Performance analysis of OFDM system based on IEEE 802.11a

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Abstract - In this paper, we analyzed the performance of OFDM system based on IEEE 802.11a specification. First, we modeled the transmitter and receiver of OFDM (Orthogonal Frequency Division Multiplexing) system. Then, we analyzed the performance of OFDM system through simulation over the JTC (Joint Technical Committee) realistic channel model. In addition we carried out the performance by using pilot training symbol, which is one of the channel estimation methods, over the same channel environments.

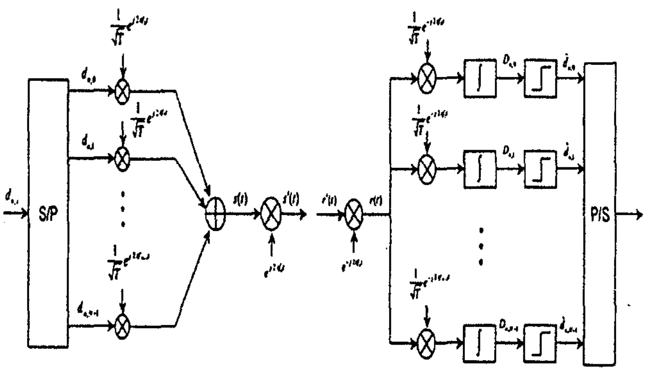
1. Introduction

Recently, there are increasing demands among wireless mobile subscribers on the broadband wireless multimedia services with high capacity and reliability. Data rate of a few tens or hundreds Mbps is required in multimedia services. However, ISI(Inter-Symbol Interference), which is the severe problem in the case of the existence of multi-path fading, can be occurred more frequently in high-speed multimedia data transmission. In other words, degradation of transmitted data due to ISI becomes severer as the target data rates become higher.

ISI can be effectively reduced in OFDM system. Data are transmitted in parallel using a number of sub-carriers in OFDM system. Through this, channel characteristics in OFDM is changed from a frequency selective fading channel into a frequency flat fading channel, which is strong against ISI by increasing the symbol duration. Also, Guard Interval (GI) is permitted in front of each OFDM symbol for preventing ISI. The tail part of each OFDM symbol is cyclically extended in GI. This process is for preventing ICI (Inter-Carrier Interference). In addition, the spectra of the individual sub-carriers are permitted to overlap. By overlapping, bandwidth can be used more efficiently. However, orthogonality condition between sub-carrier frequencies is essential. In virtue of the progress of DSP and VLSI technologies, the complex FFT (Fast Fourier Transform) implementation of OFDM became possible. Because OFDM system has these many advantages, currently, OFDM is of great interest by the researchers in the universities and research laboratories all over the world. OFDM has already been accepted for the new wireless local area network (WLAN) standards as IEEE 802.11a, IEEE 802.11g, High Performance Local Area Network type 2 (HIPERLAN/2) and Mobile Multimedia Access Communication (MMAC) systems.

In this paper, we analyzed the performance of OFDM system based on IEEE 802.11a. The organization of this paper is as follows. Section 2 represents the basic principle of OFDM. Also, we modeled OFDM system using IDFT(IFFT) and DFT(FFT). In section 3, we considered the wiedeband multi-path channel, which is modeled as a linear filter. In this section, we also provide the JTC realistic channel model for simulation. In section 4, we consider a channel estimation method using pilot training symbol. Section 5 provides the simulation results and finally, our investigations are summarized in section 6.

2. OFDM



[Fig.1] conceptual structure of OFDM system

The baseband transmitted OFDM signal through i-th subcarrier in $t = t_s$ is [1]

$$s(t)=\left\{\sum_{i=\frac{-N}{2}}^{\frac{N}{2}-1} d_{i+N/2}\exp[j2\pi\frac{i}{T}(t-t_s)]\right\},\quad t_s \le t \le t_s+T$$

$$s(t)=0 \quad , \quad o/w \qquad (1)$$

where, d_i is the QAM-mapped symbol of the i-th subchannel at time interval [$t_s \le t \le t_s + T$], N is the number of subcarriers, and T is the OFDM symbol duration.

If the k-th subcarrier from (1) is demodulated by downconverting the signal with a frequency of k/T and then integrating the signal over T seconds, the result is as written in (2)

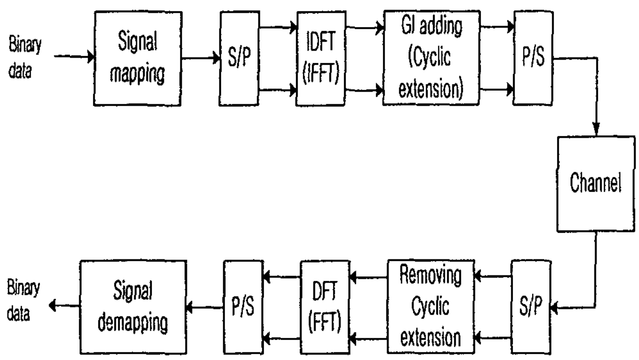
$$\int_{t_s}^{t_s+T} \exp(-j2\pi\frac{k}{T}(t-t_s))[\sum_{i=-\frac{N}{2}}^{\frac{N}{2}} d_{i+N/2}\exp(j2\pi\frac{i}{T}(t-t_s))]dt$$

$$=\sum_{i=-\frac{N}{2}}^{\frac{N}{2}} d_{i+N/2}\int_{t_s}^{t_s+T}\exp(j2\pi\frac{i-k}{T}(t-t_s))dt$$

$$= d_{i+N/2}T \quad (2)$$

By looking at the intermediate result of (2), it can be seen that a complex carrier is integrated over T seconds. When i is equal to k, in other words, when received OFDM signal is demodulated i-th sub-carrier, this integration gives the desired output $d_{i+N/2}T$, which is the QAM value for that particular subcarrier. For all other subcarriers, the integration is zero, because the frequency difference *(i-k)/T* produces an integer number of cycles within the integration interval T, such that the intergration result is always zero.

In the previous concept of OFDM is analog version. The discrete version of OFDM is based on IDFT(Tx.) and DFT(Rx.) algorithm. And IFFT and FFT are the fast algorithm pair of IDFT and DFT.



[Fig. 2] Basic block diagram of OFDM system

This is the mathematical process of OFDM system with IDFT and DFT. The IDFT output sequence of a OFDM symbol is

$$x_n = \frac{1}{N}\sum_{i=0}^{N-1} X_i \exp(j2\pi ni/N) ,$$
$$(n = 0,1,2,.....,N-1) \quad (3)$$

The IDFT output sequence of infinite OFDM symbol is

$$x_{n,l} = \sum_{n=-\infty}^{\infty}\frac{1}{N}\sum_{i=0}^{N-1} X_{i,l}\exp(j2\pi ni/N) \quad (4)$$

where X_i is the data mapped onto QPSK or QAM. The DFT output sequence of a received OFDM symbol is

$$Y_k = \sum_{n=0}^{N-1} x_n'\exp(-j2\pi nk/N), \quad (i = 0,1,2,.....,N-1)$$
$$= \sum_{n=0}^{N-1}[\frac{1}{N}\sum_{i=0}^{N-1} X_i\exp(j2\pi ni/N)]\exp(-j2\pi nk/N)$$
$$= \sum_{n=0}^{N-1}[\frac{1}{N}\sum_{i=0}^{N-1} X_i]\exp(j2\pi n(i-k)/N) \quad (5)$$

i) if i=k,

$$Y_k = \sum_{n=0}^{N-1}[\frac{1}{N}\sum_{i=0}^{N-1} X_i]\exp(j2\pi n(0)/N)$$
$$= N\frac{1}{N}X_k = X_k$$

ii) if i≠k, by a geometric sequence

$$Y_k = 0$$

3. Wideband Multipath channel modeling

The wideband multipath channel is generally modeled as a tapped delay linear filter. That is shown in eq. (6) and Figure 3.

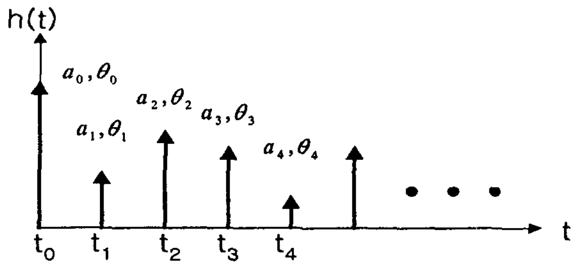
$$h(t) = \sum_{l=0}^{L-1} a_l\delta(t-t_l)e^{j\theta_l} \quad (6)$$

where a_l is path strength, t_l is time delay, and θ_l is phase shift.

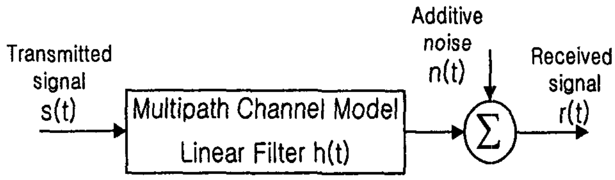
In this paper, we use the JTC realistic channel model for simulation. The channel impulse response of the JTC channel model is [3][4]

$$h(t) = \sum_{l=0}^{L-1}\sqrt{p_l}\alpha_l\delta(t-\tau_l)e^{j\theta_l} \quad (7)$$

where p_l is the amplitude of l-th component in the JTC power delay profile, α_l is a Rayleigh-distributed random variable, $\sqrt{p_l}\alpha_l$ is the signal amplitude of l-th path, τ_l is



a time delay and θ_l is a uniformly distributed random variable in [0, 2π]



[Fig. 3] Linear filter model

We assume the channel bandwidth is 10MHz, which is typical in many measurements.

4. Channel Estimation with pilot training symbol

In an OFDM link, binary data bits are transmitted after being mapped onto QPSK or QAM signals. When we examine the constellation of received data, we can find a random phase shift and an amplitude change, caused by carrier frequency offset, timing offset, and fading. Therefore, it is important to estimate channel for reliable communications. To estimate channel at the receiver, knowledge is required about the reference phase and amplitude of the constellation on each sub-carrier. There are many channel estimation methods, such as one- and two-dimensional channel estimation, decision-directed channel estimation, and a channel estimation method using pilot training symbol. In this paper, we use the pilot training symbol method for the channel estimation. The method is suitable for packet-type communications such as wireless LAN for a follow reason. In many packet transmission systems, the packet length is short enough to assume a time invariant channel during the length of the packet. This means that there is no need to estimate time fading, which greatly simplifies the channel estimation problem. However, any delay in the reception of a packet will also delay the acknowledgment and hence decrease the effective throughput of the system. An additional disadvantage is the fact that the receiver needs to buffer several OFDM symbols, thereby requiring extra hardware [1].

In the channel estimation method using pilot training symbol, a known pilot symbol is inserted in front of the transmitted data. How the transmitted data are distorted can be known from the distortion of the known pilot symbol.

5. Simulation

The some assumptions for computer simulation follow. The modulation scheme is the coherent QPSK. The power control and synchronization are perfect. The channel bandwidth is 10 MHz. The raw data rate is 16Mbps. The length of GI is 1/4 of symbol duration. The IFFT(FFT) length is 64, which means 64 sub-carrier is used. Some of previous assumptions are based on IEEE 802.11a specification. The performance is analyzed by using following three JTC power profiles.

Tap	Channel A	
	Relative delay (nsec)	Average power (dB)
1	0	0
2	100	-3.6
3	200	-7.2
4	300	-10.8
5	500	-18.0
6	700	-25.2

[Table 1] Outdoor Urban High-rise Low-antenna

Tap	Channel A	
	Relative delay (nsec)	Average power (dB)
1	0	0
2	100	-8.5

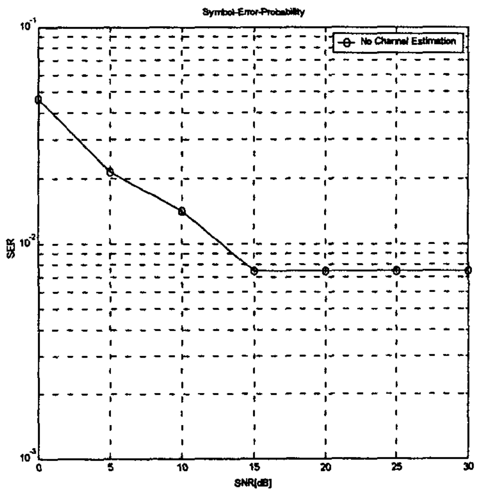
[Table 2] Indoor Office

Tap	Channel B	
	Relative delay (nsec)	Average power (dB)
1	0	0
2	200	-0.9
3	800	-4.9
4	1200	-8.4
5	2300	-7.8
6	3700	-23.9

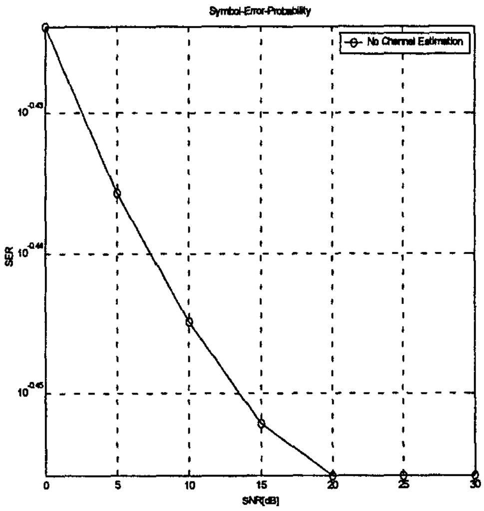
[Table 3] Outdoor Urban High-rise Low-antenna

We chose different channel profiles for analyzing the performance of OFDM system for different delay spread. At First we simulated with intermediate length of delay spread. Second, we simulated with relatively short length of delay spread. Third, we simulated with relatively long length of delay spread. Lastly, following previous steps, we simulated with channel estimation using one pilot symbol.

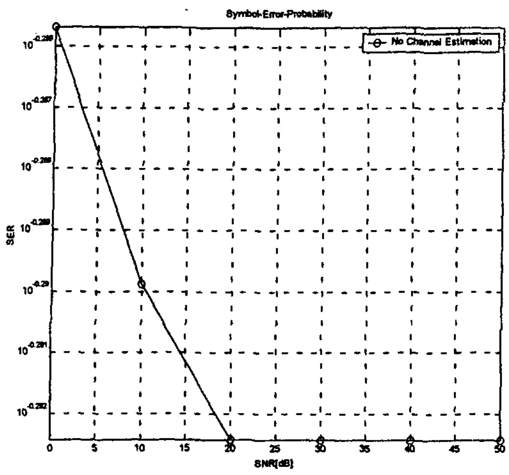
The simulation results are followed.



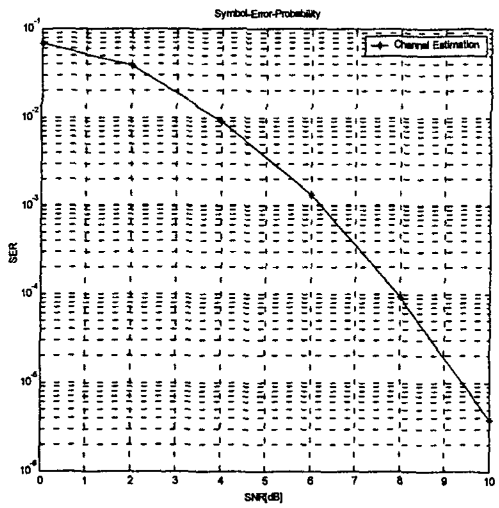
[Fig. 4] Outdoor Urban High-rise Low-antenna (Channel A)



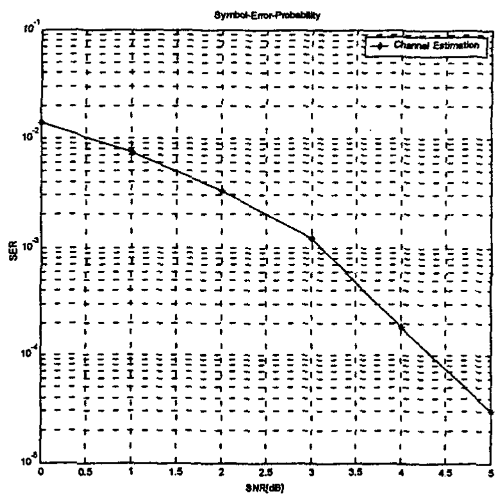
[Fig. 5] Indoor Office (Channel A)



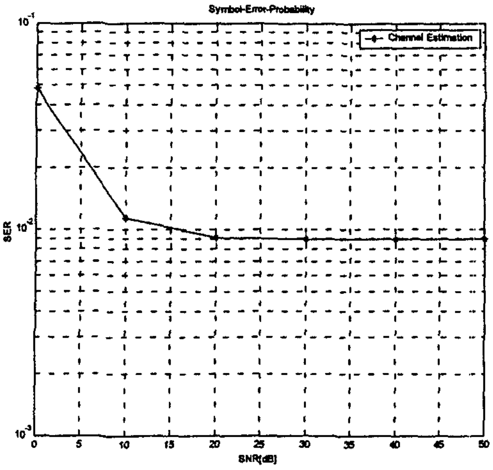
[Fig. 6] Outdoor Urban High-rise Low-antenna
(Channel B)



[Fig. 7] Outdoor Urban High-rise Low-antenna
(Channel A – with Channel Estimation)



[Fig. 8] Indoor Office
(Channel A – With Channel Estimation)



[Fig. 9] Outdoor Urban High-rise Low-antenna
(Channel B – With Channel Estimation)

Through previous three results, the more channel delay spread is relatively short (Fig. 5), the more the performance is relatively good. However, it is impossible that subscribers are provided reliable communications with these performances. The channel estimation is required for reliable communications. The next three results are with channel estimation using a pilot symbol. By estimating channel, we can eventually get reliable results. In the last simulation result, however, saturation is occurred. This case is that the delay spread is longer than the assumed Guard Interval. In this case, ISI and ICI are occurred.

6. Conclusion

In this paper, we analyzed the performance of OFDM system based on IEEE 802.11a. We modeled the transmitter and receiver of OFDM system and analyzed the performance of OFDM system using JTC power delay profile. We evaluated performance by using pilot training symbol over the same channel environments. The performance degradation cause by the distortion of channel is able to overcome by the channel estimation. However, in the case that the delay spread is longer than the assumed Guard Interval, the performance degradation still exists.

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