IEEE P802.11
Wireless LANs

PROPOSAL FOR 5-GHz PHY

Date: January 16, 1998

Author:
John H. Cafarella
MICRILOR, Inc.
17 Lakeside Office Park, Wakefield, MA 01880
Phone: 781-246-0103
Fax: 781:246-0157
e-Mail: JohnCafarella@worldnet.att.net

Abstract

This is the first draft of MICRILOR's proposal for the 5-GHz PHY standard.

Physical Layer Specification for the 5 GHz UNII Band

1.1 Introduction

1.1.1 Scope

1.1.2 Physical Layer Functions

1.2 Physical Layer Convergence Procedure Sub-Layer

1.2.1 Introduction

During transmission the MPDU shall be prepended with a PLCP Preamble and PLCP Header to create the PPDU. At the receiver the PLCP Preamble and Header are processed to aid in demodulation and delivery of the MPDU.

1.2.2 Physical Layer Convergence Procedure Frame Format

Figure 1 shows the format for the PPDU, including the PLCP preamble, the PLCP header and the MPDU frame. The PLCP Preamble contains the Synchronization (SYNC) and Start Frame Delimiter (SFD) fields. The PLCP Header contains the 802.11 signaling (SIGNAL) and length (LENGTH) fields. Each of these is described in clause 1.2.3 PLCP Field Definitions.

Figure 1 - PLCP Frame Format

1.2.3 PLCP Field Definitions

The PHY Preamble consists of the SYNC and SFD fields, while the PHY Header contains the SIGNAL, LENGTH and R/S-CRC fields. These are transmitted as a sequence of 5-bit channel symbols. See clause 1.4.6.6

Modulation and Channel Data Rates for a description of the modulation formats, as well as the meaning of the symbol-modulator bits, interpreted as the 5-bit pattern [DBPSK,R_1,R_2,R_3,R_4], and as used below.

1.2.3.1 PLCP Synchronization (SYNC)

The synchronization field shall consist of forty (40) symbols which employ one of eight (8) search codes, but which contain all zeroes for the data, i.e., [00000] as the 5-bit modulator-symbol pattern. This field is provided so that the receiver can perform necessary operations to initiate reception of a frame (e.g., signal detection, timing alignment).

1.2.3.2 PLCP Start Frame Delimiter (SFD)

After the SYNC field a single symbol will be transmitted which carries a DBPSK "1", i.e. [10000] as the 5-bit modulator-symbol pattern, with the leftmost bit leading. This field provides for reliable detection of the end of the PHY Preamble.

1.2.3.3 PLCP Signal Field (SIGNAL)

After the SFD, the 1-symbol SIGNAL field will be transmitted; the DBPSK bit must be zero, i.e., [**0**xxxx] as the 5-bit modulator-symbol pattern, with the leftmost bit leading and equal to zero, followed by s_1, etc., as a serial stream. Table 1 shows the correspondence between the bits of the signal field and the symbol-modulator bits. This SIGNAL field determines the modulation used in the main body of the frame. The SIGNAL field shall be interpreted according Table 2.

Table 1 - SIGNAL Symbol

Modulator bit position	SIGNAL Field bit
DBPSK	**0**
R_1	S_1
R_2	S_2
R_3	S_3
R_4	S_4

Table 2 - SIGNAL Field Interpretation

s_1	S_2	s_3	s_4	
0	0	1	0	24-Mbps (4x4-ary DBOK)
0	1	0	0	18-Mbps (Constrained 4x4-ary DBOK)
0	0	0	0	10-Mbps (16-ary DBOK)
				All other patterns reserved

See clause 1.4.6.6 Modulation and Channel Data Rates for definitions of modulations.

1.2.3.4 PLCP Length Field (LENGTH)

The LENGTH field is three symbols with the DBPSK bit equal to zero, i.e., [**0**xxxx] as the 5-bit symbol pattern, with the leftmost bit leading and equal to zero. The 12 non-zero-bits form a binary number which specifies the length of the MPDU in bytes. The relationship between the bits of the 3 LENGTH symbols and the 12-bit Length number is shown in Table 3. The lsb of the Length is b_0.

Table 3 - Correspondence Between LENGTH Symbols and Number

Modulator bit position	1st Symbol after SIGNAL	2nd Symbol after SIGNAL	3rd Symbol after SIGNAL
DBPSK	0	0	0
R_1	B_0	b_4	b_8
R_2	B_1	b_5	b_9
R_3	B_2	b_6	B_{10}
R_4	B_3	b_7	B_{11}

1.2.3.5 PLCP CRC Field (R/S-CRC)

The SIGNAL and SERVICE fields shall be protected with a Reed-Solomon (15,11) code, shortened to 8 symbols, for CRC. This is encoded using the polynomial $(x+1)(x+\alpha)(x+\alpha^2)(x+\alpha^3)=x_4+\alpha^3x+1$,

$$(x+1)(x+a)(x+a^2)(x+a^3) = x^4 + a^{12}x^3 + a^4x^2 + x + a^6$$

where α is a primitive root of x^4+x+1 over GF{2^4}. The four check symbols of the r/s-CRC field provide the minimum Hamming distance of 4, as required for control fields by **IEEE 802 Functional Requirements Document**, Draft 6.10, 12 November, 1991. All modulator symbols for the SIGNAL, SERVICE and R/S-CRC fields are in GF{2^4}.

1.2.4 PLCP PHY Data Scrambler and Descrambler

Scrambling is optional. It offers users the ability to randomize inter-BSA interactions at the modulation level. Scrambling operates on the spreading codes during the MPDU portion of the PPDU.

Scrambling is intended for use with scrambled code channels (SCC), as described in 1.4.6.3.3 Data Code Channels: Scrambled, although nothing prohibits its use with cyclic code channels (CCC) as described in 1.4.6.3.2 Data Code Channels: Cyclic. When implemented, scrambling will be frame-synchronous and commence with the first channel symbol of the MPDU. Scrambling shall not be used on the PHY Preamble or Header.

The scrambler shall employ a 17-stage (binary) Linear Feedback Shift Register (LFSR) generator using polynomial $x^{17}+x^3+1$. This is clocked once per channel symbol when scrambling. The LFSR generator shall be seeded with a 16-bit SCC with a most-significant “1” added to prevent the possibility of all “0”s as initial condition for the LFSR; thus, the lsb of the seed vector is the lsb of the SCC.

The bits of the LFSR generator form a 17-bit binary word $[w_0w_1w_2w_3w_4w_5w_6w_7w_8w_9w_{10}w_{11}w_{12}w_{13}w_{14}w_{15}w_{16}]$ whose bits obey the recursion

$$w_{16}^{+} = w_0^{-} \oplus w_3^{-}$$

Where the - and + superscripts indicate the instances just before and after, respectively, the symbol clock which updates the LFSR generator. Bits w_1 and w_0 are used for code selection when using optional SCC, as described in 1.4.6.3.3 Data Code Channels: Scrambled. Bits w_7 to w_2 form a 5-bit scrambling symbol which is combined with the n^{th}-symbol spreading code C_n according to

$$C_n^{'} = (-1)^{w_2} R_1^{w_3} R_2^{w_4} R_3^{w_5} R_4^{w_7} C_n$$

where $C_n^{'}$ replaces C_n as the spreading code to be combined with the data symbol as specified in 1.4.6.6 Modulation and Channel Data Rates. (See1.4.6.6 Modulation and Channel Data Rates for explanation of notation in the above equation.)

1.2.5 PLCP Data Modulation and Modulation Rate Change

1.2.6 PLCP Transmit Procedure

1.2.7 PLCP Receive Procedure

1.3 Physical Layer Management Entity

1.4 Physical Medium Dependent Sublayer

1.4.1 Scope and Field of Application

1.4.2 Overview of Service

1.4.3 Overview of Interactions

1.4.4 Basic Service and Options

1.4.5 PMD_SAP Detailed Service Specification

1.4.6 PMD Operating Specifications General

The following clauses provide general specifications for the Physical Medium Dependent sub-layer. These specifications apply to both transmit and receive functions and general operation of the PHY.

1.4.6.1 Operating Frequency Range

The PHY shall operate in the frequency range of 5.15-5.35 GHz and 5.725-5.825 GHz as allocated by regulatory bodies in the USA.

1.4.6.2 Number of Operating Frequency Channels

The channel center frequencies and CHNL_ID numbers shall as shown in the following table.

Table 4 - DSSS PHY Frequency Channel Plan

		Regulatory Domains					
CHNL_ID	Frequency	10h FCC					
1	5175 MHz	X					
2	5225 MHz	X					
3	5275 MHz	X					
4	5325 MHz	X					
5	5750 MHz	X					
6	5800 MHz	X					

1.4.6.3 Number of Operating Code Channels

Preamble acquisition is performed using a repeated, unmodulated search spreading code, while data transfer employs data spreading codes combined with Walsh-function codes as selected by the data. Code channels are formed by using various possible combinations of a search code and data codes.

1.4.6.3.1 Search Code Channels

Search code channels correspond uniquely to the selection of one of eight search codes.

Table 5 - Search Code Channels

SRCH_ID	Search Code	SRCH_ID	Search Code
0	S_0	4	S_4
1	S_1	5	S_5
2	S_2	6	S_6
3	S_3	7	S_7

1.4.6.3.2 Data Code Channels: Cyclic

The spreading codes shall be set $\{C_0C_1C_2C_3\}$ or set $\{C_4C_5C_6C_7\}$. The spreading code will be changed from symbol-to-symbol in cyclic manner through four codes. Because the change from search to data spreading codes happens at the same place in the PPDU, all permutations of the two groups constitute distinct channels. These are cyclic code channels (CCC).

CCC_ID	Code Seq.	CCC_ID	Code Seq.	CCC_ID	Code Seq.	CCC_ID	Code Seq.
1	$C_0C_1C_2C_3$	13	$C_2C_0C_1C_3$	25	$C_4C_5C_6C_7$	37	$C_6C_4C_5C_7$
2	$C_0C_1C_3C_2$	14	$C_2C_0C_3C_1$	26	$C_4C_5C_7C_6$	38	$C_6C_4C_7C_5$
3	$C_0C_2C_1C_3$	15	$C_2C_1C_0C_3$	27	$C_4C_6C_5C_7$	39	$C_6C_5C_4C_7$
4	$C_0C_2C_3C_1$	16	$C_2C_1C_3C_0$	28	$C_4C_6C_7C_5$	40	$C_6C_5C_7C_4$
5	$C_0C_3C_1C_2$	17	$C_2C_3C_0C_1$	29	$C_4C_7C_5C_6$	41	$C_6C_7C_4C_5$
6	$C_0C_3C_2C_1$	18	$C_2C_3C_1C_0$	30	$C_4C_7C_6C_5$	42	$C_6C_7C_5C_4$
7	$C_1C_0C_2C_3$	19	$C_3C_0C_1C_2$	31	$C_5C_4C_6C_7$	43	$C_7C_4C_5C_6$
8	$C_1C_0C_3C_2$	20	$C_3C_0C_2C_1$	32	$C_5C_4C_7C_6$	44	$C_7C_4C_6C_5$
9	$C_1C_2C_0C_3$	21	$C_3C_1C_0C_2$	33	$C_5C_6C_4C_7$	45	$C_7C_5C_4C_6$
10	$C_1C_2C_3C_0$	22	$C_3C_1C_2C_0$	34	$C_5C_6C_7C_4$	46	$C_7C_5C_6C_4$
11	$C_1C_3C_0C_2$	23	$C_3C_2C_0C_1$	35	$C_5C_7C_4C_6$	47	$C_7C_6C_4C_5$
12	$C_1C_3C_2C_0$	24	$C_3C_2C_1C_0$	36	$C_5C_7C_6C_4$	48	$C_7C_6C_5C_4$

1.4.6.3.3 Data Code Channels: Scrambled

The scrambled code channels (SCC) are optional, and can only be used when the optional data-scrambling mode described in 1.2.4 PLCP PHY Data Scrambler and Descrambler is in effect. The spreading codes shall be the set $\{C_0C_1C_2C_3\}$ or the set $\{C_4C_5C_6C_7\}$. The sequence with which specific codes are used, beginning on the first channel symbol of the MPDU portion of the frame, shall be determined by the two lowest-order bits $[w_1,w_0]$ of the LFSR described in 1.2.4 PLCP PHY Data Scrambler and Descrambler. These shall have the correspondence shown in Table 6, where set $\{C_A,C_B,C_C,C_D\}$ is a permutation of either $\{C_0C_1C_2C_3\}$ or $\{C_4C_5C_6C_7\}$.

Table 6 - SCC Selection

w_1	w_0	Code
0	0	C_A
0	1	C_B
1	0	C_C
1	1	C_D

To effect communications, it is necessary for users to agree upon the 16-bit SCC, which set of four codes, and also which permutation of those four codes. This constitutes $3x2^{20}$, or approximately 30 million distinct scrambled code channels.

1.4.6.4 Channelization Concepts

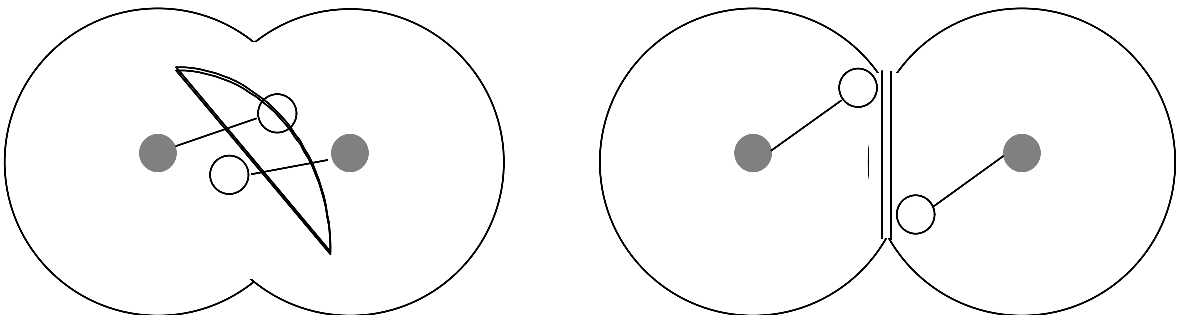
There is room in the each 100-MHz sub-band for 2 frequency channels. In addition, there are 8 SRCH_Ids as well as 48 CCC_IDs. (The optional SCC are not considered in this section.) This provides a total, in each 100-MHz, of 2x8x48=768 combinations with which to effect BSA isolation. The “channel” identification is the concatenation of the frequency, search code and data code channels:

CH_ID = CHNL_ID / SRCH_ID/ CCC_ID

For example, channel 1/5/33 transmits on a center frequency of 5175 MHz using search code S_5 during acquisition, and cyclic data code sequence $C_5C_6C_4C_7$ during the data portion of the frame.

When overlap of BSA coverage is required, adjacent BSAs should be operated on different CHNL_Ids. This is possible with two channels (i.e., within a single 100-MHz sub-band) if the BSAs are placed on a approximately rectangular grid. Using all 6 possible channels (300 MHz total) supports other geometries. Even when BSAs have frequency isolation, it is still imperative to employ different SRCH_IDs and CCC_IDs to the greatest extent possible to avoid undesired injection of frames between BSAs.

When overlapped operation of BSAs is not required, then it is sufficient to employ different SRCH_IDs and CCC_IDs to enable filtering of cross-BSA frames at the lowest level (i.e., not requiring driver interaction).



Overlapped: STAs can connect to more-distant AP Non-Overlapped: STAs connect only to nearest AP

Figure 2 - Overlapped and Non-Overlapped BSA Coverage

1.4.6.5 Spreading Sequences

All codes contain 16 binary values within a channel symbol. One of 8 "search" spreading codes (Table 7) is used for synchronization (SYNC, SFD and SIGNAL fields). During the remainder of a frame a sequence of 4 "data" spreading codes (Table 8) is used for data transmission; the 8 such data codes are called "coset leaders", and are grouped as two sets of four codes. The Walsh functions, combined with the coset leaders to carry the data in the transmitted waveform, are also presented below (Table 9), along with the Rademacher functions (Table 10) used to construct the Walsh functions. The codes are presented in three representations: hexadecimal, binary logical, and binary algebraic. The leftmost value is the first element of a transmitted symbol waveform.

Table 7 - Search-Mode Spreading Codes

Code	Hex	Binary logical	Binary algebraic
S_0	44BC	0100010010111100	+1,-1,+1,+1,+1,-1,+1,+1,-1,+1,-1,-1,-1,-1,+1,+1
S_1	A0DC	1010000011011100	-1,+1,-1,+1,+1,+1,+1,+1,-1,-1,+1,-1,-1,-1,+1,+1
S_2	D223	1101001000100011	-1,-1,+1,-1,+1,+1,-1,+1,+1,+1,-1,+1,+1,+1,-1,-1
S_3	0A76	0000101001110110	+1,+1,+1,+1,-1,+1,-1,+1,+1,-1,-1,-1,+1,-1,-1,+1
S_4	425C	0100001001011100	+1,-1,+1,+1,+1,+1,-1,+1,+1,-1,+1,-1,-1,-1,+1,+1
S_5	23A4	0010001110100100	+1,+1,-1,+1,+1,+1,-1,-1,-1,+1,-1,+1,+1,-1,+1,+1
S_6	245C	0010010001011100	+1,+1,-1,+1,+1,-1,+1,+1,+1,-1,+1,-1,-1,-1,+1,+1
S_7	A243	1010001001000011	-1,+1,-1,+1,+1,+1,-1,+1,+1,-1,+1,+1,+1,+1,-1,-1

codes S_0-S_3 have better autocorrelation side lobes than codes S_4-S_7. These codes are shifted time-reversed replicas in pairs.

Table 8 - Data-Mode Spreading Codes

Code	Hex	Binary logical	Binary algebraic
C_0	0158	0000000101011000	+1,+1,+1,+1,+1,+1,+1,-1,+1,-1,+1,-1,-1,+1,+1,+1
C_1	0461	0000010001100001	+1,+1,+1,+1,+1,-1,+1,+1,+1,-1,-1,+1,+1,+1,+1,-1
C_2	131F	0001001100011111	+1,+1,+1,-1,+1,+1,-1,-1,+1,+1,+1,-1,-1,-1,-1,-1
C_3	1626	0001011000100110	+1,+1,+1,-1,+1,-1,-1,+1,+1,+1,-1,+1,+1,-1,-1,+1
C_4	020E	0000001000001110	+1,+1,+1,+1,+1,+1,-1,+1,+1,+1,+1,+1,-1,-1,-1,+1
C_5	0737	0000011100110111	+1,+1,+1,+1,+1,-1,-1,-1,+1,+1,-1,-1,+1,-1,-1,-1
C_6	1049	0001000001001001	+1,+1,+1,-1,+1,+1,+1,+1,+1,-1,+1,+1,-1,+1,+1,-1
C_7	1570	0001010101110000	+1,+1,+1,-1,+1,-1,+1,-1,+1,-1,-1,-1,+1,+1,+1,+1

Each group of four data codes has better inter-coset correlation properties than mixing all 8 together.

Table 9 - Walsh-Function Codes

Func	Hex	Binary logical	Binary algebraic
W_0	0000	0000000000000000	+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1
W_1	00FF	0000000011111111	+1,+1,+1,+1,+1,+1,+1,+1,-1,-1,-1,-1,-1,-1,-1,-1
W_2	0F0F	0000111100001111	+1,+1,+1,+1,-1,-1,-1,-1,+1,+1,+1,+1,-1,-1,-1,-1
W_3	0FF0	0000111111110000	+1,+1,+1,+1,-1,-1,-1,-1,-1,-1,-1,-1,+1,+1,+1,+1
W_4	3333	0011001100110011	+1,+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1
W_5	3366	0011001101100110	+1,+1,-1,-1,+1,+1,-1,-1,+1,-1,-1,+1,+1,-1,-1,+1
W_6	3636	0011011000110110	+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,-1,+1,-1,-1,+1
W_7	3663	0011011001100011	+1,+1,-1,-1,+1,-1,-1,+1,+1,-1,-1,+1,+1,+1,-1,-1
W_8	5555	0101010101010101	+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1
W_9	55AA	0101010110101010	+1,-1,+1,-1,+1,-1,+1,-1,-1,+1,-1,+1,-1,+1,-1,+1
W_{10}	5A5A	0101101001011010	+1,-1,+1,-1,-1,+1,-1,+1,+1,-1,+1,-1,-1,+1,-1,+1
W_{11}	5AA5	0101101010100101	+1,-1,+1,-1,-1,+1,-1,+1,-1,+1,-1,+1,+1,-1,+1,-1
W_{12}	6666	0110011001100110	+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1,+1
W_{13}	6633	0110011000110011	+1,-1,-1,+1,+1,-1,-1,+1,+1,+1,-1,-1,+1,+1,-1,-1
W_{14}	6363	0110001101100011	+1,-1,-1,+1,+1,+1,-1,-1,+1,-1,-1,+1,+1,+1,-1,-1
W_{15}	6336	0110001100110110	+1,-1,-1,+1,+1,+1,-1,-1,+1,+1,-1,-1,+1,-1,-1,+1

Table 10 - Rademacher-Function Codes

Func	Hex	Binary logical	Binary algebraic
R_0	0000	0000000000000000	+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1,+1
R_1	00FF	0000000011111111	+1,+1,+1,+1,+1,+1,+1,+1,-1,-1,-1,-1,-1,-1,-1,-1
R_2	0F0F	0000111100001111	+1,+1,+1,+1,-1,-1,-1,-1,+1,+1,+1,+1,-1,-1,-1,-1
R_3	3333	0011001100110011	+1,+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1,+1,+1,-1,-1
R_4	5555	0101010101010101	+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1,+1,-1

The Rademacher codes are used to construct the algebraic form of the Walsh codes. For W_N we employ the standard binary representation of N, i.e.,

$$N = \sum_{k=0}^{k_{\max}} 2^{kb_k} \qquad b_k \in \{0,1\}$$

then

$$W_N = \prod_{k=1}^{k_{\max}} R_k^{b_k}$$

The notation S_N, C_N, W_N and R_N, etc., refers to the identity of the code, or the corresponding function. Where needed, to index the sub-elements (bits) of the codes a second subscript is added e.g. W_{Nn}.

1.4.6.6 Modulation and Channel Data Rates

The FSD field of the PHY Preamble is transmitted at 1 bit/symbol using DBPSK for high reliability. The SIGNAL, LENGTH and R/S-CRC fields of the PHY Header are transmitted at 4 bit/symbol using 16-ary BOK.

The MPDU is transmitted at 5, 9 or 12 bits/symbol, respectively. The primary data-transfer modulation is 12 bits/symbol using 4x4-ary DBOK to effect 24-Mbps data rate at 32-Mchip/s spreading or 12-Mbps data rate at 16-Mchip/s spreading. The 5-bit/symbol rate provides the "degraded-speed" mode, used, e.g., under poor propagation conditions. The 9-bit/symbol modulation provides constant-amplitude signaling for improved power-amplifier efficiency when needed. All modes are shown in Table 11.

Table 11 - Combinations of Data Rate and Modulation

Data Rate	Modulation (& Coding)	Used For	Regulatory
2 Mbps	DBPSK	FSD	FCC
8 Mbps	16-ary OK	SIGNAL, LENGTH, R/S-CRC	
24 Mbps	4x4-ary DBOK	MPDU	
18 Mbps	Constrained 4x4-ary DBOK	MPDU	
10 Mbps	16-ary DBOK	MPDU	

1.4.6.6.1 DBPSK Signaling

Differential **B**i-**P**hase **S**hift **K**eying (DBPSK) conveys a single bit of data per channel symbol by altering the carrier phase by 0 or π radians between symbols. The encoding of DBPSK data determines the n[th] symbol baseband pattern (just prior to the MSK modulator) to be

$$(-1)^{d_{0n}}\, p_{n-1} C_n$$

where

d_{0n} is the n[th] DBPSK data bit,

$p_{n-1} = \prod_{m=0}^{n-1} (-1)^{d_{0n}}$ is the previous carrier polarity (±1 depending upon the history of bits d_{0n} for all previous symbols), and

C_n is the spreading code used on the nth symbol. The "0" subscript on the DBPSK data bits is maintained for later reference to other modulations.

1.4.6.6.2 16-ary OK Signaling

16-ary Orthogonal **K**eying (16-ary OK) conveys 4 bits of information by transmitting one of 16 possible orthogonal waveforms for each symbol waveform. The form of orthogonal keying is chip-wise combination of a spreading code with one of a set of 16 Walsh functions. The combination of codes is performed by multiplication of the algebraic {±1} values. The encoding of 16-ary OK data determines the n[th] symbol baseband pattern (just prior to the MSK modulator) to be

$$R_1^{d_{n1}} R_2^{d_{n2}} R_3^{d_{n3}} R_4^{d_{n4}} C_n$$

where

$[d_{n1},d_{n2},d_{n3},d_{n4}]$ is the 4-bit data pattern for the n^{th} symbol (d_{n1} is first in), and

C_n is the spreading code used on the nth symbol. Note that here the second subscript on the symbol data bits runs 1 to 4, not 0 to 3.

Demodulation of this signaling technique comprises estimating which of the 16 possible waveforms was transmitted (i.e., selecting the correlator channel with the largest magnitude), which yields 4 bits of information.

1.4.6.6.3 16-ary DBOK Signaling

Differential **B**i-**O**rthogonal **K**eying (DBOK) combines DBPSK modulation from symbol-to-symbol with orthogonal keying for each symbol waveform. The form of orthogonal keying is chip-wise combination of a spreading code with one of a set of Walsh functions. For 16-ary DBOK the spreading code is combined with one of 16 Walsh functions (codes), the selection of which conveys 4 bits of information. The combination of codes is performed by multiplication of the algebraic {±1} values. The encoding of 16-ary DBOK data determines the n^{th} symbol baseband pattern (just prior to the MSK modulator) to be

$$(-1)^{d_{n0}} R_1^{d_{n1}} R_2^{d_{n2}} R_3^{d_{n3}} R_4^{d_{n4}} p_{n-1} C_n$$

where

$[d_{n0},d_{n1},d_{n2},d_{n3},d_{n4}]$ is the 5-bit data pattern for the n^{th} symbol (d_{n0} is first in), and

$p_{n-1} = \prod_{m=0}^{n-1} (-1)^{d_{0n}}$ is the previous carrier polarity (±1 depending upon the history of bit d_{n0} for all previous symbols), and

C_n is the spreading code used on the nth symbol.

Demodulation of this signaling technique comprises:

a) estimating which of the 16 possible waveforms was transmitted (i.e., selecting the correlator channel with the largest magnitude), which yields 4 bits of information, then
b) performing a DBPSK demodulation between the largest-magnitude complex correlator outputs for the current and previous symbols, which yields the 5^{th} bit.

1.4.6.6.4 4x4-ary DBOK Signaling

The 16 Walsh functions used for 16-ary DBOK can be decomposed into 4 sub-groups of 4 each Walsh functions, i.e., $X_0=\{W_0,W_1,W_2,W_3\}$, $X_1=\{W_4,W_5,W_6,W_7\}$, $X_2=\{W_8,W_9,W_{10},W_{11}\}$, $X_3=\{W_{12},W_{13},W_{14},W_{15}\}$. Each of these can be used to effect 4-ary DBOK signaling. 4x4-ary DBOK is a modulation which results from performing 4-ary DBOK in each of the above sub-groups, then algebraically summing the resulting waveforms. Such a modulation conveys 12 bits per symbol. This incurs a 6-dB peak-to-average envelope fluctuation.

The encoding of 4x4-ary DBOK data determines the n^{th} symbol envelope to be

$$\Big((-1)^{d_{n0}} R_1^{d_{n1}} R_2^{d_{n2}} p_{0,n-1} + (-1)^{d_{n3}} R_1^{d_{n4}} R_2^{d_{n5}} R_3\, p_{1,n-1}$$
$$+ (-1)^{d_{n6}} R_1^{d_{n7}} R_2^{d_{n8}} R_4\, p_{2,n-1} + (-1)^{d_{n9}} R_1^{d_{n10}} R_2^{d_{n11}} R_3 R_4\, p_{3,n-1} \Big) C_n$$

where

$[d_{n0},d_{n1},d_{n2},d_{n3},d_{n4},d_{n5},d_{n6},d_{n7},d_{n8},d_{n9},d_{n10},d_{n11}]$ is the current 12-bit data pattern (d_{n0} is first in),

$p_{0,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{0m}}$ is the previous polarity for sub-group X_0 (±1 depending upon the history of bit d_{n0} for all previous symbols),

$p_{1,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{3m}}$ is the previous polarity for sub-group X_1 (±1 depending upon the history of bit d_{n3} for all previous symbols),

$p_{2,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{6m}}$ is the previous polarity for sub-group X_2 (±1 depending upon the history of bit d_{n6} for all previous symbols),

$p_{3,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{9m}}$ is the previous polarity for sub-group X_3 (±1 depending upon the history of d_{n9} for all previous symbols), and

C_n is the spreading code used on the nth symbol.

1.4.6.6.5 Constrained 4x4-ary DBOK Signaling

It is desirable in some applications to avoid the 6-dB peak/average envelope ratio of 4x4-ary DBOK. Constant-envelope signals can be made to result if 3 of the 12 information bits of the 4x4-ary DBOK signaling are given up to constrain the set of generated waveforms. Constrained 4x4-ary DBOK uses 4-ary DBOK in 3 sub-groups, then modulates in the fourth sub-group based upon the data for the other sub-groups. The result is a constant-envelope waveform consistent with saturated (efficient) power amplification.

The encoding of constrained 4x4-ary DBOK data determines the n^{th} symbol envelope to be

$$\Big((-1)^{d_{n0}} R_1^{d_{n1}} R_2^{d_{n2}} p_{0,n-1} + (-1)^{d_{n3}} R_1^{d_{n4}} R_2^{d_{n5}} R_3\, p_{1,n-1} + (-1)^{d_{n6}} R_1^{d_{n7}} R_2^{d_{n8}} R_4\, p_{2,n-1} + (-1)^{F(d_0,d_3,d_6)} R_1^{G(d_1,d_4,d_7)} R_2^{G(d_2,d_5,d_8)} R_3 R_4\, p_{3,n-1} \Big) C_n$$

where

$[d_{n0},d_{n1},d_{n2},d_{n3},d_{n4},d_{n5},d_{n6},d_{n7},d_{n8}]$ is the current 9-bit data pattern (d_{n0} is first in),

$p_{0,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{0m}}$ is the previous polarity for sub-group X_0 (±1 depending upon the history of bit d_{n0} for all previous symbols),

$p_{1,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{3m}}$ is the previous polarity for sub-group X_1 (±1 depending upon the history of bit d_{n3} for all previous symbols),

$p_{2,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{6m}}$ is the previous polarity for sub-group X_2 (±1 depending upon the history of bit d_{n6} for all previous symbols),

Table 12 - F and G

a	b	c	F(a,b,c)	G(a,b,c)
0	0	0	1	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

$p_{3,n-1} = \prod_{m=0}^{n-1} (-1)^{d_{9m}}$ is the previous polarity for sub-group X_3 (±1 depending upon the history of $d_{n9}=F(d_{n0},d_{n3},d_{n6})$for all previous symbols), and

C_n is the spreading code used on the nth symbol. The functions F(a,b,c) and G(a,b,c) are given in Table 12. The function F demands that the pattern [a,b,c,F] have odd parity, while the function G demands that the pattern [a,b,c,G] have even parity.

1.4.6.7 Transmit and Receive In-Band and Out-of-Band Spurious Emissions

The PHY shall conform with in-band and out-of-band spurious emissions as set by regulatory bodies. For the USA, refer to FCC 15.247, 15.202, and 15.209. For Europe, refer to ETS 300-328.

1.4.6.8 Transmit to Receive Turnaround Time

The transmit-to-receive turn-around time shall be less than 10 µs, including the power-down ramp specified in clause 1.4.7.7 Transmit Power On and Power Down Ramp.

1.4.6.9 Receive to Transmit Turnaround Time

The receive-to-transmit turn-around time shall be less than 5 µs, including the power-up ramp specified in clause 1.4.7.7 Transmit Power On and Power Down Ramp.

1.4.6.10 Slot Time

The slot time for the PHY shall be the sum of the carrier-detect time specified in clause 1.4.8.4 Clear Channel Assessment and twice the receive-to-transmit turn-around time specified in clause 1.4.6.9 Receive to Transmit Turnaround Time.

1.4.6.11 Transmit and Receive Antenna Port Impedance

When exposed, the transmitter and receiver antenna port(s) shall be of nominal impedance 50Ω.

1.4.6.12 Transmit and Receive Operating Temperature

1.4.7 PMD Transmit Specifications

The following clauses describe the transmit functions and parameters associated with the Physical Medium Dependent sub-layer.

1.4.7.1 Maximum Transmit Power Levels

The maximum allowable output power, as measured in accordance with practices specified by the FCC, is shown in Table 2. In the USA, the radiated emissions should also conform to the ANSI uncontrolled radiation emission standards (ANSI/IEEE C95.1-1992).

Table 13 - Maximum Transmit Power Levels

Maximum output power	Sub-Band	Comments
50 mW	5150-5250 MHz	
250 mW	5250-5350 MHz	
10200 mW	5725-5825 MHz	

1.4.7.2 Minimum Transmitted Power level

The minimum transmit power shall be no less than 1 mW.

1.4.7.3 Transmit Power Level Control

Power control shall be provided for transmitted power greater than 100 mW.

1.4.7.4 Transmit Spectrum Mask

The peak of the transmitter power spectrum in taken to be 0 dBr. The transmit power spectral density $P_T(f)$ (including spurious products) shall be:

$$P_T(f) \quad < \quad -50\frac{|f-f_c|-16}{11} \qquad 16 \le |f-f_c| \le 27$$

$$P_T(f) \quad < \quad -50 \qquad |f-f_c| > 27$$

Where f_c is the carrier frequency, f is the spectral variable, both in MHz, and T_c is the chip rate. The transmitter spectral mask is shown in Figure 3. The measurements shall be made using 100 kHz resolution bandwidth and 30 kHz video bandwidth.

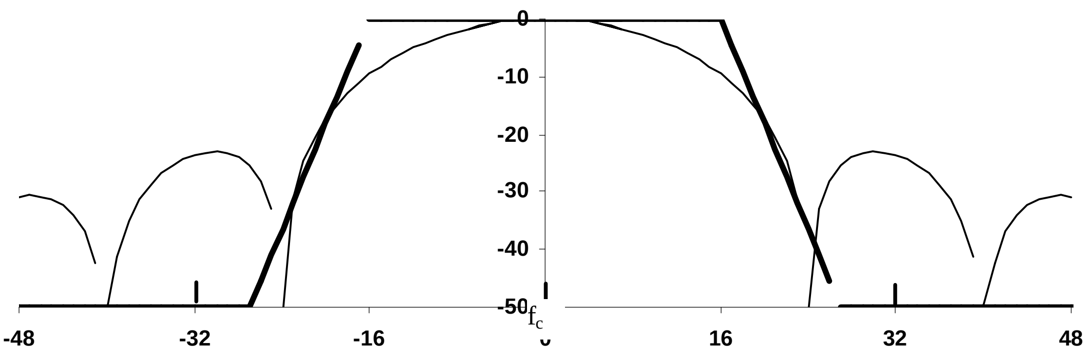


Figure 3 –Transmit Spectrum Mask

1.4.7.5 Transmit Center Frequency Tolerance

The transmit center-frequency tolerance shall be ±10 ppm.

1.4.7.6 Chip Clock Frequency Tolerance

The chip-clock-frequency tolerance shall be ±4 ppm.

1.4.7.7 Transmit Power On and Power Down Ramp

The transmitter power-on and power-off, measured from 10%-to-90% and 90%-to-10% of steady-state power, respectively, shall not exceed 2 µs. The transmit power ramps must be consistent with the out-of-band emissions as specified in clause 1.4.6.7 Transmit and Receive In-Band and Out-of-Band Spurious Emissions.

1.4.7.8 RF Carrier Suppression

The RF carrier suppression, measured at the channel center frequency, shall be at least 10 dB below the peak of the MSK power spectrum. The RF carrier suppression shall be measured while transmitting randomized data. The peak of the MSK spectrum shall be referenced to 100-kHz resolution.

1.4.8 PMD Receiver Specifications

1.4.8.1 Receiver Minimum Input Level Sensitivity

The frame error rate (FER) shall be less than 5% at an MPDU length of 1024 bytes for an input level of –80 dBm measured at the antenna connector (or equivalent specification, if antenna is built-in). This FER shall pertain to the 10-Mbps (16-ary DBOK @ 32-Mchip/s) modulation, and shall be exclusive of frame retransmission protocol(s).

1.4.8.2 Receiver Maximum Input Level

The frame error rate (FER) shall be less than 5% at an MPDU length of 1024 bytes for an input level of -4 dBm measured at the antenna connector (or equivalent specification, if antenna is built-in). This FER shall pertain to the 10-Mbps (16-ary DBOK @ 32-Mchip/s) modulation, and shall be exclusive of frame retransmission protocol(s).

1.4.8.3 Receiver Adjacent Channel Rejection

Adjacent channel rejection is defined between two channels (CHNL_ID) as specified in clause 1.4.6.2 Number of Operating Frequency Channels. The adjacent-channel-rejection specification applies to any pair of channels. The adjacent rejection shall be 35 dB, or greater, at a FER of 5% using the 4x4-ary DBOK modulation described in clause 1.4.6.6.4 4x4-ary DBOK Signaling and an MPDU length of 1024 bytes. The adjacent channel rejection shall be measured as follows:

The input signal shall use the 12-bit/symbol, 4x4-ary DBOK modulation (24-Mbps) at a level 6-dB greater than that specified in clause 1.4.7.2 Minimum Transmitted Power level. The adjacent-channel signal shall use the 12-bit/symbol, 4x4-ary DBOK modulation (24-Mbps) at a level 41-dB greater than that specified in clause 1.4.7.2 Minimum Transmitted Power level. The adjacent channel signal shall be derived from a separate signal source. SRCH_IDs and CCC_IDs shall be different for the two channels. The FER shall be no worse than 5%.

1.4.8.4 Clear Channel Assessment

The PHY shall provide the capability to perform Clear channel Assessment (CCA) according to the following *Carrier-Sense* methods:

Mode 1 (required): Carrier sense. CCA shall report a busy medium upon detecting the preamble portion of a transmission specified under 802.11-17, using the search code in effect within the BSA.

Mode 2 (optional): Energy detection. CCA shall report a busy medium upon detecting signal energy in the band.

The CCA shall be TRUE if neither mode 1 nor mode 2 (if selected) indicates channel-activity condition. CCA operation is subject to the following criteria:

a) Signal sense must occur for signals above the minimum receive signal level indicated in clause 1.4.8.1 Receiver Minimum Input Level Sensitivity;
b) Signal sense must occur within the CCA carrier-sense time of 10 μs after initiation of signal;

c) If an 802.11-17 PLCP Header is received, then the PHY shall hold the CCA signal inactive (channel busy) for the full duration as indicated by the PLCP LENGTH field, even if loss of carrier sense should occur before the end of reception.