Adaptive Coded Modulation for OFDM System

Assist. Prof. Dr. Serkout N. Abdullah
sar_abd2000@yahoo.com

Zainab Mageed Abid
zainab.mageed@yahoo.com

Abstract

This paper studies the adaptive coded modulation for coded OFDM system using punctured convolutional code, channel estimation, equalization and SNR estimation. The channel estimation based on block type pilot arrangement is performed by sending pilots at every sub carrier and using this estimation for a specific number of following symbols. Signal to noise ratio is estimated at receiver and then transmitted to the transmitter through feedback channel ,the transmitter according to the estimated SNR select appropriate modulation scheme and coding rate which maintain constant bit error rate lower than the requested BER. Simulation results show that better performance is confirmed for target bit error rate (BER) of (10^{-3}) as compared to conventional modulation schemes, the convolutional coded modulation offers a SNR gains of 5 dB compared to uncoded state at BER of 10^{-3}. The proposed adaptive OFDM scheme maintains fixed BER under changing channel conditions.

الخلاصة

في هذه المقالة تم دراسة منظومة التقسيم المتعدد المتعامد للتردد متعددة السرعة ومتكيفة و مرمزة باستخدام نوع الترميز Punctured Convolutional و تخمين وتعديل القناة وتخمين نسبة الإشارة إلى الضوضاء.تم دراسة طريقة لتخمين جودة القناة تسمى Block تعتمد على إرسال معلومات معروفة لدى المستلم على كل الترددات وهي ملائمة للقناة التي تتغير حالتها ببطء و طريقة لتخمين نسبة الإشارة إلى الضوضاء، يتم قياس مستوى الإشارة إلى الضوضاء في جهة الاستلام وإعادة إرسالها إلى المرسل من خلال قناة التغذية العكسية المثالية اعتمادا على مستوى الإشارة إلى الضوضاء يقوم المرسل باختيار الأسلوب المناسب للاتصال الذي يتضمن وحدة تضمين مرمزة تحقق نسبة خطا محددة مسبقا على أن لا يتجاوز عتبة نسبة الخطأ المطلوبة .لقد أظهرت النتائج العملية عند نسبة خطا 10^{-3} أداء جيد لهذه المنظومة مقارنة بمنظومة التضمين المر مز الغير متكيف وكذلك التضمين المر مز أعطى تحسن ل SNR قدره 5 dB مقارنة بالتضمين الغير مر مز. هذه المنظومة تحقق نسبة خطا ثابتة تحت ظروف القناة المتغيرة.

Key words: OFDM, adaptive, SNR estimation, convolutional code, channel estimation

INTRODUCTION

The idea of adaptive modulation and coding (AMC) is to dynamically change the modulation and coding scheme in subsequent frames with the objective of adapting the overall throughput or power to the channel condition. In fact, when employing orthogonal frequency division multiplexing (OFDM) over a spectrally shaped channel the occurrence of bit errors is normally concentrated in a set of severely faded sub carriers, which should be excluded from data transmission. On the other hand, the frequency domain fading, while impairing the signal-to-noise ratio of some sub-carriers, may improve others above the average signal-to-noise ratio. Hence, the potential loss of throughput due to the exclusion of faded sub carriers can be mitigated by using higher order modulation modes on the sub-carriers exhibiting higher signal-to-noise ratio. In addition, other system parameters, such as the coding rate of error correction coding schemes, can be adapted at the transmitter according to the channel frequency response [**Benvenuto and Tosato, 2004**].

ADAPTIVE CODING AND MODULATION

The main concept of adaptive coding and modulation is to maintain a constant performance by varying transmitted power level, modulation scheme, coding rate or any combination of these schemes .This allows us to vary the data rate without sacrificing BER performance .Since in land mobile communication systems , the local mean value of the received signal level varies due to the fading channel, Adaptive coding and modulation is an effective way to achieve high data rates and it has proved to be a bandwidth efficient technology to transmit multimedia information over mobile wireless channels. It can be described as follows:

$$\text{Modulation mode} = \left(\begin{array}{ll} M_1 & cq< I_1 \\ M_2 & I_1<cq< I_2 \\ & . \\ & . \\ & . \\ M_n & I_{n-1}<cq \end{array} \right) \quad (1)$$

Where M_1, M_2... M_n, are *n* different modulation modes varying from lower multi-level modulation to higher multilevel modulation with increasing order. cq is the estimated channel quality expressed in terms of the signal-to-noise ratio (SNR) of the mobile wireless channel, $I_1, I_2,\ldots, I_{n-1}$ are the switching thresholds between different modulation modes.

The selection of modulation mode for the next transmission heavily depends on the current channel quality estimation. If the channel quality can be measured accurately, ideal switching between different modes is available. The system could have the highest performance under such circumstances, if the switching thresholds are selected carefully. In other words, in the scenario of no channel quality estimation error, the effectiveness of the adaptive modulation system will be decided mainly by the selection of the switching thresholds **[Long and Lo, 2003].**

Modulation scheme and coding rate are the most common parameters used in adaptive modulation. Basic guidelines for efficient usage of these parameters are as follows **[Sampei and Harada, 2007]:**

1) Modulation Scheme Control: Modulation scheme control is the only technique to enhance the upper limit of spectral efficiency in terms of bit/s/Hz in single-input and single-output systems. However, if only the modulation scheme is used as a controllable modulation parameter MP, its dynamic range is not so wide. Table(1) summarizes theoretically obtained required energy per symbol to noise spectral density E_s/N_o to satisfy a required BER (BER_{req}) for each modulation scheme under additive white Gaussian noise (AWGN) conditions, where Gray mapping is assumed and no channel coding is employed. When all the modulation schemes in this table are selectable, the system's dynamic range is about 16 dB. On the other hand, when a channel is in a flat Rayleigh fading condition, the system's dynamic range is more than 20 dB, which is wider than that covered by an adaptively controlled modulation scheme. One solution to this problem is to introduce a non transmission mode as one of the selectable MPs and to choose this mode when the received signal level is too low to guarantee transmission of even a binary phase-shift keying (BPSK).

In this case, however, the ratio of the non transmission time period (outage probability) increases as the average received signal level decreases.

2) Coding Rate Control: When coding rate control is introduced to adaptive modulation schemes, because the required E_s/N_o for a specific BER can be lowered, one can have more chance to use higher user rates compared to non coding rate controlled systems under the same received signal level; thus, coding rate control enhances average system throughput. Moreover, the coding rate control has another advantage; one can reduce the required signal-to-noise power ratio (SNR) or SINR gap between adjacent MP modes, because an arbitrary number of coding rates can be prepared by a combination of punctured codes and regular bit puncturing.

The rules which follow to Choose MP Set are:

1. List all the possible combinations of modulation Schemes and coding rates, and sort these combinations of MPs in the order of the required SNR or SINR.
2. If there are several MP sets that can achieve the same spectral efficiency, a set with the lowest required SNR is chosen.
3. If there are several MP sets located very closely in the required SNR, some of them can be removed.

In Figure (1), the curves from left to right represent the BER of QPSK, 16QAM, 64QAM and 256-QAM in AWGN channel, respectively. In order to decide the proper switching levels from this plot, operating point, or desired BER must be decided. In this study, BER of (10^{-3}) is used as operating point. This means that the system will try and keep a BER lower than (10^{-3}) with the most spectrally efficient modulation scheme whenever possible. At this point spectral efficiency should be defined as the number of information bits encoded on a modulated transmission symbol. For example, QPSK has a spectral efficiency of 2 bits per symbol, 16 QAM has 4 bits per symbol, 64 QAM has 6 bits per symbol and 256 QAM has 8 bits per symbol.

THE ADAPTIVE OFDM SYSTEM

The proposed adaptive OFDM system used in the test is shown in Figure (2). The system consists of a transmitter, a receiver and a Rayleigh communication channel .The transmitter codes the input data by the convolutional coder that is efficient in the multipath fading channel. The convolutional coder uses the code rate (R=1/2) and the constraint length (k=7). The encoded data are punctured to generate high code rates from a mother code rate of 1/2, the coded serial bit sequences are converted to the parallel bit sequences and then modulated. 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. Doppler frequency is assumed to be 5Hz (slow flat fading). In the receiver side, the received signal is serial to parallel converted and passed to a FFT operator, which converts the signal hack to the frequency domain. This frequency domain signal is coherently demodulated. Then the binary data is decoded by the Viterbi hard decoding algorithm. The simulation parameters are listed in Table (2)

The system is operating at a sampling rate of 20MHz. It uses 64-point FFT. The OFDM symbol duration worth's 66 sample where 64 is for data while 2 is cyclic prefix . This corresponds to efficiency of (0.96). Using different modulation schemes combined with puncturing of the convolutional encoder, 5 different data rate are defined. Data rate is a function of the modulation (QPSK, 16-QAM, 64-QAM and 256-QAM) and the code rate. The data rate is calculated using,

$$\text{Data rate} = (\text{bits}_{\text{carrier}} * N_{\text{carriers}} * CR) / T_{\text{OFDM}} \quad (2)$$

Where $\text{bits}_{\text{carrier}}$ is the number of bits per carrier, i.e. 2 for QPSK, N_{carriers} is the number of subcarriers with information, CR is the code rate and T_{OFDM} is the OFDM symbol duration.

The frame length is variable consists of fixed number of pilot symbols N_p and variable number of data symbols N_d.

SIGNAL TO NOISE RATIO ESTIMATION

The adaptive modulation scheme needs the accurate information of the multipath channel and estimates the SNR value by measuring the quantity of noise among the received signal. There have been two methods of measuring the quantity of noise among the received signal that passed through the channel. The first method uses the previously known pilot symbol as the reference signal that is speedy and stable measuring method. The second method uses the demodulated signal as the reference signal and has the BER value sufficiently low for the accurate measurement of the SNR. Therefore, the pilot symbol is not necessary. SNR estimation algorithm is shown in Fig. (3).

The SNR value is computed by comparison between the received signal power and the noise power that $<|x|^2>$ is the received signal power and $<|y|^2>$ is the noise power **[Chu, Park and etc, 2007].**

CHANNEL ESTIMATION

Channel estimation can be achieved by transmitting pilot OFDM symbol as a preamble. The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol.

The first one, block type pilot channel estimation, has been developed under the assumption of slow fading channel. This assumes that the channel transfer function is not changing very rapidly. The estimation of the channel for this block-type pilot arrangement can be based on Least Square (LS) or Minimum Mean-Square (MMSE). The later, the comb-type pilot channel estimation has been introduced to satisfy the need for equalizing when the channel changes even in one OFDM block. The comb-type pilot channel estimation consists of algorithms to estimate the channel at pilot frequencies and to interpolate the channel. The interpolation of the channel for comb-type based channel estimation depends on linear interpolation**.**

Assuming P is the transmitted pilot data, the received signal after FFT is:

$$Y(k) = H(k)P(k) + W(k) \qquad (3)$$

Where w (k) is the noise components, and since, the pilot data is known at the receiver, then the simplest way to estimate the channel is by dividing the received signal by the known pilot:

$$\hat{H}(k)=Y(k)/P(k) \qquad (4)$$

Where $\hat{H}$ (k) is the estimate of the channel, and without noise, this gives the correct estimation. When noise is present, there could be an error [**Omran, 2007**].

RESULTS

Figure (4) shows the estimator's performance in all modulation schemes, the SNR estimator works well with QPSK modulation. As shown in Figure (4) , for M-QAM modulation at low SNR, the estimate is not good. This is because at low SNR, there are a greater number of symbol errors that occur. Those symbols are the input to the estimator. The more reliable the symbol information is, the better the SNR estimate is for QAM schemes. This is why the estimates are better at high SNR.

The levels in table (3) are concluded 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 6.8 dB. Therefore, 1/2 QPSK is chosen as it is the most robust. Between 6.8 and 12.5 dB, there is only one scheme that gives performance below (10^{-3}), and that is 1/2 QPSK. Between 12.5 and 15.5 dB, 1/2 16-QAM gives the desired BER at a better spectral efficiency than 1/2 QPSK. Between 15.5 and 23dB, 3/4 16- QAM gives the desired BER at a better spectral efficiency than 1/2 16-QAM. Between 23 and 30 dB, 3/4 64-QAM gives the desired BER at a better spectral efficiency than 3/4 16-QAM. And at SNR higher than 30dB, 256-QAM gives the best spectral efficiency while providing the desired BER performance.

In Figure (7), the performance of adaptive coded modulation begins by overlapping the QPSK curve. It is analogous to the spectral efficiency curve, as QPSK is the primary transmission mode used in low SNR. However, as the SNR is increased to 13 dB, we see an interesting result. The performance of adaptive coded modulation begins to improve beyond what QPSK can provide.

Consider a channel that has a deep fade. Options here are to use one of five modulation modes, which differ in spectral efficiency and robustness. If the fading considered to be extremely deep, perhaps half of all bits will be in error. Here, it is advantageous to send fewer bits because the total number of errors will be decreased, which influences bit error rates much more than total number of bits sent. When the channel is not in a fade, then many bits are wanted to be sent. In this situation, The BER is lowered by increasing the number of bits sent because errors become less frequent. It is the combination of these two principles that allows the BER performance of adaptive systems to be more robust than static systems while simultaneously providing better spectral efficiency at most ranges of SNR.

In Figure (8), a plot of the spectral efficiency of adaptive coded modulation versus SNR in dB. Here, spectral efficiency will be defined to be the number of bits sent per modulation symbol.
Note that at low SNR, the system achieves 2 bits per symbol, as QPSK is primarily used. However, as the SNR increases, the throughput also improve steadily, which indicates that more spectrally efficient transmission mode is beginning to use.

The curve begins to level out at close to 30 dB, as 256QAM becomes the transmission mode used most often and QPSK is rarely used. As SNR improves, the system is more able to choose more efficient transmission mode.

CONCLUSION

The main conclusions drawn from this study are:

1. The ACM scheme enhances the performance of the OFDM wireless communication system since it combines two adaptive schemes based on modulation and coding. The results show that the ACM scheme adjusts effectively to the channel environment because it allocates (1/2 QPSK) to the decreasing SNR value and (1/2 16-

QAM, 3/4 16-QAM, 3/4 64-QAM and 3/4 256-QAM) to the increasing SNR value.

2. When channel has deep fade one of five modulation modes which differ in spectral efficiency and robustness is used, if fading is extremely deep half of all bits will be in error, it is advantageous to send fewer bits because the total number of errors will be decreased. When channel is not in a fade many bits are send, In this situation BER is lowered by increasing the number of bits sent because errors are small. It is the combination of these two principles that allows the BER performance of adaptive system to be more robust than static system.
3. The ACM system provides better spectral efficiency at most ranges of SNR' at low SNR, the system achieves 2 bits per symbol, as QPSK is primarily used. However, as the SNR increases, the throughput also improve steadily, which indicates that more spectrally efficient transmission mode is used.
4. The concept of adaptive modulation optimizes the bandwidth efficiency for wireless communications without excessive complexity.

REFERENCES

Buthaina Mosa Omran ,“IMPROVEMENT TECHNIQUES FOR SATELLITE DIGITAL VIDEO BROADCASTING USING OFDM”, P.HD. Thesis, in electronic and communication engineering, University of Baghdad, 2007.

F.Y. Long and K.T. Lo ,“Measurements for performance degradation of adaptive modulation scheme caused by channel quality estimation error” IEE, Proceeding Communication Vol 150, No. 2, April 2003.

Fernando H. Gregorio,“802.11a - OFDM PHY Coding and Interleaving”, Helsinki University of Technology.

Hyung Suk Chu, Byung Su Park and Chong Koo An ,"Wireless Image Transmission based on Adaptive OFDM System",IEEE, 2007.

Nevio Benvenuto and Filippo Tosato, “On the selection Of Adaptive Modulation and Coding Modes Over OFDM”, IEEE Communications Society, 2004.

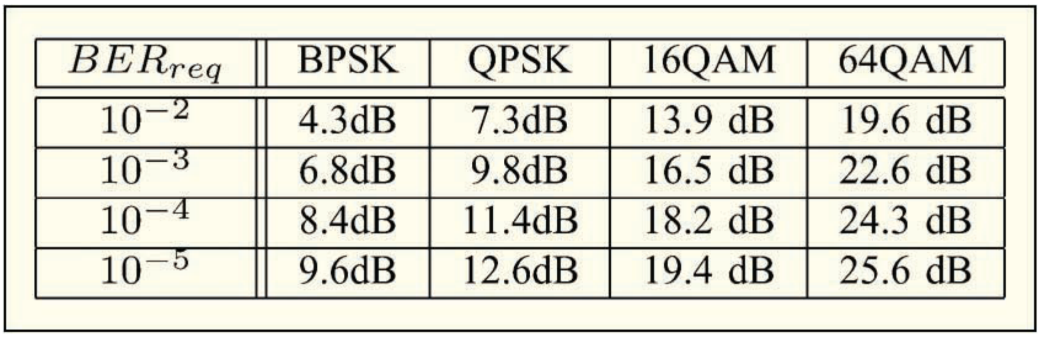
Seiichi Sampei and Hiroshi Harada, “System Design Issues and Performance Evaluations for Adaptive Modulation in New Wireless Access Systems”, Proceedings of the IEEE, Vol. 95, No. 12, December 2007.

Sinem Coleri, Mustafa Ergen, Anuj Puri, and Ahmad Bahai , “Channel Estimation Techniques Based on Pilot Arrangement in OFDM Systems”, IEEE Transactions On Broadcasting, VOL. 48, NO. 3, September 2002.

LIST OF ABBREVIATIONS:

ACM : Adaptive Coded Modulation
AWGN : Additive Wight Gaussian Noise
BER : Bit Error Rate
LS : Least Square
MMSE : Minimum Mean Square Error
OFDM : Orthogonal Frequency Division Multiplexing
QAM : Quadrature Amplitude Modulation
QPSK : Quadrature Phase Shift Keying
SNR : Signal to Noise Ratio

Table 1 Theoretical Required E_s/N_o to Satisfy a BER_{req} under AWGN Conditions



BER_{req}	BPSK	QPSK	16QAM	64QAM
10^{-2}	4.3dB	7.3dB	13.9 dB	19.6 dB
10^{-3}	6.8dB	9.8dB	16.5 dB	22.6 dB
10^{-4}	8.4dB	11.4dB	18.2 dB	24.3 dB
10^{-5}	9.6dB	12.6dB	19.4 dB	25.6 dB

Table 2 simulation parameters

Sampling rate	20 MHz
Number of FFT points	64
Number of carriers ($N_{carriers}$)	64
No. of input serial bits	100 000 bit
OFDM symbol period (T_{OFDM})	3.3 µs (66 sample)
Cyclic prefix	0.1 µs (2 sample)
FFT symbol period	3.2 µs (64 sample)
Data rate	19, 32,48,72,96 Mbps
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM
Demodulation	Coherent detection
Coding	Convolutional coding (Rate=1/2, constraint length=7) with Puncturing (3/4)
Fading	Slow flat fading
Doppler frequency	5 Hz
Channel	One path(AWGN+ Rayleigh fading)

Table 3 Transmission modes with convolutionaly coded modulation in AWGN channel

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Modulation	QPSK	16-QAM	16-QAM	64-QAM	256-QAM
Coding rate	1/2	1/2	3/4	3/4	3/4
Rate (bits/symbol)	1	2	3	4.5	6
SNR (dB) at BER=10^{-3}	6.8	12.5	15.5	23	29

Table 4 Transmission modes with convolutionaly coded modulation in Rayleigh fading

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Modulation	QPSK	16-QAM	16-QAM	64-QAM	256-QAM
Coding rate	1/2	1/2	3/4	3/4	3/4
Rate (bits/symbol)	1	2	3	4.5	6
SNR (dB) at BER=10^{-3}	7.5	13	16	24	30

channel, fd =5 HZ

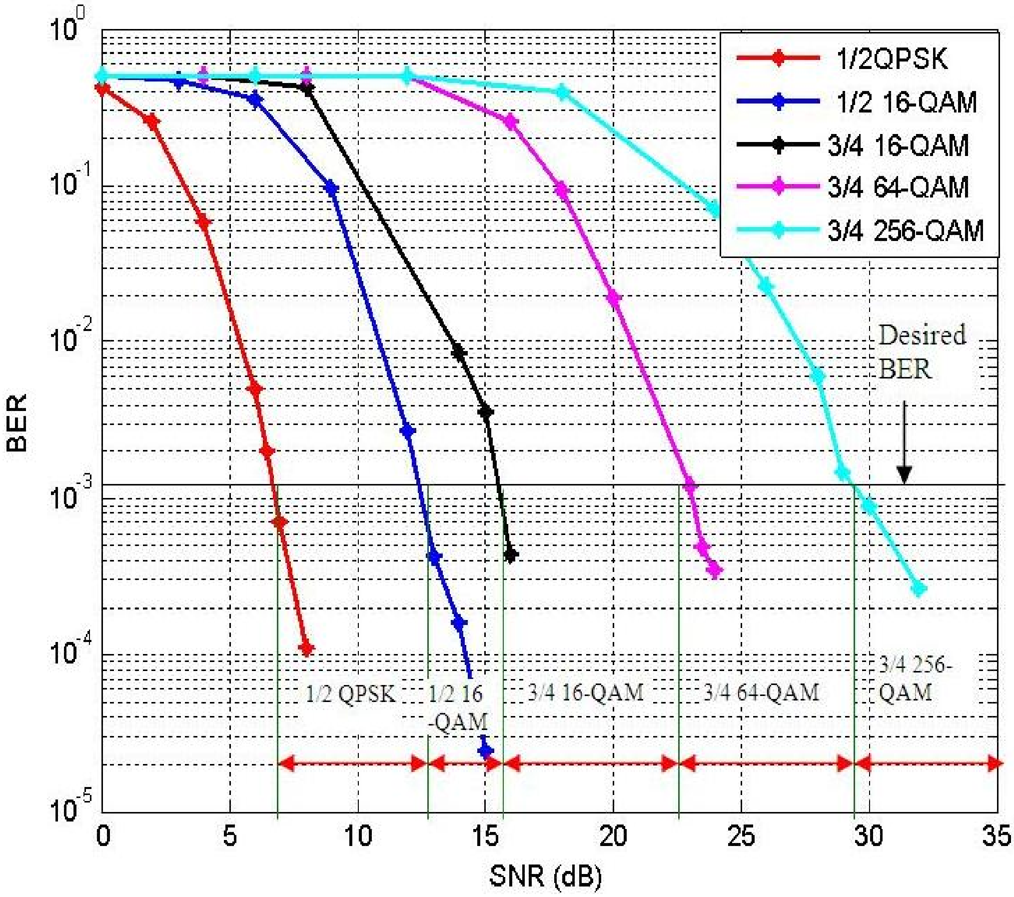


Fig. 1 BER Performance of coded OFDM in AWGN

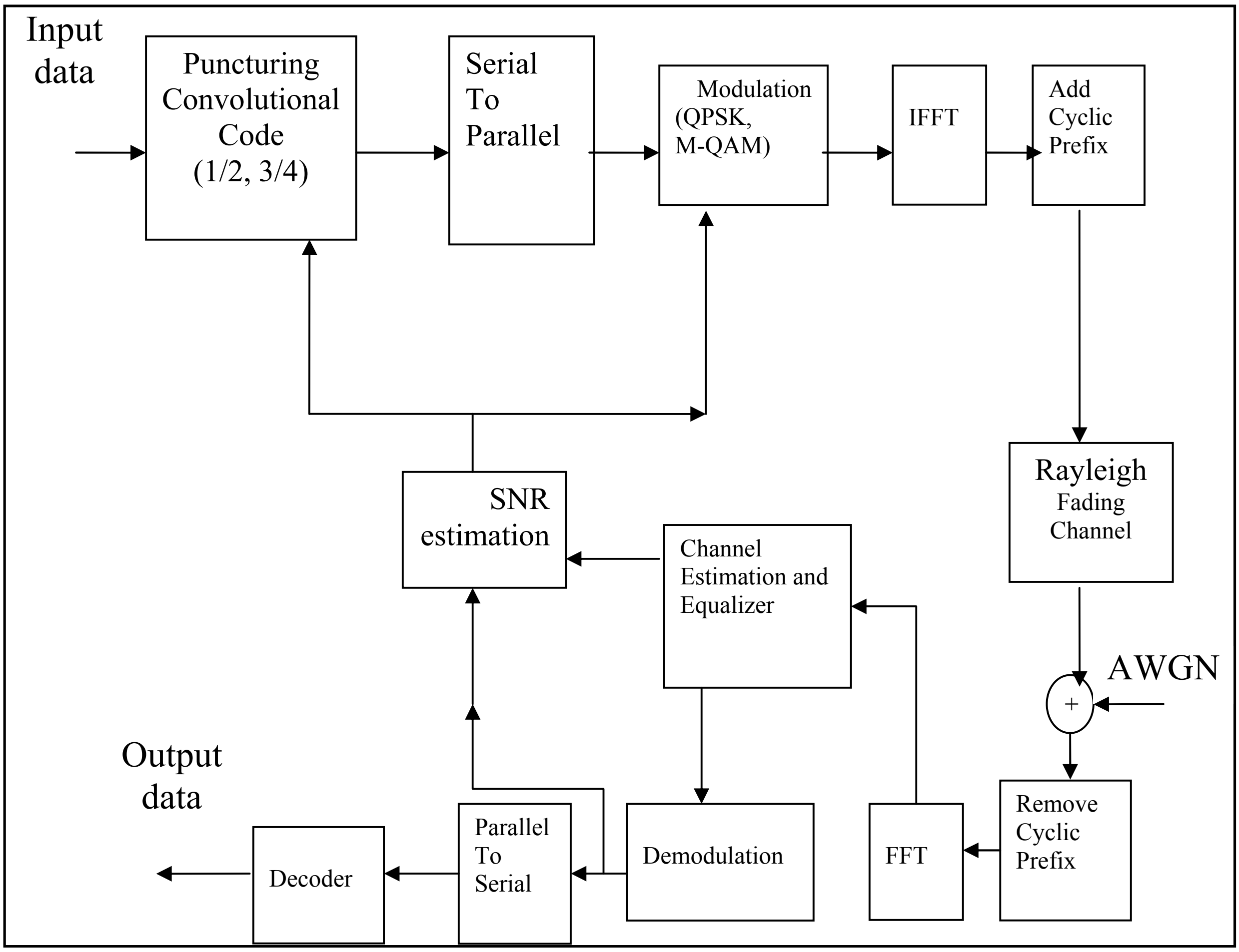


Fig. 2 Adaptive OFDM System Block Diagram

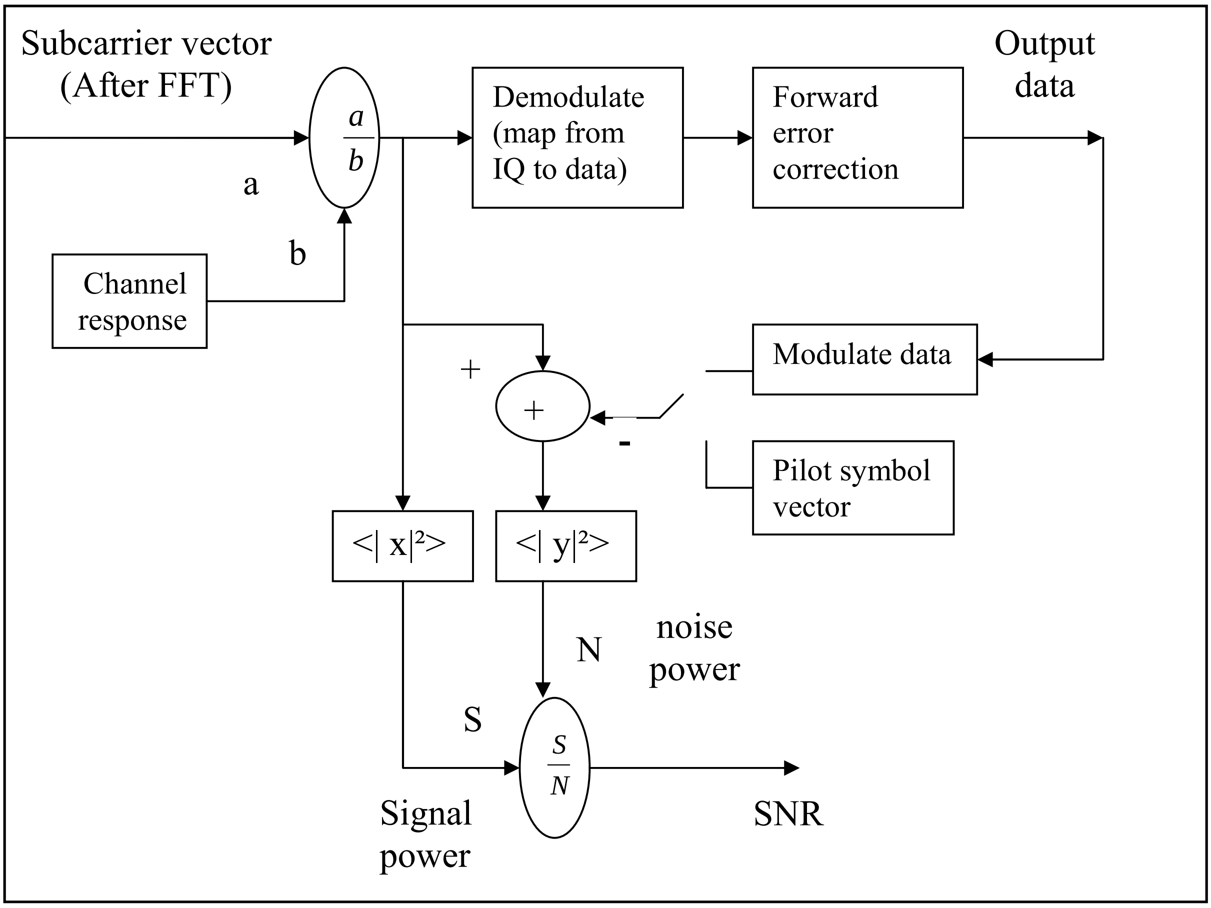


Fig. 3 SNR estimation algorithm

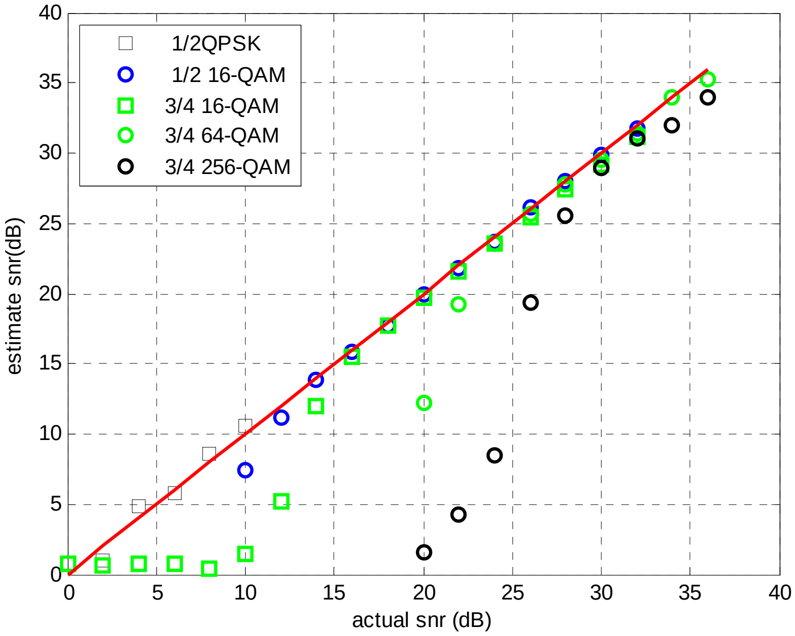


Fig. 4 SNR Estimation for all modulation schemes

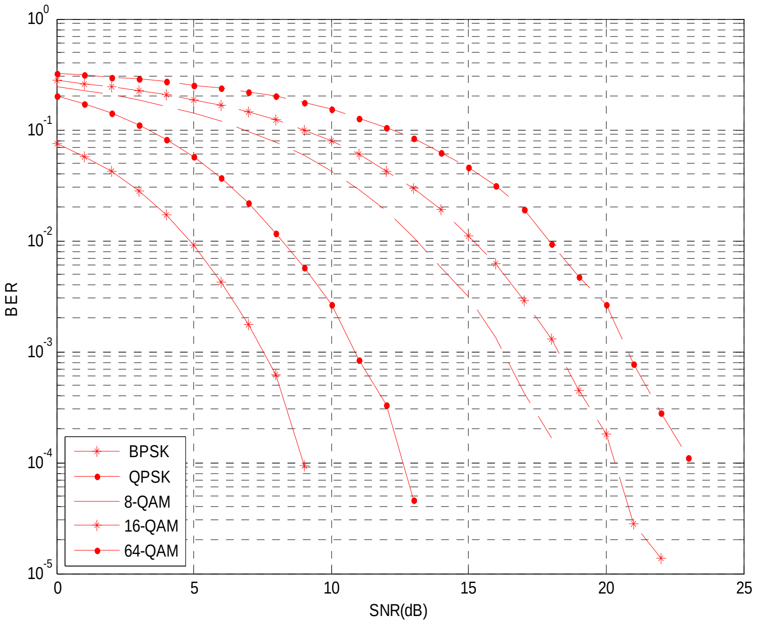


Fig. 5 BER performance of an un-coded OFDM system operating in an AWGN channel with different modulation schemes

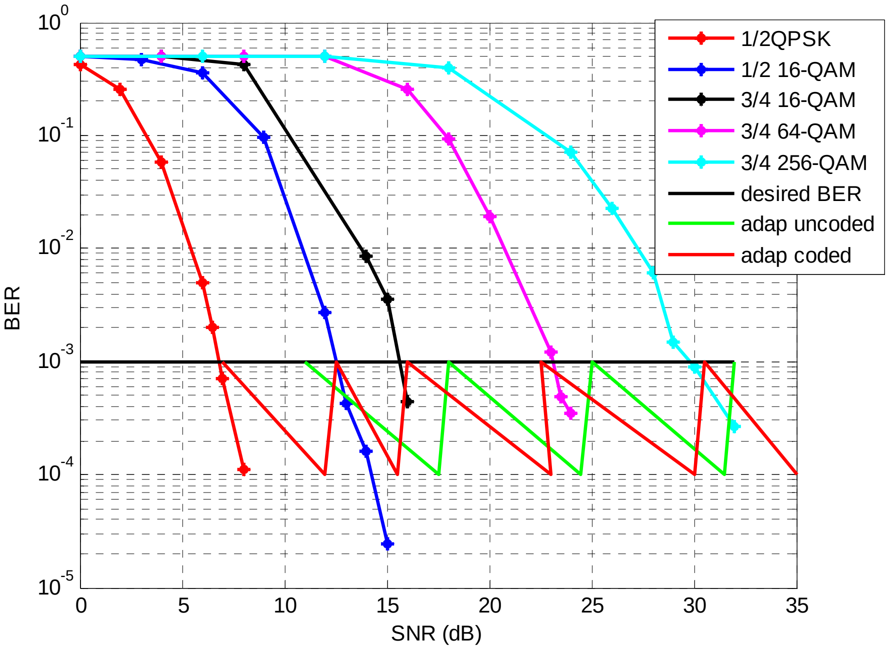


Fig. 6 BER Performance of Adaptive coded Modulation in AWGN Channel with practical SNR estimation

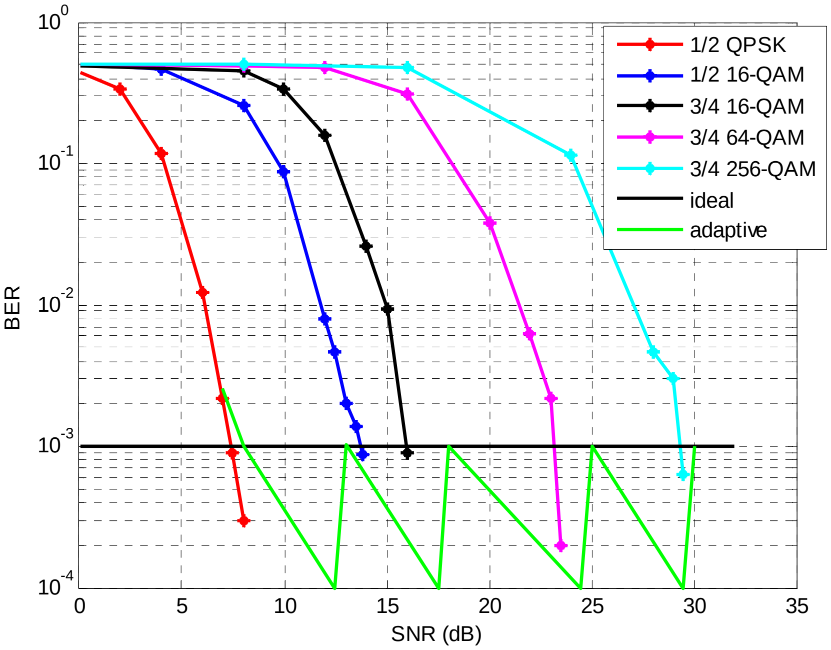


Fig. 7 BER Performance of Adaptive coded Modulation in Rayleigh fading channel with practical SNR estimation

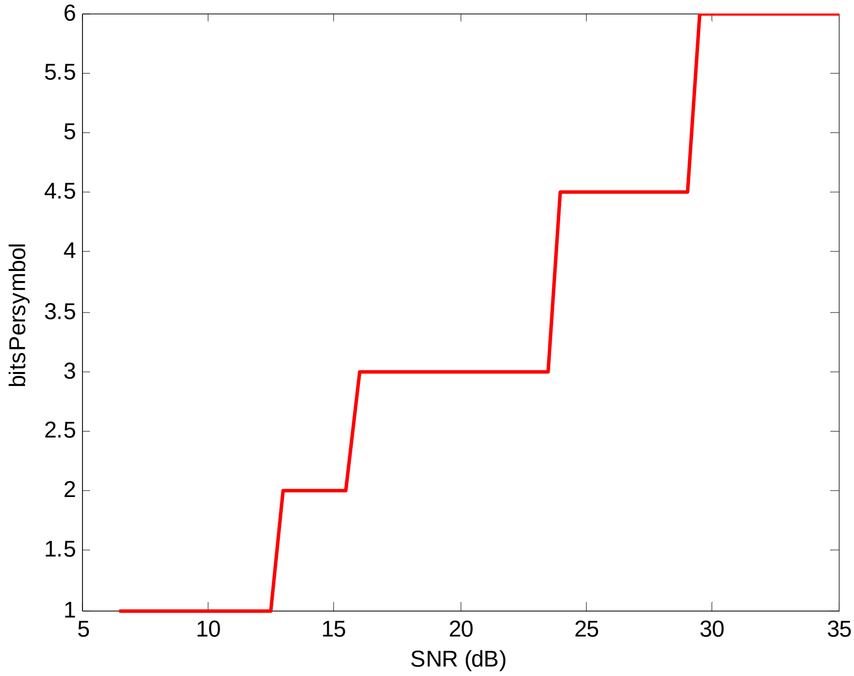


Fig. 8 Spectral Efficiency for Adaptive coded Modulation vs. SNR for a Rayleigh channel