Bit Error and Packet Error Probability for Rectangular Mary-QAM in OFDM Transmission System over Rayleigh Fading Channels

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Abstract

Orthogonal frequency division multiplexing (OFDM) or multicarrier transmission has been shown to be an effective technique to combat multipath fading in wireless communications. It has been successfully used for HF radio applications and has been chosen as the standard for digital audio broadcasting and digital terrestrial TV broadcasting in Europe and high-speed wireless local areas networks.

This paper describes the concept behind parallel data transmission and the configuration of an OFDM transmitter and receiver when used four type of rectangular Mary QAM modulation (QAM, 16QAM, 64QAM & 256QAM). Two type of error evaluated (bit error rate BER & packet error rate PER) for two typical channels, AWGN channel & (one or two path) Rayleigh fading channels.

For AWGN channel, two curves are plotted (with & without) using guard time and compared with theoretical performance. While different curves are plotted for one path Rayleigh fading channels (with & without) using channel estimation and compared with theoretical performance. We explained how we configured the OFDM transmitter and receiver by using MATLAB computer software.

We discussed the results of our extended simulation of OFDM where we simulated the broadband WLAN system by using a pilot system assisted OFDM transmission system. We showed the effectiveness of the pilot system assisted OFDM transmission system for (one or two) path Rayleigh fading channel when using guard time is less than multipath delay spread or greater than multipath delay spread.

الخلاصـــــة

التعدد ألتقسيمي الترددي المتعامد (OFDM) أو الإرسال متعدد الحاملات هو تقنية فعالة مؤثرة لمقاومة تأثير المسارات متعددة الخفوت في نظام الاتصالات اللاسلكية multipath fading in wireless communication في قنوات الترددات الراديوية العالية (HF radio channels) والذي يعتبر كاستخدام أساسي للبث الراديوي الرقمي والتلفزيوني في أوربا وفي شبكات محطات الإذاعة اللاسلكية ذات السرع العالية.

في هذا البحث تم دراسة إرسال البيانات في نظام التعدد ألتقسيمي الترددي المتعامد بين المرسلة والمستقبلة ولأربعة أنواع من أنواع التضمين وهي (QAM,16QAM,64QAM&256QAM)modulation. لقد تم حساب

نوعين من الأخطاء. النوع الأول نسبة احتمالية خطا البت BER والنوع الثاني نسبة احتمالية خطا الرزمة PERلنوعين من القنوات.
النوع الأول قناة ضوضاء كاوسي AWGN channel حيث تم حساب BER & PER عند استخدام وعدم استخدام الفترة الحارسة (Guard time) مع مقارنة النتائج مع النتائج النظرية للقناة كذلك تم حساب BER & PER لقناة الترددات العالية Rayleigh fading channels عندما تمر الإشارة بمسار واحد للخفوت وعند استخدام وعدم استخدام Channel estimation
مع مقارنة النتائج مع النتائج النظرية للقناة. كذلك تم حساب BER & PER عند استخدام أحدى طرق channel estimation وهي pilot system assisted OFDM عندما تمر الإشارة بمسار واحد أو مسارين للخفوت وكذلك عندما يكون زمن الفترة الحارسة Guard time اكبر أو اقل من زمن التشتت multipath delay spread. لقد تمت عملية المحاكاة باستخدام الحاسبة عن طريق MATLAB computer software.

1. Rayleigh Fading Channel

The path between the base station and mobile station of terrestrial mobile communications is characterized by various obstacles and reflections. The radio wave transmitted from a base station radiates in all directions including reflected waves that are reflected off of various obstacles, diffracted wave, scattering waves and the direct wave from the base station to the mobile station. Since the path lengths of the direct, reflected, diffracted, and scattering wave are different, the time each takes to reach the mobile station will be different. In addition the phase of the incoming wave varies because of reflections. As result, the receiver receives a superposition consisting of several waves having different phase and time of arrival. The time of arrival is retarded in comparison with this direct wave is called a delayed wave. Then; the reception environment characterized by a superposition of delayed waves is called a multipath propagation environment. In a multipath propagation environment. The total received signal is a vector sum of individually delayed signals, their relative phase angles depending on the frequency and the echo amplitudes and delays. Therefore, since the echo amplitudes and delays are time varying, one observes large variations of the received signal strength at a single frequency as a function of time, or of the strength at a given time as a function of frequency; the latter is termed "selective fading". Another effect of multipath reception is the delay spread of the received signal, consisting of several components that arrive at different time, with delay differences exceeding one symbol period Ts, the signal components of the symbol present at the receiver input may be impaired by components of previously sent symbols. This effect is called intersymbol interference (ISI). Further more, time variance of the channel is due to Doppler spread, and is realized by fast fading or slow fading. In the frequency domain, signal distortion due to fast fading increases as the Doppler spread increases, thus causing the channel impulse response to change rapidly within the symbol duration. In a slow fading channel, the Doppler spread is much less than the base band bandwidth and results primarily in a loss in SNR [1,2,3].

2. Orthogonal Frequency Division Multiplexing (OFDM)

The principle of Orthogonal Frequency Division Multiplexing OFDM is to split a high rate data stream (serial data) into a number of lower rate data streams (parallel data) that are transmitted parallel over a number of overlapped subcarriers these subcarriers are modulated with subcarriers spacing, which is selected such that modulated subcarriers are orthogonal over symbol duration. Increasing symbol duration will result in lower rate parallel subcarriers.

This decreases the relative amount of dispersion in time caused by multipath delay spread. So that, the Rayleigh fading channel looks flat on each carrier [4,5]. OFDM allows the spectrum of each tone to overlap, and because they are orthogonal, they do not interfere with each other. By allowing the tones to overlap, the overall amount of spectrum required is reduced, as shown in **Fig.(1)**.

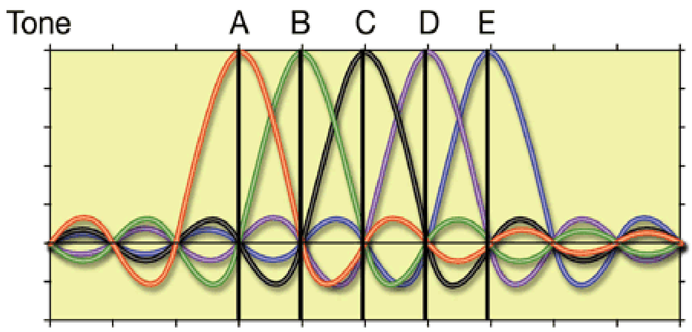


Figure (1) OFDM tones

To maintain orthogonality between tones, it is necessary to ensure that the symbol time contains one or multiple cycles of each sinusoidal tone waveform. This is normally the case, because the system numerology is constructed such that tone frequencies are integer multiples of the symbol period, as is subsequently highlighted, where the tone spacing is 1/T. Viewed as sinusoids, **Fig.(2)** shows three tones over a single symbol period, where each tone has an integer number of cycles during the symbol [3,4,5,6,7].

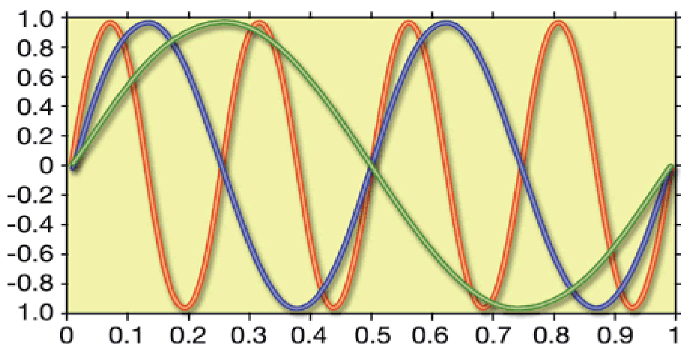


Figure (2) Integer number of sinusoid periods

3. Subcarrier Modulation

In QAM modulation, we considered the use of multiple signal phases and multiple signal amplitudes, respectively, for transmitting k information bits per symbol (per waveform) over the (AWGN or Rayleigh fading) channels. Quadrature amplitude modulation (QAM) or Quadrature amplitude shift keying (QASK) signal is represented as.

$$\mathbf{s(t) = A_c\sqrt{\tfrac{2\varepsilon}{T}}\cos(2\pi f_c t) - A_s\sqrt{\tfrac{2\varepsilon}{T}}\sin(2\pi f_c t)} \quad \ldots\ldots \quad \mathbf{(1)}$$

$$0 \le t \le T\ ,\ m = 1\ ,\ 2\ ,\ \ldots\ ,\ M$$

where:

A_c & A_s: are the information signal amplitudes of the Quadrature carriers and

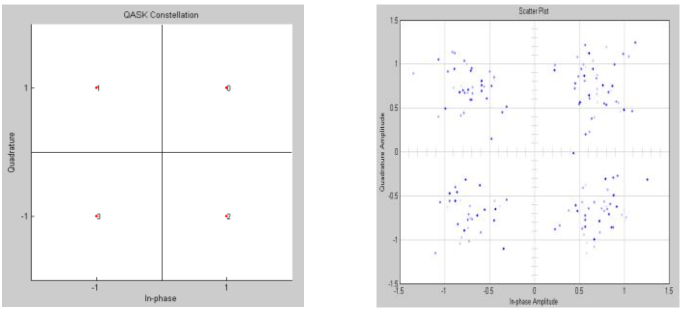
$u(t) = \sqrt{\frac{2\varepsilon}{T}}$, $0 \le t \le T$.

Pulse shapes other than rectangular may be used to reduce the spectral occupancy of the transmitted signal [1]. Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarrier amplitude and phase, which is represented by a complex In-phase and Quadrature-phase (IQ) vector. Both the amplitude and the phase can be changed simultaneously, with some bits of the input information being encoded onto the amplitude and others onto the phase.

Figure (3-a) shows an example of subcarrier modulation mapping. This example shows QAM, which maps 2 bits for each symbol. Each combination of the 2 bits of data corresponds to a unique IQ vector, shown as a dot on the **Fig.(3-a)**. A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied.

Subcarrier modulation can be implemented using a lookup table, making it very efficient to implement. In the receiver, mapping the received IQ vector back to the data word performs subcarrier demodulation. During transmission, noise and distortion becomes added to the signal due to thermal noise or multipath fading, signal power reduction and imperfect channel equalization.

Figure (3-b) shows an example of a received QAM signal in AWGN channel for SNR of 10 dB. Each of the IQ points is blurred in location due to the channel noise. For each received IQ vector the receiver has to estimate the most likely original transmission vector. This is achieved by finding the transmission vector that is closest to the received vector. Errors occur when the noise exceeds half the spacing between the transmission IQ points, making it cross over a decision boundary [8].



(a) **(b)**

Figure (3) a. IQ modulation constellation QAM, with gray coding of the data to each location
b. IQ plot for QAM data with added noise

4. Implementation of OFDM using Fast Fourier Transform (FFT)

Figure (4) illustrates the configuration of an OFDM system (transmitter & receiver).

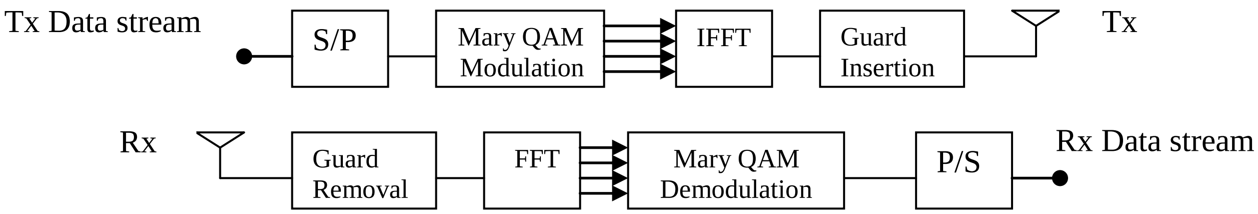


Figure (4) OFDM radio transmission system (transmitter and receiver)

Using digital modulation formal (Mary QAM modulation), the transmitted OFDM symbol wave form can be represented as:

$$s(t) = \mathrm{Re}\{\sum_{K=0}^{N-1} d(k)\exp(j2\pi f_k t)\} \quad \text{.................................} \quad (2)$$

where:

d(k): is the modulated data symbol

f_k: is sub carrier frequency of k^{th} sub carrier which is equal to ($f_c + k\Delta f$)

f_c: is the carrier frequency

Δf: is sub carrier spacing (bandwidth) equal to (1/NTs)

Ts=1/Rs symbol duration, Rs symbol rate

This expression represents the pass band OFDM signal, if the equivalent complex base band notation is used the complex base band OFDM signal is written as

$$s(t) = \sum_{k=0}^{N-1} d(k)\exp(j2\pi k\Delta f t) \quad \text{.......................................} \quad (3)$$

If the signal is sampled at a rate of Ts, then (t=nTs), and for orthogonality (Δf=1/NTs=Rs/N), then Eq3 can be rewritten as:

$$s(n) = \sum_{k=0}^{N-1} d(k)\exp(j2\pi kn / N) \quad \text{.....................................} \quad (4)$$

Eq4 is exactly the Inverse Discrete Fourier transform (IDFT) of the data sequence d(k). Fast Fourier Transform (FFT) algorithm is used to implement the DFT for complexity reductions in design. For radix-2 FFT, the number of complex calculation is $N \log_2 N$ while for DFT, the number of complex calculation is N^2. This difference grows for larger numbers of sub carriers. All operation that occurs in the transmitter is reversed in the receiver [9,10,11].

5. Guard Time and Cyclic Extension

The modulated data are fed into an Inverse Fast Fourier Transform (IFFT) and an OFDM signal is generated. The real part & an imaginary part of an OFDM signal includes carrier frequencies f_i (i = 0 , 1 , 2 , … , N – 1)with their own frequency f_0,

$$f_i = f_0 + \frac{i}{Ts} \quad \text{..} \quad (5)$$

The signal offered to the receiver contains not only a direct line of sight radio wave, but also a large number of reflected radio waves that arrive at the receiver at different times. Delayed signals are a result of reflections from terrain features such as trees, hills, mountains, vehicles or building. These reflected delayed waves interfere with the direct wave and cause inter symbol interference (ISI) .One way to eliminate ISI almost completely, a guard time is introduced for each OFDM symbol. The guard time is chosen larger than the expected delay spread such that the multipath components form one symbol cannot interfere with the next symbol. However, the problem of Inter Carrier Interference ICI would arise. ICI is a crosstalk between different sub carriers, which means that they are no longer orthogonal (orthogonality is lost). To eliminate ICI, the OFDM symbol is cyclically extended in the guard time, which is done by taking symbol period samples from the end of OFDM symbol and appending them to the start of OFDM symbol. This ensures that the OFDM symbol always has integer number of cycles within the FFT interval, as long as the delay is smaller than the guard time. As a result, multipath signals with delays smaller than the guard time cannot cause ICI (i.e. the OFDM symbol with no guard period added, which is equal to the length of the IFFT size used to generate the signal) has an integer number of cycles. Because of this, placing copies of the symbol end-to-end results in a continuous signal, with no discontinuities at the joins. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time. The total length of the symbol is:

$$T_f = T_G + T_{FFT} \quad \ldots\ldots (6)$$

Figure (5) shows the insertion of a guard period.

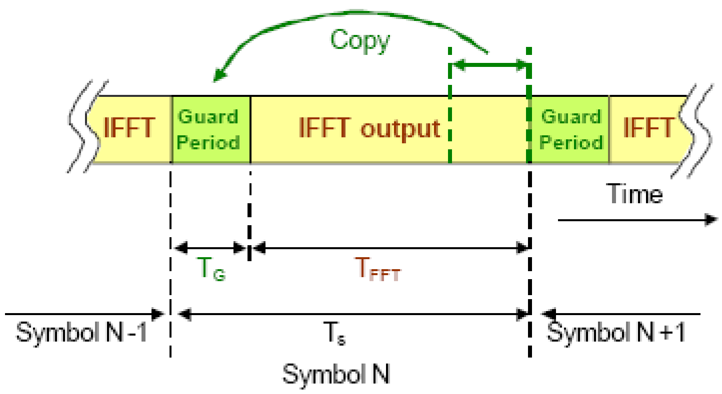


Figure (5) Addition of a guard period to an OFDM signal

where:

T_f: is the total length of the symbol in samples,
T_G: is the length of the guard period in samples, and
T_{FFT}: is the size of the IFFT used to generate the OFDM signal.

The ratio of the guard time interval to the useful symbol duration is application dependent. Because the insertion of a guard time will reduce the data throughput, T_G is usually smaller than Ts/4. In practice, these samples (guard time T_G) are not enough to make a real OFDM signal. The reason is that there is no over sampling present. To introduce over sampling, a number of zero can be added to the input data vector in the middle and one zero in the start. These are also used to center the spectrum, this ensures the zero data vales are mapped onto frequencies close to plus & minus half the sampling rate, while the non zero data values are mapped onto the sub carriers around 0Hz, then, the OFDM vector concatenated to form a time signal (parallel/serial) conversion. The signal is then passed through the channel. Channel is modeled by a linear system with frequency response c(t) together with a source of additive white Gaussian noise [3,5,8,9,10,11,12,13].

At receiver, received signal r(t) is filtered by a band pass filter, which is assumed to have sufficiently wide passband to introduce only negligible distortion in the signal, An orthogonal detector is then applied to the signal where the signal is down converted to the IF band. Then the signal is rearranged again into vectors (serial/parallel) conversion and guard interval is dropped. Fast Fourier Transform (FFT) is computed in order to obtain Fourier coefficient of the signal (complex vector of symbols) [4,6,13,14].

Table (1) shows the theoretical result of BER performance in Rectangular Mary QAM modulation schemes in AWGN channel and single-path Rayleigh fading channel for OFDM system [15].

Table (1) Theoretical BER performance for Mary QAM modulation in AWGN and one path rayleigh fading channel

Modulation Scheme	Theoretical BER	
	AWGN	One-path Rayleigh fading
QAM	$\frac{1}{2} erfc(\sqrt{E_b / No})$	$\frac{1}{2}\left[1-\frac{1}{\sqrt{1+\frac{1}{E_b / N_o}}}\right]$
16-QAM	$\frac{3}{8} erfc\left[\sqrt{\frac{2}{5} E_b / N_o}\right]-\frac{9}{24} erfc^2\left[\sqrt{\frac{2}{5} E_b / N_o}\right]$	$\frac{3}{8}\left[1-\frac{1}{\sqrt{1+5/(2E_b / N_o)}}\right]$
64-QAM	$\frac{7}{24} erfc\left[\sqrt{\frac{1}{7} E_b / N_o}\right]-\frac{49}{384} erfc^2\left[\sqrt{\frac{1}{7} E_b / N_o}\right]$	$\frac{7}{24}\left[1-\frac{1}{\sqrt{1+7/(E_b / N_o)}}\right]$
256-QAM	$\frac{15}{64} erfc\left[\sqrt{\frac{4}{85} E_b / N_o}\right]-\frac{225}{2048} erfc^2\left[\sqrt{\frac{4}{85} E_b / N_o}\right]$	$\frac{15}{64}\left[1-\frac{1}{\sqrt{1+85/(4E_b / N_o)}}\right]$

6. Performance by Computer Simulation

This section calculates the BER & PER of an OFDM system by using MATLAB computer-simulation software [8].

Number of parallel channel = IFFT length = 64
Channel Spacing is 20 MHz is used for 64 point IFFT
Symbol Rate = Sr = 312.5 (ksymbol/sec) = Carrier Spacing (F_c) (=20 MHz/64)
Symbol time = Ts = 1/Sr=3.2 μsec=IFFT
Guard time = *TG* = Ts/4 = 800 nsec
OFDM block length = *Tf* = *TG* + *TFFT* =4 μsec
Rate in OFDM = 1/Tf = 250 (ksymbol/sec)
Number of OFDM symbol for one loop = 6
Pilot Symbol = Pilot Subcarriers = 1 for each 6 symbol
Modulation Schemes QAM, 16-QAM, 64-QAM, 256-QAM
Number of modulation level = 2 for QAM
= 4 for 16QAM
= 6 for 64QAM
= 8 for 256QAM

To obtain BER and PER performance in OFDM system. First, we generate random serial data from (0 to 3) for Rectangular QAM modulation and from (0 to 15) for Rectangular 16QAM and so on. In general, we generate (0 – M-1) for rectangular Mary QAM modulation.

Of length 1 by (number of parallel channel)*(number of OFDM symbol for one loop)*(modulation level).Then the serial data vector converted into a parallel data vector consisting of (number of parallel channel) by (number of OFDM symbol for one loop)*(modulation level) vector to transmit the data in parallel in order to enable parallel transmission with 64subchannels where each channel modulated using Rectangular Mary-QAM modulation scheme. Then parallel data on the frequency axis fed into the 64-point IFFT circuit, in the circuit, the parallel data were converted into serial data on the time axis by using OFDM, then guard interval (cyclic prefix) of 25% of symbol period is added, were inserted to eliminate ISI caused by multipath fading. Then, the signal transmitted to the air. The transmitted signal passed through the radio channel (equivalent low pass system). At the receiver, the received signal is first contaminated by AWGN.

To determine the relationship between Eb/No and BER. That means we must vary the attenuation level while keeping Eb/No constant. The attenuation level is calculated as follows. First, energy per bit Eb and noise power density No are defined:

$$Eb = \frac{S_{pow}}{br} \; (W.T/bit) \quad \text{...} \; (7)$$

$$No = \frac{n_{pow}}{Sr} \; (W/Hz) \quad \text{...} \; (8)$$

where:

S_{pow} , n_{opw}, br and Sr: are the signal power per carrier per symbol.

The noise power per symbol, the bit rate, and the symbol rate, respectively. From combining Eq.7 and Eq.8 .We get:

$$\frac{Eb}{No} = \frac{Spow}{br} * \frac{Sr}{npow}$$

After manipulation, we get:

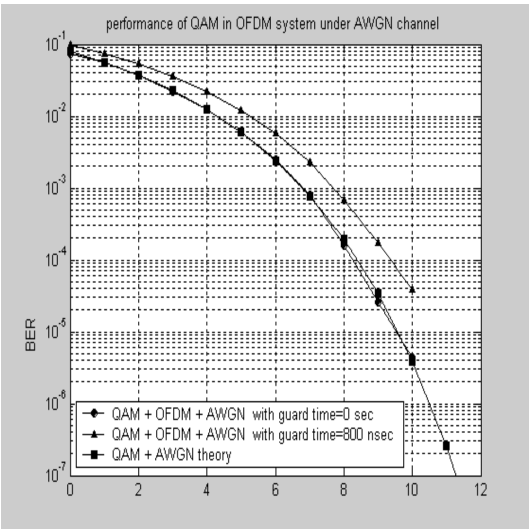
$$npow = \frac{Spow}{br} * \frac{Sr}{Eb/No} \quad \text{...} \; (9)$$

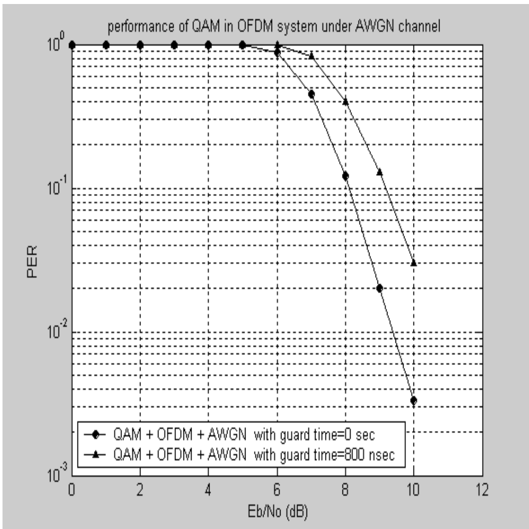
Since Eb/No is in decibels, Eq.9 can be written as:

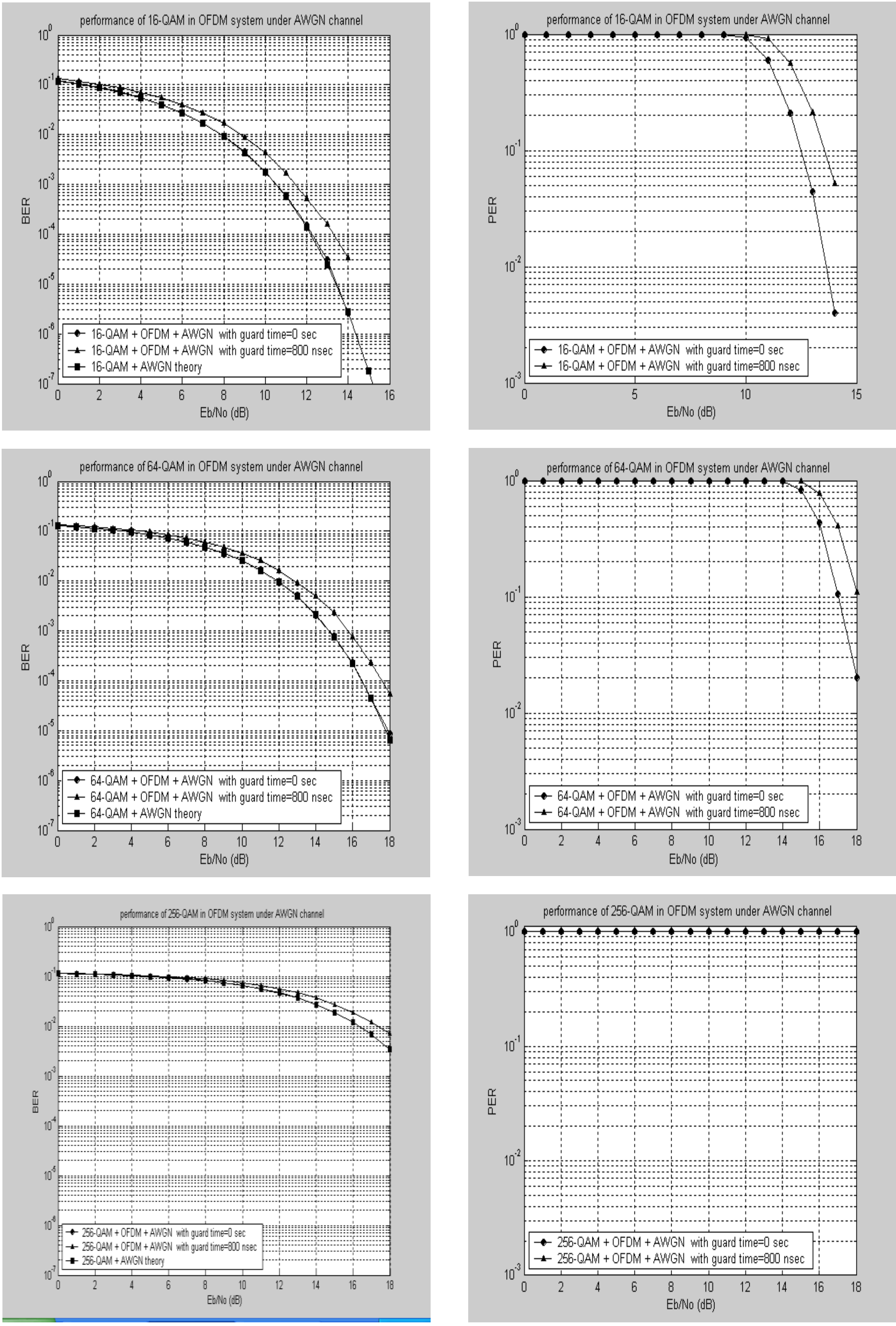
$$npow = \frac{Spow}{br} * \frac{Sr}{10^{Eb/(10*No)}} \quad \text{..................................} \; (10)$$

The noise signal must be expressed in voltage and Gaussian noise is normally distributed equally in in-phase and quadrature-phase channels. Therefore, Attenuation level $= \sqrt{\frac{1}{2} npow}$. At the receiver, the guard interval removed form received signal. Then the data on the time axis were fed into the 64-point FFT circuit. In the circuit, the serial data were converted into parallel data on the frequency axis .After that, the demodulated data were converted into a 1 by (number of parallel channel)*(number of OFDM symbol for one loop)*(modulation level) Vector. Next, we calculated the bit error rate BER defined as the number of error data divided by number of transmitted data. At the same time, we calculated the packet error rate PER. Defined as the error of transmitted data symbol in one packet. In this case, six OFDM symbol exist in one packet. If more than one of these transmitted data symbol in one packet makes a mistake, a packet error occurs. The packet error rate defined as the number of error packet divided by the number of transmitted packet, the BER and PER are obtained after long simulation .The BER & PER performance under AWGN channel is shown in **Fig.(6)** where it is compared with theoretical results for four types of Rectangular modulation (4QAM, 16QAM, 64QAM & 256QAM). In the simulation results for the BER, there was a 0.9691 dB shift form the theoretical value when using guard time interval equal to 1/4 symbol time and exact the theoretical value when without using guard time interval (guard time equal to 0 symbol time). The shift from theoretical value was caused by the cutting off of the guard interval power from the received signal. It is calculated as follows:

$$\textbf{Shifted value (dB)} = -10\log_{10}(\text{fft\_length}/(\text{fft\_length}+\text{guard\_length})) \quad .. \ (11)$$
$$= -\log_{10}(64/(64+16)) = +0.9691 \text{ dB}$$



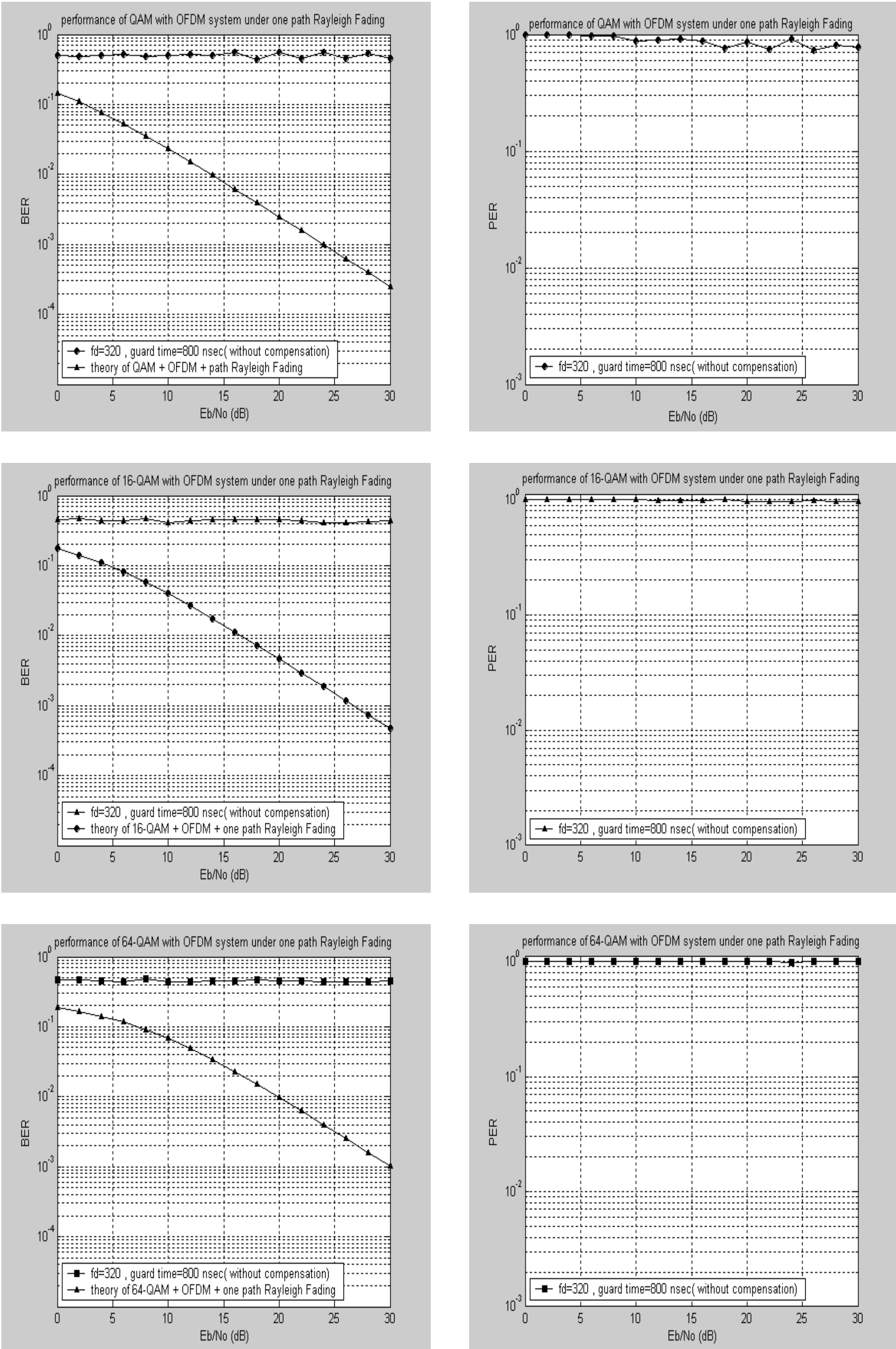


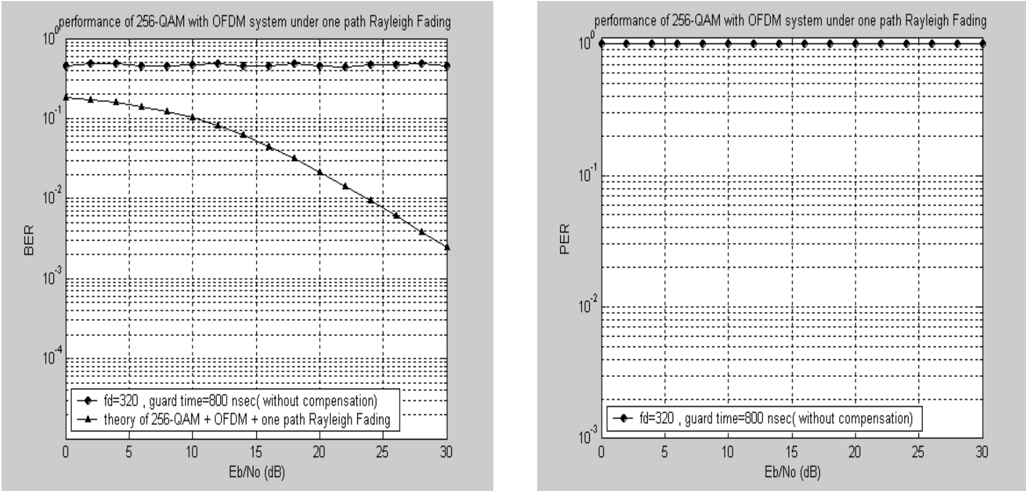


(a) **(b)**

Figure (6) Performance of Mary QAM modulation in OFDM system under AWGN channel (with and without guard time) (a) BER (b) PER

Figure (7) show the BER & PER performance under one-path Rayleigh fading channel with Doppler shift of 320Hz which means fading period equal to 3.125 msec. In this simulation, if we cannot compensate for the amplitude and phase fluctuation caused by propagation characteristics, we cannot recover the data. (BER is closed to 0.5 & PER is closed to 1).





(a) **(b)**

Figure (7) Performance of Mary QAM modulation in OFDM system under one path Rayleigh fading channel (without compensator) (a) BER (b) PER

Figure (9) show the BER and PER performance compared with the theoretical value for one-path Rayleigh fading with Doppler shift of 320Hz which means fading period equal to 3.125 msec., when an assumption ideal channel estimation is achieved (perfect compensation) after adding 11 zeros in the center of data and zero in the beginning (over sampling present) before fed into the 64-point IFFT as shown in the **Fig.(8)** to obtain real OFDM simulation [5].

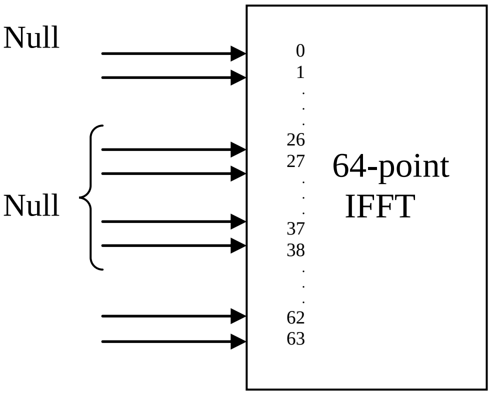
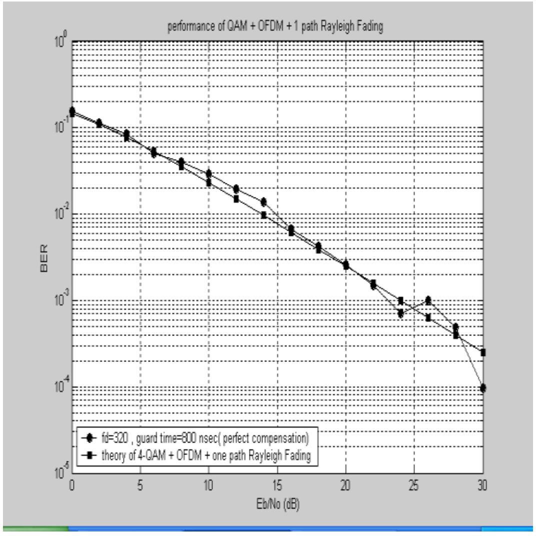
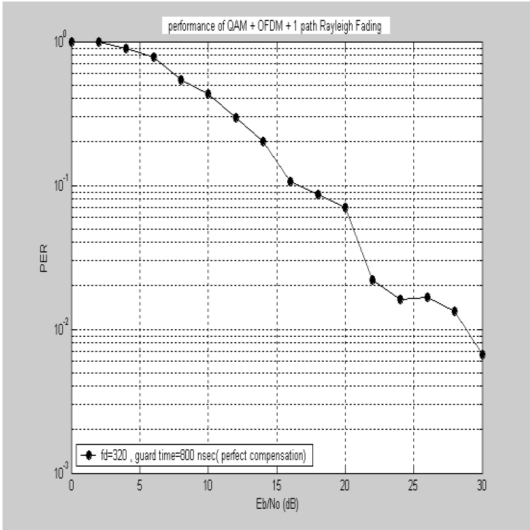
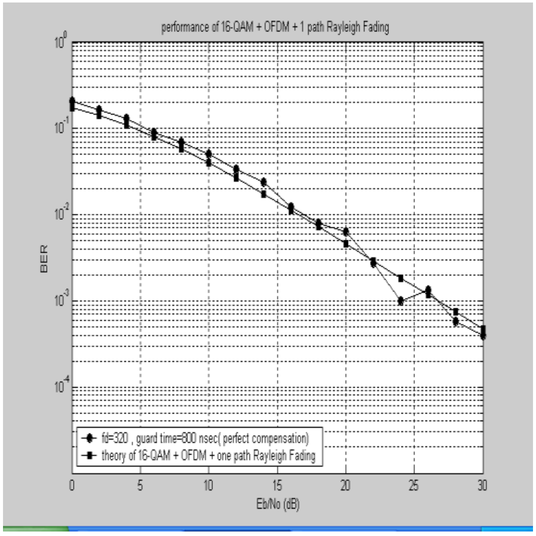


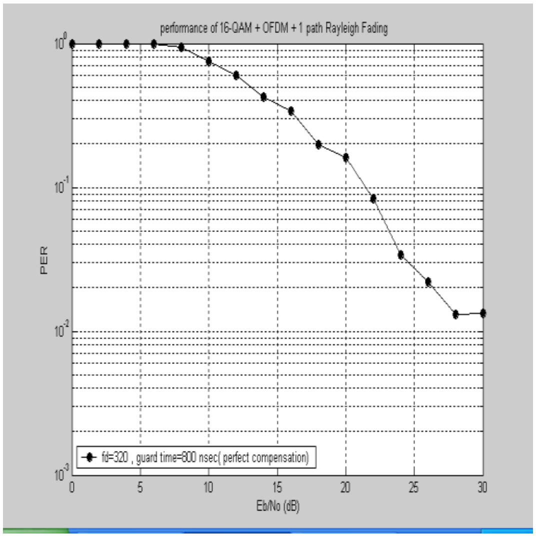
Figure (8) Input and output of IFFT

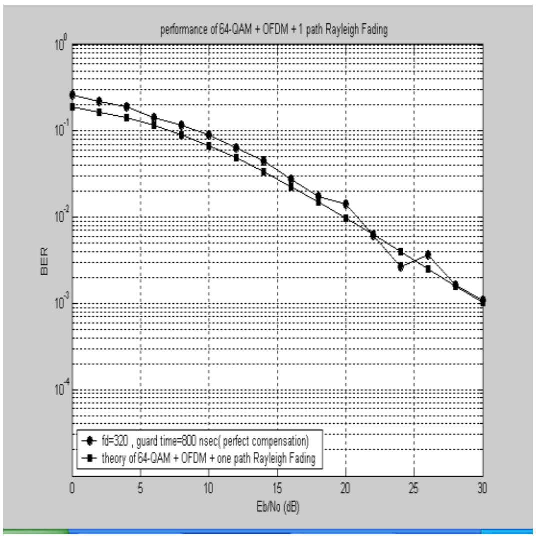
In this case ,we achieved 52 sub carrier transmission by using an OFDM technique based on a 64-point IFFT circuit and guard time equal to 1/4 symbol time, i.e. Nominal Bandwidth 16.25 MHz (=312.5 kHz × 52). In the simulation result for the BER, there was a +0.9691dB shift from the theoretical value. The shift of the value was caused by the cutting off of the guard interval power form the received signal as shown in Eq.11.

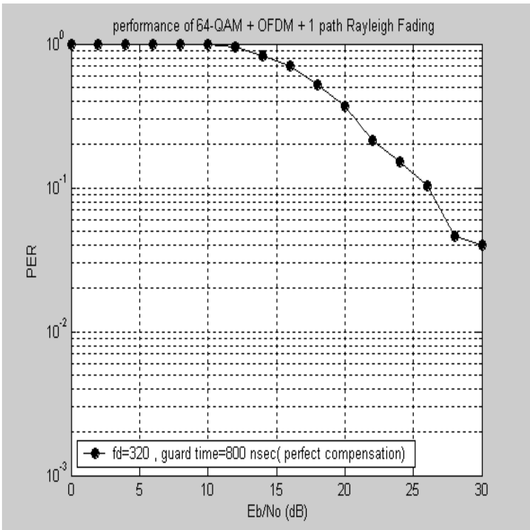

performance of QAM + OFDM + 1 path Rayleigh Fading
BER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)
theory of 4-QAM + OFDM + one path Rayleigh Fading

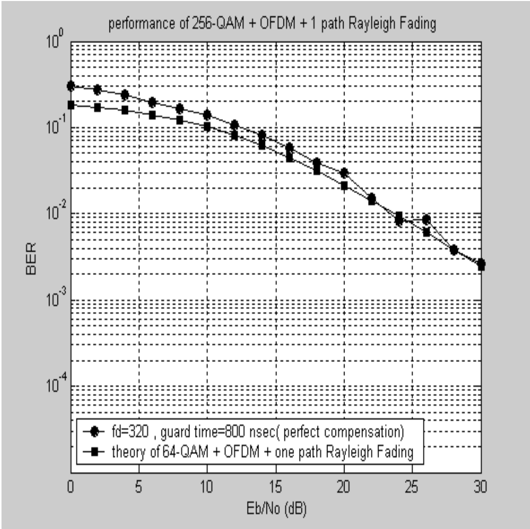

performance of QAM + OFDM + 1 path Rayleigh Fading
PER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)

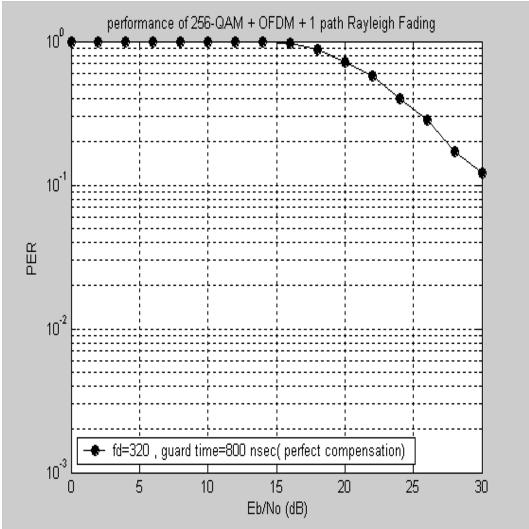

performance of 16-QAM + OFDM + 1 path Rayleigh Fading
BER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)
theory of 16-QAM + OFDM + one path Rayleigh Fading


performance of 16-QAM + OFDM + 1 path Rayleigh Fading
PER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)


performance of 64-QAM + OFDM + 1 path Rayleigh Fading
BER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)
theory of 64-QAM + OFDM + one path Rayleigh Fading


performance of 64-QAM + OFDM + 1 path Rayleigh Fading
PER
Eb/No (dB)
fd=320 , guard time=800 nsec(perfect compensation)





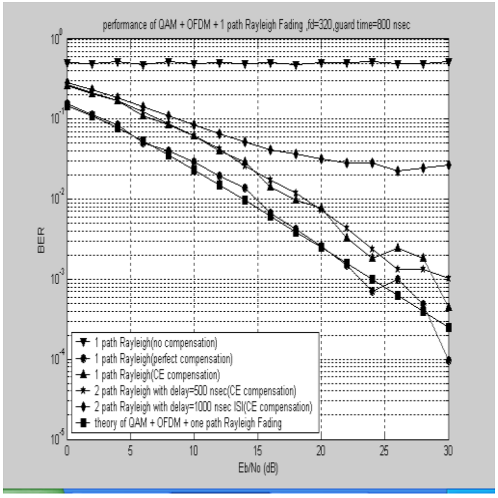
(a) **(b)**

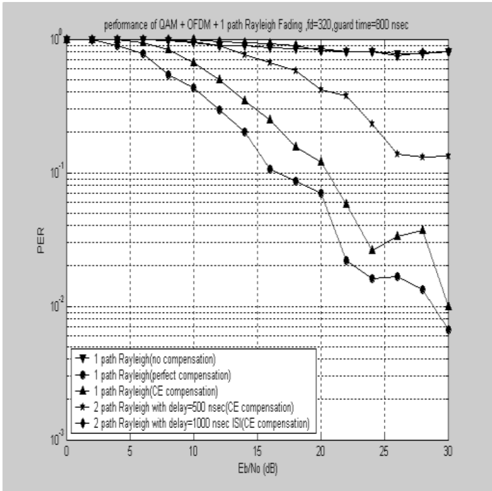
Figure (9) Performance of Mary QAM modulation in OFDM system under one path Rayleigh fading channel (with perfect compensator) (a) BER (b) PER

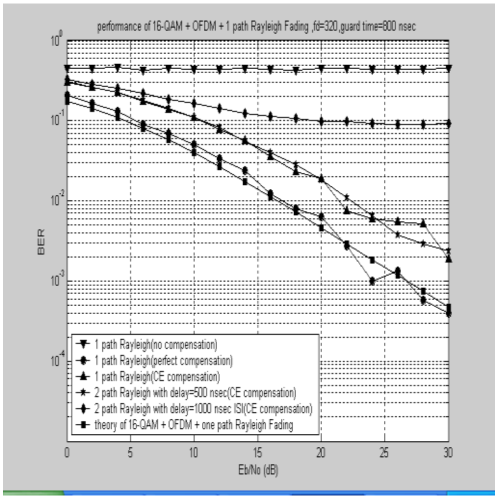
7. Pilot Symbol-Aided OFDM Modulation

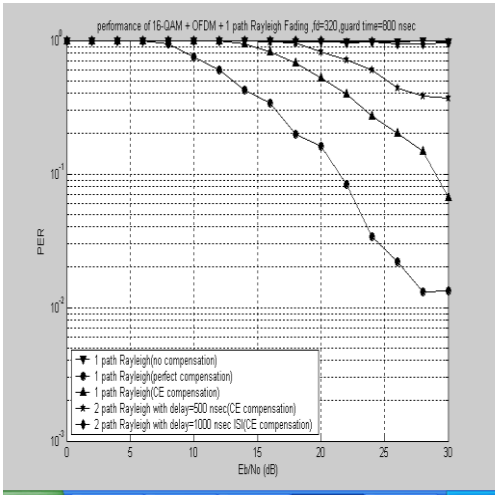
It is important to estimate the propagation characteristics in real time .one of the estimation methods is a pilot-symbol aided OFDM modulation scheme. In this method, pilot symbols are inserted at the transmitter at fixed time intervals and at the receiver we estimate the channel characteristics by using the pilot symbol because the level of fluctuation is independent in each sub carrier channel we can insert pilot carried in all frequency domains at a known time period. Then, by using the estimated channel characteristics, we can recover the transmitted data [16]. This simulation uses one channel estimation symbol and six transmitted data symbols as one frame (packet) unit. **Figure (10)** show the BER and PER performance compared with the theoretical value for one and two path Rayleigh fading channel in channel estimation compensation. From the BER performance under one-path Rayleigh fading channel, we found that if we can compensate for the amplitude and phase fluctuation caused by fading (ideal channel estimation is achieved), we can obtain a 0.9691 dB shift form the theoretical value as shown in Eq.11. However, if we cannot compensate for the fluctuation, we cannot recover the data (BER=0.5 & PER=1). On the other hand, if we use a pilot signal-assisted OFDM transmission scheme, we can obtain ≈ 4dB shift form the theoretical value this was because we input pilot data of 1/7 in one frame (packet) unit and use high value of Doppler frequency (fd=320), the fading period is 3.125 ms. So channel estimation is not accurate enough to follow those fast fading.

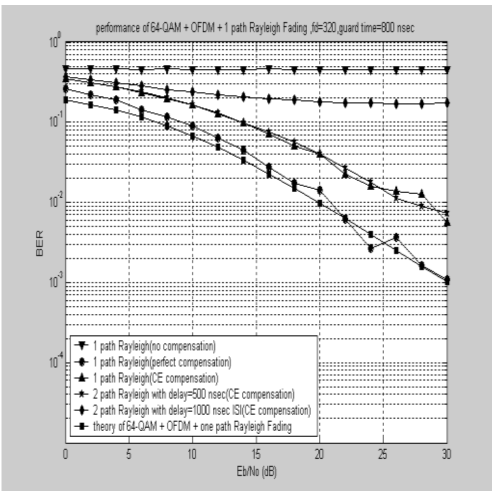
In a two path channel, the BER performance of the pilot signal-assisted OFDM system partly depends on the position of the delayed wave in two-path Rayleigh fading channel. If the delay time of the delayed wave is equal (500nsec) which is means that, its shorter than the guard interval which is equal to (800nsec), all fluctuations of the amplitude and phase can be removed by using pilot signals and the BER performance is the same as that in single-path Rayleigh fading channel. However, if the delay time is equal to (1000nsec) which is longer than the guard integral which is equal to (800nsec), ISI contaminates the next symbol and the BER performance degrades. For two cases, it's assumed that one delayed wave have mean power of 1dB smaller than that of the direct wave.

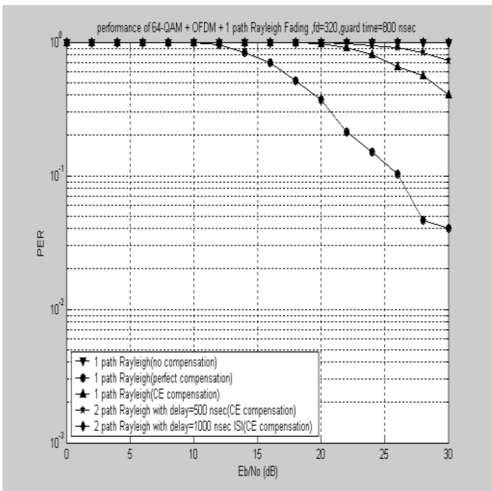


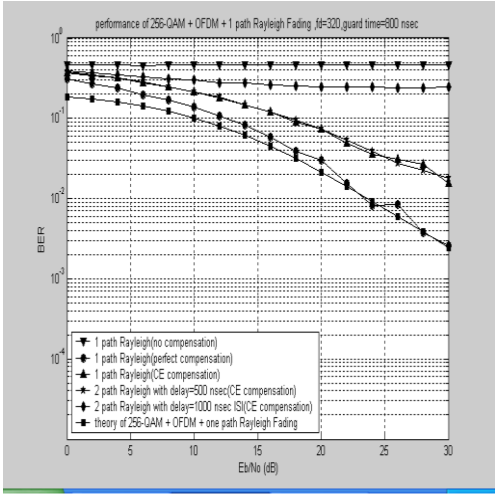




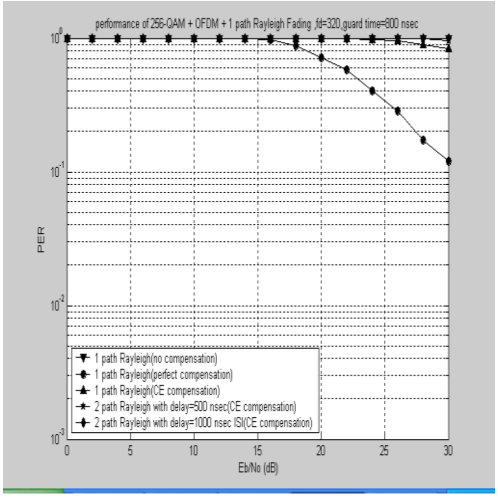








(a)



(b)

Figure (10) Performance of Mary QAM modulation in OFDM system under one path rayleigh fading channel (with perfect & CE compensation)

8. Conclusions

This paper describes the concept behind parallel data transmission and the configuration of an OFDM transmitter and receiver. We explained how we configured the OFDM transmitter and receiver by using computer simulation. OFDM system uses orthogonal subcarrier. It achieves high spectral efficiency, saving in bandwidth, and allows separating the subcarrier without causing any interference with each other. Fast Fourier Transform (FTT) is used to modulate and demodulate OFDM system to establish the orthogonality in subcarrier and reduces the complexity needed by the conventional multicarrier modulation system. Guard time with cyclic extension is inserted for each OFDM symbol to eliminate ISI completely and reduces ICI.

In OFDM simulation, for AWGN channel, the insertion of guard time caused 0.9691 dB shift from theoretical value, while for one path Rayleigh fading channel, if we cannot compensate for the amplitude and phase fluctuation caused is propagation characteristics of the channel, we cannot recover the data. While, when assumption ideal channel estimation (perfect compensation) is achieved we have 0.9691 dB shifts from theoretical value.

Finally for simulation of broad band WLAN system by using a pilot symbol assisted OFDM transmission system in one path Rayleigh fading channel, we can obtain the BER shifted from theoretical value. While for two path Rayleigh fading channel, the BER depends on the position of the delayed wave. If the delay time of the delayed wave is shorter than the guard time, the BER performance is the same as that in single path Rayleigh fading channel. However, if the delay time is longer than the guard interval, ISI contaminates the next symbol and the BER performance degrades.

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