Adaptive Modulation for Orthogonal Frequency Division Multiplexing

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is one of the promising technologies to improve the spectral efficiency, enhance system capacity and mitigate inter-symbol interference in the wireless communication system. Adaptive modulation (AM) with OFDM has been suggested as a bandwidth efficient transmission technique in wireless fading environments. In this paper, adaptive modulation techniques is used with OFDM system to improve the throughput performance of the system using four modulation schemes BPSK, QPSK, 8QAM, and 16QAM. Two algorithms to estimate SNR are suggested. The first algorithm is to estimate the SNR for each OFDM symbol in the frame. The second algorithm is to estimate the channel SNR for each subcarrier in the OFDM symbol. The comparison between the results of the two algorithms on the performances of BER and throughput for OFDM system is shown. Furthermore, the effect of various types of channel equalization on performances of system will be determined. The obtained results show that a significant improvements in terms of bit error rate (BER) and throughput can be achieved demonstrating the superiority of the adaptive modulation schemes compared to fixed transmission schemes.

Keywords: OFDM, Adaptive Modulation, zero forcing, minimum mean square error, feedback channel, channel state information.

التضمين المتكيف لنظام التقسيم الترددي المضاعف المتعامد

الخلاصة

نظام التقسيم الترددي المضاعف المتعامد (OFDM) هو أحد التقنياتِ الوَاعِدةِ لتَحسين الكفـــاءةِ الطيفيةِ، ويُحسّنُ قدرةَ النظامِ ويُسكّنُ التداخل بينَ الرموز (ISI) في نظام الاتصالات اللاســلكي . اُقترح التضمين المتكيف مع نظام (OFDM) كتقنية لعرض نطاق ترددي فعال في بيئات التلاشي اللاسلكية. في هذه الورقة ، تقنية التضمين المتكيف تستخدم مـــع نظـــام (OFDM) لتحســين أداء الإنتاجية (throughput) للنظام باستخدام أربعة أنواع مـــن التضـــمين (BPSK) و (QPSK) و (8QAM) و (16QAM) . وتم تطبيق طريقتين لتقدير (SNR)، الطريقة الأولى بواسطة تخمين (SNR) لكل رمز OFDM داخل الحزمة ، أما الطريقة الثانية بواسطة تخمين (SNR) لكل حامل ثانوي داخل رمز OFDM ، وتم إظهار نتائج المقارنة بين الطريقتين على أداء معدل خطأ (BER) و طاقة الإنتاجية لنظام (OFDM) . سنقوم أيضا بحساب تأثير أنواع مختلفة من تسوية القناة على

أداء النظام . إن النتائج المكتسبة توضح إن هنالك تحسينات هامة من ناحية معدل خطأ (BER) و طاقة الإنتاجية والتي برهنت تفوق أنظمة التضمين المتكيف بالمقارنة مع أنظمة التضمين الثابت .

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has been proposed for use in high speed wireless data applications because of its relatively simple receiver structure compared to single carrier transmission in frequency selective fading channels. In OFDM, the bandwidth is subdivided among orthogonal subcarriers over which information is modulated. If the number of subcarriers is large enough, each individual subchannel is characterized by flat fading rather than frequency selective fading, thereby precluding the need for otherwise necessary equalization to combat intersymbol interference [1]. Therefore, OFDM is generally known as an effective modulation technique for high data rate services such as digital audio broadcasting (DAB), digital video broadcasting (DVB) [1,2] and wireless LAN standards such as the American IEEE® Std.802.11™ (WiFi) and its European equivalent HIPRLAN/2. It has also been proposed for wireless broadband access standards such as IEEE Std. 802.16™ (WiMAX) and as the core technique for the fourth-generation (4G) wireless mobile communications [3].

Adaptive modulation scheme is an efficient scheme to increase the transmission rate that can be reliably transmitted over fading channels by changing the channel modulation scheme according to the estimated channel state information (CSI), Since its implementation depends on the channel environment of the system and control period by using feedback information [2,4]. For this reason some form of adaptive modulation is being proposed or implemented in many next generation wireless systems. The basic premise of adaptive modulation is a real-time balancing of the link budget in flat fading through adaptive variation of the transmitted power level [5,6], symbol transmission rate, constellation size, BER, coding rate/scheme, or any combination of these parameters. Thus, without wasting power or sacrificing BER, these schemes provide a higher average link spectral efficiency (bps/Hz) by taking advantage of flat fading through adaptation. Good performance of adaptive modulation requires accurate channel estimation at the receiver and a reliable feedback path between the receiver and transmitter. The impact of estimation error and delay on adaptive modulation schemes has been studied in [1,7]. Adaptive modulation provides many parameters that can be adjusted relative to the channel fading, including data rate, transmit power, instantaneous BER, symbol rate, and channel code rate or scheme [8]. A simple adaptive transmission system diagram is shown in Fig. (1), The Transmitter sends data symbols through wireless mobile channel and obtains estimated channel state information CSI (or system parameters) from the receiver via channel fedback channel for adjusting the transmission modes to optimize the system performance.

ADAPTIVE OFDM

Adaptive Modulation

With fixed modulation, the modulator (transmitter) does not have any information on the received SNR or other channel parameters available. It is usually designed for a certain minimum SNR, which is related to the maximum coverage distance of the link, in such a way that the maximum allowed error probability is guaranteed within the coverage area. In an adaptive modulation method, on the other hand, channel information is made available to the transmitter. In its simplest form, the instantaneous SNR is made available but for more complex channels, more channel information can be made available [6]. The following steps have to be considered to design an Adaptive modulation (AM) system:

i- Channel quality estimation: In order to appropriately select the system parameters to be employed for the next transmission, a reliable estimate of the CSI during the next active transmission time slot is necessary. Pilot symbol assisted modulation (PSAM) has been proposed as an attractive technique to detect the CSI in the fading environment by periodically inserting known symbols, from which the receiver derives its amplitude and phase reference [10].

ii- Adaptation rate: The adaptation rate determines what kind of channel variations the AM algorithm is tracking. If the channel is changing faster than it can be estimated and feedback to the transmitter, adaptive transmission techniques will perform poorly, and other means to mitigate the effects of fading should be used. It is easy to understand that faster adaptation leads to larger capacity gain, since the channel variations are exploited in a more accurate manner. However, fast adaptation has practical limitations such as hardware constraints. Besides, fast adaptation increases the number of mode-change messages sent to the receiver, which consume bandwidth and time resources [10].

iii- Feedback: The feedback messages inform the transmitter of the CSI estimated or the transmission mode decided by the receiver. The feedback load should be minimized since it consumes resources that would be otherwise used for data [10]. For example, compression of channel quality indication (CQI) feedback with Compressive Sensing is employed in [7] to reduce the feedback load. Perfect feedback channel is assumed in this paper. The adaptive modulation process algorithm is shown in Fig. (2).

where M_1, M_2, ..., M_n, are n different modulation modes varying from lower multilevel modulation to higher multilevel modulation with increasing order. SNR is the estimated signal-to-noise ratio of the mobile wireless channel, I_1, I_2,.., I_{n-1} are the switching thresholds between different modulation modes.

Thresholds SNR values are satisfied for each modulation scheme that is used in adaptive modulation process and selected according to desired BER level. The received feedback information (CSI) is used to compute estimated SNR that is used with thresholds SNR values to select appropriate modulation scheme that has BER under the desired BER level for received signal and to give good spectrum efficiency (bit/sec/Hz).With higher SNR estimation, high modulation level will be chosen and spectrum efficiency will be increased. Figure (3), shows the relation between SNR estimated and time of transmitted symbols according to a threshold value for target BER to satisfy the modulation schemes for each symbols (four type BPSK, QPSK, 8QAM, and 16QAM).

The throughput rate is defined as the number of information bits transmitted successfully per unit time and is measured in bit/sec. Throughput (η) is defined as [2]:

$$h = R_b * \frac{N_{suc}}{N_{trans}} \quad \text{..... (1)}$$

where R_b is the total information bit rate, N_{trans} and N_{suc} are the total number of transmitted and correctly received data blocks, respectively.

Channel Estimation Algorithms

The channel estimation can be performed by inserting pilot tones into all of the (N_c) subcarriers of OFDM symbols with a specific period (block type), By sending N_p consecutive blocks of pilot symbols in the beginning used to find channel state information (CSI) and channel frequency response that is used to equalize many OFDM data symbols tracking in each frame. At the receiver, Least Sequre (LS) estimator method used with received pilots to find channel frequency response for each pilot blocks and taken the average value to get accurate channel frequency response parameter ($\hat{H}$) at each subcarrier as [2]:

$$\hat{H}_i = \frac{1}{N_p}\sum_{p=1}^{N_p}\frac{(P_{i,p})_{received}}{(P_{i.p})_{transmitts}} = \frac{1}{N_p}\sum_{p=1}^{N_p} H_{i,p}] \qquad ... (2)$$

where $i=1,\ldots,N_c$, N_p is number of pilot blocks in each frame, $(P_{i,p})_{transmitted}$, $(P_{i,p})_{received}$ are transmitted and received pilots level for i^{th} subcarrier respectively, and $H_{i,p}$ is the channel frequency response at the i^{th} subcarrier estimated by the p^{th} channel estimation sequence .

Two schemes are performed in this paper:

1- First scheme: SNR estimated by this scheme determined for each OFDM symbol. By sending N_p consecutive block of pilot transmitted as channel estimation sequence (CES) in the frame. Each block can easily generate an estimate of the channel frequency response (CFR) vector [9]

$$H_i = (H[p,0]\ldots H[p,i]\ldots H[N_p, N_c - 1]) \qquad ... (3)$$

where H[p,Nc] is the CFR at the i^{th} subcarrier estimated by the p^{th} CES. Calculate $\hat{H}_i$ by averaging the N_p estimates of CFR at the ith subcarrier as in equation (2). Thus, the noise at the ith subcarrier in the p^{th} CES is:

$$\hat{W}[p,i] = \hat{H}_i - H[p,i] \qquad ...(4)$$

The signal power can be estimated as:

$$P_s = \frac{1}{N_c}\sum_{i=1}^{N_c}\left|\hat{H}_i\right|^2 \qquad ...(5)$$

and the noise power can be estimated as:

$$P_n = \frac{1}{N_p N_c}\sum_{p=1}^{N_p}\sum_{i=1}^{N_c}\left|\hat{W}[p,i]\right|^2 \qquad ...(6)$$

Thus, we have the estimated SNR as:

$$\hat{SNR} = \frac{P_s}{P_n} \qquad ... (7)$$

Now, each symbol will be modulated by one type of modulation according to threshold of that modulation value and SNR estimation.

2- Second scheme: SNR estimated by this scheme determined for each subcarriers in the OFDM symbol. First, the frequency channel response ($\hat{H}_i$) can be calculated using received pilot signals as in equation (2). The transmitted pilot signals are already known, and each transmitted pilot signal value is assumed to be equal to one. The evaluated channel response includes the fading term, so we can compensate the amplitude and phase of received signal [2].

$$d_i = \frac{d_{i,r}}{\hat{H}_i} \qquad \text{... (8)}$$

where $\hat{H}_i$, d_i and $d_{i,r}$ is frequency channel response, compensated data, and uncompensated received data on the i^{th} subcarrier, respectively. Next, the method to calculate the channel noise power is performed. Since, the transmitted pilot signal is known, a reference signal $P_{i,ref}$ can be made by using the estimated channel response $\hat{H}_i$ and transmitted pilot signal $P_{i,t}$.

$$P_{i,ref} = P_{i,t} .\hat{H}_i \qquad \text{...(9)}$$

Noise term is a random signal with zero mean, so average channel response $\hat{H}_i$ on the i^{th} subcarrier does not include noise term since noise term of received pilot signal is cancelled due to its random characteristic. Reference signal also does not include the noise term. Therefore, noise power on the i^{th} subcarrier is a square of difference between received pilot signal and reference signal.

$$N_{o,i}=(P_{i,r} - P_{i,ref})^2 \qquad \text{...(10)}$$

Finally, the ratio of signal power to noise power (Es,i/ No,i) on the i^{th} subcarrier can be calculated:

$$E_{s,i}/N_{o,i}=(P_{i,r})^2/N_{o,i} \qquad \text{...(11)}$$

From equation (11), a feedback information is prepared (as SNR estimation) for the next modulation.

Frequency Domain Equalization (FDE)

As mobile radio channels are affected by multipath fading, some form of channel equalization is needed to compensate for the intersymbol interference (ISI). The complex equalizer tap weights (Q_n) can be made depending on different criteria, two of the most well-known are the Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) [9]. The ZF criterion forces ISI to be zero at the sampling instant of each subcarrier. For ZF equalizer, the coefficients for n^{th} subcarrier are given by [9]:

$$Q_n = \frac{1}{H(n)} \qquad \text{... (12)}$$

where H(n) is the channel frequency response within the bandwidth of the n^{th} subcarrier. The disadvantage of the ZF criterion is that it enhances noise at the n^{th} subcarrier if H_n is small, which corresponds to spectral nulls (deep fading).

MMSE-FDE is more complex, more appealing since it can make compromise between the residual inter-symbol interference (ISI) (in the form of gain and phase mismatches) and noise enhancement. Therefore, it can minimize the combined effect of ISI and noise. This is particularly attractive for equalizing the channels of severe frequency-selective fading, the coefficients for n^{th} subcarrier are given by [9]:

$$Q_n = \frac{H^*(n)}{\left|H(n)\right|^2 + 1/SNR} \quad ...(13)$$

where *, and |·| denote conjugate transpose and module of a complex value, respectively.

SYSTEM MODEL

The block diagram of adaptive OFDM system used is shown in the Fig.(4). The system consists of a transmitter, a receiver and a Rayleigh communication channel. At the transmitter, the data serial bit sequences are converted to the parallel bit sequences and then modulated with one of various modulation mappings. The modulation mapping is chosen according to the SNR estimated and threshold value required for each modulation scheme to maintain the required BER The adaptive modulators select from different QAM modulation formats: BPSK,QPSK, 8QAM, and16QAM. This means that 0, 1, 2, 3 and 4 bit per subcarrier can be transmitted. To estimate the channel conditions and obtain CSI, two blocks of pilot symbols (N_p=2) are inserted before each thirty data symbol blocks that means 32 blocks is the length of transmitted frame. The OFDM time signal is generated by an inverse FFT and is transmitted over the Rayleigh fading channel after the cyclic extension has been inserted.

At the receiver, after converted the received signal from serial to parallel, the data is prepared to enter FFT block as (N_c=128) subcarriers demodulation. Frequency Domain Equalizer (FDE) is frequently used after the FFT operation to compensate the impact of the channel, two types of FDE are used, ZF-Equalizer and MMSE-Equalizer. The information obtained from pilot symbols are used to find frequency channel response that is used in FDE and to estimate SNR for the channel by the two schemes above (first, for each symbols and second, for each subcarriers) and feedback it to transmitter to select appropriate modulation scheme. After FDE process the symbols are demodulated and converted to serial bits form. In this paper, the comparison between the results of the two algorithms to estimate SNR on the performances of BER and throughput for OFDM system is shown. Furthermore, the effects of different types of frequency domain channel equalization on the performance and comparison between used ZF-FDE and MMSE-FDE on adaptive OFDM system are discussed.

SIMULATION RESULTS

The Standard parameters that have been used in simulation are listed in Table (1). This system is software implemented with the m-file of MATLAB 7.0 technical programming language.

BER and throughput Performances

The BER performance versus SNR values of OFDM system using various modulation schemes is illustrated in Fig.(4).

The curves from left to right represent the BER of BPSK, QPSK , 8QAM and 16QAM in three paths Rayleigh fading channel, respectively. In order to decide the proper switching levels from this plot, operating point, or desired BER must be decided. In this paper, a BER of (10^{-3}) is used as an operating point. This means that the adaptive OFDM system will try and keep a BER lower than (10^{-3}) with the most spectrally efficient modulation scheme whenever possible. Therefore, with this operating point, and the given BER plots, Table (2) shows SNR ranges for each modulation scheme.

These levels are obtained in the following way: At an operating BER of (10^{-3}), there is no modulation scheme that gives the desired performance at an SNR below 11 dB. Therefore, BPSK is chosen as it is the only choice. Between 11 and 14.8 dB, there is only one scheme that gives performance below (10^{-3}), and that is BPSK with spectral efficiency (1 bit/symbol). Between 14.8 and 19.5 dB, QPSK gives the desired BER at a better spectral efficiency (2 bits/symbol) than BPSK. Between 19.5 and 22.3 dB, 8QAM gives the desired BER at a better spectral efficiency (3 bits/symbol) than QPSK. And at SNR higher than 22.3 dB, 16-QAM gives the best spectral efficiency (4 bits/symbol) while providing the desired BER performance.

The BER and throughput performances versus SNR values of Adaptive OFDM system using various modulation schemes and based on SNR estimation for entire OFDM symbol (first scheme) are illustrated in Fig.(5), and Fig.(6) respectively and based on SNR estimation for each subcarriers(second scheme) of OFDM signals are illustrated in Fig.(7), and Fig.(8) respectively.

The comparison between BER and throughput performance versus SNR values of adaptive OFDM system with the two schemes of SNR estimation are shown in Fig.(9), and Fig.(10). From the two figures, at low SNR (exactly under 17.1 dB) good throughput performance with first scheme that is dependent on transmitting same modulation type on all subcarriers in each OFDM symbol according to instantaneous estimation of SNR.

In second scheme, at SNR below 17.1db, the fixed BPSK and QPSK achieves the better throughput performance than the adaptive modulation this is because computed throughput depends on correct received symbols and the adaptive modulation scheme uses different modulation schemes in each subcarrier in the OFDM symbols, that makes the probability of errors at low SNR in the one of subcarriers in symbol is high compared with transmitting one modulation scheme in the entire symbol. At SNR between 17.1 dB and 25 dB better BER and throughput performances for the second scheme can be shown compared with the first scheme. The second scheme chooses appropriate modulation type for each subcarrier suitable to SNR estimation for that subcarrier to give high throughput and low BER.

In Fig.(11) the BER performance versus SNR values of OFDM system with MMSE equalizer using various modulation schemes is illustrated. Table (3) shows SNR ranges for each modulation scheme computed at BER of (10^{-3}) that is used as an operating point.

The comparison between BER and throughput performance versus SNR values of adaptive OFDM system with two type of equalizer ZF and MMSE equalizers are shown in Fig.(12) , and Fig.(13).

The use of MMSE reduces BER and increases throughput performances for adaptive OFDM by 2.1dB benefit compared with used ZF equalizer at 10^{-3} SNR, that is MMSE is more efficient to equalization channel effect and ISI.

To show the effect of Doppler frequency, the throughput performances versus SNR values of Adaptive OFDM with ZF-FDE system using different values of Doppler frequencies are illustrated in Fig. (14), and Fig.(15). From these figures, it can be seen that 8QAM and 16QAM give more degraded throughput performance than that BPSK and QPSK at high frequency. This is because the change of channel conditions is too fast to be followed by channel estimator in the receiver, so that many errors occur in data demodulation processing particularly in the last part of data symbols. It is also found that 8QAM and l6QAM are more sensitive than BPSK and QPSK to fast fading channel, so many errors occur in 8QAM and 16QAM.

In general, it can be seen from Figures that when Doppler frequency increases, the throughput performance of the system becomes worse. Therefore, this fluctuation in the channel conditions will lead to bit errors shown as a worse throughput performance, since the chosen adaptation scheme may no longer be optimal. Additionally, as the Doppler rate increases, the SNR no longer remains static over an individual frame. Maximum Doppler frequency is directly proportional to the mobile velocity, thus as mobile velocity increases and faster variations are introduced in the channel causing the performance of adaptive modulation to drop.

CONCLUSIONS

The important points that are noted during simulation and discussion of the results as:

1. Adaptive modulation improves the spectral efficiency of a radio link for a given maximum required quality (error probability). At low SNR, the system achieves 1 bits per symbol, as BPSK is primarily used. However, as the SNR increases, the throughput also improves steadily. More enhancement is achieved by the use of MMSE-FDE, there is 3 Mb/s improvement using MMSE-FDE over using ZF-FDE when the comparison is made at SNR =20 dB.
2. Two SNR methods are investigated, the first with block SNR estimation, give more throughput performance at SNR below 17.1 dB, than second with SNR estimation for each subcarrier, which gives higher throughput performance with SNR between 17.1 and 25 dB. The two methods with BER under 10-3 for most range of SNR (SNR larger than 11 dB).
3. As the Doppler frequency increases, the throughput performance of the system becomes worse, that is more bit error has occurred because the signal undergoes more fast fading channel, since the choice of adaptive scheme may no longer be optimal. If the comparison is made at SNR =20 dB, the throughput performance decreases by 3.2 Mb/s when Doppler frequency increases from 10Hz to 80Hz.

REFERENCES

[1] Souryal, M. R. and R. L. Pickholtz, “Adaptive Modulation with Imperfect Channel Information in OFDM ,"IEEE Int. Symp. on Comm. (ICC), vol. 6, pp. 1861-1865, 2001.

[2] Ahn, C.-J.. and l. Sasase “ The Effects of Modulation Combination, Target BER, Doppler Frequency, and Adaptation Interval on the Performance of Adaptive OFDM in Broadband Mobile Channel ,” IEEE Trans. on Consumer Electronics, Vol. 48, No. 1, pp 167-174, February 2002.

[3] Shen, Y. and E. Martinez, "Channel Estimation in OFDM System ," Freescale Semiconductor, www.freescale.com, January 2006.

[4] Lakanchnh, D. S. Noppanakeepong, S. Yoshizawa, and Y. Miyanaga, "Adaptive OFDM Modulation Techniques Over Fading Channel for Wireless Communication Systems with an 80 MHz Bandwidth ," IEEE 3rd International Nanoelectronics Conference (INEC), pp. 1441-1442, 2010.

[5] Inderjeet, K. T. Kamal, M. Kulkarni, and G. Daya, , "Adaptive OFDM Vs. Single Carrier Modulation with Frequency Domain Equalization ," IEEE International Conference on Computer Engineering and Technology (ICCET.2009), Vol. 1, pp. 238-242, 2009.

[6] Svensson, A. " An Introduction to Adaptive QAM Modulation Schemes for Known and Predicted Channels ," in proc. IEEE (JPROC), Vol. 95, No. 12, pp. 2322-2336, 2007.

[7] Gao, H. R. Song, and J. Zhao, " Compression of CQI Feedback with Compressive Sensing in Adaptive OFDM Systems ," IEEE International Conference on Wireless Communications & amp; Signal Processing (WCSP), pp. 1-4, 2010.

[8] Chung, S. T. and A.J. Goldsmith, " Degrees of Freedom in Adaptive Modulation: A Unified View ," IEEE Trans. Comm., Vol. 49, No. 9, pp. 1561-1571, Sep. 2001.

[9] Lei, M. I. Lakkis, H. Harada, and S. Kato, "MMSE-FDE based on Estimated SNR for Single-Carrier Block Transmission (SCBT) in Multi-Gbps WPAN (IEEE 802.15.3c)," IEEE Int. Conf. on Communications Workshops(ICCW.2008), pp 52-56, 2008.

[10] Yang,T. S. " Performance Analysis of Adaptive Transmission Aided by Long Range Channel Prediction for Realistic Single and Multi-Carrier Mobile Radio Channels", Doctor of Philosophy thesis, Dept. of Electrical Engineering, North Carolina State University, Raleigh 2004.

Table (1) Simulation parameters

PARAMETER	VALUE
Data rate	3M symbol/sec
Modulation types	BPSK, QPSK, 8QAM, 16QAM
Number of subcarriers (N_c)	128
Cyclic prefix interval (CP)	16 (chips)
Frame size	32 symbols (N_P = 2, data = 30)
No. of fading channel paths	L=3
Delays of Paths	(0, 0.333, 0.666) µsec
Doppler frequency	10 Hz

Table (2) Transmission modulation modes with ZF-FDE

	Mode 1	Mode 2	Mode 3	Mode 4
Modulation	BPSK	QPSK	8QAM	16QAM
Rate (bit/symb)	1	2	3	4
SNR(dB) at BER=10^{-3}	**11**	**14.8**	**19.5**	**22.3**

Table (3) Transmission modulation modes with MMSE-FDE

	Mode 1	**Mode 2**	**Mode 3**	**Mode 4**
Modulation	BPSK-MMSE	QPSK-MMSE	8QAM-MMSE	16QAM-MMSE
Rate (bit/ symb)	1	2	3	4
SNR(dB) at BER=10^{-3}	**8.9**	**12.3**	**16**	**18**

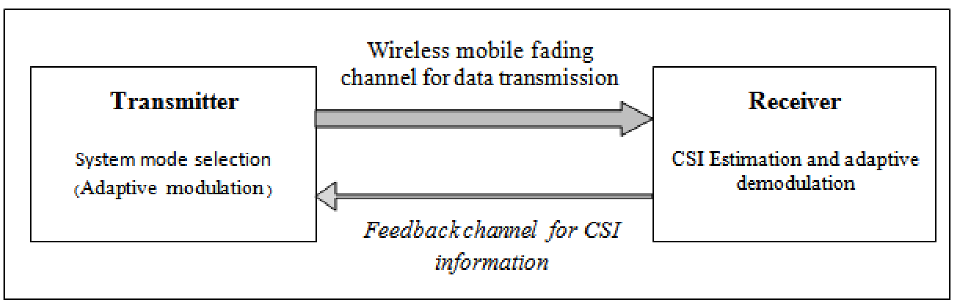


Figure (1) Scheme diagram of a simple adaptive transmission system.

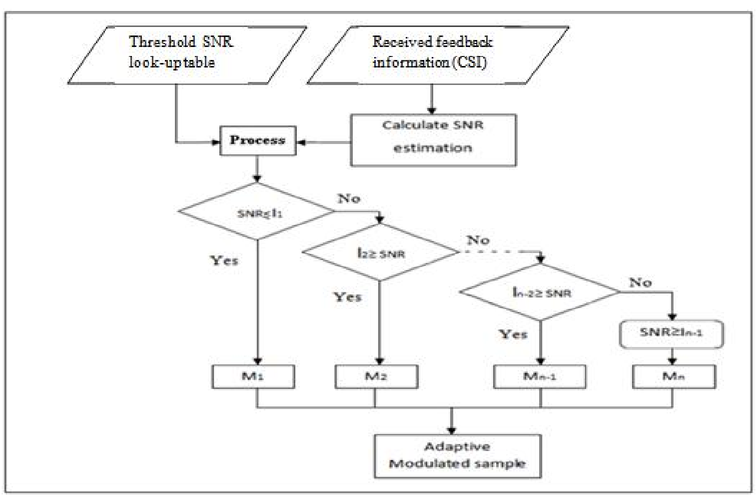


Figure (2) Adaptive modulation process algorithm.

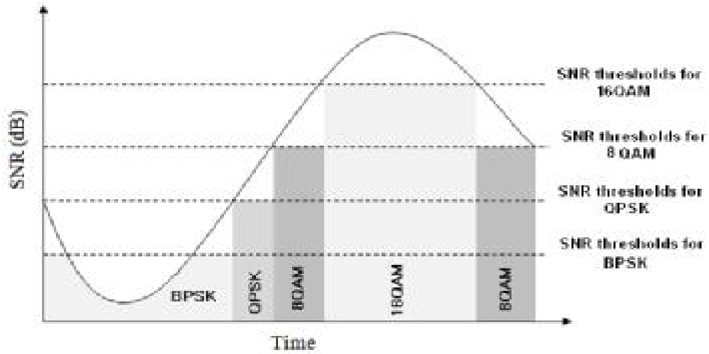


Figure (3) Threshold value of an modulation schemes.

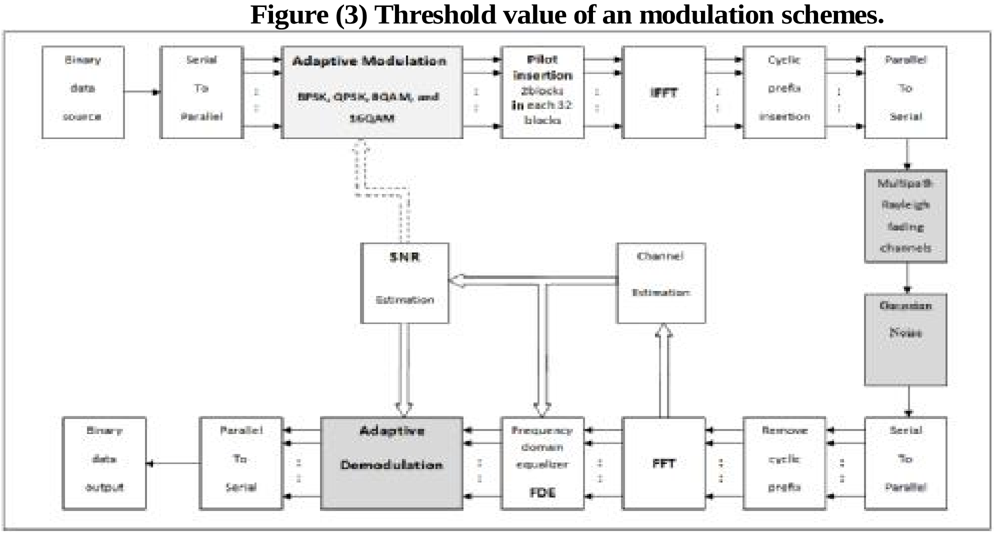


Figure (4a) Block diagram of adaptive Modulation technique in OFDM system.

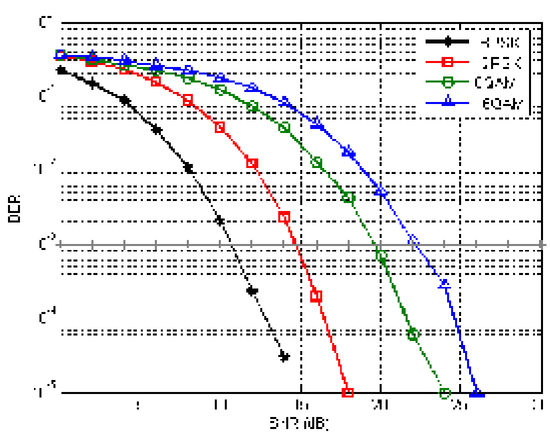
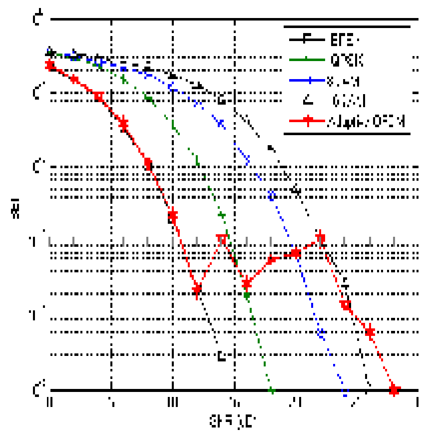


Figure (4b) BER performance of OFDM using fixed modulation modes with ZF-FDE



Figure(5) BER performance of Adaptive OFDM using scheme 1

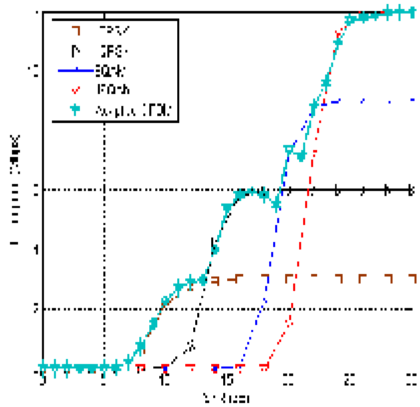


Figure (6) Throughput performance of Adaptive OFDM using scheme 1

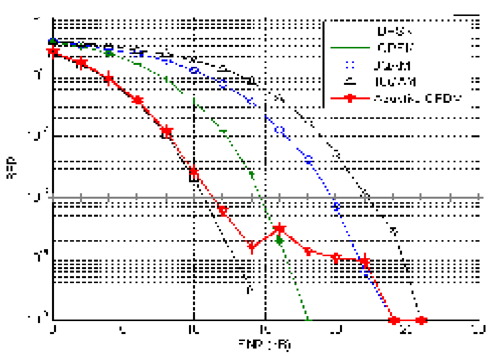


Figure (7) BER performance of Adaptive OFDM using scheme 2

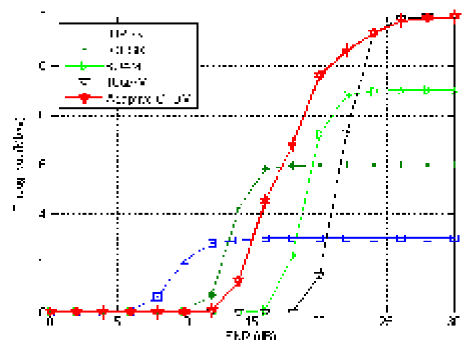


Figure (8) Throughput performance of Adaptive OFDM using scheme 2

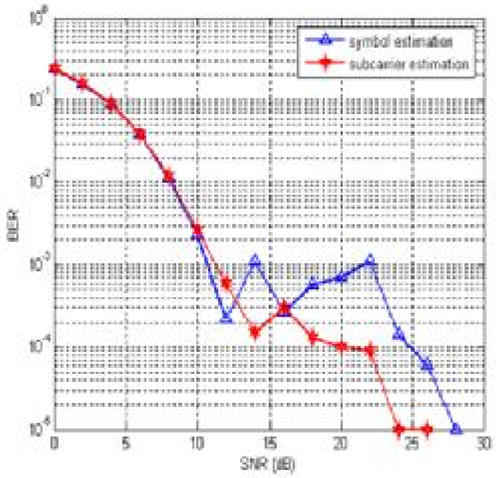


Figure (9) BER performance of Adaptive OFDM using two

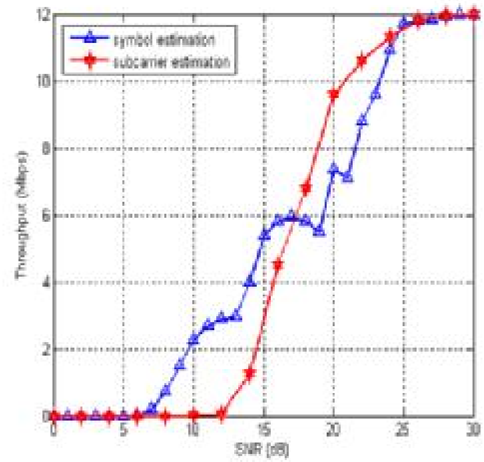


Figure (10) Throughput performance of Adaptive OFDM

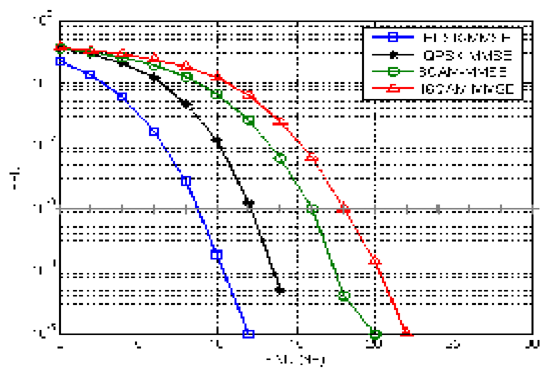


Figure (11) BER performance of OFDM with MMSE using various modulation

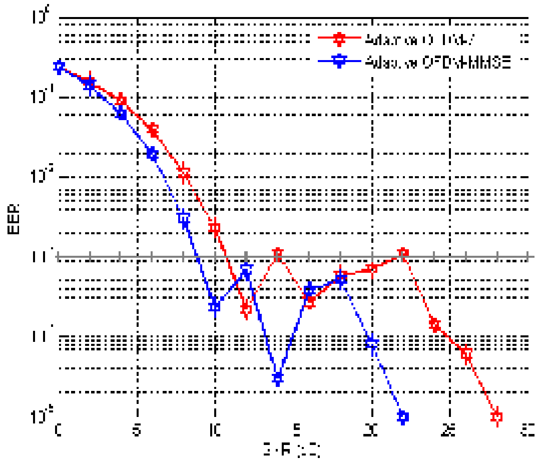


Figure (12) BER performance of Adaptive OFDM using two equalizer

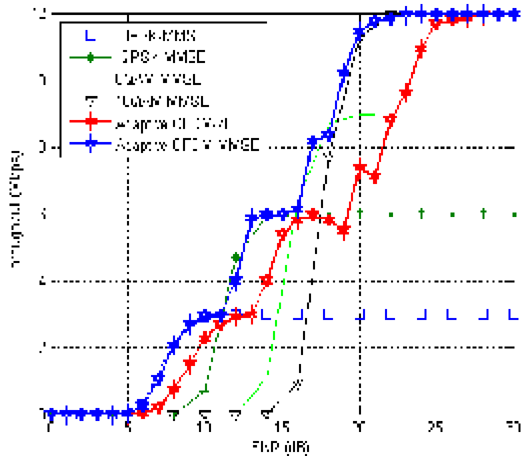


Figure (13) Throughput performance of Adaptive OFDM using two equalizer

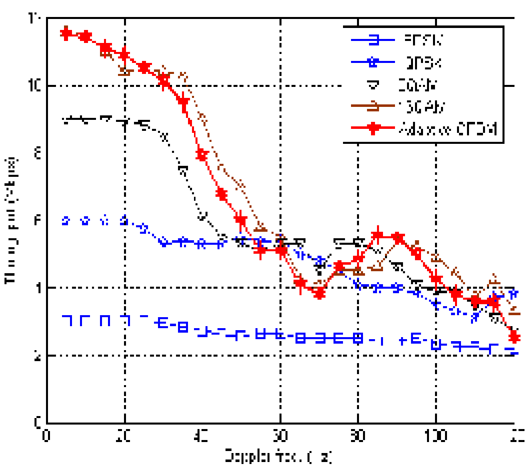


Figure (14) Throughput performance of Adaptive OFDM and various modulation with SNR=25 dB for different Doppler frequency

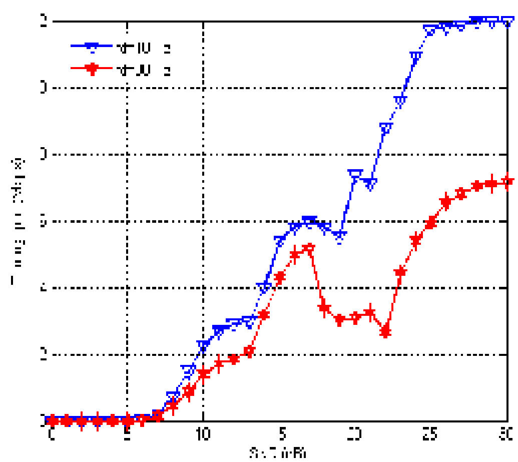


Figure (15) Throughput performance of Adaptive OFDM with 10Hz and 80Hz