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Implementation of Adaptive Modulation in OFDM System

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Abstract *—This paper investigates various modulation techniques for OFDM including BPSK, QPSK, 8 QAM, 16 QAM, 32 QAM, 64 QAM, 128 QAM, 256 QAM and 512 QAM and system performance is improved with high folds by choosing the modulation technique based on the channel conditions. In this paper, transmitter and receiver models are simulated according to the parameters established by the standard IEEE 802.11a, to evaluate the performance. Also, convolution coding is used to improve the system performance. Use of adaptive modulation can effectively control the BER of the transmission, as sub carriers that have a poor* E_b/N_o *(db) can be allocated a low modulation scheme such as BPSK. For good* E_b/N_o *(db), the high modulation scheme giving priority to spectral efficiency can be considered. Eb/No of the channel is estimated before the transmission. The modulation scheme is set based on the SNR of the channel. The proposed adaptive modulation for OFDM maintains fixed BER under changing channel condition.*

Keywords*-BER; convolution coding; digital modulation; OFDM; SNR*

I. INTRODUCTION

In recent years, orthogonal frequency-division multiplexing (OFDM) has emerged as the standard of choice in a number of important high-data-rate applications. The radio environment is harsh, due to the many reflected waves and other effects.Using adaptive equalization techniques at the receiver could be the solution, but there are practical difficulties in operating this equalization in real-time at several Mb/s with compact, low-cost hardware. A promising candidate that eliminates a need for the complex equalizers is the Orthogonal Frequency Division Multiplexing (OFDM), a multiple carrier modulation technique. Specifically, OFDM serial-to-parallel converts theincoming high-rate data stream into low-rate streams, thentransmits each low-rate data stream over a unique orthogonalcarrier. The data rate of each transmitted stream is effectively reduced by a factor of from the original data rate. Utilizing this strategy, OFDM drastically reduces intersymbolinterference (ISI) by avoiding multipath in frequency-selectivechannels. [1]

In this paper, we develop a model of an OFDM system using simulation in Matrix laboratory language (MATLAB) on which BER calculations for various digital modulation schemes like BPSK, QPSK, and QAMis carried out. The convolution coding and interleaving is applied to improve BER performance of OFDM system. The OFDM signal is transmitted over the AWGN channel for various signal-to-noise ratio (SNR) values. To evaluate the performance, for each SNR level, the received signal was demodulated and the received data was compared to the original information. The result of the simulation is shown in the plot of the bit error rate versus E_b/N_o, which provides information about the system's performance

II. OFDM SYSTEM

Orthogonal Frequency Division Multiplexing (OFDM) is an emerging multi-carrier modulation scheme, which has been adopted for several wireless standards such as IEEE 802.11a and HiperLAN2.OFDM is a combination of modulation and multiplexing. In OFDM, multiplexing is applied to the independent signals but these independent signals are a subset of the one main signal. In OFDM the signal itself is first split into independent channels, modulated by data and then multiplexed to create the OFDM carrier. OFDM is a special case of Frequency Division Multiplexing (FDM).

In coded OFDM (COFDM), a rate (k/n) coder followed by an interleaver is added prior to serial-to-parallel conversion. This effectively allows each symbols k to be sent over distinct frequencies. This introduction of redundancy and frequency diversity overcomes much of the signal degradation due to fading. The downside of such a coding is reduced throughput [by a factor of n/k]. [2]

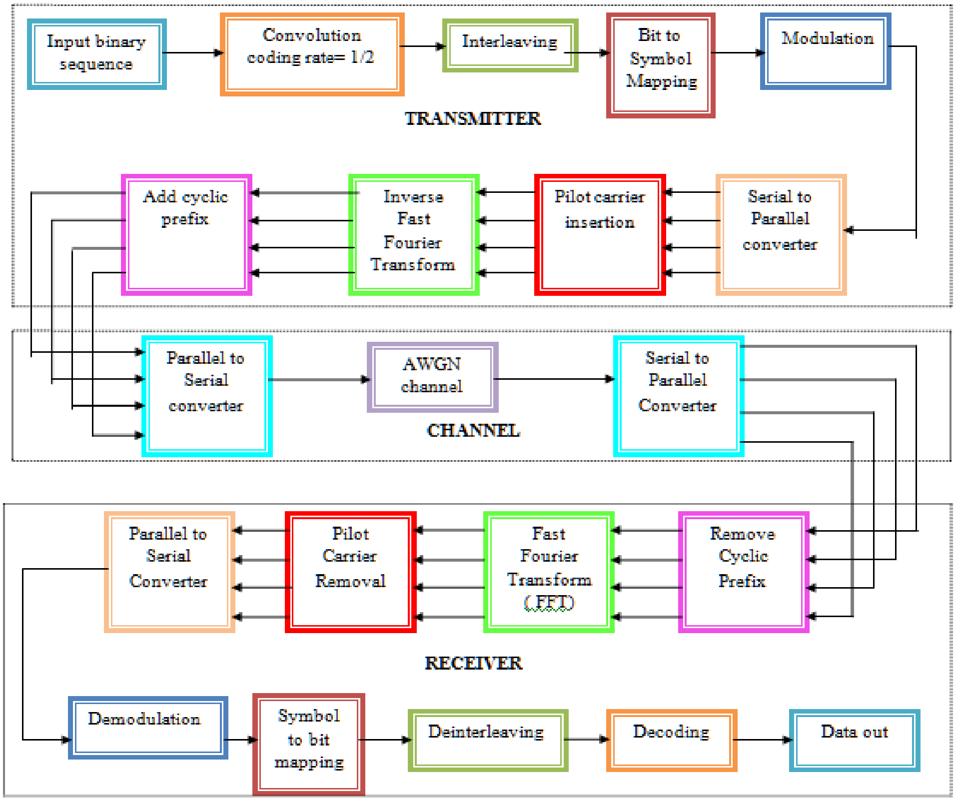

Figure 1: Block Diagram of OFDM system

III. ADAPTIVE MODULATION

Adaptive modulation is a powerful technique for maximising the data throughput of subcarriers allocated to a user. Adaptive modulation involves measuring the SNR of each subcarrier in the transmission, then selecting a modulation scheme that will maximise the spectral efficiency, while maintaining an acceptable BER. This technique has been used in Asymmetric Digital Subscriber Line (ADSL), to maximise the system throughput. ADSL uses OFDM transmission over copper telephone cables.

OFDM systems use a fixed modulation scheme over all subcarriers for simplicity. But each subcarrier in a multiuser OFDM system can potentially have a different modulation scheme depending on the channel conditions. Any modulation scheme can be used including BPSK, QPSK, 8-QAM, 16-QAM, 64-QAM, 128 QAM, 256QAM, 512QAM etc, each providing a tradeoff between spectral efficiency and the bit error rate. The spectral efficiency can be maximised by choosing the highest modulation scheme that will give an acceptable Bit Error Rate (BER). [6]

3.1. Advantages of adaptive modulation

In systems that use a fixed modulation scheme the subcarrier modulation must be designed to provide an acceptable BER under the worst channel conditions. This results in most systems using BPSK or QPSK. But these modulation schemes give a poor spectral efficiency (1 - 2 b/s/Hz) and result in an excess link margin most of the time. Using adaptive modulation, the remote stations can use a much higher modulation scheme when the radio channel is good which increases the spectral efficiency of the system. Adaptive modulation also reduces the need for Forward Error Correction.

3.2. Limitations of adaptive modulation

Overhead information needs to be transferred, as both the transmitter and receiver must know what modulation is currently being used. As the mobility of the remote station is increased, the adaptive modulation process requires regular updates, further increasing the overhead.Adaptive modulation requires accurate knowledge of the radio channel. Any errors in this knowledge can result in large increases in the BER, due to the small link margin used. [3]

IV. SIMULATION DESIGN

4.1. System design Parameters

The design parameters are derived according to the system requirements. The design parameters for an OFDM system are as follows:

- *Number of subcarriers:* The selection of large number of subcarriers helps to combat multipath effects. But, at the same time, this also increases the synchronization complexity at the receiver side.
- *Symbol duration and CP length:* A perfect choice of ratio between the CP length and symbol duration should be selected, so that multipath effects are combated and not significant amount bandwidth is lost due to CP. A user environment specific maximum tolerable delay spread should be known beforehand in determining the CP length which should be less than cyclic prefix
- *Subcarrier spacing:* Subcarrier spacing depends on available bandwidth and number of subcarriers used.
- *Modulation type per subcarrier:* The performance requirement will decide the selection of modulation scheme. Adaptive modulation can be used to support the performance requirements in changing environment.
- *FEC coding:* A suitable selection of FEC coding will make sure the robustness of the channel to the random errors.

Table 1. Parameters consider in simulation

Parameters	**Values**
Number of OFDM symbols	10000
Total data	260000
Number of bits per OFDM symbol	26
Number of data sub-carriers	26
Number of data sub-carriers after coding	52
Number of FFT points	64
Cyclic prefix	16 (1/4)
OFDM symbol	80 (64 +16)
Modulation scheme	BPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM
Coding	Convolutional, code rate ½, constraint length 7, generator polynomial [171, 133]

4.2. Bit error rate curve for various digital modulation techniques in OFDM

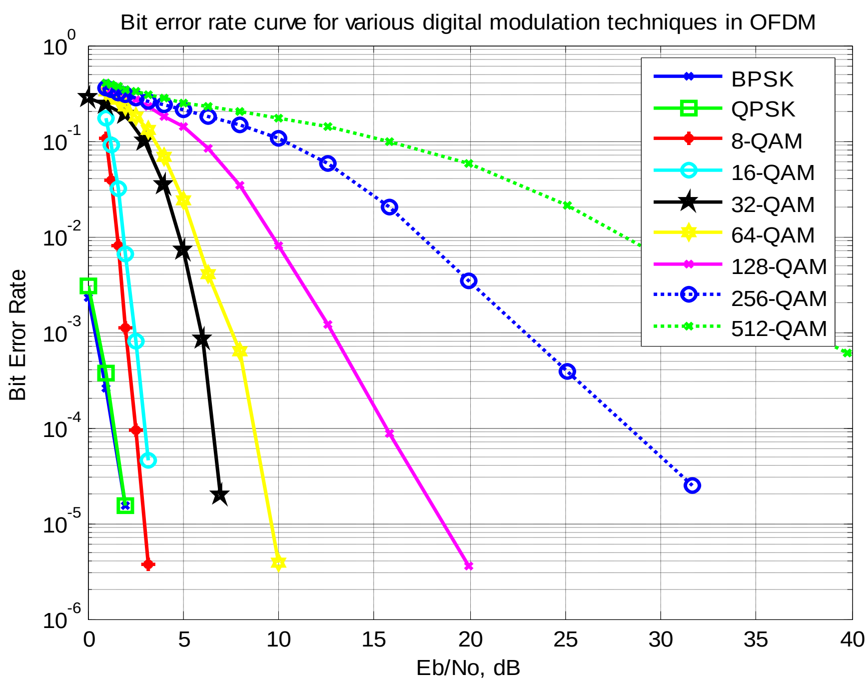

Figure 2: Demonstrates plot of BER against E_b/N_o for various digital modulation techniques

Table 2. Required E_b/N_o (db) to maintain a BER below a given threshold for various digital modulation techniques

Modulation scheme	BER < 10^{-2}	BER < 10^{-3}	BER < 10^{-4}	BER < 10^{-5}
BPSK	---	0.4	1.4	2
QPSK	---	0.5	1.5	2
8 QAM	1.5	2	2.5	3
16 QAM	1.9	2.5	3.1	---
32 QAM	3	4	4.9	6.1
64 QAM	6	7	8	10
128 QAM	9	13	16	20
256 QAM	17	23	28	32
512 QAM	27	32	48	---

The Bit error rate curve for BPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM digital modulation techniques in OFDM is shown in Fig. 4.10 and Table 4.11. The above figure and table show that for various digital modulation techniques, on fixing BER (Bit Error Rate), simulated E_b/N_o (db) values can be compared and depending on these values, adaptive modulation technique can be applied. At the permissible BER of the system, the modulation techniques can be selected for given E_b/N_o (db) of channel. For small E_b/N_o (db) values the calculated error rate is quite large and ISI is produced due the relative high power of noise. As E_b/N_o (db) is increased the error rate start decreasing, as expected. This is a quite different than expected and it is due to the fact that the program is simulating only 10^4 OFDM symbols. If the number of transmitted OFDM symbols is increased, then a more accurate error rate can be obtained, but this necessitates a high processing power PC and time.

4.3. Selection of modulation technique at given E_b/N_o (db) at fixed BER

For figures 5.1, 5.2, 5.3, 5.4, red bold lines show the E_b/N_o of channel estimated with time. They assume that the modulation scheme is updated continuously with no delay.

4.3.1 Fixing BER at 10^{-2} with best spectral efficiency at given E_b/N_o (db)

Figure 3 shows application of adaptive modulation to an individual subcarrier as the channel E_b/N_o varies with time with permissible limit of BER at 10^{-2}. The conclusion is tabled in tabular form:

Table 3: Selection of modulation technique at given Eb/No (db) at BER< 10^{-2}

E_b/N_o(db) range	Modulation scheme
1.5-1.9	8QAM
1.9-3	16 QAM
3-6	32 QAM
6-9	64 QAM
9-17	128 QAM
17-27	256 QAM

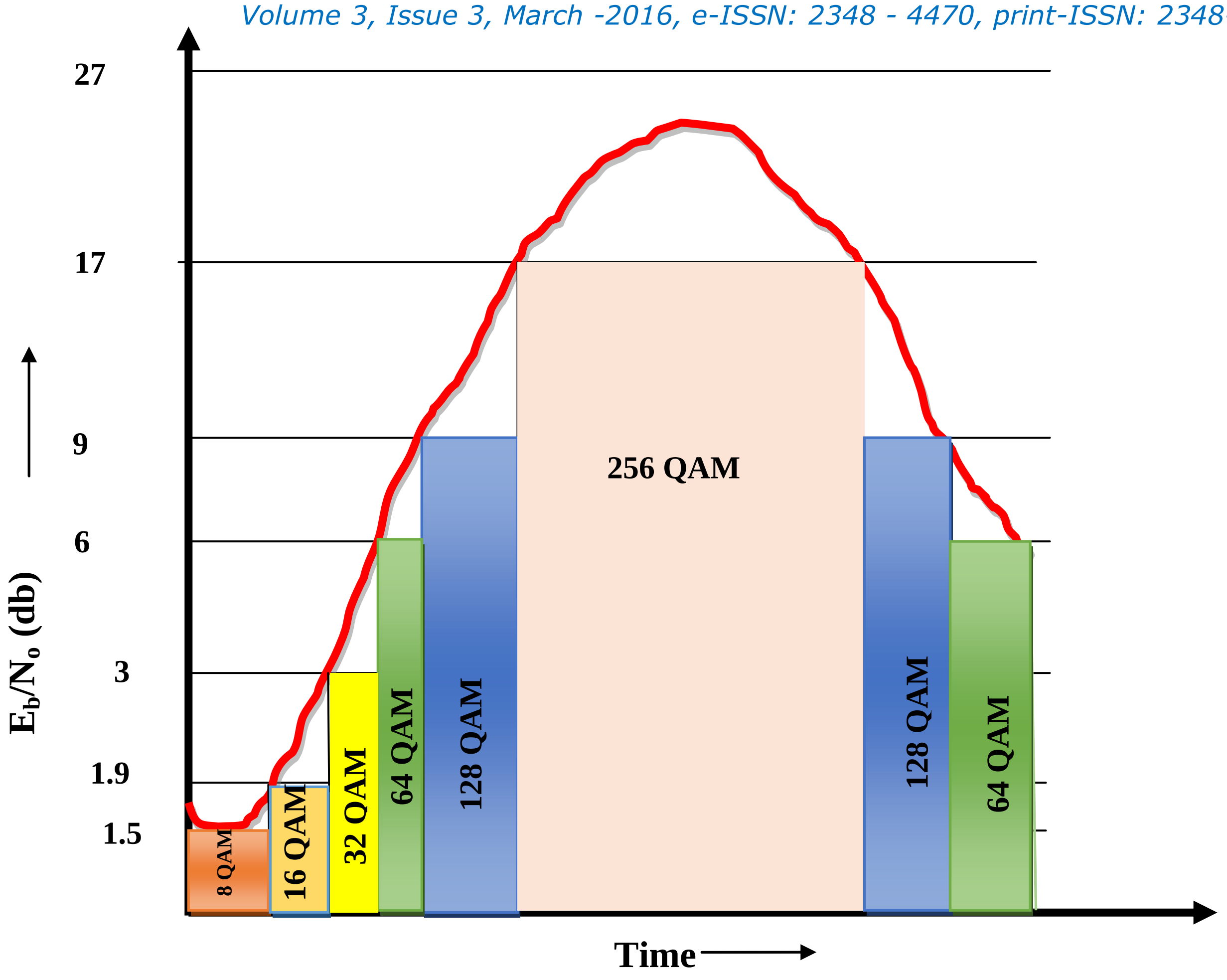

Figure 3: Adaptive modulation at permissible BER 10^{-2}

4.3.2 Fixing BER at 10^{-3} with best spectral efficiency at given E_b/N_o (db)

Figure 4 shows application of adaptive modulation to an individual subcarrier as the channel E_b/N_o varies with time with permissible limit of BER at 10^{-3}. The conclusion is tabled in tabular form:

Table 4: Selection of modulation technique at given E_b/N_o (db) at BER< 10^{-3}

E_b/N_o(db) range	**Modulation scheme**
0.4-0.5	BPSK
0.5-2	QPSK
2-2.5	8QAM
2.5-4	16 QAM
4-7	32 QAM
7-13	64 QAM
13-23	128 QAM
23-32	256 QAM

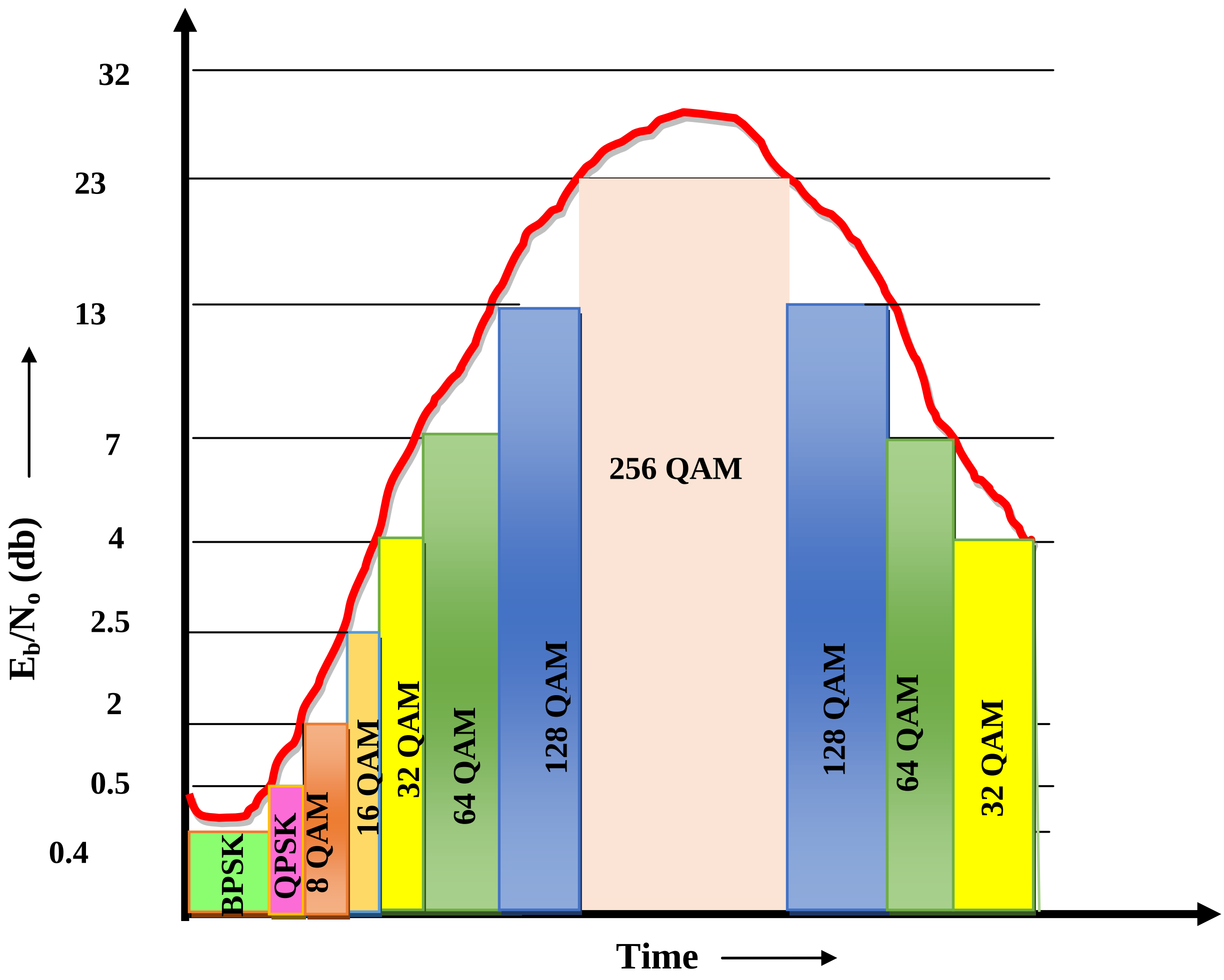

Figure 4: Adaptive modulation at permissible BER 10^{-3}

4.3.3 Fixing BER at 10^{-4} with best spectral efficiency at given E_b/N_o (db)

Figure 5 shows application of adaptive modulation to an individual subcarrier as the channel E_b/N_o varies with time with permissible limit of BER at 10^{-4}. The conclusion is tabled in tabular form:

Table 5: Selection of modulation technique at given E_b/N_o (db) at BER< 10^{-4}

E_b/N_o(db) range	Modulation scheme
1.4-1.5	BPSK
1.5-2.5	QPSK
2.5-3.1	8QAM
3.1-4.9	16 QAM
4.9-8	32 QAM
8-16	64 QAM
16-28	128 QAM
28-48	256 QAM

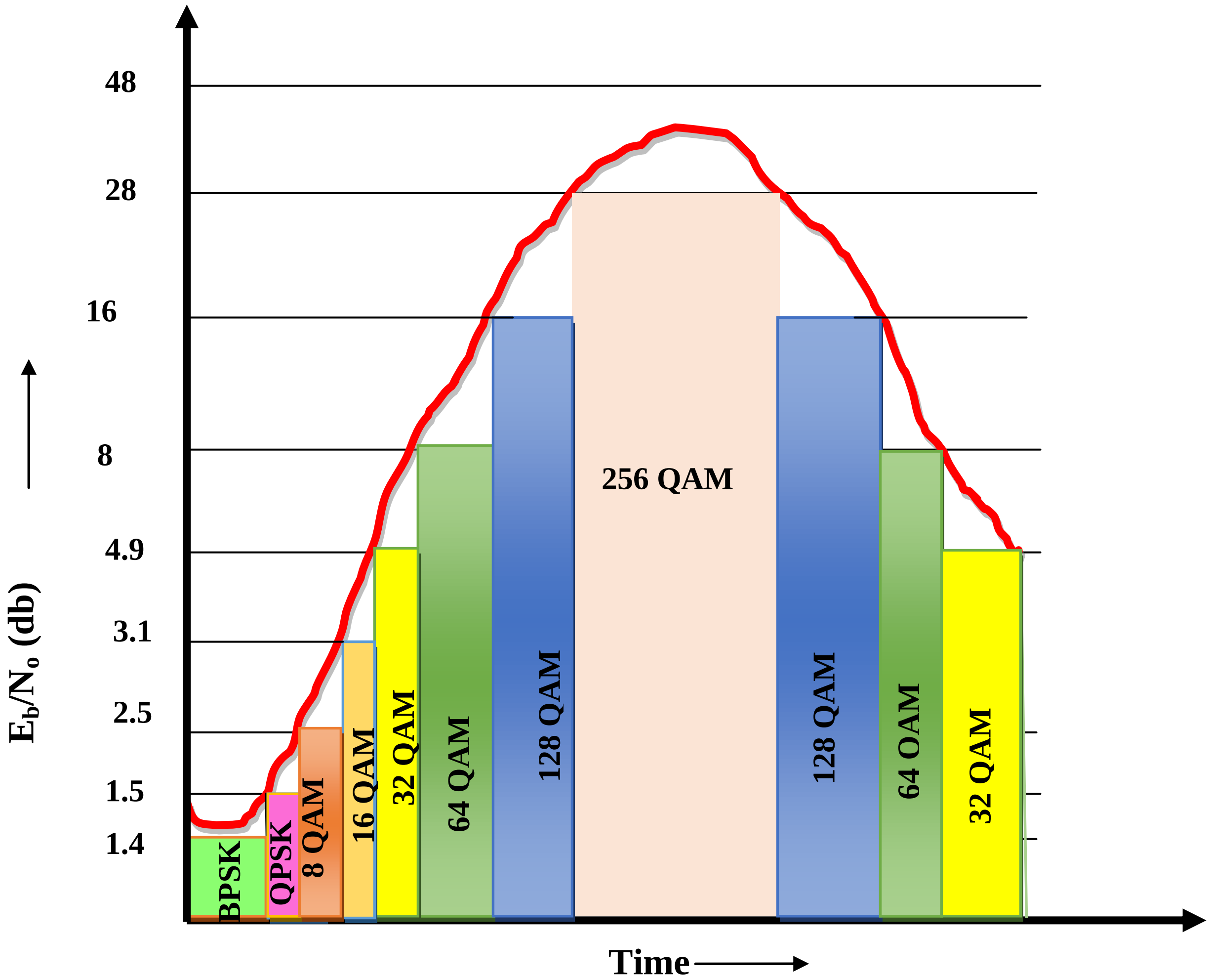

Figure 5: Adaptive modulation at permissible BER 10^{-4}

CONCLUSION

The modulation scheme is set based on the E_b/N_o (db) of the channel. TheE_b/N_o (db) must be greater than the threshold chosen from Table 4-11 to maintain a maximum BER. Excess SNR results in the BER being lower than the BER threshold.

In systems that use a fixed modulation scheme the subcarrier modulation must be designed to provide an acceptable BER under the worst channel conditions. This results in most systems using BPSK or QPSK. But these modulation schemes give a poor spectral efficiency (1 - 2 b/s/Hz).

Using adaptive modulation, the remote stations can use a much higher modulation scheme when the radio channel is good. Thus as a remote station approaches the base station the modulation can be increased from 1 -2 b/s/Hz (BPSK-QPSK) up to 3 - 9 b/s/Hz (8-QAM – 512-QAM), significantly increasing the spectral efficiency of the overall system.

Use of adaptive modulation can effectively control the BER of the transmission, as subcarriers that have a poor E_b/N_o (db) can be allocated a low modulation scheme such as BPSK rather than causing large amounts of errors with a fixed modulation scheme. For good E_b/N_o (db), the high modulation scheme giving priority to spectral efficiency can be considered. E_b/N_o of the channel is estimated before the transmission. The modulation scheme is set based on the SNR of the channel.

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