

**IEEE P802.11
Wireless LANs**

PROPOSAL FOR HIGH-DATA-RATE 2.4-GHz PHY

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Abstract

This is the first draft of MICRILOR's proposal for the 2.4-GHz High-Data-Rate PHY standard.

High-Rate Direct-Sequence Spread Spectrum Physical Layer Specification for the 2.4 GHz ISM Band

1.1 Introduction

1.1.1 Scope

1.1.2 High-Rate DSSS Physical Layer Functions

1.2 DSSS 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 DSSS PLCP preamble, the DSSS 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 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,R₁,R₂,R₃,R₄], 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., [0xxxx] as the 5-bit modulator-symbol pattern, with the leftmost bit leading and equal to zero, followed by s₁, 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	0	0	10-Mbps (16-ary DBOK)
1	0	0	0	8.7-Mbps (16-ary DBOK with (15,13) FEC)
0	1	0	0	18-Mbps (Constrained 4x4-ary DBOK)
				All other patterns reserved

Note: In half-bandwidth (16-Mchip/s) operation these data rates are halved. 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., [0xxxx] 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	1 st Symbol after SIGNAL	2 nd Symbol after SIGNAL	3 rd 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/DSSS 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. While this is equivalent to data scrambling in the 5-bit/symbol mode, it must actually operate on the spreading codes, rather than the data symbols, in order to preserve the constant-envelope property in the 9-bit/symbol mode.

Scrambling is intended for use with scrambled code channels (SCC), as described in Data Code Channels: Scrambled, although nothing prohibits its use with cyclic code channels (CCC) as described in 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 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. (See

1.4.6.6 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 10-Mbps DSSS Physical Layer Management Entity

1.4 10-Mbps DSSS 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 high-rate DSSS Physical Medium Dependent sub-layer. These specifications apply to both transmit and receive functions and general operation of the high-rate DSSS PHY.

1.4.6.1 Operating Frequency Range

The DSSS PHY shall operate in the frequency range of 2.4 to 2.4835 GHz as allocated by regulatory bodies in the USA, Canada and Europe or in the 2.471 to 2.497 GHz frequency band as allocated by regulatory authority in Japan.

1.4.6.2 Number of Operating Frequency Channels

The channel center frequencies and CHNL_ID numbers shall be the same as for the lower-rate DSSS PHY standard, as shown in the following table. (See clause 15.4.6.2 for discussion.)

Table 4 - DSSS PHY Frequency Channel Plan

CHNL_ID	Frequency	Regulatory Domains					
		10h FCC	20h IC	30h ETSI			40h MKK
1	2412 MHz	HB	HB	HB			
2	2417 MHz	HB/FB	HB/FB	HB/FB			
3	2422 MHz	HB/FB	HB/FB	HB/FB			
4	2427 MHz	HB/FB	HB/FB	HB/FB			
5	2432 MHz	HB/FB	HB/FB	HB/FB			
6	2437 MHz	HB/FB	HB/FB	HB/FB			
7	2442 MHz	HB/FB	HB/FB	HB/FB			
8	2447 MHz	HB/FB	HB/FB	HB/FB			
9	2452 MHz	HB/FB	HB/FB	HB/FB			
10	2457 MHz	HB/FB	HB/FB	HB/FB			
11	2462 MHz	HB	HB	HB			
12	2467 MHz			HB			
13	2472 MHz			HB			
14	2484 MHz						HB

FB indicates **Full-bandwidth** (32-Mchip/s MSK-modulated) transmission; **HB** indicates **Half-bandwidth** (16-Mchip/s MSK modulated) transmission.

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 {C₀C₁C₂C₃} or set {C₄C₅C₆C₇}. 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.						
1	C ₀ C ₁ C ₂ C ₃	13	C ₂ C ₀ C ₁ C ₃	25	C ₄ C ₅ C ₆ C ₇	37	C ₆ C ₄ C ₅ C ₇
2	C ₀ C ₁ C ₃ C ₂	14	C ₂ C ₀ C ₃ C ₁	26	C ₄ C ₅ C ₇ C ₆	38	C ₆ C ₄ C ₇ C ₅
3	C ₀ C ₂ C ₁ C ₃	15	C ₂ C ₁ C ₀ C ₃	27	C ₄ C ₆ C ₅ C ₇	39	C ₆ C ₅ C ₄ C ₇
4	C ₀ C ₂ C ₃ C ₁	16	C ₂ C ₁ C ₃ C ₀	28	C ₄ C ₆ C ₇ C ₅	40	C ₆ C ₅ C ₇ C ₄
5	C ₀ C ₃ C ₁ C ₂	17	C ₂ C ₃ C ₀ C ₁	29	C ₄ C ₇ C ₅ C ₆	41	C ₆ C ₇ C ₄ C ₅
6	C ₀ C ₃ C ₂ C ₁	18	C ₂ C ₃ C ₁ C ₀	30	C ₄ C ₇ C ₆ C ₅	42	C ₆ C ₇ C ₅ C ₄
7	C ₁ C ₀ C ₂ C ₃	19	C ₃ C ₀ C ₁ C ₂	31	C ₅ C ₄ C ₆ C ₇	43	C ₇ C ₄ C ₅ C ₆
8	C ₁ C ₀ C ₃ C ₂	20	C ₃ C ₀ C ₂ C ₁	32	C ₅ C ₄ C ₇ C ₆	44	C ₇ C ₄ C ₆ C ₅
9	C ₁ C ₂ C ₀ C ₃	21	C ₃ C ₁ C ₀ C ₂	33	C ₅ C ₆ C ₄ C ₇	45	C ₇ C ₅ C ₄ C ₆
10	C ₁ C ₂ C ₃ C ₀	22	C ₃ C ₁ C ₂ C ₀	34	C ₅ C ₆ C ₇ C ₄	46	C ₇ C ₅ C ₆ C ₄
11	C ₁ C ₃ C ₀ C ₂	23	C ₃ C ₂ C ₀ C ₁	35	C ₅ C ₇ C ₄ C ₆	47	C ₇ C ₆ C ₄ C ₅
12	C ₁ C ₃ C ₂ C ₀	24	C ₃ C ₂ C ₁ C ₀	36	C ₅ C ₇ C ₆ C ₄	48	C ₇ C ₆ C ₅ C 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 PLCP/DSSS PHY Data Scrambler and Descrambler is in effect. The spreading codes shall be the set {C₀C₁C₂C₃} or the set {C₄C₅C₆C₇}. 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 [w₁,w₀] of the LFSR described in PLCP/DSSS 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 {C₀C₁C₂C₃} or {C₄C₅C₆C₇}.

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 3x2²⁰, or approximately 30 million distinct scrambled code channels.

1.4.6.4 Channelization Concepts

There is room in the (e.g., US) band for only 2 FB frequency channels (32 Mchip/s); however, there are 8 SRCH_Ids as well as 48 CCC_IDs. (The optional SCC are not considered in this section.) This provides a total 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 3/5/33 transmits on a center frequency of 2422 MHz using search code S5 during acquisition, and cyclic data code sequence C5C6C4C7 during the data portion of the frame.

When substantial overlap of BSA coverage is required, adjacent BSAs should be operated on CHNL_IDs separated in frequency sufficiently to provide at least 35-dB of isolation. For FB operation (32-Mchip/s MSK) this is possible if the BSAs are placed on an approximately rectangular grid. When BSAs have some 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).

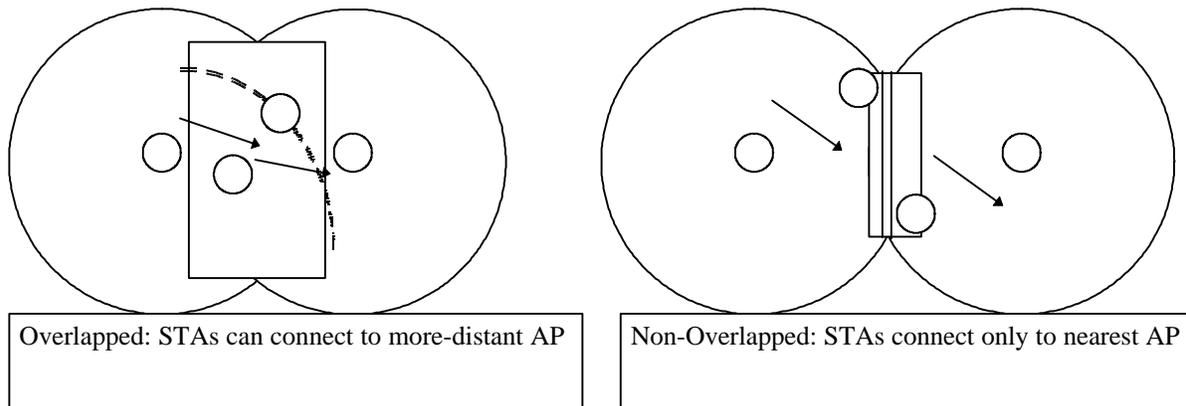


Figure 2 - Overlapped and Non-Overlapped BSA Coverage

1.4.6.5 Spreading Sequences

All codes contain 16 binary values within a channel symbol. One of 8 “search” spreading codes (a transmitted symbol waveform.

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
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 S₀-S₃ have better autocorrelation side lobes than codes S₄-S₇. 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.,

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

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 or 9 bits/symbol, respectively, with optional rate 13/15 FEC on the 5-bit/symbol modulation. The primary data-transfer modulation is 5 bits/symbol using 16-ary DBOK to effect 10-Mbps data rate at 32-Mchip/s spreading or 5-Mbps data rate at 16-Mchip/s spreading. FEC provides the “degraded-speed” mode, used, e.g., under poor propagation conditions. The 9-bit/symbol modulation is the “enhanced-speed” mode, used, e.g., at short range. All modes are shown in Table 11.

Table 11 - Combinations of Chip Rate, Data Rate and Modulation

Chip Rate	Data Rate	Modulation (& Coding)	Used For	Regulatory
32 Mchip/s (FB)	2 Mbps	DBPSK	FSD	FCC, IC, ETSI
	8 Mbps	16-ary OK	SIGNAL, LENGTH, R/S-CRC	
	10 Mbps	16-ary DBOK	MPDU	
	8.7 Mbps	16-ary DBOK/(15,13)FEC	MPDU	
	18 Mbps	Constrained 4x4-ary DBOK	MPDU	
16 Mchip/s (HB)	1 Mbps	DBPSK	FSD	FCC, IC, ETSI, MCK
	4 Mbps	16-ary BOK	SIGNAL, LENGTH, R/S-CRC	
	5 Mbps	16-ary DBOK	MPDU	
	4.3 Mbps	16-ary DBOK/(15,13)FEC	MPDU	
	9 Mbps	Constrained 4x4-ary DBOK	MPDU	

1.4.6.6.1 DBPSK Signaling

Differential **Bi-Phase Shift Keying** (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,

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

previous symbols), and

C_n is the spreading code used on the n^{th} 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 Keying (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 $\{\pm 1\}$ 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 n^{th} 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 Bi-Orthogonal Keying (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 $\{\pm 1\}$ 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

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

previous symbols), and

C_n is the spreading code used on the n^{th} symbol.

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, then
- performing a DBPSK demodulation between the largest-magnitude complex correlator outputs for the current and previous symbols, which yields the 5th bit.

1.4.6.6.4 (15,13) Forward Error Correction

The FEC option encodes 13 5-bit information symbols into 15 5-bit channel symbols. The two check symbols enable correction of any single-symbol error due to a failure of the orthogonal signaling component. Single-error-correction capability enables fixed block decoding in hardware; combined with the small block size this offers low latency decoding.

The FEC technique recognizes that the DBPSK component of 16-ary DBOK signaling requires 4-dB lower symbol SNR than does the orthogonal-signaling component. In the absence of orthogonal-signaling errors the probability of error for the DBPSK component is truly negligible. On the other hand, when a demodulation error is made in the selection of the orthogonal waveform, then the DBPSK error probability is approximately 50%; furthermore, for two adjacent symbols the DBPSK decisions are so effected. Table 12 shows how these statistics are accommodated in the coding technique.

Table 12 - FEC Coding Block

													check symbols	
d ₀₀	D ₁₀	d ₂₀	d ₃₀	D ₄₀	D ₅₀	d ₆₀	d ₇₀	d ₈₀	d ₉₀	d _{A0}	d _{B0}	d _{C0}	d _{D0}	D _{E0}
d ₀₁	D ₁₁	d ₂₁	d ₃₁	D ₄₁	D ₅₁	d ₆₁	d ₇₁	d ₈₁	d ₉₁	d _{A1}	d _{B1}	d _{C1}	d _{D1}	D _{E1}
d ₀₂	D ₁₂	d ₂₂	d ₃₂	D ₄₂	D ₅₂	d ₆₂	d ₇₂	d ₈₂	d ₉₂	d _{A2}	d _{B2}	d _{C2}	d _{D2}	D _{E2}
d ₀₃	D ₁₃	d ₂₃	d ₃₃	D ₄₃	D ₅₃	d ₆₃	d ₇₃	d ₈₃	d ₉₃	d _{A3}	d _{B3}	d _{C3}	d _{D3}	D _{E3}
d ₀₄	D ₁₄	d ₂₄	d ₃₄	D ₄₄	D ₅₄	d ₆₄	d ₇₄	d ₈₄	d ₉₄	d _{A4}	d _{B4}	d _{C4}	d _{D4}	D _{E4}

Note: **hexadecimal notation used for symbol subscripts** of this section to avoid commas in subscripts, e.g., d_{D3} instead of d_{13,3}.

Encoding

- 1) The 13 4-bit input symbols [d_{n1},d_{n2},d_{n3},d_{n4}], 0≤n≤12, are encoded using a (15,13) Reed-Solomon code over GF{2⁴}, producing the check symbols [d_{D1},d_{D2},d_{D3},d_{D4}] and [d_{E1},d_{E2},d_{E3},d_{E4}];
- 2) The code polynomial is x²+α¹¹x+1, where α is a primitive root of x⁴+x+1;
- 3) The DBPSK bits d_{n0} are separated into even and odd streams, and parity on these is computed independently, producing d_{D0} and d_{E0}.

Decoding

- 1) As the symbols emerge from the demodulator on receive the syndrome is computed, while the information symbols are buffered;
- 2) If the syndrome is [0,0,0,0],[0,0,0,0] then the buffered information symbols are read out unchanged;
- 3) If the syndrome is not identically all zeros, then the information symbols are read out and corrected as follows;
- 4) The 4-bit symbol in error (the “error symbol”) is changed to its correct value;
- 5) Parity is computed on the even bits d_{n0}, and, if in error the bit closest to the error symbol is complimented;
- 6) Parity is computed on the odd bits d_{n0}, and, if in error the bit closest to the error symbol is complimented.

This single-error-correcting code cannot detect multiple errors within a coding block; the frame CRC provides the overall integrity check.

1.4.6.6.5 Constrained 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., X₀={W₀,W₁,W₂,W₃}, X₁={W₄,W₅,W₆,W₇}, X₂={W₈,W₉,W₁₀,W₁₁}, X₃={W₁₂,W₁₃,W₁₄,W₁₅}. 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, but this incurs a 6-dB peak-to-average envelope fluctuation.

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 nth symbol envelope to be

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

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 X₀ (±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 X₁ (±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 X₂ (±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 X₃ (±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 13. 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.

Table 13 - 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

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

The high-rate DSSS 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 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 Transmit Power On and Power Down Ramp.

1.4.6.10 Slot Time

The slot time for the high-rate DSSS PHY shall be the sum of the carrier-detect time specified in clause Clear Channel Assessment and twice the receive-to-transmit turn-around time specified in clause 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 regulatory bodies, 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 14 - Maximum Transmit Power Levels

Maximum output power	Geographic location	Compliance Document
1000 mW ($G_T < 6$ dBi)	USA	FCC 15.247
100 mW (EIRP)	Europe	ETS 300-328
200 mW (≤ 10 mW/MHz)	Japan	MPT ordinance 79

In the USA, the output power must be reduced from 1000 mW by 1/3 (in dB) of the amount by which the antenna gain exceeds 6 dBi. Canada substantially conforms to the USA regulations.

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. A maximum of 4 power levels may be provided. A radio capable of transmitting more than 100 mW shall at least be capable of switching down to 100 mW.

1.4.7.4 Transmit Spectrum Mask

1.4.7.4.1 Full-Bandwidth Channels

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

$$P_T(f) < -50 \frac{|f - f_c| - 16}{11} \text{ dBr} \quad 16 \leq |f - f_c| \leq 27$$

$$P_T(f) < -50 \text{ dBr} \quad |f - f_c| > 27$$

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

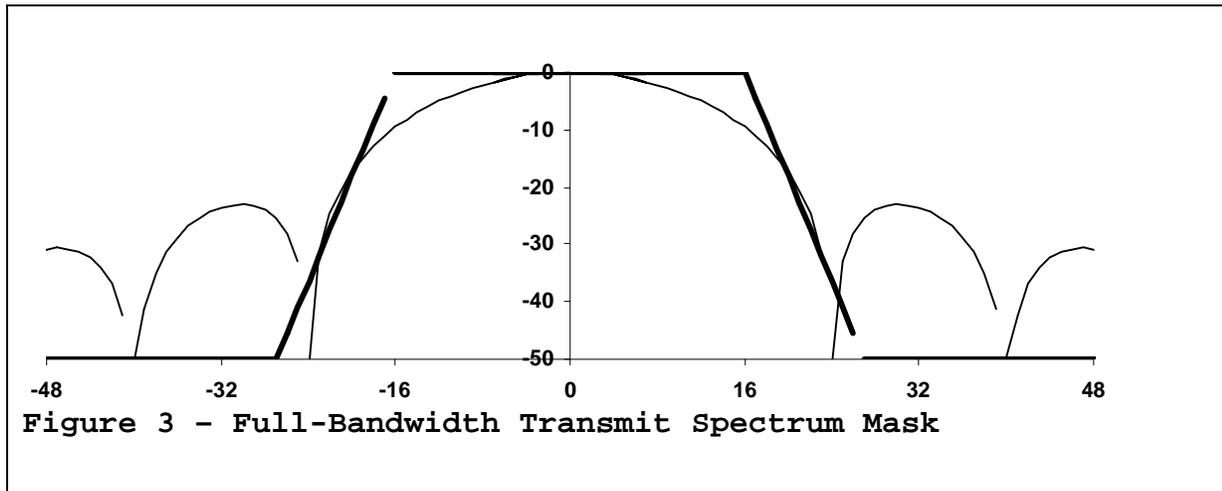


Figure 3 - Full-Bandwidth Transmit Spectrum Mask

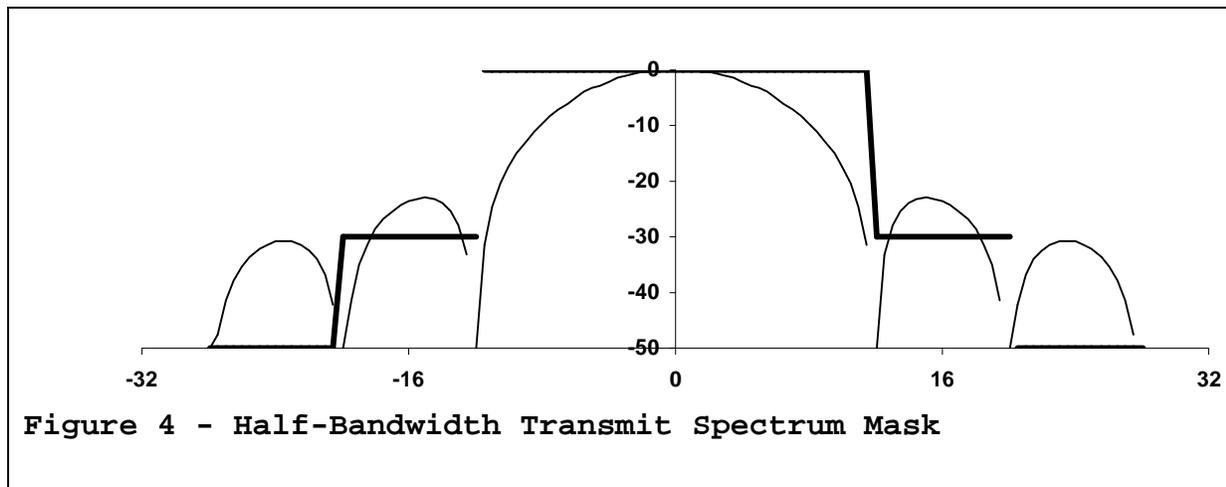
1.4.7.4.2 Half-Bandwidth Channels

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

$$P_T(f) < -30 \text{ dBr} \quad 12 \text{ MHz} \leq |f - f_c| \leq 20 \text{ MHz}$$

$$P_T(f) < -50 \text{ dBr} \quad |f - f_c| > 20 \text{ MHz}$$

Where f_c is the carrier frequency and f is the spectral variable, both in MHz. The transmitter spectral mask is shown in Figure 4. The measurements shall be made using 100 kHz resolution bandwidth and 30 kHz video bandwidth.



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 μ s. 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 Number of Operating Frequency Channels. The adjacent-channel-rejection specification applies to a pair of FB channels separated by ≥ 40 MHz, a pair of HB channels separated by ≥ 30 MHz, or between a pair of channels, one FB and one HB, separated by ≥ 30 MHz. The adjacent rejection shall be 35 dB, or greater, at a FER of 5% using the 16-ary DBOK modulation described in clause

1.4.6.6 Modulation and Channel Data Rates and an MPDU length of 1024 bytes. The adjacent channel rejection shall be measured as follows:

The input signal shall use the 5-bit/symbol, 16-ary DBOK modulation (10-Mbps or 5-Mbps, respectively, depending upon whether it is FB or HB) at a level 6-dB greater than that specified in clause Minimum Transmitted Power level. The adjacent-channel signal shall use the 5-bit/symbol, 16-ary DBOK modulation (10-Mbps or 5-Mbps, respectively, depending upon whether it is FB or HB) at a level 41-dB greater than that specified in clause 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 high-rate DSSS PHY shall provide the capability to perform Clear channel Assessment (CCA) according to the following *Carrier-Sense* methods:

Mode 1 (required): DSSS under 802.11-18. CCA shall report a busy medium upon detecting the preamble portion of a DSSS transmission specified under 802.11-18, using the search code in effect within the BSA.

Mode 2 (optional): DSSS under 802.11-15. CCA shall report a busy medium upon detecting any portion of a 1- or 2-Mbps DSSS transmission using 11-Mchip/s PSK spreading and the Barker code specified in 802.11-15.

Mode 3 (optional): FH under 802.11-14. CCA shall report a busy medium upon detecting any portion of a 1- or 2-Mbps FHSS transmission using 1-symbol/s on center frequencies and with modulation specified in 802.11-14.

Modes 2 and 3, if implemented, must be maskable.

The CCA shall be TRUE if none of the un-masked modes indicates carrier sense condition. CCA operation is subject to the following criteria:

- a) Carrier sense must occur for signals above the minimum receive signal level indicated in clause Receiver Minimum Input Level Sensitivity;
- b) Carrier sense must occur within the CCA carrier-sense time of 10 μ s after initiation of signal;
- c) If an 802.11-18 PLCP Header is received, then the high-rate DSSS 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;
- d) If an optional (Mode 2 or Mode 3) carrier sense occurs, then the CCA signal inactive (channel busy) shall persist until the signal is no longer detectable.