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Performance Analysis of Framelet Based OFDM System Under Different Channel Conditions

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ABSTRACT

In this paper, the Framelet Transform (FT) is proposed as a new modulation technique in the realization of Orthogonal Frequency Division Multiplexing (OFDM). Framelet Transform (FT) is used in the OFDM structure to serve as a modulator instead of conventional Fast Fourier techniques. As a result, the proposed FT-OFDM system improves Bit Error Rate (BER) performance, and keeps bandwidth efficiency and spectrum shape as good as conventional Fast Fourier transform (FFT)-based OFDM. The new structure was tested and compared with conventional FFT- OFDM, Wavelet based OFDM system (DWT-OFDM), Multi-Wavelet based OFDM system (DMWT-OFDM), Packet-Wavelet based OFDM system (PWT-OFDM) and the proposed Framelet based OFDM system (FT-OFDM), for Additive White Gaussian Noise (AWGN), flat, and multi-path selective fading channels.

Keywords: Framelet Transform, Framelet Based OFDM System.

تحليل أداء مازج تقسيمات التردد المتعامدة بأستخدام التحويل الاطاري تحت مختلف ظروف القناة

الخلاصـــــة

في هذا البحث ،تم اقتراح استخدام تحويل((Framelet Transform (FT كأسلوب للتضمين في تطبيق مازج تقسيمات التردد المتعامدة (OFDM). حيث يستخدم تحويل Framelet في هيكل OFDM لتكون بمثابة المضمن بدلا من تقنيات فورييرFast Fourier Transform). ونتيجة لذلك ، يظهر تحسن ملحوظ في أداء النظام OFDM - FT المقترح، وتحافظ على كفاءة عرض النطاق الترددي والشكل الطيفي جيدة كما في النظام التقليدي مع استخدام تحويل فوريير السريع (FFT) مع نظام OFDM الأعتيادي. وقد تم اختبار هذا الهيكل الجديد ومقارنته مع النظام التقليدي FFT - OFDM ، ونظام DWT – OFDM، ونظامDMWT – OFDM، ونظام PWT - OFDM تحت ظروف وتأثيرات مختلفة للقناة الناقلة للأشارة.

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INTRODUCTION

As demand for higher data rates is continuously rising, there is always a need to develop more efficient wireless communication systems. The work described in this paper is an effort in this direction. OFDM is a technique for transmitting data in parallel by using a large number of modulated sub-carriers, these sub-carriers (or sub-channels) divide the available bandwidth and are sufficiently separated in frequency (frequency spacing) so that they are orthogonal, the orthogonality of the carriers means that each carrier has an integer number of cycles over a symbol period [1], due to this, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, although their spectra overlap. The separation between carriers is theoretically minimal so there would be a very compact spectral utilization [2].

The nature of OFDM only allows the signal to be modulated in amplitude and phase such as QAM and PSK, and both can be coherent or non-coherent modulation techniques. Unlike non-coherent modulation, coherent modulation uses a reference phase between the transmitter and the receiver which brings accurate demodulation together with receiver complexity [3]. Coherent PSK carries the information to be transmitted by the phase of a tone in OFDM. Therefore, channel knowledge is required for demodulation. For OFDM, the phase difference may be between adjacent tones of the same OFDM block or the tones at the same position of adjacent OFDM blocks. In either case, channel knowledge is not required for demodulation [4]. Conventionally, orthogonal frequency division multiplexing (OFDM) is implemented using Fast Fourier transform (FFT). However, FFT has a major drawback arising from using rectangular window, which creates sidelobes. Moreover, the pulse shaping function used to modulate each subcarrier extends to infinity in the frequency domain. This leads to high interference and lower performance levels. Intercarrier interference (ICI) and intersymbol interference (ISI) can be avoided by adding a cyclic prefix (CP) to the head of OFDM symbol. But, this reduces the spectrum efficiency [5].

FILTER BANK STRUCTURE OF FRAMELET TRANSFORM

To implement the framelet transform, an appropriate filter bank structure must be selected first. Fig. (1) shows 1-D analysis and synthesis filter banks spanned over three levels. The filter bank shown in Fig. (1) illustrates the basic design of 1D-FT [6]. The Framelet Transform is implemented on discrete-time signals using the oversampled analysis and synthesis filter bank, as shown in Fig. (1). The analysis filter bank consists of three analysis filters, one low pass filter denoted by $h_0(-n)$ and two distinct high pass filters denoted by $h_1(-n)$ and $h_2(-n)$. As the input signal travels through the system, the analysis filter bank decomposes it into three subbands, each of which is then down-sampled by 2. From this process, the signals $X_L(n)$, $X_{H1}(n)$, and $X_{H2}(n)$ each of which with size of N/2, are obtained, which represent the low frequency (or coarse) subband, and the two high frequency (or detail) subbands, respectively [6]. The upsampled signals are filtered by the corresponding synthesis low-pass $h_0(n)$ and two high-pass $h_1(n)$ and $h_2(n)$ filters and then added to reconstruct the original signal. Note that the filters in the synthesis stage, are not necessary the same as those in the analysis stage. For an orthogonal filter bank, hi~(n) are just the time reversals of hi(n). Wavelet frames, having the form described above, have twice as many wavelets as is necessary. Yet, note that the filter bank illustrated in both Fig. (1), is oversampled by 3/2, not by 2 [6]. So, why should the FT transform be called to have double density property?, this is because the iteration makes the redundancy factor approach 2, i.e., a J = 2 filter bank is oversampled by 7/4, which means that when the filter bank is iterated by a single time on its lowpass branch (h_0), the total oversampling rate will be 7/4, and for J = 3 filter bank is oversampled by 15/8, and so on. A general decomposition at level J is oversampled by $\frac{2\times 2^J-1}{2^J}=2-\frac{1}{2^J}$, and as $J\to\infty$, the factor tends to 2 [7]. In [6] a detail description to compute a single level discrete framelet transform for 2-D signal using separable and non-separable method was specified briefly.

FRAMELET BASED OFDM SYSTEM

The transceiver of the proposed Framelet-OFDM system is shown in Fig. (2). The main task of the transmitter is to perform the discrete framelet modulation. Here, the signal is up-sampled and filtered by the filters in the framelet blocks, these blocks comprises of an Inverse Framelet Transform (IFT) at the transmitter and a Framelet Transform (FT) at the receiver as shown in Fig. (2). The IFT and FT blocks replace the IFFT and FFT blocks of Fourier based OFDM system, these blocks are comprise of a one low pass filter (LPF) and two high pass filters (HPF) in order to perform framelet operations, which equivelantly represents the modulation stage, additionally, there is also no requirement CP blocks in the transmitter or receiver as it already found in conventional OFDM system; this is due to the good overlapping nature of the framelets that provides high orthogonality to the processed data, that make the framelet-based OFDM acquire higher spectral containment and therefore does not need a cyclic prefix to deal with the delay spreads of the channel, and the circular convolution provided by the addition of CP will gained here from the circular repetition nature (periodicity) for the rows of the framelets' transformation matrix, as indicated in Fig.(3) below.

SIMULATION RESULTS OF THE PROPOSED SYSTEM

Using MATLAB version 7.9, five types of OFDM systems were simulated: FFT- OFDM, DWT-OFDM, DMWT-OFDM, PWT-OFDM and the proposed FT-OFDM. The BER performances of the five systems were found for different channel models: AWGN channel, AWGN plus Flat Rayleigh Fading channel, and AWGN plus Selective Rayleigh Fading channel, using both of QAM and PSK as symbol mapping schemes. The system parameters used through the simulations are listed in Table(1).

OFDM SIMULATION USING M-PSK SIGNAL MAPPING.

Using different PSK phases, the compared FT, FFT, DWT, DMWT, PWT based OFDM systems have been simulated and a comparison between their performance will be shown in the next sections.

BER PERFORMANCE OF M-PSK-OFDM SYSTEM IN AWGN CHANNEL.

OFDM system has been simulated under AWGN channel which is known as the ideal communication channel. Below, the result of systems BER vs. E_b/N_o graph is plotted. A comparison between the performance of the investigated FFT-OFDM, DWT-OFDM, DMW-OFDM, and PWT-OFDM versus the proposed FT-OFDM was made. In order to show the trade off between system capacity and system robustness, the modulation techniques including (Q-8-16-64)PSK were used with each one of the compared systems and the results of the simulation for the five systems are calculated and depicted in Fig. (4). From Fig. (4), it is clear that the FT-OFDM system is much better than the other four systems FFT-OFDM, DWT-OFDM, DMW-OFDM, and PWT-OFDM. According to the simulated curves for QPSK-OFDM in Fig. (4.b), it is found that the proposed system reach 10^{-5} BER at 6dB, while both PWT and FFT OFDM reaches 10^{-5} BER at 9.5dB. On the other hand, DWT-OFDM reaches 10^{-5} BER at 7.5dB, and finally, DMW-OFDM reaches 10^{-5} BER at about 8dB, via AWGN channel. As a result, at bit error rate of 10^{-5}, about 1.5dB of E_b/N_0 is gained by using the proposed FT-OFDM system as compared to DWT-OFDM, 2dB to DMWT-OFDM, and about 3.5dB as compared to both PWT and FFT-OFDM. This is a reflection of the fact that the orthogonal frames of the Framelet transform is more significant than the orthogonal bases used in FFT-OFDM, PWT-OFDM, DWT-OFDM, and DMWT-OFDM. For other higher order signal mapping phases, the results of the simulation for the five compared systems are calculated as shown in Fig. (4) and depicted in Table (2), which gives the BER performance for all of the compared systems in AWGN channel. Again, it is clear that the proposed Framelet based OFDM is much better than the other four systems FFT-OFDM, PWT-OFDM, DWT-OFDM, and DMWT-OFDM.

BER PERFORMANCE OF M-PSK-OFDM SYSTEM IN AWGN PLUS FLAT RAYLEIGH FADING CHANNEL.

In this type of channel, the signal will be affected by the flat fading in addition to AWGN, hence, all the spectral components of the transmitted signal are affected in a similar manner; the fading is said to be frequency nonselective or, equivalently, frequency flat. This is the case for narrowband systems in which the transmitted signal bandwidth is much smaller than the channel's coherence bandwidth [8], in addition to an AWGN. The result of the simulation is shown in Fig. (5) and Table (3), which were recorded according to Doppler frequency of 11 Hz .

From Fig. (5.b), and for QPSK mapping scheme, it can be seen that the proposed FT-OFDM system shows better performance over the other simulated systems. Since at BER=10^{-5}, the E_b/N_0 required for FT-OFDM is about 30dB, while in FFT-OFDM the E_b/N_0 is about 36.5dB, and for PWT-OFDM it is about 37dB, and for both DWT and DMWT-OFDM, it is about 35dB and 31dB respectively. For other modulation phases, a comparison is made as shown in Table (3) and Fig. (5), and it is clear that the FT-OFDM model again has the best performance over FFT based OFDM, DWT based OFDM, PWT-OFDM and DMWT-OFDM. This is due to excellent orthogonality, and less time variant than the other compared functions.

BER PERFORMANCE OF M-PSK-OFDM SYSTEM IN AWGN PLUS SELECTIVE RAYLEIGH FADING CHANNEL.

The purpose of this section is to show the BER performance of the investigated FFT-OFDM, DWT-OFDM, DMWT-OFDM, PWT-OFDM, systems and the proposed FT-OFDM systems in the selective fading channel; the spectral components of the transmitted signal are affected by different amplitude gains and phase shifts. Variations in amplitude can produce signals that are too weak to be detected, also, differences in phase produce signals that constructively and destructively interfere. The fading is said to be frequency selective. This applies to wideband systems in which the transmitted signal bandwidth is higher than the channel’s coherence bandwidth [8]. The frequency components of the transmitted signal with frequency separation exceeding the coherence bandwidth are subjected to different amplitude fluctuation and phase rotation. A 4-rays Rayleigh-distributed multi-path fading channel is assumed here, where the parameters of the channel in this case corresponding to multipath are (-8dB, -12dB, -14dB) paths gain and the paths delay are (1,3,6) µsec relative to the first component respectively.

The results of the first test of the proposed system over the selective fading channel with Doppler frequency of 11Hz and PSK signal mapping are shown in Fig. (6), which also corresponds to walking speed of 4.8 kmph. Other tests are done on the proposed system over selective fading channel which are similar to those tests are stated in Fig. (6). It is clearly shown from Fig. (6.b) that the FFT-OFDM needs E_b/N_0 more than 41dB to reach 10^{-5} BER, while DWT-OFDM needs E_b/N_0 around 39dB to reach 10^{-5} of BER, and PWT-OFDM need E_b/N_0 of 44dB. Finally, DMWT-OFDM requires 40.5dB, while the proposed system FT-OFDM doesn’t exceed 38dB. This means that the proposed system provide good resistance against channel selectivity without the need to the addition of cyclic prefix extension, which leads to efficient use of the transmission bandwidth.

OFDM SIMULATION USING M-QAM SIGNAL MAPPING.

As performed previously with PSK, but with QAM signal mapping instead of PSK that have been used previously.

BER PERFORMANCE OF M-QAM- OFDM SYSTEM IN AWGN CHANNEL.

This section includes the results of simulating QAM-OFDM system under AWGN as have been seen previously, the QAM phases used here are 16-64-256 QAM for all of the compared OFDM systems. From Fig. (7.a), it can be seen that FT-OFDM provides lower error rate than other systems. Take for example, at BER of 10^{-5}, it is apparent that FT-OFDM has E_b/N_o equal to10dB, and that of DWT-OFDM at the same BER is about 11.5dB, and for DMWT-OFDM it is 12dB, and for both of FFT and PWT-OFDM it is about 13.5dB. So, the gained E_b/N_o by using QAM scheme appears to be less than that achieved with the use of PSK scheme; but, in both cases the FT-OFDM was the best system in terms of performance, this is due to the fact that the noise effect QAM data in both of its amplitude and phase, while for PSK only the phase will be affected by noise since it has no data in the amplitude. For the other two phases (64 and 256 QAM) schemes, the results are shown in Fig. (7) and Table (5).

BER PERFORMANCE OF M-QAM-OFDM SYSTEM IN AWGN PLUS FLAT RAYLEIGH FADING CHANNEL.

In this section, a flat Rayleigh fading channel, where spectral components of the transmitted signal are affected equally by amplitude gains and phase shifts, has been simulated in addition to AWGN. The same channel parameters that have been used with PSK mapping schemes are applied here, with Doppler frequency of 11Hz, the results for the simulation are plotted in Fig. (8) and listed in Table (6). From Fig. (8.b), the curves for 16QAM show that the FT-OFDM is better than the other systems, since FT-OFDM system reaches 10^{-5} BER at 38.5dB E_b/N_0, while DMWT-OFDM has 41 dB, and DWT-OFDM reaches 10^{-5} BER at 42dB. On the other hand, PWT reaches 10^{-5} of BER at 46dB E_b/N_0 and FFT-OFDM reaches 10^{-5} BER at 45 dB. For 64- and 256-QAM schemes, Fig. (8) and Table (6) display the results.

BER PERFORMANCE OF M-QAM-OFDM SYSTEM IN AWGN PLUS SELECTIVE RAYLEIGH FADING CHANNEL.

In the selective fading channel, the spectral components of the transmitted signal are affected by different amplitude gains and phase shifts. This occurs with wideband systems in which the transmitted signal bandwidth is higher than the channel's coherence bandwidth. The same channel parameters that have been used with PSK mapping schemes would be used here, where, a 4-rays Rayleigh-distributed multi-path fading channel is assumed, with path gains of (-8dB, -12dB, -14dB) and paths delay of (1,3,6) µsec relative to the first component respectively. With Doppler frequency of 11 Hz, the results for the simulation are plotted in Fig. (9) and listed in Table (7). From Fig. (9.b), the curves for 16QAM show that the FT-OFDM is better than the other systems, because FT-OFDM system reaches 10^{-5} BER at 43dB E_b/N_0, while for DMWT-OFDM is about 44dB, and DWT- OFDM reaches 10^{-5} BER at 46 dB. On the other hand, PWT and FFT-OFDM both reach 10^{-5} BER at 47dB. For 64 and 256 QAM schemes, Fig. (9) and Table (7) display the results.

CONCLUSIONS

- In this paper, it has been shown that the proposed Framelet-OFDM is viable, i.e. it is possible to transmit data using this system, using all types of mapping techniques(QAM, PSK, DPSK) that are used with OFDM in practice, without loss in performance or requiring additional resources. Additionally, the signals generated by OFDM overlap only in frequency domain, while FT-OFDM generated signals overlap in both frequency and time domain.
- The proposed Framelet based OFDM system do not required CP, thereby enhancing the spectrum efficiency. According to the IEEE broadband wireless

standard 802.16.3, avoiding CP gives wavelet OFDM an advantage of roughly 20% in bandwidth (BW) efficiency. Moreover, as pilot tones are not necessary for Frameet based OFDM system, they perform better in comparison to existing OFDM systems like 802.11a or HiperLAN, where 4 out of 52 sub-bands are used for pilots. This gives wavelet based OFDM system another 8% advantage over typical OFDM implementations.

- This paper presents a performance study of FT-OFDM using M-ary modulation schemes via. PSK, QAM and DPSK for FT, FFT, DWT, DMWT, and PWT based OFDM techniques using the system parameters for WLAN standard IEEE 802.11g. The performance analysis of the WLAN system is based on BER versus E_b/N_o for above mentioned modulation formats in Additive White Gaussian Noise channel and the Rayleigh and Rician fading channel which are the channel scenarios that mostly applied for wireless applications.
- The results show that at BER of 10^{-5}, and when PSK is used as a mapping scheme, the minimum E_b/N_0 gain achieved by FT-OFDM is about 0.2dB, and a maximum of 3dB, when DPSK is used as a mapping technique, the minimum E_b/N_0 gain achieved by FT-OFDM is about zero, i.e., it is better than three of the four compared systems and equal to one of them, and a maximum of 4dB, finally, based on QAM mapping scheme, the minimum E_b/N_0 gain achieved by FT-OFDM is about 0.5dB, and a maximum of 2.5dB.

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Table (1) : Simulated 802.11g system parameters

Parameter	Value	Parameter	Value
System Bandwidth B.W	20 MHz	Symbol Rate (Rs)	250000 S/sec
Carrier Frequency f_c	2.4 GHz	Useful number of Subcarriers	52
Guard Interval type	Cyclic Prefix (CP)	Number of null subcarriers	12
Guard Interval Duration T_g	800 ns (16sample)	Total number of Subcarriers N	64
Symbol Observation Interval T	400 ns	FFT,FT,DWT,DMWT,PWT size	64 points
subcarrier spacing (Δf)	31.25 kHz	Modulation Scheme	PSK,DPSK, QAM
Doppler frequency f_d	11 Hz	User Walking Speed (V)	4.8 kmph

Table (2) : Simulation results for PSK-OFDM System in AWGN Channel.

PSK	BER = 10^{-5}	FT-OFDM	DMWT-OFDM	DWT-OFDM	FFT-OFDM	PWT-OFDM
8PSK	E_b/N_o	10	11	11	13	13
16PSK	E_b/N_o	14	16	16	17	17
64PSK	E_b/N_o	24	26	26	27.5	27.5

Table (3) : Simulation results for PSK-OFDM in AWGN plus Flat Rayleigh Fading Channel.

PSK	BER = 10^{-5}	FT-OFDM	DMWT-OFDM	DWT-OFDM	FFT-OFDM	PWT-OFDM
8PSK	E_b/N_o	35	37	35.2	43	41
16PSK	E_b/N_o	41	47	42	48	49
64PSK	E_b/N_o	53	55	53.8	58	60

Table (4) : Simulation results for PSK-OFDM System in AWGN plus Selective Rayleigh Fading Channel.

PSK	BER = 10^{-5}	FT-OFDM	DMWT-OFDM	DWT-OFDM	FFT-OFDM	PWT-OFDM
8PSK	E_b/N_o	43	44.5	46	48	49
16PSK	E_b/N_o	44	47	47	51	50
64PSK	E_b/N_o	53	55	55.5	57	61

Table (5): Simulation results for QAM-OFDM System in AWGN Channel.

QAM	BER = 10^{-5}	FT-OFDM	DWT-OFDM	DMWT-OFDM	PWT-OFDM	FFT-OFDM
64QAM	E_b/N_o	14	16.5	16.5	18	18
256QAM	E_b/N_o	19	21	21	22.5	22.5

Table (6) : Simulation results for QAM-OFDM System in AWGN plus Flat Rayleigh Fading Channel.

QAM	BER = 10^{-5}	FT-OFDM	DWT-OFDM	DMWT-OFDM	PWT-OFDM	FFT-OFDM
64QAM	E_b/N_o	45	46.5	46	50	49
256QAM	E_b/N_o	49	50	51.5	53	55

Table (7): Simulation results for QAM-OFDM System in AWGN plus Sel Rayleigh Fading Channel.

QAM	BER = 10^{-5}	FT-OFDM	DWT-OFDM	DMWT-OFDM	PWT-OFDM	FFT-OFDM
64QAM	E_b/N_o	46	50	46	49.5	55
256QAM	E_b/N_o	51	54	52.5	53	56

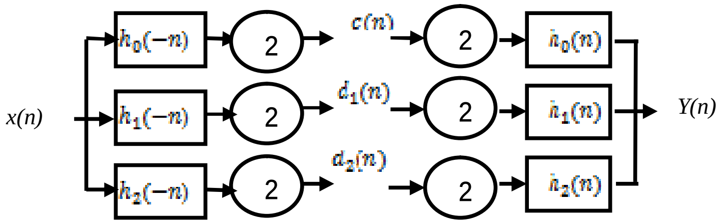


Figure (1): Filter Bank for 1D Framelet

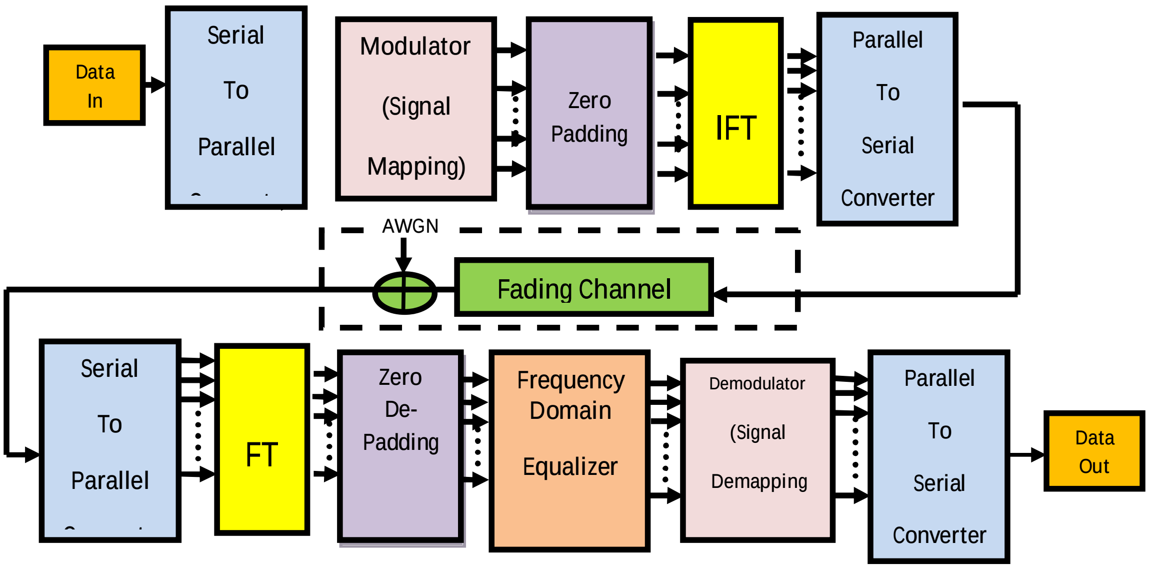


Figure (2) The system model of the proposed Framelet based OFDM transceiver.

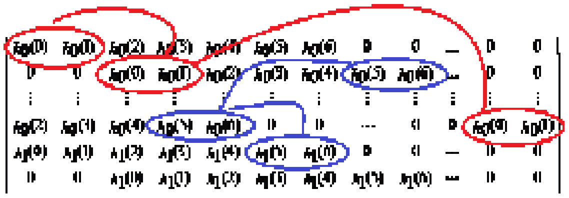


Figure (3): Circular repetition in Framelet Transformation matrix

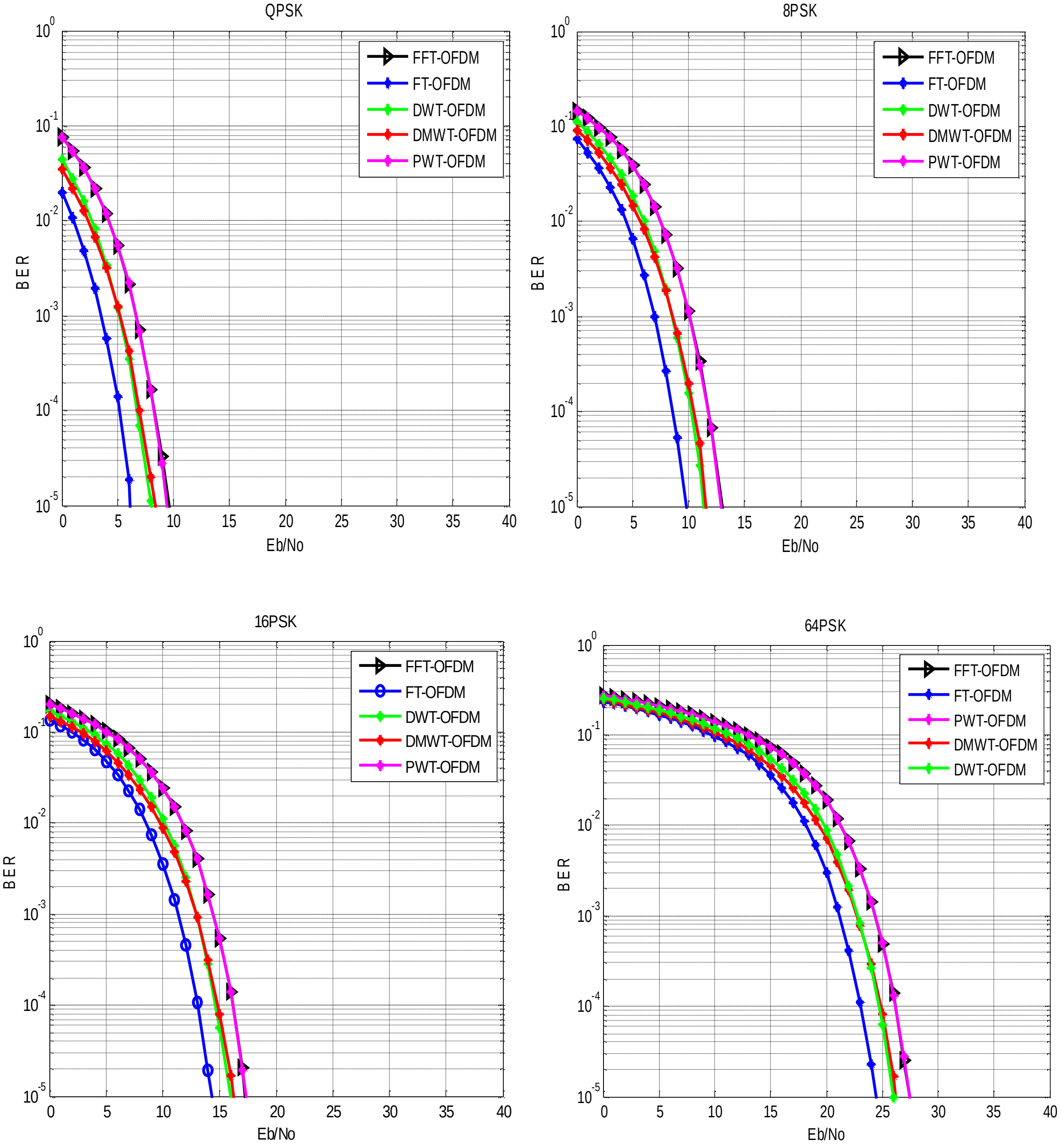
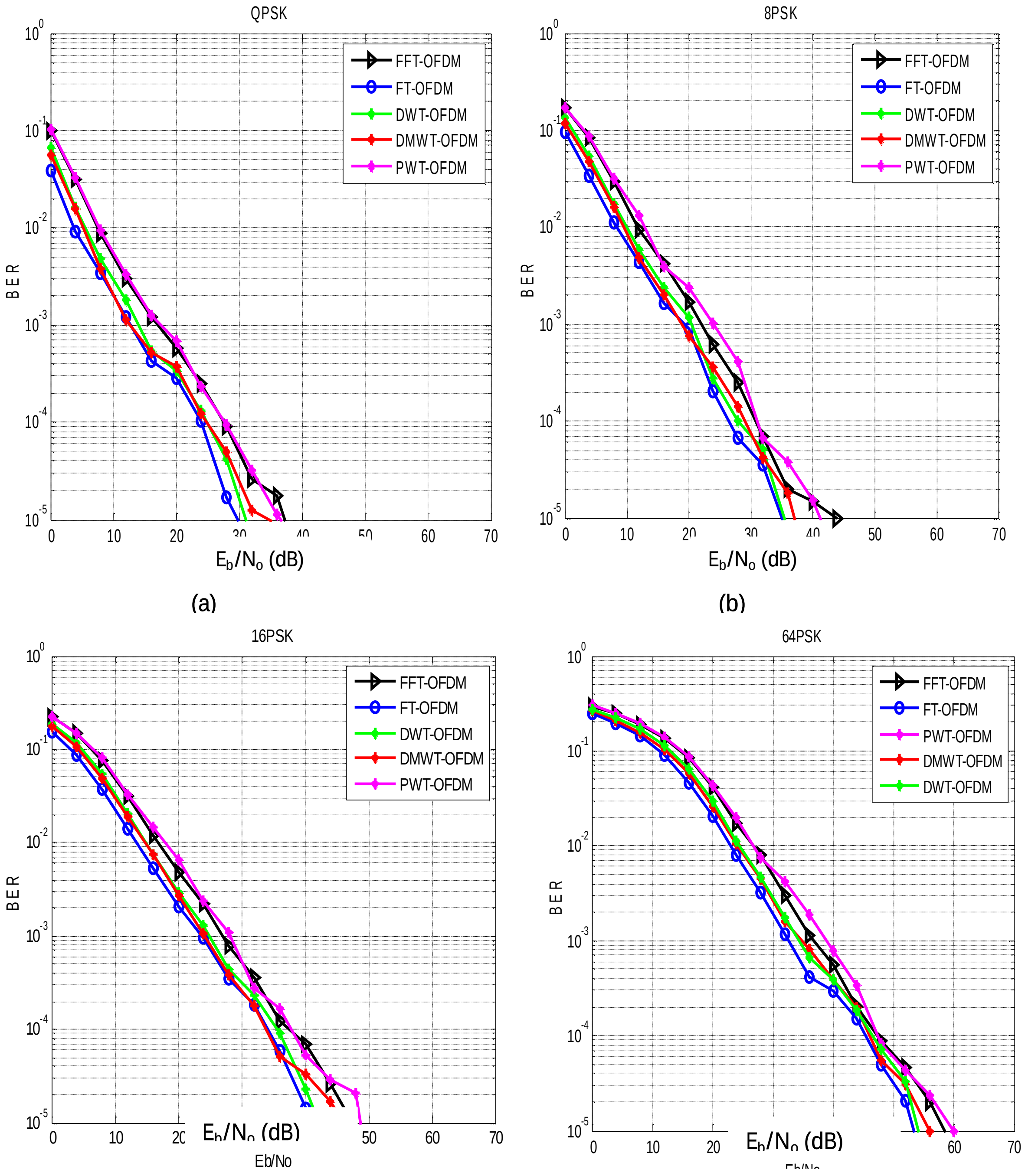


Figure (4) : PSK-OFDM System in AWGN Channel (a) QPSK (b) 8PSK (c) 16PSK (d) 64PSK



(a)

(b)

(c)

(d)

Figure (5) : PSK-OFDM System in AWGN plus Flat Rayleigh Fading Channel (a) QPSK (b) 8PSK (c) 16PSK (d) 64PSK

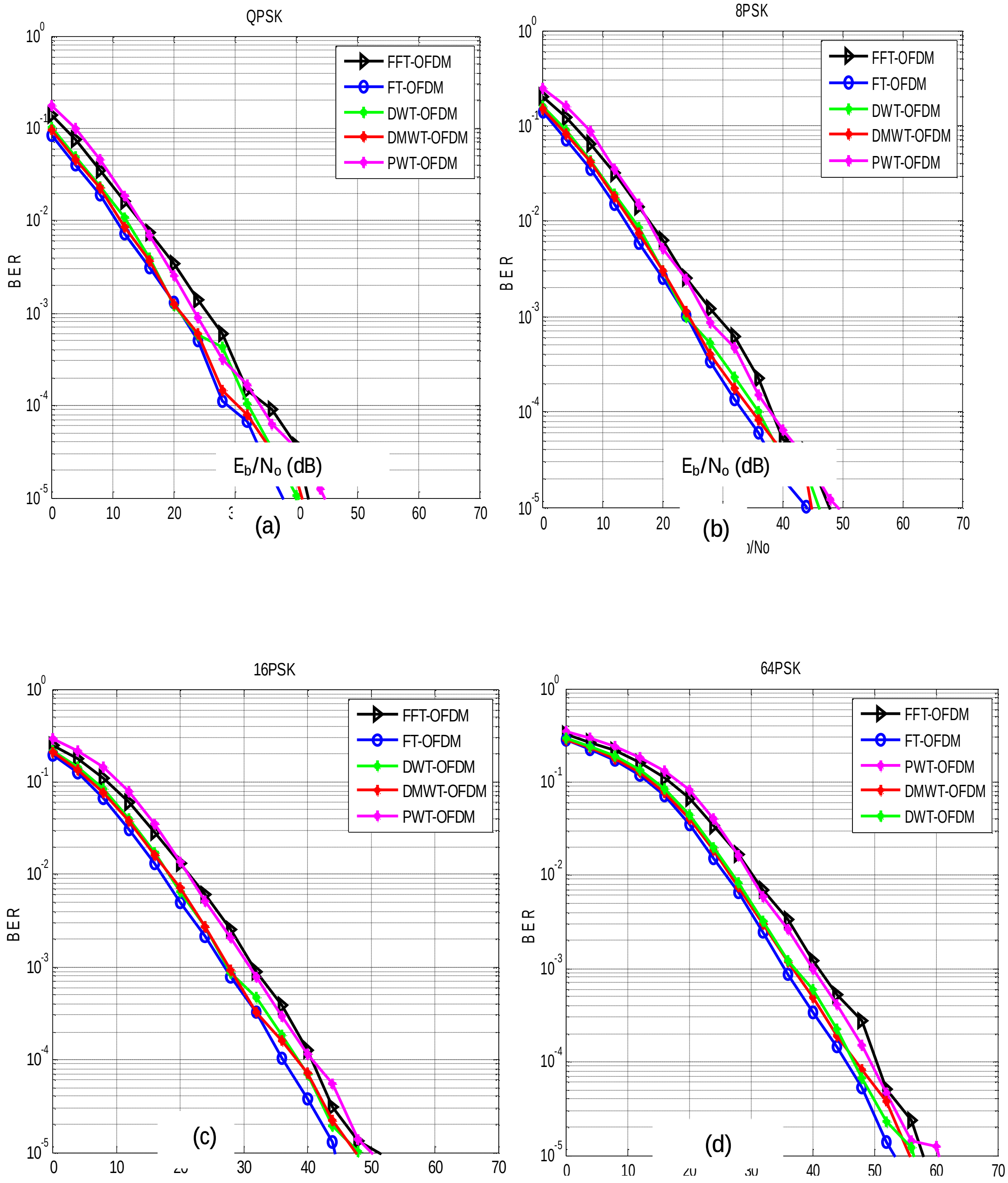
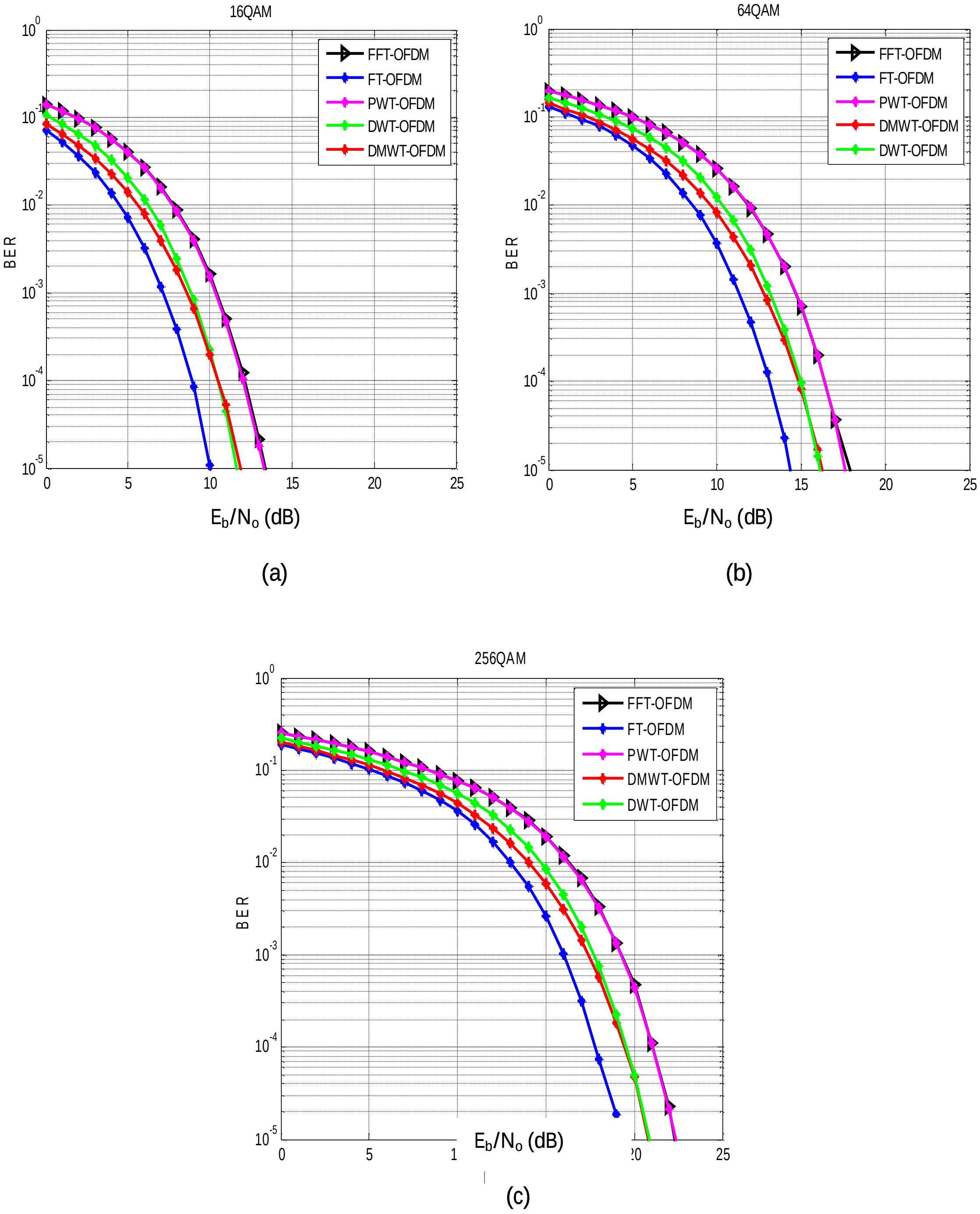


Figure (6) : PSK-OFDM System in AWGN plus Selective Rayleigh Fading Channel (a) QPSK (b) 8PSK (c) 16PSK (d) 64PSK

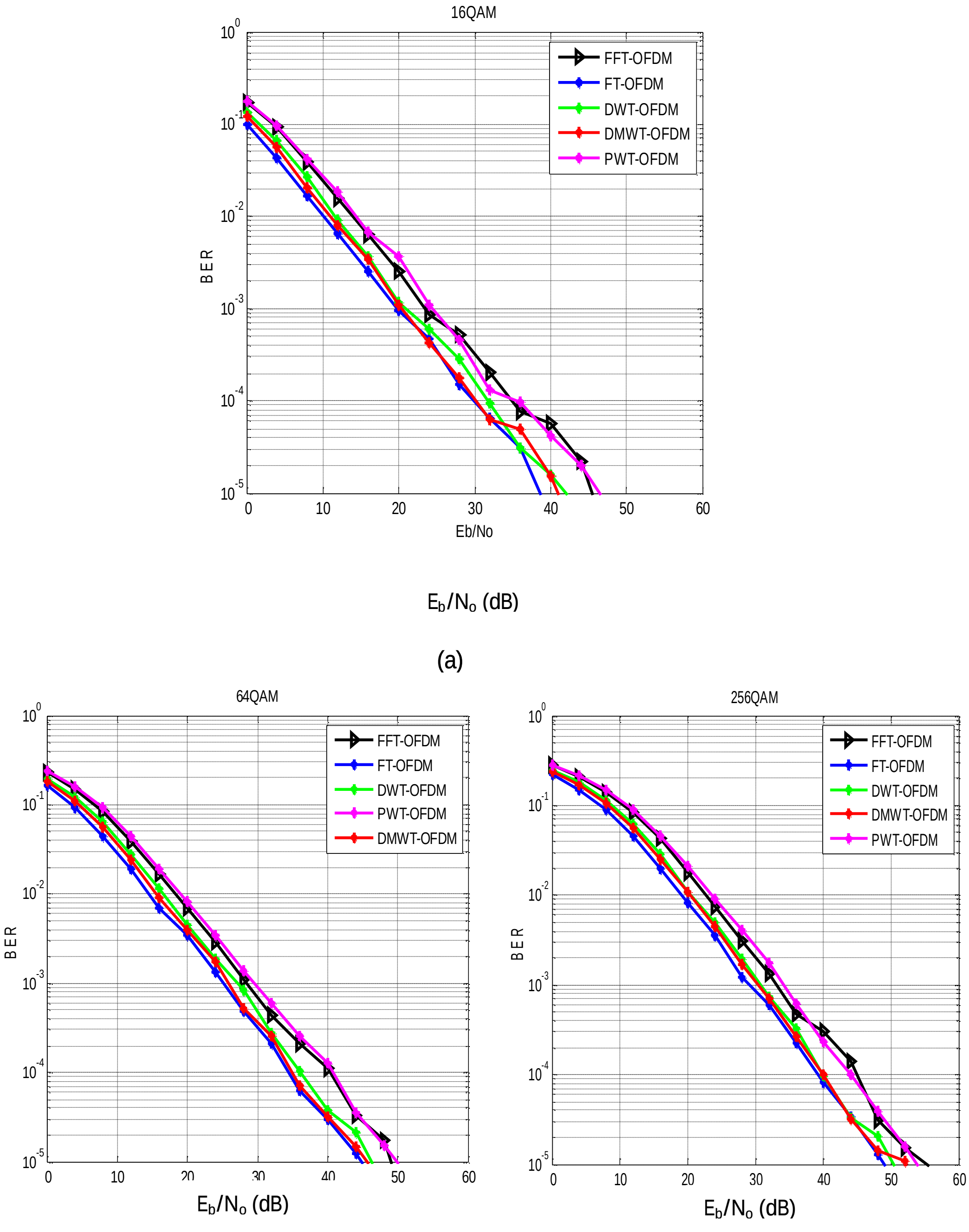


(a)

(b)

(c)

Figure (7) : QAM-OFDM System in AWGN Channel (a) 16QAM (b) 64QAM(c) 256QAM

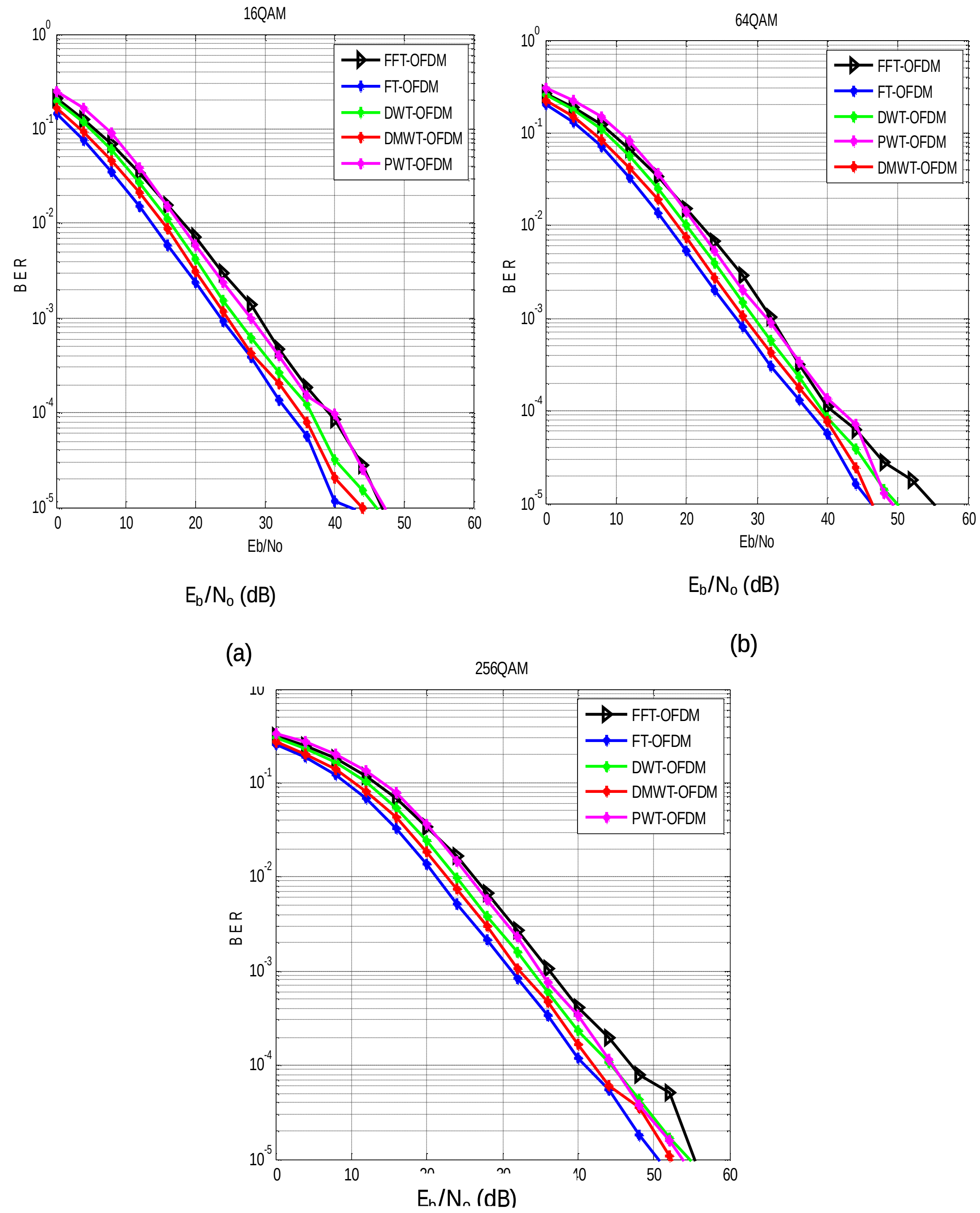


(a)

(b)

(c)

Figure (8) : QAM-OFDM System in AWGN plus Flat Rayleigh Fading Channel. (a) 16QAM (b) 64QAM(c) 256QAM



(a) (b) (c)

Figure (9) : QAM- OFDM System in AWGN plus Selective Rayleigh Fading Channel (a) 16QAM (b) 64QAM (c) 256QAM