwidth.

(F_s/BW). This is the ratio of “sampling frequency” to the nominal channel bandwidth. Required values of this parameter are specified in clause 8.3.4.3.3 for WirelessMAN-OFDM and clause 8.3.4.4.3 for WirelessMAN-OFDMA.

(T_g/T_b). This is the ratio of CP time to “useful” time. All PHYs shall support the following values: 1/32, 1/16, 1/8, 1/4.

N_{FFT}. This is the number of points in the FFT, if an FFT is used in the implementation.

8.3.4.2.1.2 Derived Parameters

The following parameters are defined in terms of the primitive parameters of clause 8.3.4.2.1.1.

$F_s = (F_s/BW) \cdot BW$ = Sampling Frequency

$\Delta f = F_s/N_{FFT}$ = Carrier Spacing

$T_b = 1/\Delta f$ = Useful Time

$T_g = (T_g/T_b) \cdot T_b$ = CP Time

$T_s = T_b + T_g$ = OFDM Symbol Time

$1/F_s$ = Sample Time

8.3.4.2.2 Duplexing modes

To provision bi-directional operation in licensed bands, the PHY shall support FDD, H-FDD or TDD. In license-exempt bands only TDD shall be supported.

TDD flexibility permits efficient allocation of the available bandwidth and hence is capable of efficiently allocating the available traffic transport capacity for applications whose uplink to downlink traffic transport demand ratio can vary with time. TDD operates in single, paired or non-contiguous blocks of frequencies. FDD /H-FDD can be used by applications that require fixed asymmetric allocation between their uplink and downlink traffic transport demand. FDD and H-FDD operate in paired downlink / uplink sub-bands.

8.3.4.2.3 Channel Coding

8.3.4.2.3.1 Scrambling (Randomization)

Data randomization is performed on data transmitted on the DL and UL. The randomization is performed on each allocation (DL or UL), which means that for each allocation of a data block (subchannels on the frequency domain and OFDM symbols on the time domain) the randomizer shall be used independently. If the amount of data to transmit does not fit exactly the amount of data allocated, padding of FFx ('1' only) shall be added to the end of the transmission block, up to the amount of data allocated.

The shift-register of the randomizer shall be initialized for each new allocation or for every 1250 bytes passed through (if the allocation is larger then 1250 bytes).

The Pseudo Random Binary Sequence (PRBS) generator shall be $1 + X^{14} + X^{15}$ as shown in Figure 197. Each data byte to be transmitted shall enter sequentially into the randomizer, msb first. Preambles are not randomized.The seed value, which must be used to calculate the randomization output is combined in an XOR operation with the first bit of data of each burst. The randomizer sequence is applied only to information bits.

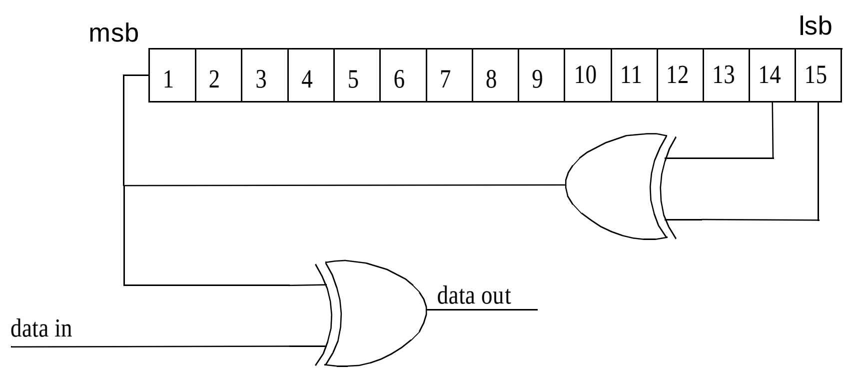

Figure 197—PRBS for Data Randomization

The bit issued from the randomizer shall be applied to the FEC encoder.

In the downlink, the scrambler shall be re-initialized at the start of each frame with the sequence:

1 0 0 1 0 1 0 1 0 0 0 0 0 0 0.

The uplink initialization of the randomizer is defined for OFDM in clause 8.3.4.3.4.1. and for OFDMA in clause 8.3.4.4.4.1.

8.3.4.2.3.2 FEC

A FEC, consisting of the concatenation of a Reed-Solomon outer code and a rate-compatible convolutional inner code, shall be supported on the uplink and downlink. Support of BTC is optional. The Reed-Solomon-Convolutional coding rate 1/2 shall always be used as the coding mode when requesting access to the network (except when using focused contention or CDMA ranging) and in the FCH burst or DL Frame Prefix.

8.3.4.2.3.2.1 Concatenated Reed-Solomon / convolutional code (RS-CC)

The Reed-Solomon encoding shall be derived from a systematic RS (N=255, K=239, T=8) code using GF(2^8), where:

- N number of overall bytes after encoding
- K-number of data bytes before encoding
- T- number of data bytes which can be corrected

The following polynomials are used for the systematic code:

- Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots(x+\lambda^{2T-1}), \lambda = 02_{HEX}$
- Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

This code is shortened and punctured to enable variable block sizes and variable error-correction capability. When a block is shortened to K' data bytes, the first 239-K' bytes of the encoder block shall be zero. When a codeword is punctured to permit T' bytes to be corrected, only the first 2T' of the total 16 codeword bytes shall be employed. The bit/byte conversion shall be msb first.

Each RS block is encoded by the binary convolutional encoder, which shall have native rate of 1/2, a constraint length equal to K=7, and shall use the following generator polynomials codes to derive its two code bits:

$$\begin{aligned} G_1 &= 171_{OCT} \qquad FOR\ X \\ G_2 &= 133_{OCT} \qquad FOR\ Y \end{aligned} \tag{14}$$

The generator is depicted in Figure 172.

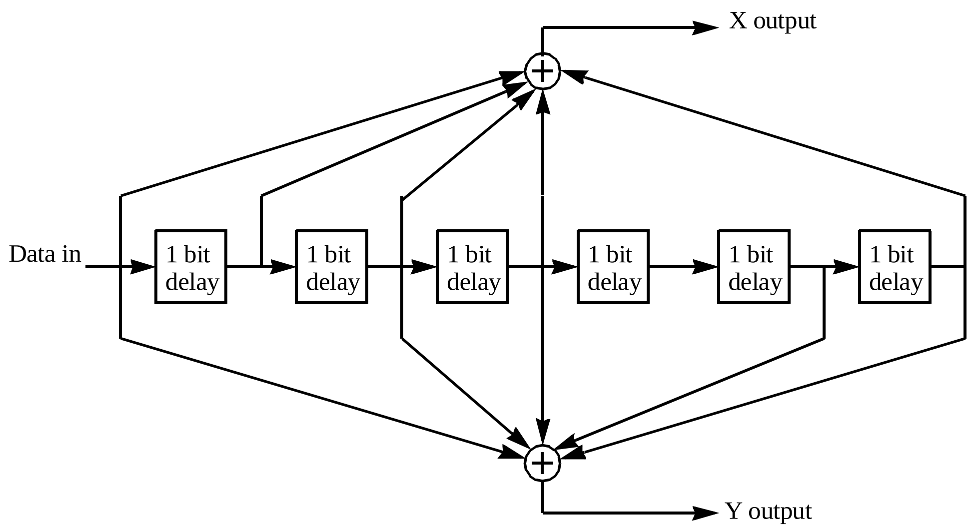

Figure 198—Convolutional encoder of rate 1/2

The convolutional encoding shall be terminated using tail biting, which is achieved by initializing the encoders memory with the last data bits of the RS block being encoded.

Puncturing patterns and serialization order which shall be used to realize different code rates are defined in Table 198. In the table, “1” means a transmitted bit and “0” denotes a removed bit, whereas X and Y are in reference to Figure 172.

Table 217—The inner Convolutional code with Puncturing Configuration

	Code Rates		
Rate	2/3	3/4	5/6
d_{free}	6	5	4
X	10	101	10101
Y	11	110	11010
XY	$X_1Y_1Y_2$	$X_1Y_1Y_2X_3$	$X_1Y_1Y_2X_3Y_4X_5$

8.3.4.2.3.2.2 Block Turbo Coding (BTC)

The BTC is based on the product of two simple component codes, which are binary extended Hamming codes or parity check codes from the set depicted in Table 202.

Table 218—BTC component codes

Component code (n,k)	Code type
(64,57)	Extended Hamming Code
(32,26)	Extended Hamming Code
(16,11)	Extended Hamming Code
(32,31)	Parity Check Code
(16,15)	Parity Check Code
(8,7)	Parity Check Code

Table 203 specifies the generator polynomials for the Hamming codes. To create extended Hamming codes, an overall even parity check bit is added at the end of each code word.

Table 219—Hamming code generator polynomials

n’	k’	Generator polynomial
7	4	X^3+X^1+1
15	11	X^4+X^1+1
31	26	X^5+X^2+1
63	57	X^6+X+1

The component codes are used in a two dimensional matrix form, which is depicted in Figure 200. The k_x information bits in the rows are encoded into n_x bits, by using the component block (n_x, k_x) code specified for the respective composite code. After encoding the rows, the columns are encoded using a block code (n_y, k_y), where the check bits of the first code are also encoded. The overall block size of such a product code is $n = n_x \times n_y$, the total number of information bits $k = k_x \times k_y$ and the code rate is $R = R_x \times R_y$, where $R_i = k_i / n_i$, $i=x, y$. The Hamming distance of the product code is $d = d_x \times d_y$. Data bit ordering for the composite BTC matrix is the first bit in the first row is the lsb and the last data bit in the last data row is the msb.

Figure 199 illustrates an example of a BTC encoded with $(8, 4) \times (8, 4)$ extended Hamming component codes.

D_{11}	D_{21}	D_{31}	D_{41}	E_{51}	E_{61}	E_{71}	E_{81}
D_{12}	D_{22}	D_{32}	D_{42}	E_{52}	E_{62}	E_{72}	E_{82}
D_{13}	D_{23}	D_{33}	D_{43}	E_{53}	E_{63}	E_{73}	E_{83}
D_{14}	D_{24}	D_{34}	D_{44}	E_{54}	E_{64}	E_{74}	E_{84}
E_{15}	E_{25}	E_{35}	E_{45}	E_{55}	E_{65}	E_{75}	E_{85}
E_{16}	E_{26}	E_{36}	E_{46}	E_{56}	E_{66}	E_{76}	E_{86}
E_{17}	E_{27}	E_{37}	E_{47}	E_{57}	E_{67}	E_{77}	E_{87}
E_{18}	E_{28}	E_{38}	E_{48}	E_{58}	E_{68}	E_{78}	E_{88}

Figure 199—Example of an encoded BTC block

Transmission of the block over the channel shall occur in a linear fashion, with all bits of the first row transmitted left to right followed by the second row, etc. For the $(8,4)\times(8,4)$ example in Figure 199, the output order for the 64 encoded bits would be: D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22},..., E_{88}.

To match a required packet size, BTCs may be shortened by removing symbols from the BTC array. In the two-dimensional case, rows, columns or parts thereof can be removed until the appropriate size is reached.

There are three steps in the process of shortening product codes:

- The first step is to remove I_x rows and I_y columns from the 2-dimensional code. This is equivalent to shortening the constituent codes that make up the product code.
- The second step of shortening is achieved by removing *B* individual bits from the first row of the 2-dimensional code starting with the lsb.
- The third step is dependant upon the specified product code having a non-integral number of data bytes. In this case, the *Q* left over lsb bits are zero filled by the encoder. After decoding at the receive end, the decoder shall strip off these unused bits and only the specified data payload is passed to the next higher level in the physical layer. The same general method is used for shortening the last code word in a message where the available data bytes do not fill the available data bytes in a code block.

These three processes of code shortening are depcited in Figure 200. In the first 2 dimensional BTC, a non-shortened product code is shown. By comparison, a shortened BTC is shown in the adjacent 2 dimensional array. The new coded block length of the code is $(n_x-I_x)(n_y-I_y)-B$. The corresponding information length is given as $(k_x-I_x)(k_y-I_y)-B-Q$. Consequently, the code rate is given by:

$$R = \frac{(k_x-I_x)(k_y-I_y)-B-Q}{(n_x-I_x)(n_y-I_y)-B} \quad (15)$$

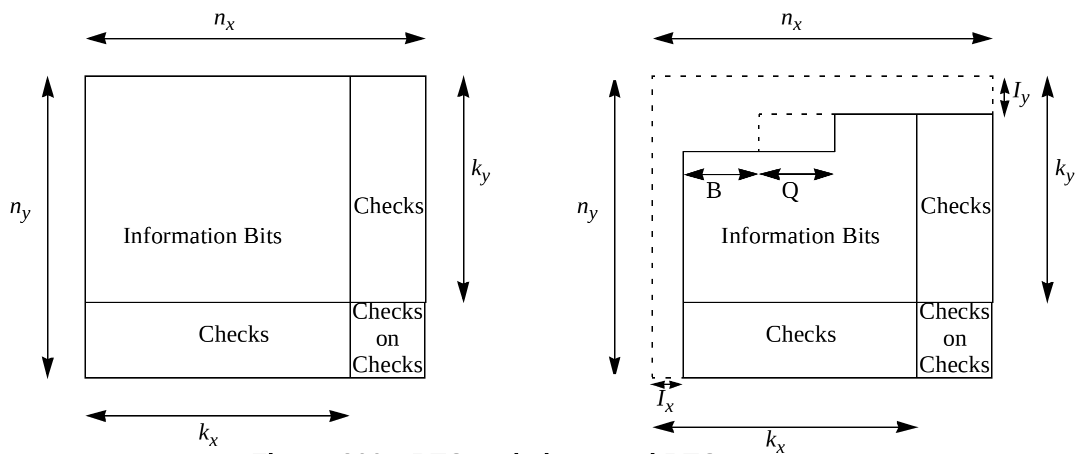

Figure 200—BTC and shortened BTC structure

8.3.4.2.3.3 Interleaving

All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of coded bits per the smallest possible allocation, N_{CBPS}. Hence, for OFDM, N_{CBPS} = 192 and for OFDMA, N_{CBPS} = 144. The interleaver is defined by a two step permutation. The first ensures (for OFDM) that adjacent coded bits are mapped onto nonadjacent carriers. The second permutation insures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of lowly reliable bits.

Let N_{CBPS} be the number of bits per carrier, i.e. 2, 4 or 6 for QPSK, 16QAM or 64QAM, respectively. Let s = max(N_{CBPS}/2,1). Let *k* be the index of the coded bit before the first permutation at transmission, *m* be the index after the first and before the second permutation and *j* be the index after the second permutation, just prior to modulation mapping.

The first permutation is defined by the rule:

$$m = (N_{CBPS}/16) \cdot k_{mod\,16} + floor(k/16) \qquad k = 0, 1, \ldots, N_{CBPS} - 1 \qquad (16)$$

The second permutation is defined by the rule:

$$j = s \cdot floor(m/s) + (m + N_{CBPS} - floor(16 \cdot m/N_{CBPS}))_{mod\,s} \qquad m = 0, 1, \ldots, N_{CBPS} - 1 \qquad (17)$$

The de-interleaver, which performs the inverse operation, is also defined by two permutations. Let *j* be the index of the received bit before the first permutation, *m* be the index after the first and before the second permutation and *k* be the index after the second permutation, just prior to delivering the coded bits to the convolutional decoder.

The first permutation is defined by the rule:

$$m = s \cdot floor(j/s) + (j + floor(16 \cdot j/N_{CBPS}))_{mod\,s} \qquad j = 0, 1, \ldots, N_{CBPS} - 1 \qquad (18)$$

The second permutation is defined by the rule:

$$k = 16 \cdot m - (N_{CBPS} - 1) \cdot floor(16 \cdot m/N_{CBPS}) \qquad m = 0, 1, \ldots, N_{CBPS} - 1 \qquad (19)$$

The first permutation in the de-interleaver is the inverse of the second permutation in the interleaver, and conversely.

8.3.4.2.4 Modulation

8.3.4.2.4.1 Data modulation

After bit interleaving, the data bits are entered serially to the constellation mapper. Gray-mapped QPSK and 16QAM as shown in Figure 180 shall be supported, whereas the support of 64QAM is optional. The constellations as shown in Figure 180 shall be normalized by multiplying the constellation point with the factor *c* as shown in Figure 180 to achieve equal average power.

Per-allocation adaptive modulation and coding shall be supported in the DL. The UL shall support different modulation schemes for each user based on the MAC burst configuration messages coming from the Base Station. Complete description of the MAC / PHY support of adaptive modulation and coding is provided in clause 6.2.7.

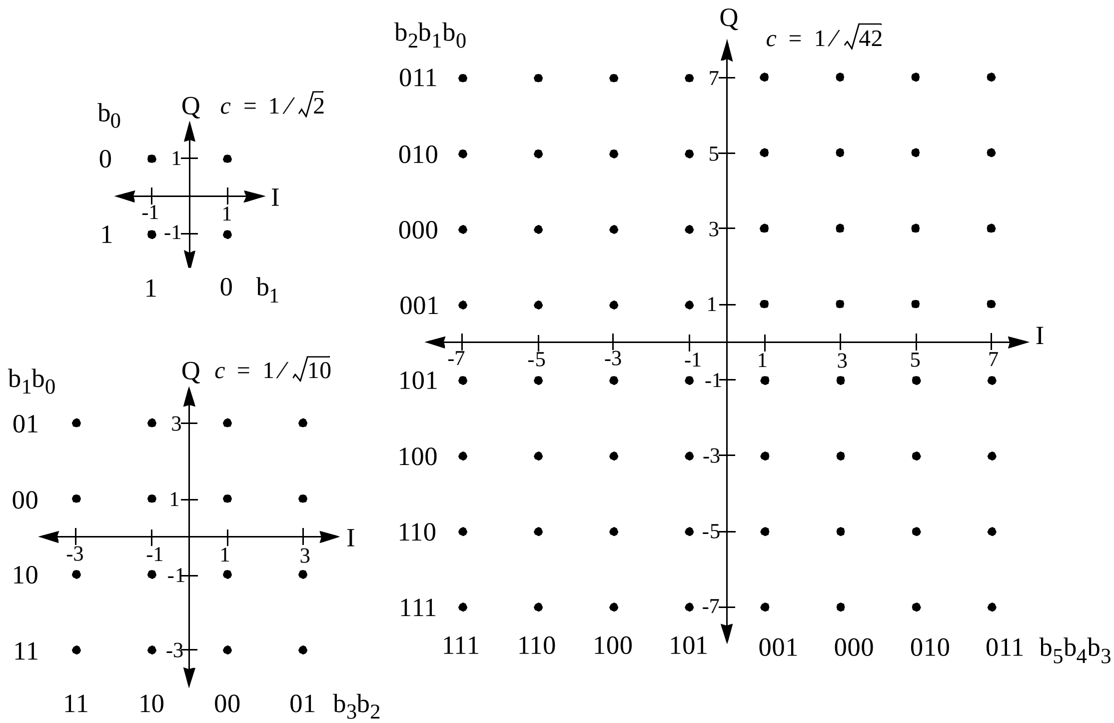

Figure 201—QPSK, 16 QAM and 64 QAM constellations

The constellation-mapped data shall be subsequently modulated onto the allocated data carriers.

8.3.4.2.4.2 Modulation and coding in the DL frame prefix

Rate_ID's, which are used to describe burst profiles, and indicate modulation, coding as well as the cyclic prefix to be used in the first DL burst immediately following the FCH, are shown in Table 220. The Rate_ID encoding is static and cannot be changed during system operation

Table 220—Rate ID encodings

Rate_ID	modulation RS-CC rate
0	QPSK 1/2
1	QPSK 3/4
2	16QAM 1/2
3	16QAM 3/4
4	64QAM 2/3
5	64QAM 3/4
6-15	Reserved

8.3.4.2.4.3 Pilot Modulation

Pilot carriers shall be inserted into each data burst in order to constitute the Symbol and they shall be modulated according to their carrier location within the OFDM symbol. The PRBS generator depicted hereafter shall be used to produce a sequence, w_k. The polynomial for the PRBS generator shall be $X^{11} + X^9 + 1$.

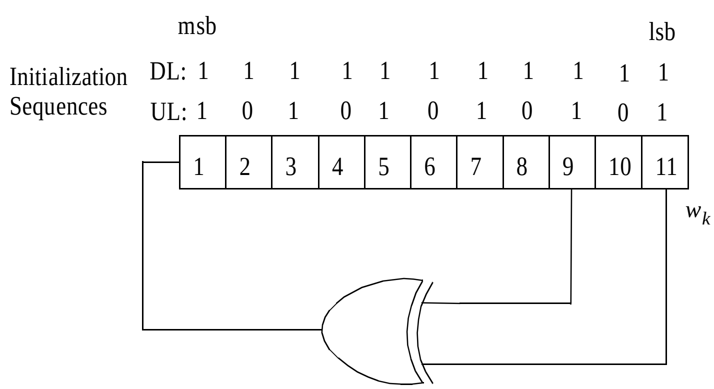

Figure 202—PRBS for pilot modulation

The value of the pilot modulation, on carrier *k*, shall be derived from w_k.

For OFDM mode, the value of the pilot is dependent also on the symbol index l, relative to the beginning of the frame. The pilot *k*, in symbol *l* is given by w_k XOR w_l, where w_l is constructed in the same way as w_k, and is initialized on the first symbol of each frame.

When using data transmission on the DL, the initialization vector of the PRBS is: [11111111111] except for the OFDMA DL PHY preamble (see clause 8.3.4.4.3.4). When using data transmission on the UL the initialization vector of the PRBS will be: [10101010101]. The PRBS shall be initialized so that its first output bit coincides with the first usable carrier (as defined in Table 232 for OFDM and in Table 241 and Table 242 for OFDMA). A new value shall be generated by the PRBS on every usable carrier. For the PBRS allocation, the DC carrier and the side-band carriers are not considered as usable carriers. Each pilot shall be transmitted with a boosting of 2.5 dB over the average power of each data tone, with the exception of the OFDMA UL preamble. The Pilot carriers shall be modulated according to the following formula:

$$\mathrm{Re}\{C_k\} = \frac{8}{3}\left(\frac{1}{2} - w_k\right) \qquad \mathrm{Im}\{C_k\} = 0 \tag{20}$$

For OFDMA, a ranging pilot modulation exception is defined in 8.3.4.4.5.1.4.

8.3.4.2.4.4 Transmitted Signal

Eq. 21specifies the transmitted signal voltage to the antenna, as a function of time, during any OFDM symbol.

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi t f_c t} \sum_{\substack{k = -N_{used}/2 \\ k \neq 0}}^{N_{used}/2} a_k \cdot e^{j2\pi k \Delta f (t - T_g)} \right\} \tag{21}$$

where

t = time, elapsed since the beginning of the subject OFDM symbol, with $0 < t < T_S$.

a_k = a complex number; the data to be transmitted on the carrier whose frequency offset index is *k*, during the subject OFDM symbol. It specifies a point in a QAM constellation.

T_g = guard time

T_S = OFDM symbol duration, including guard time

Δf = carrier frequency spacing

8.3.4.2.5 Control Mechanisms

8.3.4.2.5.1 Synchronization

8.3.4.2.5.1.1 Network Synchronization

For TDD realizations, all Base-Stations may have the facility to be time synchronized to a common timing signal. For FDD realizations, it is recommended (but not required) that all BSs be time synchronized to a common timing signal. In the event of the loss of the network timing signal, BSs shall continue to operate and shall automatically resynchronize to the network timing signal when it is recovered.

For both FDD and TDD realizations, frequency references derived from the timing reference may be used to control the frequency accuracy of Base-Stations provided that they meet the frequency accuracy requirements of clause 8.3.4.2.5.1.3. This applies during normal operation and during loss of timing reference.

8.3.4.2.5.1.2 Frame timing reference

Base stations may be synchronized to a common timing reference. The synchronizing references shall be a 1pps timing pulse and a 10MHz frequency reference. These signals are typically provided by a GPS receiver.

8.3.4.2.5.1.3 Subscriber Station Synchronization

For any duplexing all SSs shall acquire and adjust their timing such that all uplink OFDM symbols arrive time coincident at the Base-Station to a accuracy of +/- 50% of the minimum guard-interval or better.

The frequency accuracy of the BS RF and Baseband reference clocks shall be at least 4 ppm. The user reference clock could be at a 20ppm accuracy, and the user should synchronize to the DL and extract his clock from it, after synchronization the RF frequency would be accurate to 4% of the carrier spacing.

8.3.4.2.5.2 Ranging

Ranging for time (coarse synchronization) and power is performed during two phases of operation; during registration of a new subscriber unit either on first registration or on re-registration after a period TBD of inactivity; and second during FDD or TDD transmission on a periodic basis.

During registration, a new subscriber registers during the random access channel and if successful is entered into a ranging process under control of the base station. The ranging process is cyclic in nature where default time and power parameters are used to initiate the process followed by cycles where (re)calculated parameters are used in succession until parameters meet acceptance criteria for the new subscriber. These parameters are monitored, measured and stored at the base station and transmitted to the subscriber unit for use during normal exchange of data. During normal exchange of data, the stored parameters are updated in a periodic manner based on configurable update intervals to ensure changes in the channel can be accommodated. The update intervals will vary in a controlled manner on a subscriber unit by subscriber unit basis.

Ranging on re-registration follows the same process as new registration.

8.3.4.2.5.3 Power control

As with frequency control, a power control algorithm shall be supported for the uplink channel with both an initial calibration and periodic adjustment procedure without loss of data. The base station should be capable of providing accurate power measurements of the received burst signal. This value can then be compared against a reference level, and the resulting error can be fed back to the subscriber station in a calibration message coming from the MAC sublayer. The power control algorithm shall be designed to support power attenuation due to distance loss or power fluctuations at rates of at most TBD dB/second with depths of at least TBD dB. The exact algorithm implementation is vendor-specific. The total power control range consists of both a fixed portion and a portion that is automatically controlled by feedback. The power control algorithm shall take into account the interaction of the RF power amplifier with different burst profiles. For example, when changing from one burst profile to another, margins should be maintained to prevent saturation of the amplifier and to prevent violation of emissions masks.

8.3.4.2.6 PMP Frame structure

When implementing a TDD system, the frame structure is built from BS and SS transmissions. Each burst transmission consists of two or more OFDM symbols. In each frame, the TX/RX transition gap (TTG) and

RX/TX transition gap (RTG) need to be inserted between the downlink and uplink and at the end of each frame respectively to allow the BS to turn around (time plan for a single frame is shown in Figure 203). TTG and RTG shall be at least 5µs and an integer multiple of the physical slot (PS) duration. For license-exempt implementations, TDD is the only duplexing arrangement allowed.

In FDD systems there is no need for TTG and RTG as the downlink and uplink transmit on independent frequencies (for H-FDD terminals, scheduling rules should avoid TX and RX activity of the same terminal within the TTG and RTG gap time).

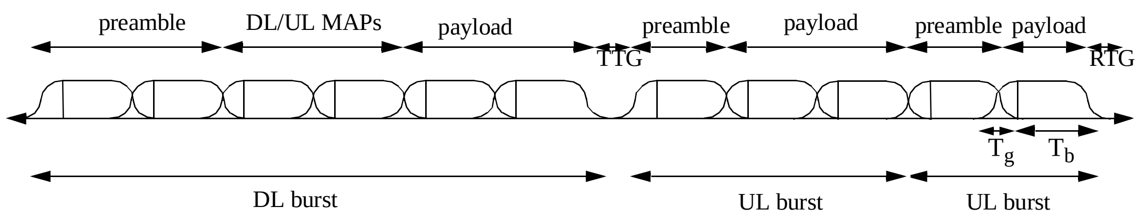

Figure 203—Time Plan - One TDD time frame

For all duplexing types (TDD and FDD), the cell radius is dependent on the time left open for initial system access. This time should be at least equal to the maximum tolerable round trip delay plus the number of OFDM symbols necessary to transmit the ranging burst.

The framing structure used for the DL includes the transmission of a FCH, which is transmitted in the most robust burst profile of the system followed by transmission using burst profiles as defined in the FCH. The MAC layer also defines the DL transmission frame length and the length of the different transmission parts.

In the OFDM mode, the transitions between burst profiles takes place only on OFDM symbol boundaries, in mode OFDMA the transitions between modulations and coding take place on OFDM symbol boundaries in time domain and on subchannels within an OFDM symbol in frequency domain.

8.3.4.2.7 Channel quality measurements

8.3.4.2.7.1 Introduction

RSSI, CINR, and uncoded BER signal quality measurements and associated statistics can aid in such processes as BS selection/assignment and burst adaptive profile selection. As channel behavior is time-variant, both mean and standard deviation statistics for RSSI and CINR are defined, while only a mean statistic for uncoded BER is defined.

The process by which RSSI measurements are taken does not necessarily require receiver demodulation lock; for this reason, RSSI measurements offer reasonably reliable channel strength assessments even at low signal levels. On the other hand, although CINR measurements require receiver lock, they provide information on the actual operating condition of the receiver, including interference and noise levels, and signal strength. CINR measurements also tend to have much more resolution than BER measurements in assessing channel quality, especially at high CINRs.

8.3.4.2.7.2 RSSI mean and standard deviation

When collection of RSSI measurements is mandated by the BS, a SS shall obtain an RSSI measurement from the data associated with MAC MAP messages. From a succession of RSSI measurements, the SS shall derive and update estimates of the mean and the standard deviation of the RSSI, and report them when solicited via RNG-REQ messages.

Mean and standard deviation statistics shall be reported in units of dBm. To prepare such reports, statistics shall be quantized in 1 dB increments, ranging from a maximum of -60 dBm (encoded 0x3F) to a minimum of -123 dBm (encoded 0x00). Values outside this range shall be assigned the closest extreme value within the scale.

The method used to estimate the RSSI of a single message is left to individual implementation, but the relative accuracy of a single signal strength measurement, taken from a single message, shall be +/- 2 dB, with an absolute accuracy of +/- 4 dB. This shall be the case over the entire range of input RSSIs. In addition, the range over which these single-message measurements are measured should extend 3 dB on each side beyond the –60 dBm to -123 dBm limits for the final averaged statistics that are reported.

The (linear) mean RSSI statistics (in mW), derived from a multiplicity of single messages, shall be updated using

$$\hat{\mu}_{RSSI}[k] = \begin{cases} R[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{RSSI}[k-1] + \alpha R[k] & k > 0 \end{cases} \quad \text{mW}$$

where k is the time index for the message (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.), $R[k]$ is the RSSI in mW measured during message k, and α is an averaging parameter specified by the BS. The mean estimate in dBm shall then be derived from

$$\hat{\mu}_{RSSI\ dBm}[k] = 10\log(\hat{\mu}_{RSSI}[k]) \quad \text{dBm}.$$

To solve for the standard deviation in dB, the expectation-squared statistic shall be updated using

$$\hat{x}^2_{RSSI}[k] = \begin{cases} |R[0]|^2 & k = 0 \\ (1-\alpha)\hat{x}^2_{RSSI}[k-1] + \alpha|R[k]|^2 & k > 0 \end{cases}$$

and the result applied to

$$\hat{\sigma}_{RSSI\ dB} = 5\log(\left|\hat{x}^2_{RSSI}[k] - (\hat{\mu}_{RSSI}[k])^2\right|) \quad \text{dB}.$$

8.3.4.2.7.3 CINR mean and standard deviation

When Carrier-to-Interference-and-Noise-Ratio (CINR) measurements are mandated by the BS, a SS shall obtain a CINR measurement from the data associated with MAC MAP messages. From a succession of these measurements, the SS shall derive and update estimates of the mean and the standard deviation of the CINR, and report them when solicited via RNG-REQ messages

Mean and standard deviation statistics for CINR shall be reported in units of dB. To prepare such reports, statistics shall be quantized in 1 dB increments, ranging from a minimum of -10 dB (encoded 0x00) to a maximum of 53 dB (encoded 0x3F). Values outside this range shall be assigned the closest extreme value within the scale.

The method used to estimate the CINR of a single message is left to individual implementation, but the relative and absolute accuracy of a CINR measurement derived from a single message shall be +/-1 dB and +/-2 dB, respectively, for all input CINRs above 0 dB. In addition, the range over which these single-packet measurements are measured should extend 3 dB on each side beyond the –10 dB to 53 dB limits for the final reported, averaged statistics.

One possible method to estimate the CINR of a single message is to compute the ratio of signal power to residual error for each data sample, and then average the results from each data sample, using

$$CINR[k] = \sum_{n=0}^{N-1} \frac{|s[k,n]|^2}{|r[k,n]-s[k,n]|^2}$$

where $r[k,n]$ received sample n within message k; $s[k,n]$ the corresponding detected or pilot sample (with channel state weighting) corresponding to received symbol n.

The mean CINR statistic (in dB) shall be derived from a multiplicity of single messages using

$$\hat{\mu}_{CINR\ dB}[k] = 10\log(\hat{\mu}_{CINR}[k]),$$

where

$$\hat{\mu}_{CINR}[k] = \begin{cases} CINR[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{CINR}[k-1] + \alpha CINR[k] & k > 0 \end{cases}$$

k is the time index for the message (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.); $CINR[k]$ is a linear measurement of CINR (derived by any mechanism which delivers the prescribed accuracy) for message k; and α is an averaging parameter specified by the BS.

To solve for the standard deviation, the expectation-squared statistic shall be updated using

$$\hat{x}^2_{CINR}[k] = \begin{cases} |CINR[0]|^2 & k = 0 \\ (1-\alpha)\hat{x}^2_{CINR}[k-1] + \alpha|CINR[k]|^2 & k > 0 \end{cases}$$

and the result applied to

$$\hat{\sigma}_{CINR\ dB} = 5\log\left(\left|\hat{x}^2_{CINR}[k] - (\hat{\mu}_{CINR}[k])^2\right|\right) \quad \text{dB}.$$

8.3.4.2.7.4 Uncoded mean BER

When uncoded BER measurements are mandated by the BS, a SS shall obtain an uncoded BER measurement from the data associated with MAC MAP messages. From a succession of these measurements, the SS shall derive and update an estimate of the mean of the uncoded BER. The SS shall then be capable of reporting this mean BER estimate via RNG-REQ messages.

The mean statistic shall be reported in integer-quantized $10\log_{10}$(BER) units, spanning from –3 (BER=5e-1 in linear terms) to –66 (BER=2.5e-7 in linear terms). Values that exceed the extremes of –3 and –66 shall be encoded using the codes for the extreme values. These results shall be encoded into 6-bit words such that 0x00 represents -66 and 0x3F represents -3.

The uncoded BER of a single message shall be derived XORing an uncoded bit stream with a reference bit stream, and recording the number of dissimilar bit locations as well of the length of the bit stream. The BER is then calculated from the ratio of the number of bit errors to the total number of bits in the message to form the BER measurement, $BER[k]$, for message k.

The bit decisions for the uncoded bit stream are derived by directly slicing the incoming symbol stream, without passing the data to the FEC for decoding. The bit decisions for the reference stream are derived by obtaining bit decisions from the FEC output (or the output of sub-element within the FEC, such as the inner code decoder) and re-encoding these bit decisions.

The mean BER statistic shall then be updated using

$$\hat{\mu}_{BER}[k] = \begin{cases} BER[0] & k = 0 \\ (1-\alpha)\hat{\mu}_{BER}[k-1] + \alpha BER[k] & k > 0 \end{cases}$$

where k is the time for message k (with the initial message being indexed by $k = 0$, the next message by $k = 1$, etc.); and α is an averaging parameter supplied by the BS as a system parameter.

The logarithmic form used for BER reports shall be computed using

$$\hat{\mu}_{BER\ dB}[k] = 10\log(\hat{\mu}_{BER}[k]) \quad \text{dB}.$$

8.3.4.2.8 Transmitter Requirements

8.3.4.2.8.1 Transmit Power Level Control

The transmitter shall support monotonic power level control of 45dB minimum with resolution of 3dB.

8.3.4.2.8.2 Transmitter Spectral Flatness

The average energy of the constellations in each of the n spectral lines shall deviate no more than the following:

Table 221—Spectral Flatness

Spectral Lines	Spectral Flatness
Spectral lines from $-N_{used}/4$ to -1 and +1 to $N_{used}/4$	+/-2dB from their average energy measured over all N_{used} active tones
Spectral lines from $-N_{used}/2$ to $-N_{used}/4$ and $+N_{used}/4$ to $N_{used}/2$	+2/-4dB from their average energy measured over all N_{used} active tones

This data will be taken from the channel estimation step.

8.3.4.2.8.3 Transmitter Constellation Error and Test Method

The relative constellation RMS error, averaged over carriers, OFDM frames, and packets, shall not exceed a burst profile dependent value according to Table 222.

Table 222—Allowed relative constellation error versus data rate

Burst type	Relative constellation error (dB)
QPSK-1/2	-10
QPSK-3/4	-13
16QAM-1/2	-16
16QAM-3/4	-19
64QAM-1/2	-22
64QAM-2/3	-25

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signal into a stream of complex samples at 20 Msamples/s or more, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, dc offsets, phase noise, etc. For all PHY modes, measurements will be taken with all non-guard carriers active.

The sampled signal shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure [B34]:

a) Start of frame shall be detected.
b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
c) Coarse and fine frequency offsets shall be estimated.
d) The packet shall be de-rotated according to estimated frequency offset.
e) The complex channel response coefficients shall be estimated for each of the carriers.
f) For each of the data OFDM symbols: transform the symbol into carrier received values, estimate the phase from the pilot carriers, de-rotate the carrier values according to estimated phase, and divide each carrier value with a complex estimated channel response coefficient.
g) For each data-carrying carrier, find the closest constellation point and compute the Euclidean distance from it.
h) Compute the RMS average of all errors in a packet. It is given by:

$$\text{Error}_{RMS} = \frac{\sum_{i=1}^{N_f} \frac{\sum_{j=1}^{L_P} \left[\sum_{k=1}^{N_{FFT}} \{ (I(i,j,k) - I_0(i,j,k))^2 + (Q(i,j,k) - Q_0(i,j,k))^2 \} \right]}{P_0 \cdot L_P \cdot N_{FFT}}}{N_f} \quad (22)$$

where

L_P is the length of the packet;

N_f is the number of frames for the measurement;

$(I_0(i,j,k), Q_0(i,j,k))$ denotes the ideal symbol point of the i^{th} frame, j^{th} OFDM symbol of the frame, k^{th} carrier of the OFDM symbol in the complex plane;

$(I(i,j,k), Q(i,j,k))$ denotes the observed point of the i^{th} frame, j^{th} OFDM symbol of the frame, k^{th} carrier of the OFDM symbol in the complex plane;

P_0 is the average power of the constellation.

8.3.4.2.9 Receiver requirements

8.3.4.2.9.1 Receiver Sensitivity

The bit error rate (BER) shall be less than 10^{-6} at the power levels shown Table 223 for standard message and test conditions. If the implemented bandwidth is not listed, then the values for the nearest smaller listed bandwidth shall apply. The minimum input levels are measured at the antenna connector. The measurement shall be taken at the antenna port or through a calibrated radiated test environment using standardized packet formats.

Table 223—Receiver minimum input level sensitivity (dBm)

Bandwidth (MHz)	QPSK		16QAM		64QAM	
	1/2	3/4	1/2	3/4	1/2	3/4
1.5	-87	-85	-80	-78	-74	-72
1.75	-86	-84	-79	-77	-73	-71
3	-84	-82	-77	-75	-71	-69
3.5	-83	-81	-76	-74	-70	-68
5	-82	-80	-75	-73	-68	-67
6	-81	-79	-74	-72	-68	-66
7	-80	-78	-73	-71	-67	-65
10	-79	-77	-72	-70	-65	-64
12	-78	-76	-71	-69	-65	-63
14	-77	-75	-70	-68	-64	-62
20	-76	-74	-69	-67	-62	-61

Test messages for measuring Receiver Sensitivity shall be based on a continuous stream of MAC PDUs, each with a payload consisting of a $\boldsymbol{R}$ times repeated sequence $\boldsymbol{S_{modulation}}$. For each modulation, a different sequence applies:

$\boldsymbol{S_{QPSK}}$ = [0xE4, 0xB1, 0xE1, 0xB4]
$\boldsymbol{S_{16QAM}}$ = [0xA8, 0x20, 0xB9, 0x31, 0xEC, 0x64, 0xFD, 0x75]
$\boldsymbol{S_{64QAM}}$ = [0xB6, 0x93, 0x49, 0xB2, 0x83, 0x08, 0x96, 0x11, 0x41, 0x92, 0x01, 0x00, 0xBA, 0xA3, 0x8A, 0x9A, 0x21, 0x82, 0xD7, 0x15, 0x51, 0xD3, 0x05, 0x10, 0xDB, 0x25, 0x92, 0xF7, 0x97, 0x59, 0xF3, 0x87, 0x18, 0xBE, 0xB3, 0xCB, 0x9E, 0x31, 0xC3, 0xDF, 0x35, 0xD3, 0xFB, 0xA7, 0x9A, 0xFF, 0xB7, 0xDB]

For each mandatory test message, the ($\boldsymbol{R}$,$\boldsymbol{S_{modulation}}$) tuples that shall apply are:

Short length test message payload (288 data bytes): (72,$\boldsymbol{S_{QPSK}}$), (36,$\boldsymbol{S_{16QAM}}$), (6,$\boldsymbol{S_{64QAM}}$)
Mid length test message payload (864 data bytes): (216,$\boldsymbol{S_{QPSK}}$), (108,$\boldsymbol{S_{16QAM}}$), (18,$\boldsymbol{S_{64QAM}}$)
Long length test message payload (1536 data bytes): (384,$\boldsymbol{S_{QPSK}}$), (192,$\boldsymbol{S_{16QAM}}$), (32,$\boldsymbol{S_{64QAM}}$

The test condition requirements are: ambient room temperature, shielded room, conducted measurement at the RF port if available, radiated measurement in a calibrated test environment if the antenna is integrated, and RS FEC is enabled. The test shall be repeated for each test message length and for each ($\boldsymbol{R}$,$\boldsymbol{S_{modulation}}$) tuple as identified above, using the mandatory FEC scheme. The results shall meet or exceed the sensitivity requirements set out in Table 223.

8.3.4.2.9.2 Receiver Adjacent and Alternate channel C/I

The adjacent channel rejection and alternate channel rejection shall be measured by setting the desired signal's strength 3dB above the rate dependent receiver sensitivity (see Table 223) and raising the power level of the interfering signal until the specified error rate is obtained. The power difference between the interfering signal and the desired channel is the corresponding adjacent channel rejection. The interfering signal in the adjacent channel shall be a conforming OFDM signal, unsynchronized with the signal in the channel under test. For non-adjacent channel testing the test method is identical except the interfering channel will be any channel other than the adjacent channel or the co-channel.

For the PHY to be compliant, the minimum C/I shall exceed the following:

Table 224—Adjacent and Non-Adjacent Channel C/I

Modulation/Coding	Adjacent Channel C/I (dB)	Non-Adjacent Channel C/I (dB)
QPSK-1/2	TBD	TBD
QPSK-3/4	TBD	TBD
16QAM-1/2	TBD	TBD
16QAM-3/4	TBD	TBD
64QAM-1/2	TBD	TBD
64QAM-2/3	TBD	TBD

8.3.4.2.9.3 Receiver Maximum Input Signal

The receiver shall be capable of receiving a maximum on-channel signal of -30dBm, and must tolerate a maximum signal of 0dBm without damage.

8.3.4.2.9.4 Receiver Linearity

The receiver shall have a minimum Input Intercept Point (IIP3) of -10dBm.

~~8.3.4.2.9.5 Receiver Gain Control and RSSI Parameters~~

~~The minimum RSSI resolution shall be 1dB with accuracy TBD dB.~~

8.3.4.2.10 Frequency Control Requirements

8.3.4.2.10.1 Transmit/Receive Center Frequency and Symbol Clock Frequency Tolerance

At the BS, the transmitted center frequency, receive center frequency and the symbol clock frequency shall be derived from the same reference oscillator. At the BS the reference frequency tolerance shall be +/- 4 ppm in licensed bands and +/- 7.5 ppm in license-exempt bands.

At the SS, both the transmitted center frequency and the symbol clock frequency shall be synchronized to the BS with a tolerance of maximum 2% of the carrier spacing.

For mesh capable devices, all devices shall have a +/- 20ppm maximum frequency tolerance and achieve synchronization to its neighboring nodes with a tolerance of maximum 3% of the carrier spacing.

During the synchronization period, the SS shall acquire frequency synchronization within the specified tolerance before attempting any uplink transmission. During normal operation, the SS shall track the frequency changes and shall defer any transmission if synchronization is lost.

8.3.4.2.10.2 Phase Noise

TBD

8.3.4.2.11 General Requirements

8.3.4.2.11.1 Temperature Range

Table 225—Operational Temperature Classes

Class	Range (^{o}C)	Environment
1	[0,40]	TBD
2	[-20,50]	TBD
3	[-30,70]	TBD
4	[-40,85]	TBD

8.3.4.2.11.2 Antenna Interface

Any exposed transmit and receive antenna interface port shall be 50 ohms. It is permissible to integrate the antenna and eliminate any external RF port.

8.3.4.2.12 Transmit diversity: Alamouti's Space-Time Coding

Alamouti's scheme [B30] is used on the downlink to provide 2nd order (Space) transmit diversity.

There are two transmit antennas on the BS side and one reception antenna on the SS side. This scheme requires Multiple Input Single Output -MISO- channel estimation. Decoding is very similar to maximum ratio combining.

Figure 204 shows Alamouti scheme insertion into the OFDM chain. Each Tx antenna has its own OFDM chain, but they have the same Local Oscillator for synchronization purposes.

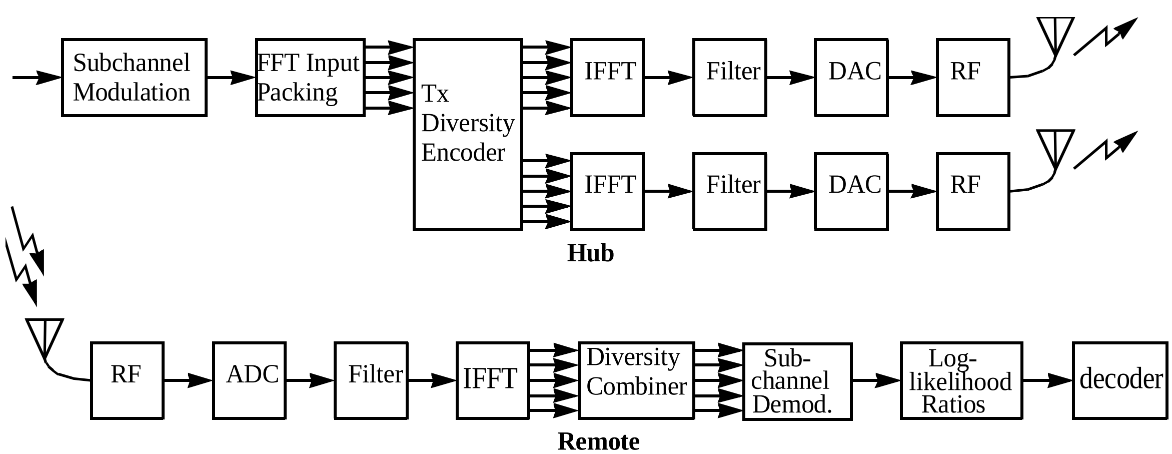

Figure 204—Illustration of the Alamouti STC

Both antennas transmit in the same time 2 different OFDM data symbols. Transmission is performed twice so as to decode and get 2nd order diversity. Time domain (Space-Time) repetition is used.

8.3.4.2.12.1 MISO channel estimation and synchronization

Both antennas transmit in the same time, and they share the same Local Oscillator. Thus, the received signal has exactly the same auto-correlation properties as for a single antenna. So, time and frequency coarse and fine estimation can be performed in the same way as for a single antenna. The scheme requires MISO channel estimation, which is allowed by splitting some preambles and pilots between the 2 Tx antennas, as described in clause 8.3.4.2.12.2

8.3.4.2.12.2 Alamouti STC Encoding

The basic scheme [B30] transmits 2 complex symbols s_0 and s_1, using the MISO channel (two Tx, one Rx) twice with channel values h_0 (for antenna 0) and h_1 (for antenna 1).

First channel use: Antenna0 transmits s_0, antenna1 transmits s_1.

Second channel use: Antenna0 transmits $-s_1^*$, antenna1 transmits s_0^*.

Receiver gets r_0 (first channel use) and r_1 (second channel use) and computes s_0 and s_1 estimates:

$$\hat{s}_0 = h_0^* \cdot r_0 + h_1 \cdot r_1^* \quad (23)$$

$$\hat{s}_1 = h_1^* \cdot r_0 - h_0 \cdot r_1^* \quad (24)$$

These estimates benefit from 2nd order diversity as in the 1Tx-2Rx Maximum Ratio Combining scheme. OFDM symbols are taken by pairs. (equivalently, 2 Tx symbol duration is twice 1 Tx symbol duration, with twice more data in a symbol.) In the transmission frame, variable location pilots are kept identical for two symbols and L is constant for the duration of two symbols (see clause 8.3.4.4.3.1 for definition of L). Alamouti's scheme is applied independently on each carrier, in respect to pilot tones positions.

Figure 205 shows Alamouti's scheme for OFDMA. Note that for OFDM, the scheme is exactly the same except that a pilot symbol is inserted before the data symbols. Also note that since pilot positions do not change from even to odd symbols, and pilots modulation is real, conjugation (and inversion) can be applied to a whole symbol (possibly in the time domain).

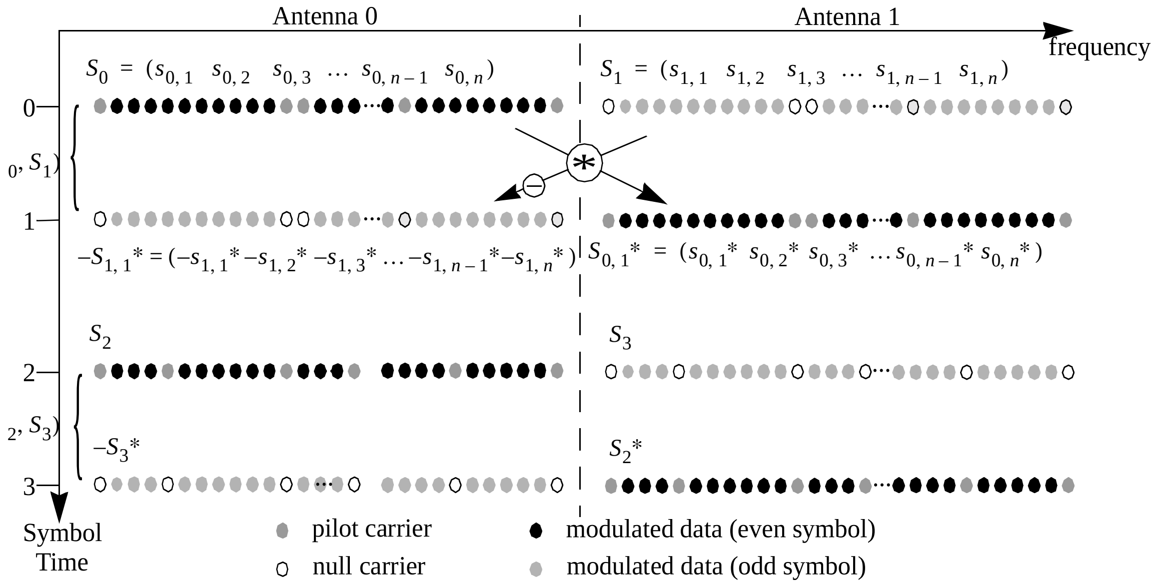

Figure 205—Alamouti Scheme Usage with OFDM/OFDMA

8.3.4.2.12.3 Alamouti STC Decoding

The receiver waits for 2 symbols, and combines them on a carrier basis according to Eq. 23 and Eq. 24 in clause 8.3.4.2.12.2.

8.3.4.2.13 Frame duration codes

Table 210 indicates the various frame durations that are allowed. The actual frame time used by the downlink channel can be determined by the periodicity of the frame start preambles.

Table 226—Frame duration codes

Code(N)	Nominal frame duration (T_F ms)	
	PMP	Mesh
0-6	*N/2+2*	*N+4*
7-11	*N-1*	*N+4*
12-255	Reserved	Reserved

For the OFDM and OFDMA PHY, the frame is an integer multiple of OFDM symbol durations, such that the actual frame duration is nearest to the nominal frame duration listed in Table 210. Both RTG and TTG shall be no less than 5 μs in duration. When using Alamouti STC Encoding, the frame shall contain (in addition to all other requirements) an even number of OFDM symbols in the DL. This requirement shall be taken into account when deriving the actual frame duration from Table 210.

For the OFDMA PHY in an FDD case, the frame duration will be an integer multiple of three OFDM symbols duration, such that the actual frame duration is nearest to the nominal frame duration listed in Table 210. For OFDMA mode in a TDD case, the frame duration will be an integer multiple of one OFDM symbol duration, plus a RTG and TTG guard interval, such that the actual frame duration is nearest to the nominal frame duration listed in Table 210.