

# A New OFDM Standard for High Rate Wireless LAN in the 5 GHz Band

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## *Abstract*

*An overview is given of the new OFDM based wireless LAN standard which is being developed by IEEE 802.11, ETSI and MMAC. Signal processing issues are described and some simulations are shown to demonstrate the achievable performance in multipath fading channels.*

**Keywords:** *wireless LAN, OFDM, signal processing*

## **1. Introduction**

In July 1998, the IEEE 802.11 standardization group decided to select OFDM as the basis for a new physical layer standard extension to the existing 802.11 MAC standard [1-3]. The new standard is targeting a range of data rates from 6 up to 54 Mbps in the 5 GHz band. Following the IEEE decision, ETSI BRAN in Europe and MMAC in Japan also based their new standards on OFDM, with the goal of creating a single world-wide physical layer standard for wireless LAN in the 5 GHz band.

This paper describes the modulation parameters of the new OFDM standard. An overview will be given of all signal processing tasks needed to transmit and receive packets according to the chosen OFDM modulation. Special attention will be given to the preamble, which is relatively short in order to minimize the loss in throughput. The latter is especially interesting since the new IEEE 802.11 OFDM standard is the first packet based OFDM standard. This makes a short preamble length much more important than in continuous transmission schemes like in the DVB, DAB and ADSL OFDM-based standards.

## **2. OFDM Parameters**

Table **Error! Reference source not found.** lists the main parameters of the draft OFDM standard. A key parameter which largely affected the choice of the other parameters is the guard interval of 800 ns. This guard interval provides robustness to root-mean-squared delay spreads up to several hundreds of nanoseconds, depending on the coding rate and modulation used. In practice, this means that the modulation is robust enough to be used in any indoor environment, including large factory buildings. It can also be used in outdoor environments, although directional antennas may be needed in this case to reduce the delay spread to an acceptable amount and to increase the range.

### 3. Channelization

Figure 1 shows the channelization for the lower and middle Unlicensed National Information Infra-structure (UNII) bands. Eight channels are available with a channel spacing of 20 MHz and guard spacings of 30 MHz at the band edges in order to meet the stringent FCC restricted band spectral density requirements. The FCC also defined an upper UNII band from 5.725 to 5.825 GHz, which carries another 4 OFDM channels. For this upper band, the guard spacing from the band edges is only 20 MHz, since the out-of-band spectral requirements for the upper band are less severe as those of the lower and middle UNII bands. Notice that different carrier frequencies may be used in Europe and Japan, but the channel spacing will be the same, while also most of the bands are expected to overlap.

**Table 1: Main Parameters of the OFDM Standard.**

Data rate	6, 9, 12, 18, 24, 36, 48, 54 Mbit/s
Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Coding rate	1/2, 2/3, 3/4
Number of subcarriers	52
Number of pilots	4
OFDM symbol duration	4 $\mu$ s
Guard interval	800 ns
Subcarrier spacing	312.5 kHz
-3 dB Bandwidth	16.56 MHz
Channel spacing	20 MHz

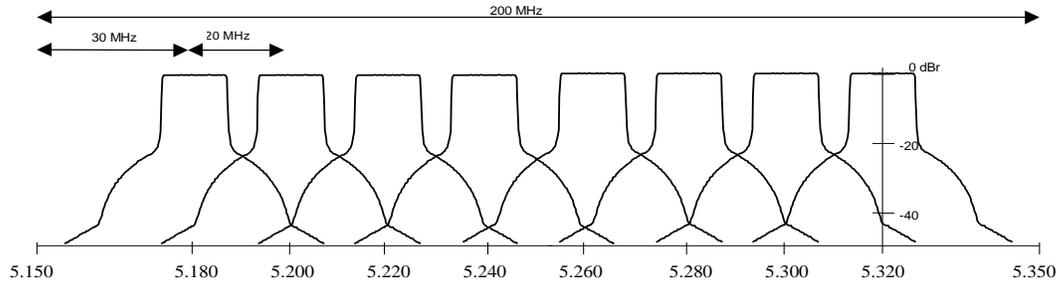
In order to limit the relative amount of power and time spent on the guard time to 1 dB, the symbol duration was chosen to be 4  $\mu$ s. This also determined the subcarrier spacing to be 312.5 kHz, which is the inverse of the symbol duration minus the guard time. By using 48 data subcarriers, uncoded data rates of 12 to 72 Mbps can be achieved by using variable modulation types from BPSK to 64-QAM. In order to correct for subcarriers in deep fades, forward error correction across the subcarriers is used with variable coding rates, giving coded data rates from 6 up to 54 Mbps. Convolutional coding is used with the industry standard rate 1/2, constraint length 7 code with generator polynomials (133,171). Higher coding rates of 2/3 and 3/4 are obtained by puncturing the rate 1/2 code.

### 4. OFDM Signal Processing

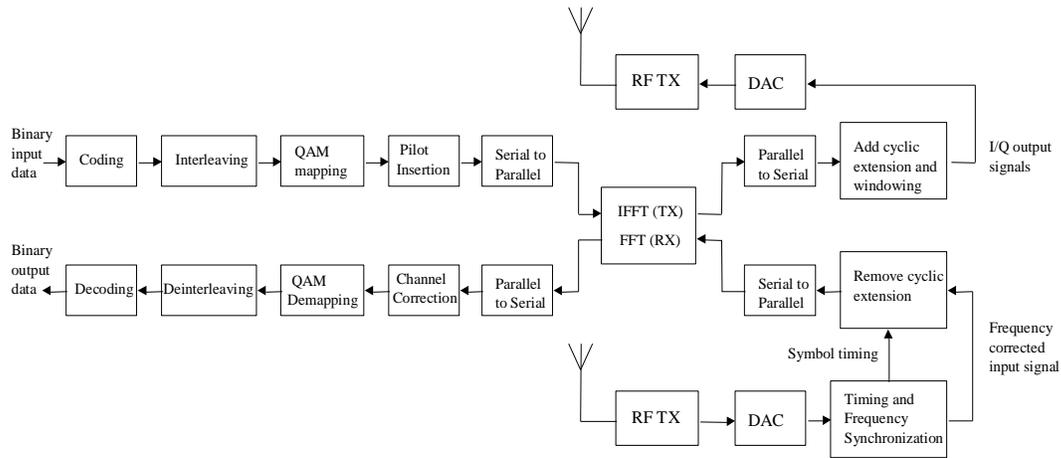
A general block diagram of an OFDM transceiver is shown in figure 2. In the transmitter path, binary input data is encoded by a rate 1/2 convolutional encoder. The rate may be increased to 2/3 or 3/4 by puncturing the coded output bits. After interleaving, the binary values are converted into QAM values. To facilitate coherent reception, 4 pilot values are added to each 48 data values, so a total of 52 QAM values is reached per OFDM symbol, which are modulated onto 52 subcarriers by applying the Inverse Fast Fourier Transform (IFFT). To make the system robust to multipath propagation, a cyclic prefix is added. Further, windowing is applied to get a narrower output spectrum. After this step, the digital output

signals can be converted to analog signals, which are then upconverted to the 5 GHz band, amplified and transmitted through an antenna.

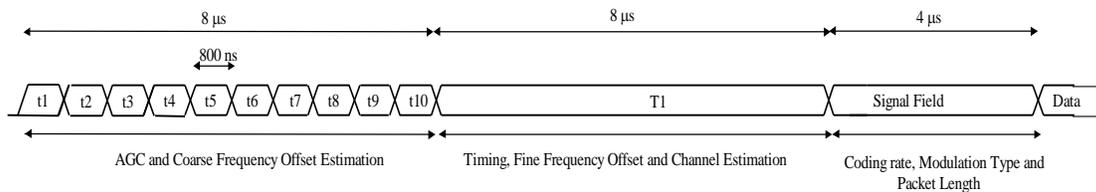
The OFDM receiver basically performs the reverse operations of the transmitter, together with additional training tasks. First, the receiver has to estimate frequency offset and symbol timing, using special training symbols in the preamble. Then, it can do a Fast Fourier Transform for every symbol to recover the 52 QAM values of all subcarriers. The training symbols and pilot subcarriers are used to correct for the channel response as well as remaining phase drift. The QAM values are then demapped into binary values, after which a Viterbi decoder can decode the information bits.



**Figure 1: Channelization in the Lower and Middle UNII Bands**



**Figure 2: Block Diagram of an OFDM Transceiver**



**Figure 3: OFDM Preamble**

Figure 3 shows the structure of the preamble which precedes every OFDM packet. This preamble is essential to perform packet detection, automatic gain control, symbol timing, frequency estimation and channel estimation. The first part of the preamble consists of 10 repetitions of a training symbol with a duration of 800 ns, which is only a quarter of the FFT interval of a normal data symbol. These short symbols are produced by using only nonzero subcarrier values for subcarrier numbers which are a multiple of 4. Hence, of all possible subcarrier numbers from -26 to +26, only the subset  $\{-24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24\}$  is used. There are two reasons for using relatively short symbols in this part of the training; first, the short symbol period makes it possible to do a coarse frequency offset estimation with a large unambiguous range. For a repetitive signal with a duration of  $T$ , the maximum measurable unambiguous frequency offset is equal to  $1/(2T)$ , since higher frequency offsets result in a phase change exceeding 180 degrees from one symbol to another. Hence, by measuring the phase drift between two consecutive short symbols with a duration of 800 ns, frequency offsets up to 625 kHz can be estimated. If training symbols with a duration equal to the FFT interval of  $3.2 \mu\text{s}$  were used, then the maximum frequency offset of only 156 kHz could be measured, corresponding to a relative frequency error of about 26 ppm at a carrier frequency of 5.8 GHz. The IEEE 802.11 standard specifies a maximum offset per user of 20 ppm, which means that the worst case offset as seen by a receiver can be up to 40 ppm, as it experiences the sum of the frequency offsets from both transmitter and receiver.

The second reason for using short symbols at the start of the training is that they provide a convenient way of performing Automatic Gain Control (AGC) and frame detection. For instance, a simple way to detect the presence of a packet is to correlate the signal with the signal delayed by a short symbol interval and detect if the correlation magnitude exceeds some threshold. The short training symbols are followed by a long training symbol which contains 52 QPSK modulated subcarriers like a normal data symbol.

However, the length of this training symbol is twice that of a data symbol, which is done for two reasons; first, it makes it possible to do a precise frequency estimation on the long symbol. The long symbol is formed by cyclically extending an IFFT output signal with a duration of  $3.2 \mu\text{s}$  for two and a half times. This makes it possible to do a frequency offset estimation by measuring the phase drift between samples that are  $3.2 \mu\text{s}$  apart within the long training symbol. The second reason for the long symbol is to obtain reference amplitudes and phases for doing coherent demodulation. By averaging the two identical parts of the long training symbol, coherent references can be obtained with a noise level that is 3 dB lower than the noise level of data symbols.

Both the long and short symbols are designed in such a way that the peak-to-average power (PAP) ratio is approximately 3 dB, which is significantly lower than the PAP ratio of random OFDM data symbols. This guarantees the training degradation caused by non-linear amplifier distortion to be smaller than the distortion of the data symbols.

After the preamble, there is still one training task left, which is tracking the reference phase. There will always be some remaining frequency offset which causes a common phase drift on all subcarriers. In order to track this phase drift, 4 of the 52 subcarriers contain known pilot values. The pilots are scrambled by a length 127 pseudo-noise sequence to avoid spectral lines exceeding the average power density of the OFDM spectrum.

In the case of the IEEE 802.11 standard, at the end of the preamble a special OFDM data symbol at the lowest 6 Mbit/s rate is sent which contains information about the length, modulation type and coding rate of the rest of the packet. By sending this information at the lowest possible rate, it is ensured that the dynamic rate selection is at least as reliable as the most reliable data rate of 6 Mbps. Further, it makes it possible for all users to decode the duration of a certain packet, even though they may not be able to decode the data content.

This is important for the IEEE 802.11 MAC protocol, which specifies that a user has to wait till the end of any packet already in the air before trying to compete for the channel.

## 5. Differences between IEEE, ETSI and MMAC

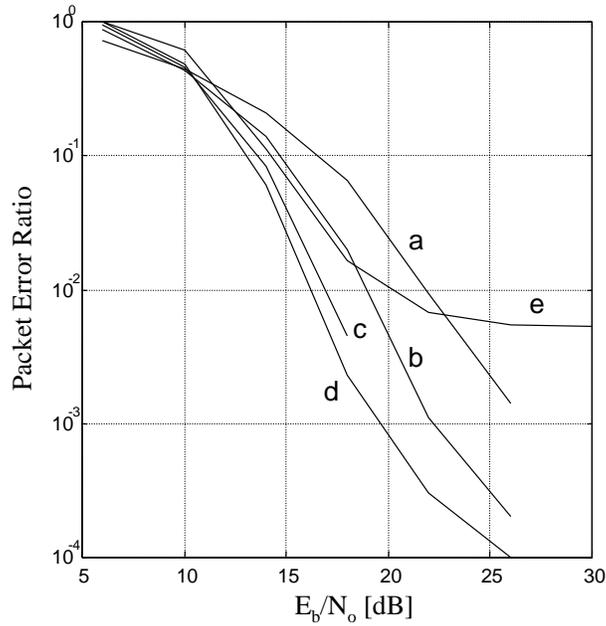
The main differences between IEEE 802.11 and HiperLAN Type 2 - which is standardized by ETSI BRAN - are in the Medium Access Control (MAC). IEEE 802.11 uses a distributed MAC based on Carrier Sense Multiple Access with Collision Avoidance, (CSMA/CA), while HiperLAN-II uses a centralized and scheduled MAC, based on wireless ATM. MMAC supports both of these MACs. As far as the physical layer is concerned, there are only a few minor differences which are summarized below:

- HiperLAN uses extra puncturing to accommodate the tail bits in order to keep an integer number of OFDM symbols in 54 byte packets [**Error! Reference source not found.**].
- In the case of 16-QAM, HiperLAN uses rate 9/16 instead of rate 1/2 in order to get an integer number of OFDM symbols for packets of 54 bytes. The rate 9/16 is made by puncturing 2 out of every 18 coded bits.
- HiperLAN uses different training sequences. The long training symbol is the same as for IEEE, but the preceding sequence of short training symbols is different. A downlink transmission starts with 10 short symbols as IEEE 802.11, but the first 5 symbols are different in order to detect the start of the downlink frame. Uplink packets may use 5 or 10 identical short symbols, with the last short symbol being inverted.

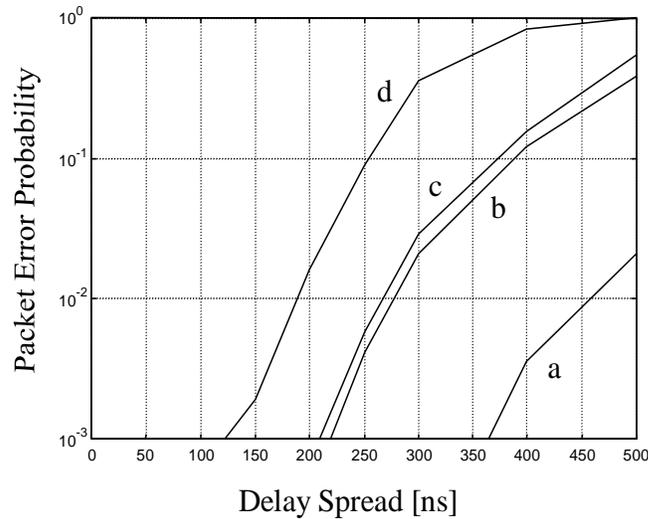
## 6. Simulation Results

Figure 4 shows packet error ratios versus mean  $E_b/N_o$  for Rayleigh fading paths with an exponentially decaying power delay profile. Five curves are shown for different delay spread values, all at a bit rate of 24 Mbps. It can be seen that as the delay spread increases, the performance improves as the system benefits from the increased frequency diversity in the channel. However, at a certain point the delay spread becomes so large that a significant amount of the multipath signals exceed the guard time of the OFDM symbols. The resulting inter-symbol interference creates an irreducible error floor which is clearly visible in curve *e* in figure 4.

The irreducible error floor does not only depend on the delay spread, but also on the coding rate and QAM type. Figure 5 shows the packet error floor versus delay spread for several data rates. For a 1% packet error ratio, the tolerable delay spread is close to 200 ns at 36 Mbit/s, while at 12 Mbit/s a delay spread of 450 ns can be tolerated. In practice, this means that the 36 Mbit/s rate can be used in most indoor environments, except some large factory buildings. The 12 Mbit/s rate can work in any indoor and even in outdoor environments. An interesting observation from figure 5 is that there is a negligible difference between the 18 and 24 Mbps rates. The first rate uses QPSK with rate  $\frac{3}{4}$  coding, while at 24 Mbps, 16-QAM with rate  $\frac{1}{2}$  coding is used. Although the first is more robust in additive white Gaussian noise, this advantage almost disappears in a frequency selective channel, because the rate  $\frac{3}{4}$  coding can correct less erroneous subcarriers than the rate  $\frac{1}{2}$  code.



**Figure 4: Packet error ratio versus mean  $E_b/N_o$  for Rayleigh fading paths with an exponentially decaying power-delay profile. Bit rate is 24 Mbps and packet size is 64 bytes. RMS delay spread is a) 25, b) 50, c) 100, d) 150, e) 250.**



**Figure 5: Packet error ratio versus rms delay spread for Rayleigh fading paths with an exponentially decaying power delay profile. Data rate is a) 12, b) 18, c) 24 and d) 36 Mbit/s.**

## 7. Conclusions

The new OFDM-based wireless LAN standard makes it possible to transmit data rates up to 54 Mbit/s with a delay spread robustness that is sufficient for most indoor wireless applications. The new standard is the first packet-based OFDM standard, which especially made it important to minimize the training overhead per packet. It was shown how the relatively short preamble can be used to perform all necessary training tasks of a packet reception. With simultaneous standardization efforts going on in the US, Europe and Japan, a final world-wide OFDM physical layer standard for the 5 GHz band is expected in the beginning of 2000

## References

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