802.11b White Paper

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1. 802.11b Glossary

This document and the documents listed above use the following abbreviations defined here.

STA	Station
BFWB	Basic Fast Walsh Block
BPSK	Binary Phase Shift Keying
CCA	Clear Channel Assessment
CDMA	Code Division Multiple Access
CCK	Complementary Code Keying
CRC	Cyclic Redundancy Code
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DFE	Decision Feedback Equalizer
DQPSK	Differential Quadrature Phase Shift Keying
DS	Direct Sequence
DSSS	Direct Sequence Spread Spectrum
Eb/No	Energy per bit to Density of Noise ratio
Es/No	Energy per symbol to Density of Noise ratio
FCS	Frame Check Sequence
FH	Frequency Hopping
FHSS	Frequency Hopping Spread Spectrum
FFT	Fast Fourier Transform
FWT	Fast Walsh Transform
HR	High Rate
ICI	Inter-Chip Interference
ISI	Inter-Symbol Interference
LSB	Least Significant Bit
MAC	Medium Access Control
MBOK	M-ary Bi-Orthogonal keying
Mbps	Millions of bits per second
Mcps	Millions of chips per second
MOK	M-ary Orthogonal keying
MPDU	MAC Protocol Data Units
MSB	Most Significant Bit
MSps	Millions of symbols per second
PBCC	Packet Binary Convolutional Coding
PHY	Physical Layer
PLCP	Physical Layer Convergence Protocol
PMD	Physical Medium Dependent
PPDU	PLCP Protocol Data Unit
PSDU	PLCP Service Data Unit
QPSK	Quadrature Phase Shift Keying
SFD	Start Frame Delimiter
STA	Station
WLAN	Wireless Local Area Network

2. Introduction to 802.11b

IEEE 802.11 specifies a 2.4 GHz operating frequency with data rates of 1 and 2 Mbps using either Direct Sequence Spread Spectrum (DSSS) or Frequency Hopping Spread Spectrum (FHSS). In IEEE 802.11b data is encoded using DSSS (Direct Sequence Spread Spectrum) technology. DSSS works by taking a data stream of zeros and ones and modulating it with a second pattern, the chipping sequence. In 802.11, that sequence is known as the Barker code, which is an 11 bits sequence (10110111000) that has certain mathematical properties making it ideal for modulating radio waves. The basic data stream is XOR’d with the Barker code to generate a series of data objects called chips. Each bit is "encoded" by the 11bits Barker code, and each group of 11 chips encodes one bit of data.

IEEE 802.11b uses 64 CCK (Complementary Code Keying) chipping sequences to achieve 11 Mbps. Rather than using the Barker code, CCK uses a series of codes called Complementary Sequences. Because there are 64 unique code words that can be used to encode the signal, up to 6 bits can be represented by any one particular code word (instead of the 1 bit represented by a Barker symbol).

The wireless radio generates a 2.4 GHz carrier wave (2.4 to 2.483 GHz) and modulates that wave using a variety of techniques. For 1 Mbps transmission, BPSK (Binary Phase Shift Keying) is used (one phase shift for each bit). To accomplish 2 Mbps transmission, QPSK (Quadrature Phase Shift Keying) is used. QPSK uses four rotations (0, 90, 180 and 270 degrees) to encode 2 bits of information in the same space as BPSK encodes 1. The trade-off is increase power or decrease range to maintain signal quality. Because the FCC regulates output power of portable radios to 1 watt EIRP (equivalent isotropic radiated power), range is the only remaining factor that can change. On 802.11 devices, as the transceiver moves away from the radio, the radio adapts and uses a less complex (and slower) encoding mechanism to send data.

The MAC layer communicates with the PLCP via specific primitives through a PHY service access point. When the MAC layer instructs, the PLCP prepares MPDUs for transmission. The PLCP also delivers incoming frames from the wireless medium to the MAC layer. The PLCP sublayer minimizes the dependence of the MAC layer on the PMD sublayer by mapping MPDUs into a frame format suitable for transmission by the PMD.

Under the direction of the PLCP, the PMD provides actual transmission and reception of PHY entities between two stations through the wireless medium. To provide this service, the PMD interfaces directly with the air medium and provides modulation and demodulation of the frame transmissions. The PLCP and PMD communicate using service primitives to govern the transmission and reception functions

The CCK code word is modulated with the QPSK technology used in 2 Mbps wireless DSSS radios. This allows for an additional 2 bits of information to be encoded in each symbol. Eight chips are sent for each 6 bits, but each symbol encodes 8 bits because of the QPSK modulation. The spectrum math for 1 Mbps transmission works out as 11 Mchips per second times 2 MHz equals 22 MHz of spectrum. Likewise, at 2 Mbps, 2 bits per symbol are modulated with QPSK, 11 Mchips per second, and thus have 22 MHz of spectrum. To send 11 Mbps 22 MHz of frequency spectrum is needed.

It is much more difficult to discern which of the 64 code words is coming across the airwaves, because of the complex encoding. Furthermore, the radio receiver design is significantly more difficult. In fact, while a 1 Mbps or 2 Mbps radio has one correlator (the device responsible for lining up the various signals bouncing around and turning them into a bit stream), the 11 Mbps radio must have 64 such devices.

Figure 1 shows the digital modulation of data with PRN sequence.

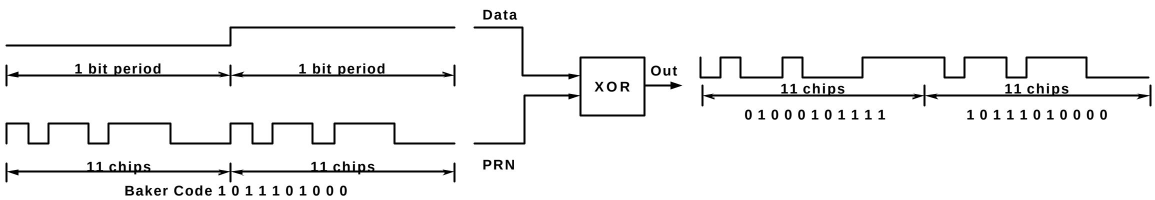

Figure 1. Digital Modulation of Data with PRN sequence

Figure 2 shows the Modified Walsh Transform uses for the reception of DSSS signal.

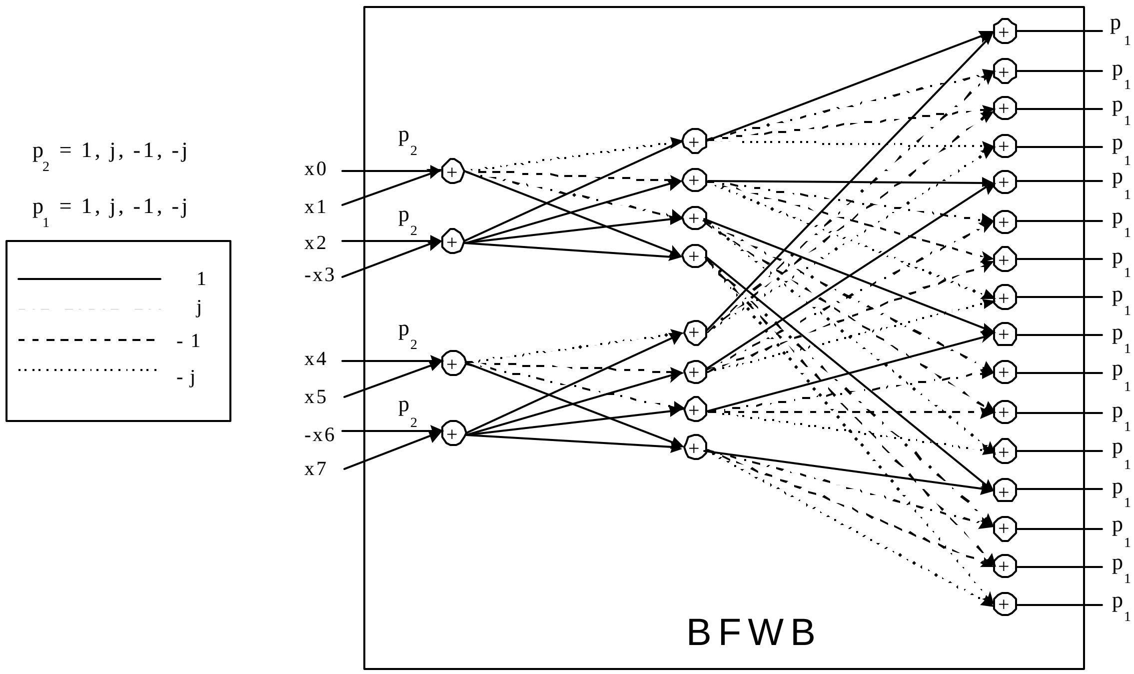

Figure 2. Basic Fast Walsh Transform Block (BFWB).

The wireless physical layer is split into two parts, called the PLCP (Physical Layer Convergence Protocol) and the PMD (Physical Medium Dependent) sublayer. The PMD takes care of the wireless encoding. The PLCP presents a common interface for higher-level drivers to write to and provides carrier sense and CCA (Clear Channel Assessment), which is the signal that the MAC (Media Access Control) layer needs so it can determine whether the medium is currently in use.

The PLCP consists of a 144 bits preamble that is used for synchronization to determine radio gain and to establish CCA. The preamble comprises 128 bits of synchronization, followed by a 16 bits field consisting of the pattern 1111001110100000. This sequence is used to mark the start of every frame and is called the SFD (Start Frame Delimiter).

The next 48 bits are collectively known as the PLCP header. The header contains four fields: signal, service, length and HEC (header error check). The signal field indicates how fast the payload will be transmitted (1, 2, 5.5 or 11 Mbps). The service field is reserved for future use. The length field indicates the length of the ensuing payload, and the HEC is a 16 bits CRC of the 48 bits header.

In a wireless environment, the PLCP is always transmitted at 1 Mbps. Thus, 24 bytes of each packet are sent at 1 Mbps. The PLCP introduces 24 bytes of overhead into each wireless Ethernet packet before we even start talking about where the packet is going. Ethernet introduces only 8 bytes of data. Because the 192 bits header payload is transmitted at 1 Mbps, 802.11b is at best only 85 percent efficient at the physical layer.

3. 802.11b Overview

The IEEE 802.11b is a Direct Sequence Spread Spectrum (DSSS) system very similar in concept to the CDMA Wireless, using a spread spectrum chip sequence.

In the 802.11b the transmission medium is wireless and the operating frequency band is 2.4 GHz. 802.11b provides 5.5 and 11 Mbps payload data rates in addition to the 1 and 2 Mbps rates provided by 802.11. To provide the higher rates, 8 chip Complementary Code Keying (CCK) is employed as the modulation scheme. The CCK uses 6 bits to encode the code sent, this increase the speed of the 802.11 by 6.The chipping rate is 11 MHz, which is the same as the DSSS system as described in 802.11, thus providing the same occupied channel bandwidth.

802.11b describes an optional mode replacing the CCK modulation with packet binary convolutional coding (HR/DSSS/PBCC).

Another optional mode of 802.11b allows data throughput at the higher rates (2, 5.5, and 11 Mbps) to be significantly increased by using a shorter PLCP preamble. This mode is called HR/DSSS/short. This Short Preamble mode can coexist with DSSS, HR/DSSS under limited circumstances, such as on different channels or with appropriate CCA mechanisms.

The High Rate PHY contains three functional entities: the PMD function, the physical layer convergence function, and the layer management function. For the purposes of MAC and MAC Management when channel agility is both present and enabled, the High Rate PHY shall be interpreted to be both a High Rate and a frequency hopping physical layer. The High Rate PHY service shall be provided to the MAC through the PHY service primitives.

To allow the MAC to operate with minimum dependence on the PMD sublayer, a physical layer convergence procedure (PLCP) sublayer is defined. This function simplifies the PHY service interface to the MAC services.

The PMD sublayer provides a means and method of transmitting and receiving data through a wireless medium (WM) between two or more STAs each using the High Rate system.

The PLME performs management of the local PHY functions in conjunction with the MAC management entity.

4. CCK used in 802.11b

CCK is a variation on M-ary Orthogonal Keying modulation, which uses I/Q modulation architecture with complex symbol structures. CCK allows for multi-channel operation in the 2.4 GHz band using the existing 802.11 DSSS channel structure scheme. The spreading employs the same chipping rate and spectrum shape as the 802.11 Barker's code word. Spreading functions, allows three non-interfering channels in the 2.4 to 2.483 GHz band

CCK is an M-ary Orthogonal Keying modulation where one of M unique (nearly orthogonal) signal codewords is chosen for transmission. The spread function for CCK is chosen from a set of M nearly orthogonal vectors by the data word. CCK uses one vector from a set of 64 complex (QPSK) vectors for the symbol and thereby modulates 6 bits (one of 64) on each 8 chips spreading code symbol. Two more bits are sent by QPSK modulating the whole code symbol. This results in modulating 8 bits onto each symbol. The formula that defines the CCK codewords has 4 phase terms. One of them modulates all of the chips (j_1) and this is used for the QPSK rotation of the whole code vector. The 3 others modulate every odd chip (j_2), every odd pair of chips (j_3) and every odd quad of chips (j_4) respectively.

$$c = \left\{ \begin{array}{c} e^{j(j_1+j_2+j_3+j_4)}, e^{j(j_1+j_3+j_4)}, e^{j(j_1+j_2+j_4)}, e^{j(j_1+j_4)}, \\ e^{j(j_1+j_2+j_3)}, e^{j(j_1+j_3)}, e^{j(j_1+j_2)}, e^{j(j_1)} \end{array} \right\}$$

Walsh functions used for the M-ary Bi-Orthogonal keying (MBOK) modulation are the most well known orthogonal BPSK vector set. To transmit enough bits per symbol, the MBOK modulation is used independently on the I and Q channels of the waveform effectively doubling the data rate. CCK on the other hand uses a complex set of Walsh/Hadamard functions known as Complementary Codes.

Walsh/Hadamard properties are similar to Walsh functions but are complex, that is, more than two phase, while still being nearly orthogonal. With complex code symbols, it is not possible to independently transmit simultaneous code symbols without suffering amplitude modulation. Since the set of complementary codes is more extensive, however, we have a larger set of nearly orthogonal codes to pick from and can get the same number of bits transmitted per symbol without simultaneous transmission of symbols.

The multi-path performance of CCK is better than MBOK due to the lack of cross rail interference. For MBOK, there are 8 BPSK chips that have a maximum vector space of 256 code words of which it is possible to find sets of 8 that are orthogonal. Two independent BPSK vector sets are selected for the orthogonal I and Q channels which modulate 3 bits on each. Two additional bits are used to BPSK modulate each of the spreading code vectors. For CCK, there are 65536 possible code words, and sets of 64 that are nearly orthogonal. This is because it really takes 16 bits to define each code vector. To get a half data rate version, a subset of 4 of the 64 vectors having superior coding distance is used.

CCK suffers less from multi-path distortion in the form of cross coupling (of I and Q channel information) than MBOK. The information in CCK is encoded directly onto complex chips, which cannot be cross-couple corrupted by multi-path since each channel finger has an $Ae^{j\theta}$ distortion. A single channel path gain-scales and phase-rotates the signal. A gain scale and phase rotation of a complex chip still maintains I/Q orthogonal. This superior encoding technique avoids the corruption resulting from encoding half the information on the I-channel and the other half on the Q-channel, as in MBOK, which easily cross-couple corrupts with the multipath's $Ae^{j\theta}$ phase rotation.

For 1 Mbps, the signal is modulated BPSK by one bit per symbol and then spread by BPSK modulating with the 11 chip Barker code at 11 Mcps. For 2 Mbps, the signal is QPSK modulated by two bits per symbol and then BPSK spread as before. For the 5.5 Mbps CCK mode, the incoming data is grouped into 4 bits nibbles where 2 of those bits select the spreading function out of the set of 4 while the remaining 2 bits QPSK modulate the symbol. The spreading sequence then DQPSK modulates the carrier by driving the I and Q modulators. To make 11 Mbps CCK modulation, the input data is grouped into 2 bits and 6 bits. The 6 bits are used to select one of 64 complex vectors of 8 chip length for the symbol and the other 2 bits DQPSK modulate the entire symbol. The chipping rate is maintained at 11 Mcps for all modes.

The signal acquisition scheme for 802.11 uses a specific preamble and header using the 1 Mbps modulation and has provision for sending the payload at different rates. The packet frame structure and protocol of 802.11 is much like 802.3 Ethernet, however it must operate wirelessly in a harsh RF environment. This means that the signal levels may become corrupted and subject to multi-path. Signal acquisition and synchronization of the preamble and header are critical. The preamble and header consists of six fields. They are: Preamble, SFD, Signal (rate), Service, Length and CRC. The header takes 48 bits, and the total length of the acquisition sequence is 192 µs. The preamble and header is modulated using the 1 Mbps modulation rate and is scrambled with a self-synchronizing scrambler. The high rate scheme will use this acquisition sequence, which already has a rate field that can be programmed for 1, 2, 5.5 or 11 Mbps.

The 802.11 packet transmission protocol is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This differs from “wired” Ethernet, which uses collision detection. Radios can’t detect collisions, therefore they use collision avoidance using a listen before talk and random back off deferral mechanism. Since all stations use the same acquisition sequence at the lowest basic rate, all stations can see the traffic and process the signals at the appropriate rate. If legacy 1 and 2 Mbps stations receive the packet header, but are not capable of processing the higher rate, they can still defer the medium based on knowing that an 802.11 signal has been sensed and knowing the length of time it will be on the air.

To insure that the modulation has the same bandwidth as the existing 802.11 DS modulation, the chipping rate is kept at 11 Mcps while the symbol rate is increased to 1.375 MSps. This accounts for the shorter symbols and makes the overall bit rate 11 Mbps. This approach makes system interoperability with the 802.11 preamble and header much easier. The spread rate remains constant and only the data rate changes and the spectrum of the CCK waveform is same as the legacy 802.11 waveform.

5. Walsh and Complementary Codes for 802.11b

Walsh codes can be obtained performing simple operations as it is illustrated in Figure 3. For the 2-ary case, taking a 2x2 matrix of 1s and inverting the lower right quadrant of the matrix form the basic symbols. To form the 4-ary case, take 4 of the 2x2 matrices and make a 4x4 matrix with the lower right hand quadrant again inverted. The procedure is repeated for the 8-ary case and beyond.

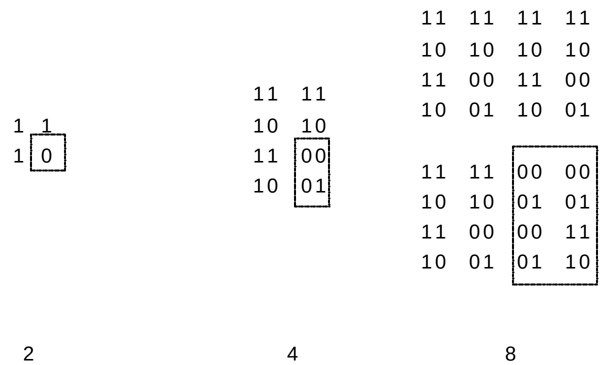

Figure 3. Forming Walsh Codes by successive folding.

Walsh functions have a regular structure and at least one member that has a substantial DC bias. In this case it is the first row with all 1s. All the rest are half 1s and half 0s. The DC bias can be reduced on the worst member of the set by multiplying all members with a cover code. This, however, introduces a (smaller) bias in half of the members.

The main concern about MBOK is caused by the fact that it uses independent codes on the in phase and quadrature signals, which creates a significant amount of cross rail interference in the presence of multi-path. To avoid this, one would ideally transmit only symbols for which processing could be done on I and Q simultaneously, and use code words that all have good autocorrelation properties, such that there is minimal inter-symbol and inter-chip interference. Such codes actually exist in the form of the complementary codes. For a code length of 8 chips, 256 possible sequences *c* can be constructed as follows, using 4 QPSK phases j_1 to j_4. Note that j_1 is present in all 8 chips, so it simply rotates the entire code word. Hence, to decode these codes set, one would need 64 correlators plus an additional phase detection of the code that gave the largest correlation output. The correlation can be significantly simplified by using techniques like the Fast Walsh transform (analogous to an FFT butterfly circuit). In fact, when the 4 input phases j_1 to j_4 are binary, then the complementary code set reduces to a modified Walsh code set.

6. Fast Transform Structure for 802.11b

The four-phase variables each take on values of [0, $\pi/2$, π, $3\pi/2$], and there are 256 (4*64) possible 8 chip codes. These codes have an inherent "Walsh" type structure that allows a simple butterfly implementation of the decoder. Although it is possible to squeeze a few more complementary codes out of this 8 chips set, the rest of the codes cannot be decoded with the modified fast Walsh transform. Figure 2 shows the basic fast Walsh block which brings in 8 chips of soft decision data shown here by x0, x1, …x 7, and produces 16 possible correlation for given values of j_1 and j_2. Figure 4 shows all 256 possible correlator outputs. The BFWB's are shown in detail in Figure 2. There are 28 butterflies needed for a length 8 transform. Each butterfly requires 4 additions (the phase rotations are trivial for 4-PSK), so the total number of operations is 112 complex additions. The direct calculation method with 64 separate correlators requires 512 complex additions, so the fast transform reduces the complexity by almost a factor of 5.

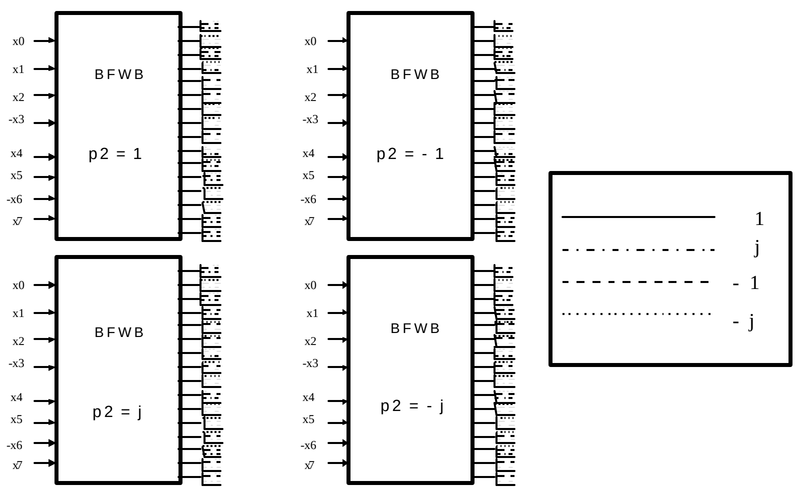

Figure 4. Modified Walsh Transform.

CCK is inherently a quadrature MOK signal. For the full data rate potential, DQPSK modulate the starting phase of the symbols to get 11 Mbps. To reduce the data rate for a more robust lower data rate, we can trim the signal set to one that has the greatest distance properties with a reduced number of vectors. For 5.5 Mbps, there are two options

- First, trim the 64-ary set to 8-ary and BPSK modulate the symbols
- Second, trim the set to 4-ary and QPSK modulate the symbols.

Either scheme achieves 4 bits per symbol but simulations conclude that the latter is more robust in multi-path.

The excellent range that the CCK modulation achieves is due to the fact that MOK has better Eb/No performance than BPSK. This performance is due the embedded coding properties of the spreading modulation. The modulation basically ties several bits together so that the receiver makes a symbol decision. If a symbol is in error then all of the bits in that symbol are suspect, but not all will necessarily be in error. Thus, the symbol error rate and the bit error rates are related. While the SNR required making a symbol decision correctly is higher than required to make a one-bit decision, it is not as high as required to make all of the bit decisions of a symbol independently and correctly. Thus, some coding gain is embedded in the basic spreading waveform. Simulations conclude CCK modulation yields achievable ranges of 100' reliably and that the high rates are more susceptible to multi-path than the lower rates as would be expected from the higher required Es/No.

7. 802.11b Equalization

Reception in a multi-path environment can be substantially improved by equalization. The typical environment for wireless LANs is the office or home. There, the multi-path delay spread is on the order of 100 ns or less. Usually, the presence of walls in the direct path makes the system work from indirect paths and that makes the impulse response have energy leading the peak of the energy. This is called precursor energy and requires more complex processing that does the trailing energy from delayed echoes. Typically, precursor processing involves complex multiplies whereas, trailing energy involves adds and subtracts.

Large warehouses and factories often have much larger delay spreads and this takes more equalization processing. There is a range of complexities in the receive processing that can be employed to meet each of these environments.

The RAKE receiver principle is good for modest multi-path of around 100 ns delay spread. The classical RAKE receiver has multiple correlators with a delay and a combine circuit following the correlators. For the CCK waveform, this would result in a complex design, as the CCK scheme requires multiple correlators for each of the multiple correlators of the RAKE technique. By linear transformation, the RAKE combiner can be moved to the input of the correlator bank where it is much simpler. In this form, it is called a Channel Matched Filter, because it complements the channel impulse response and therefore corrects for it. This removes the channel effects as far as can be done with a fixed filter, but does not correct for inter-symbol or inter-chip interference (ISI/ICI). The RAKE-only receiver can achieve near 100 ns delay spread performance without an equalizer.

For the larger delay spreads of the factory environment, an ISI/ICI equalizer is needed and that raises the complexity in several ways. First, the equalizer requires lots of gates running very fast in the receiver, and second it needs Decision Feedback Equalizer (DFE) to properly handle the ISI and ICI.

The first stage of equalization is ISI cancellation and that involves taking the output of the symbol decisions and then subtracting the left over energy of the previous symbol from the current symbol before demodulation.

The next step in equalization is canceling the ICI interference and that takes a more complex process since the ICI depends on which of the 64 vectors was received.

8. 802.11b High Rate PLCP

PSDUs are converted to and from PPDUs. During transmission, the PSDU shall be appended to a PLCP preamble and header to create the PPDU. Two different preambles and headers are defined: long preamble and header, which interoperates with the current 1 and 2 Mbps DSSS specification, and a short preamble and header. At the receiver, the PLCP preamble and header are processed to aid in demodulation and delivery of the PSDU. The short preamble and header is intended for applications where maximum throughput is desired and interoperability with legacy and non-short preamble capable equipment is not possible, that is, it can be used in networks of like equipment that can all handle this operation mode.

Figure 5 shows the format for the interoperable (long) PPDU including the High Rate PLCP Preamble, the High Rate PLCP Header, and the PSDU. The PLCP Preamble contains the following fields: Synchronization (Sync) and Start Frame Delimiter (SFD). The PLCP Header contains the following fields: Signaling (SIGNAL), Service (SERVICE), Length (LENGTH), and CCITT CRC-16 field. The format for the PPDU including the long High Rate PLCP preamble, the long High Rate PLCP header and the PSDU do not differ from the 802.11-1999 for 1 and 2 Mbps. The only exceptions are the encoding of the rate in the SIGNAL Field and the use of bits in the SERVICE field to resolve an ambiguity in PSDU length in octets when the length is expressed in whole microseconds and to indicate if the PBCC mode is being used.

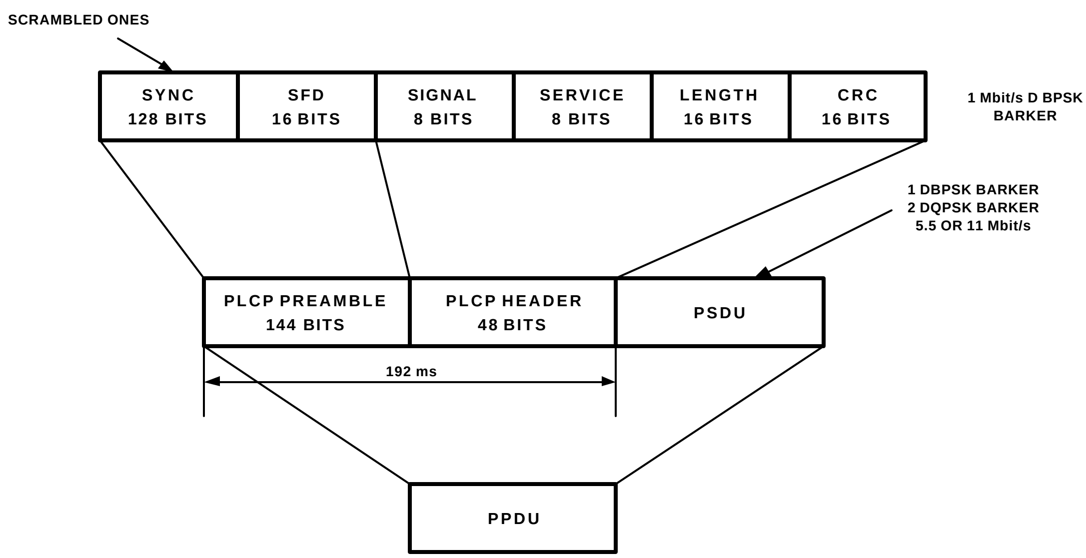

Figure 5. Long PLCP PPDU format.

The short PLCP preamble and header (HR/DSSS/short) may be used to minimize overhead and thus maximize the network data throughput. The format of the PPDU with HR/DSSS/short is illustrated in Figure 6.

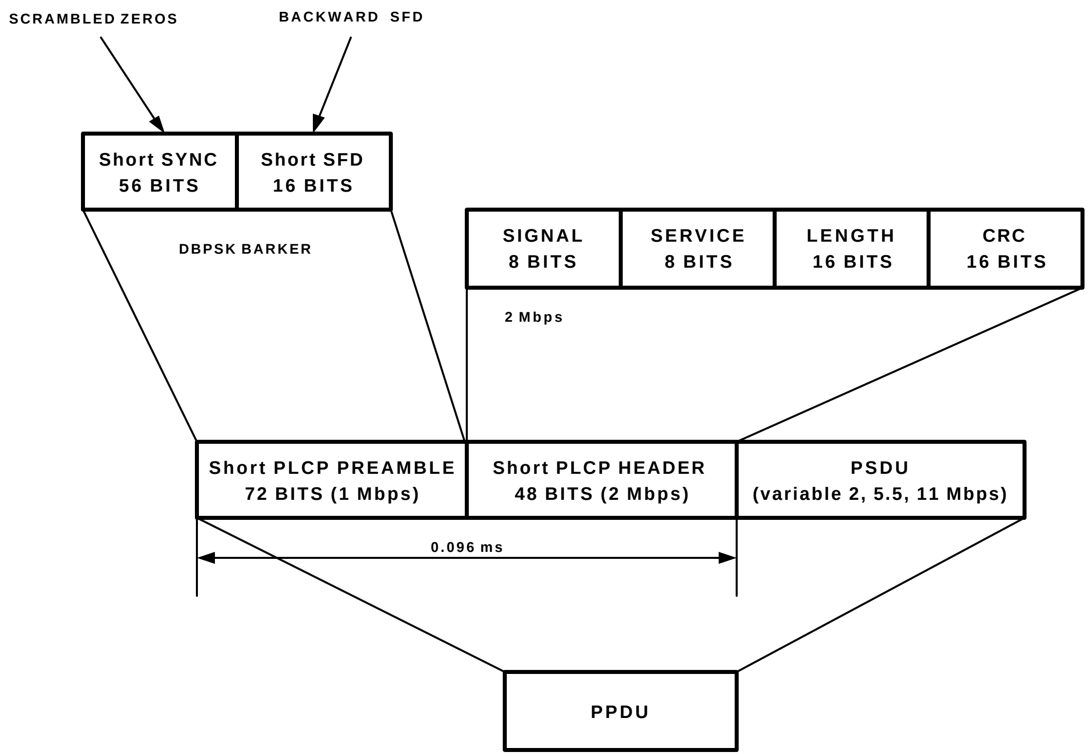

Figure 6. Short PLCP PPDU format.

A transmitter using the short PLCP only can interoperate with another receiver which is also capable of receiving this short PLCP. To interoperate with a receiver that is not capable of receiving a short preamble and header, the transmitter shall use the long PLCP preamble and header.
The short PLCP preamble uses the 1 Mbps Barker code spreading with DBPSK modulation. The short PLCP header uses the 2 Mbps Barker code spreading with DQPSK modulation and the PSDU is transmitted at 2Mbps, 5.5 Mbps or 11 Mbps.

The SYNC field consists of 128 bits of scrambled "1" bits. This field is provided so the receiver can perform the necessary synchronization operations. The initial state of the scrambler (seed) is [1101100], where the left most bit specifies the value to put in the first delay element.

The SFD indicates the start of PHY dependent parameters within the PLCP Preamble. The SFD is a 16 bits field, [1111 0011 1010 0000], where the right most bit is transmitted first in time.

The 8 bits signal field indicates to the PHY the modulation is used for transmission (and reception) of the PSDU. The data rate is equal to the SIGNAL field value multiplied by 100 kbps. The High Rate PHY supports four rates given by the following 8 bits words, which represent the rate in units of 100 kbps, where the LSB is transmitted first in time:

- X'0A' (MSB to LSB) for 1 Mbps
- X'14' (MSB to LSB) for 2 Mbps
- X’37’ (MSB to LSB) for 5.5 Mbps
- X’6E’ (MSB to LSB) for 11 Mbps

Three bits have been defined in the SERVICE field to support the high rate extension. The right most bit (bit 7) is used to supplement the LENGTH field. Bit 3 is used to indicate whether the modulation method is CCK (bit 3 = 0) or PBCC (bit 3 = 1). Bit 2 is used to indicate that the transmit frequency and symbol clocks are derived from the same oscillator. This Locked Clocks bit is set by the PHY layer based on its implementation configuration. The SERVICE field is transmitted b0 first in time and is protected by the CCITT CRC-16 frame check sequence. Values of the bits b0, b1, b4, b5 and b6 are set to 0.

The PLCP length field is an unsigned 16 bits integer, which indicates the number of microseconds required to transmit the PSDU. The transmitted value is determined from the LENGTH and DATARATE parameters in the TXVECTOR issued with the PHY-TXSTART.request primitive.

The length field provided in the TXVECTOR is in octets and is converted to microseconds for inclusion in the PLCP LENGTH field.

The LENGTH field is calculated as follows: Since there is an ambiguity in the number of octets that is described by a length in integer microseconds for any data rate over 8 Mbps, a Length Extension bit shall be placed at bit position b7 in the SERVICE field to indicate when the smaller potential number of octets is correct.

- 5.5Mbps CCK Length = number of octets * 8/5.5, rounded up to the next integer.
- 11Mbps CCK Length = number of octets * 8/11, rounded up to the next integer and the service field b7 bit indicates a ‘0’ if the rounding took less than 8/11 or a ‘1’ if the rounding took more than or equal to 8/11.

At the receiver, the number of octets in the MPDU is calculated as follows:

- 5.5 Mbps CCK number of octets = Length * 5.5/8, rounded down to the next integer
- 11 Mbps CCK number of octets = Length * 11/8, rounded down to the next integer, minus 1 if the service field b7 bit is a ‘1’.

The SIGNAL, SERVICE, and LENGTH fields shall be protected with a CCITT CRC-16 FCS (Frame Check Sequence). The CCITT CRC-16 FCS is the one’s complement of the remainder generated by the modulo 2 division of the protected PLCP fields by the polynomial: $x^{16} + x^{12} + x^{5} + 1$. The protected bits shall be processed in transmit order. All FCS calculations shall be made prior to data scrambling.

The long PLCP preamble and header are transmitted using the 1 Mbps DBPSK modulation. The SIGNAL and SERVICE field combined indicates the modulation, which is used to transmit the PSDU. The SIGNAL field indicates the rate and the SERVICE field indicates the modulation. The transmitter and receiver initiate the modulation and rate indicated by the SIGNAL and SERVICE fields starting with the first octet of the PSDU. The PSDU transmission rate is set by the DATARATE parameter in the TXVECTOR issued with the PHY-TXSTART.request primitive

The shortSYNC field consists of 56 bits of scrambled "0" bits. This field is provided so the receiver can perform the necessary synchronization operations. The initial state of the scrambler (seed) is [0011011], where the left end bit specifies the value to place in the first delay element

The shortSFD is a 16 bit field and be the time reverse of the field of the SFD in the long PLCP preamble. The field is the bit pattern 0000 0101 1100 1111. The right end bit is transmitted first in time. A receiver not configured to use the short header option will not detect this SFD.

The 8 bits SIGNAL field of the short header indicates to the PHY the data rate which is used for transmission (and reception) of the PSDU. A PHY operating with a HR/DSSS/short option supports three rates given by the following 8 bit words, where the LSB is transmitted first in time and the number represents the rate in units of 100 kbps:

- X'14'(MSB to LSB) for 2 Mbps
- X'37'(MSB to LSB) for 5.5 Mbps
- X'6E'(MSB to LSB) for 11 Mbps

The SERVICE field in the short header is the same as the SERVICE field described in the long header.

The LENGTH field in the short header is the same as the LENGTH field described in the long header.

The CRC in the short header is the same as the CRC field described in the long header (in this case, the CRC is calculated over the shortSIGNAL, shortSERVICE and shortLENGTH fields).

The short PLCP preamble is transmitted using the 1 Mbps DBPSK modulation. The short PLCP header is transmitted using the 2 Mbps modulation. The SIGNAL and SERVICE fields combined indicate the modulation, which is used to transmit the PSDU. The SIGNAL field indicates the rate and the SERVICE field indicates the modulation. The transmitter and receiver initiate the modulation and rate indicated by the SIGNAL and SERVICE fields starting with the first octet of the PSDU. The PSDU transmission rate is set by the DATARATE parameter in the TXVECTOR issued with the PHY-TXSTART.request primitive.

The polynomial $G(z) = z^{-7} + z^{-4} + 1$ is used to scramble all bits transmitted. The feed-through configuration of the scrambler and descrambler is self-synchronizing, which requires no prior knowledge of the transmitter initialization of the scrambler for receive processing.

9. 802.11b System Description

Figure 7 shows a block diagram of the CCK transmitter, where Data Rate = 8 bits/symbol *1.375 MSps = 11 Mbps.

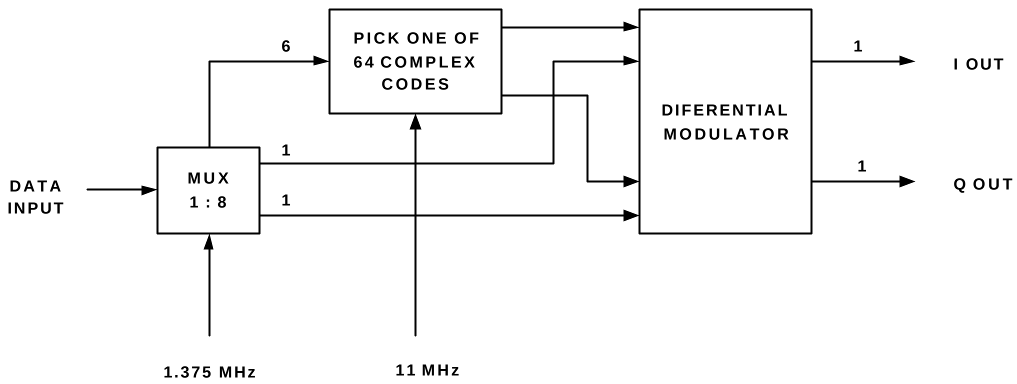

Figure 7. CCK transmitter

Figure 8 shows a block diagram of the RAKE receiver including the ISI/ICI equalizer.

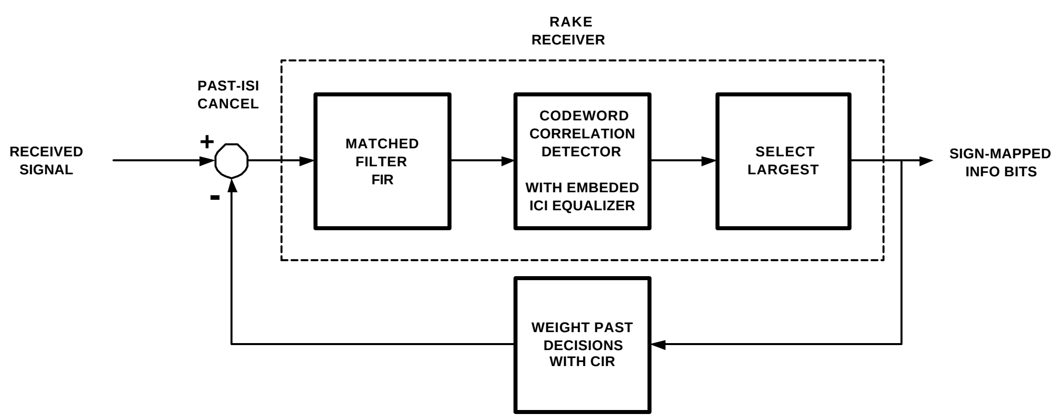

Figure 8. Rake receiver with ISI/ICI equalizer