CONCATENATED BIT INTERLEAVED CODED MODULATION-ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM

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BONAFIDE CERTIFICATE

Certified that this project report entitled "**CONCATENATED BIT INTERLEAVED CODED MODULATION-ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM**" is the bonafide work of **Ms.R.Padmashini** [Reg. no. 0920107013] who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

The modern wireless communication demands reliable data communication at high throughput in severe channel conditions like narrowband interference, fading due to multipath effect and Doppler spread. The existing single carrier systems address these problems by involving complex and computationally intensive channel equalizers. Also, security is of major concern these days. Thus it is desired to have a bandwidth efficient and reliable communication system which would be suitable for wireless channels.

In order to achieve these design objectives of wireless data communication, there are some techniques that are to be considered like channel coding, Adaptive Modulation etc. In recent years, it has been recognized that bit-interleaved coded modulation can improve the performance over a fading channel and by using an appropriate soft-decision metric as an input to a viterbi decoder.

Orthogonal Frequency Division Multiplexing (OFDM) is mostly preferred as it provides good protection against co-channel interference, impulsive parasitic noise and less sensitive to sample timing offsets than single carrier systems. OFDM concept is introduced to make efficient use of the spectrum by allowing overlap and to eliminate Inter Symbol Interference (ISI). In OFDM an advanced FDMA scheme called OFDMA, which uses the orthogonality of the system is available i.e. different users are allowed to use different subsets of the subcarriers.

BICM-OFDM system has been simulated and analyzed with various modulation schemes over AWGN and frequency non-selective, slow fading channel. It has been observed that the proposed Concatenated BICM-OFDM outperforms CM, BICM and BICM-OFDM schemes in fading channel. From the simulation results, it is inferred that proposed BICM-OFDMA with equally concatenated codes improves the performance over Rayleigh Fading Channel than concatenated BICM-OFDM.

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LIST OF ABBREVIATIONS

AWGN	-------	Additive White Gaussian Noise
BER	-------	Bit Error Rate
BICM	-------	Bit Interleaved Coded Modulation
CM	-------	Coded Modulation
CDMA	-------	Code Division Multiple Access
DAB	-------	Digital Audio Broadcasting
DVB	-------	Digital Video Broadcasting
FDMA	-------	Frequency Division Multiple Access
ICI	-------	Inter Carrier Interference
IFFT/FFT	-------	Inverse Fast Fourier Transform/Fast Fourier Transform
ISI	-------	Inter Symbol Interference
MATLAB	-------	MATrix LABoratory
OFDM	-------	Orthogonal Frequency Division Multiplexing
OFDMA	-------	Orthogonal Frequency Division Multiple Access
PSK	-------	Phase Shift Keying
PDF	-------	Probability Density Function
QAM	-------	Quadrature Amplitude Modulation
SNR	-------	Signal to Noise Ratio
SICM	-------	Symbol Interleaved Coded Modulation
TCM	-------	Trellis Coded Modulation

CHAPTER 1

INTRODUCTION

WIRELESS COMMUNICATION

Wireless communication technology, a fundamental part of modern information astructure, is growing day by day. Spectrally efficient and reliable transmission schemes are d for high speed transmission data rate over wireless link. However reliable data nmunication is one of the major problems in modern wireless channels, since these channels uld be able to tolerate the effects of signal fading channels and Inter Symbol Interference. bile data communication is even more challenging [1]. It requires continuous measurement updating the Channel State Information and adaptation of the coding/modulation techniques ording to the new environmental conditions. It also involves proper power distribution niques [2].

Channel coding is one of the main tools that increase the transmission reliability at higher rates. The purpose of the channel coding scheme is to guard the information against channel urbances, achieved by introducing data redundancy for error detection and correction. In less communication systems erroneous signal detection and its correction can be achieved by use of proper error control coding techniques. The bursty traffic sources which are tiplexed statistically, the fast and dynamic channel capacity allocation can be achieved by gle-carrier Quadrature Phase Shift keying or Quadrature Amplitude Modulation [3]. However single-carrier systems show their effectiveness in severe multipath applications requiring nsive processing at high data rates [3] only if they use adaptive equalizer. Another problem single carrier systems operating is susceptibility to interference.

PROBLEM DEFINITION

The modern wireless communication demands reliable data communication at high ghput in severe channel conditions like narrowband interference, frequency-selective fading o multipath and attenuation of high frequencies. The existing Single carrier systems address bove mentioned problems by involving complex and computationally intensive channel alizers. Also reliable data transmission and security is of major concern these days. Thus a d to make more efficient use of bandwidth transmissions without creating situations where als would be subject to above mentioned phenomenon is generally desired.

In order to achieve these design objectives of wireless data communication there are ne key design considerations like channel coding, Multiple access schemes, adaptive dulation, rate adaptive transmission etc which must be taken into considerations and are ussed in the following section.

DESIGN CONSIDERATIONS

Following parameters must be considered while designing the wireless data nmunication system, these are

1. Data Rate
2. Power
3. Bandwidth
4. Multiple Access Schemes

Multiple Access schemes narrow or wide band, are a very important means of allowing a e number of mobile users to access a finite amount of frequency spectrum simultaneously. doing this capacity can be increased. In simple words they ensure the efficient use of the uency spectrum. They are also preferred over Radio spectrums since they are very expensive.

The *Severity of Wireless Communications* is much greater than that for AWGN channels. AWGN channels, good codes can be designed by making the distance between the code ds as large as possible. But, for fading channel, the severity of channel is mainly tackled by diversity in communication. Diversity in communication means sending a copy of the sage, or part of a copy, on different paths or channels in order to increase the reliability. It be achieved by diversity in carrier frequency, space diversity, coding or combination of all hods.

In order to achieve these design objectives of wireless data communication there are ıe key design considerations like,

- Channel Coding
- Adaptive Modulation
- Rate-adaptive Transmission

Channel coding is also considered as an essential and important element of ımunication system, one of the main tools that increase the transmission reliability at higher ı rates. The purpose of the channel coding scheme is to guard the information against channel ırbances during transmission, and this can be achieved by introducing data redundancy for r detection and correction. It protects data against transmission errors to ensure adequate smission quality (bit or frame error rate). It is power efficient as compared to the uncoded , the same error-rates are achieved with much less transmit power at the expense of a łwidth expansion. Error control coding has gained fundamental importance in wireless munication systems and deals with techniques for detecting and correcting signal errors.

Adaptive modulation schemes take channel conditions into account at both the transmitter receiver end. And this knowledge of channel conditions helps transmitter and receiver in ıally deciding the channel modulation scheme for gaining increased performance which lts in high data rate as compared to non adaptive coded schemes.

Rate Adaptive Transmission design feature relies more on the quality of the wireless nel and it ensures the maximal use of the transmission bandwidth. It achieves high spectral iency by increasing the sending information rate during the good channel conditions and versa. Channel status in form of channel state information is being sent by the receiver to ransmitter on the reverse wireless link. This information will then be used by the transmitter eciding the rate plan for the next transmission. This rate adaptive transmission ensures the mal utilization of the channel bandwidth for an acceptable Bit-Error-Rate.

4 CODING THEORY

Coding theory is the study of the properties of codes and their fitness for a ecific application. Codes are used for data compression, cryptography, error-correction and re recently also for network coding. Codes are studied by various scientific disciplines- such information theory, electrical engineering, mathematics, and computer science-for the purpose designing efficient and reliable data transmission methods.

The aim of channel coding theory is to find codes which transmit quickly, contain many id code words and can correct or at least detect many errors. While not mutually exclusive, formance in these areas is a trade off. So, different codes are optimal for different lications.

Other codes are more appropriate for different applications. Deep space communications limited by the thermal noise of the receiver which is more of a continuous nature than a sty nature. Likewise, narrowband modems are limited by the noise, present in the telephone vork and also modeled better as a continuous disturbance. Cell phones are subject to rapid ng. The high frequencies used can cause rapid fading of the signal even if the receiver is ved a few inches. Again there are classes of channel codes that are designed to combat fading.

1 What Coding Can and Cannot Do?

The traditional role for error-control coding was to make a troublesome channel ptable by lowering the frequency of error events. The error events could be bit errors, sage errors, or undetected errors.

ng's role has expanded tremendously and today coding can do the following:

Reduce the occurrence of undetected errors

Reduce the cost of communications systems

Overcome Jamming

Eliminate Interference

espite all the new uses of error-control coding, there are limits to what coding can do:

On the Gaussian noise channel, for example, Shannon's capacity formula sets a lower nit on the signal-to-noise ratio that we must achieve to maintain reliable communications. annons's lower limit depends on whether the channel is power-limited or bandwidth-limited.

The deep space channel is an example of a power-limited channel because bandwidth is abundant resource compared to transmitter power. Telephone channels, on the other hand, are nsidered bandwidth-limited because the telephone company adheres to a strict 3.1 kHz channel ndwidth.

For strictly power-limited (unlimited bandwidth) channels, Shannon's lower bound on $/N_0$ is 0.69, or –1.6 dB [4]. In other words, maintain an E_b/N_0 of at least -1.6 dB to ensure iable communications, no matter how powerful an error-control code we use.

For bandwidth-limited channels with Gaussian noise, Shannon's capacity formula can be itten as the following [4]

$$E_b/N_0 >= (2^r - 1)/r \quad (1.1)$$

ıere r is the spectral bit rate in bits/s/Hz.

.2 Applications of Coding Theory

- A concern of coding theory is designing codes that help synchronization.
- A code may be designed so that a phase shift can be easily detected and corrected and that multiple signals can be sent on the same channel.
- Application of codes can be used in some mobile phone systems, is code-division multiple access. Each phone is assigned a code sequence that is approximately uncorrelated with the codes of other phones. When transmitting, the code word is used to modulate the data bits representing the voice message. At the receiver, a demodulation process is performed to recover the data.
- Another general class of codes is the automatic repeat-request codes. In these codes the sender adds redundancy to each message for error checking, usually by adding check bits. If the check bits are not consistent with the rest of the message when it arrives, the receiver will ask the sender to retransmit the message.

5 ERROR CONTROL TECHNIQUES

This section highlights the six most popular error-control coding techniques and cusses the forward error correction.

- ***Automatic Repeat Request***
    - ***Stop-and-wait ARQ***
    - ***Continuous ARQ***
- ***Hybrid ARQ***
- ***Interleaving***
- ***Erasure Decoding***
- ***Concatenation***
- ***Forward Error Correction***

Forward error correction is appropriate for applications where the user must get the ssage right the first time. The one-way or broadcast channel is one example. Today's error ection codes fall into two categories:

- ***Linear Block Codes***

Linear block codes have the property of linearity, i.e the sum of any two codewords is a code word, and they are applied to the source bits in blocks, hence the name linear block es. There are block codes that are not linear, but it is difficult to prove that a code is a good without this property.

ar block codes are summarized by their symbol alphabets (e.g., binary or ternary) and meters (n,m,d_{min}), where

. n is the length of the codeword, in symbols,
. m is the number of source symbols that will be used for encoding at once,
. d_{min} is the minimum hamming distance for the code.

- ***Convolutional Codes***

The idea behind a convolutional code is to make every codeword symbol be the weighted
m of the various input message symbols. This is like convolution used in LTI systems to find
output of a system, when the input and impulse response is known. So generally find the
tput of the system convolutional encoder, which is the convolution of the input bit, against the
tes of the convolution encoder, registers.

5 MODULATION

Modulation is a process of mixing a signal with a sinusoid to produce a new signal. This
v signal, conceivably, will have certain benefits of an un-modulated signal, especially during
ismission. The general function for a sinusoid:

$$f(t) = A\sin(\omega t + \varphi) \qquad (1.2)$$

This sinusoid has 3 parameters that can be altered, to affect the shape of the graph. The
term, A, is called the magnitude, or amplitude of the sinusoid. The next term, ω is known as
frequency, and the last term, φ is known as the phase angle. All 3 parameters can be altered
ansmit data.

Clearly the concept of modulation can be a little tricky, especially for the people who
like trigonometry. The main reason to use modulation is clearly explained by considering a
nel that essentially acts like a bandpass filter: The lowest frequency components and the
est frequency components are attenuated or unusable, in some way. If the low-frequency
ls cannot be send then shift signal up to the frequency ladder.

Modulation allows sending a signal over a bandpass frequency range. If every signal gets
vn frequency range, then transmit multiple signals simultaneously over a single channel, all
different frequency ranges. Another use of modulation is that it allows the efficient use of
na, a baseband signal to be transmitted will need an antenna of huge length, whereas once

odulated the antenna length will be reduced dramatically (antenna length almost equal 1/10 of e signal wavelength)

7 CLASSES OF MODULATION

There are three major classes of digital modulation techniques used for transmission of gitally represented data:

- Amplitude-shift keying
- Frequency-shift keying
- Phase-shift keying

finitions

determining error-rates mathematically, some definitions will be needed:

- E_b = Energy-per-bit
- E_s = Energy-per-symbol = nE_b with n bits per symbol
- T_b = Bit duration
- T_s = Symbol duration
- $N_0 / 2$ = Noise power spectral density (W/Hz)
- P_b = Probability of bit-error
- P_s = Probability of symbol-error

MODULATION TECHNIQUES

1 M-ary Quadrature Amplitude Modulation

QAM is both an analog and a digital modulation scheme. It conveys two analog message als, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, g the amplitude-shift keying digital modulation scheme or amplitude modulation analog ulation scheme. These two waves, usually sinusoids, are out of phase with each other by 90° are thus called quadrature carriers or quadrature heme. The modulated waves are summed, and the resulting waveform is a combination of both ase-shift keying and amplitude-shift keying, or in the analog case of phase modulation and nplitude modulation.

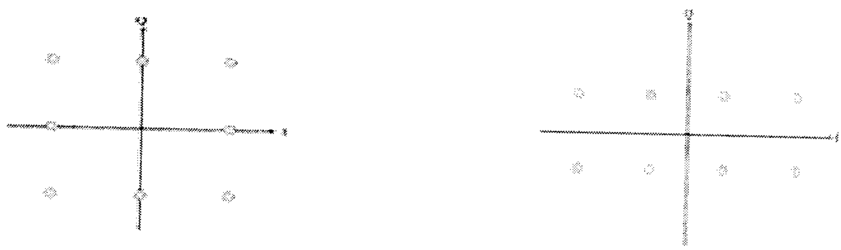


Figure 1.1 Constellation diagram for rectangular 8-QAM

erference and noise

In moving to a higher order QAM constellation (higher data rate and mode) in hostile /microwave QAM application environments, such as in broadcasting or telecommunications, rference (via multipath) typically increases. Reduced noise immunity due to constellation aration makes it difficult to achieve theoretical performance thresholds. There are several test ameter measurements which help determine an optimal QAM mode for a specific operating ironment.

following three are most significant parameters:

- Carrier/interference ratio
- Carrier-to-noise ratio
- Threshold-to-noise ratio

2 M-ary Phase Shift Keying

PSK is a digital modulation scheme that conveys data by changing, or modulating, the e of a reference signal (the carrier wave).

Any digital modulation scheme uses a finite number of distinct signals to represent digital PSK uses a finite number of ph...

sually, each phase encodes an equal number of bits. Each pattern of bits forms the symbol that represented by the particular phase. The demodulator, which is designed specifically for the mbol-set used by the modulator, determines the phase of the received signal and maps it back the symbol it represents, thus recovering the original data. This requires the receiver to be able compare the phase of the received signal to a reference signal - such a system is termed herent (and referred to as Coherent PSK).

Alternatively, instead of using the bit patterns to set the phase of the wave, it can instead used to change it by a specified amount. The demodulator then determines the changes in the ase of the received signal rather than the phase itself. Since this scheme depends on the ference between successive phases, it is termed Differential Phase-Shift Keying. DPSK can be nificantly simpler to implement than ordinary PSK since there is no need for the demodulator have a copy of the reference signal to determine the exact phase of the received signal (it is a -coherent scheme). In exchange, it produces more erroneous demodulations. The exact uirements of the particular scenario under consideration determine which scheme is used.

Multi-level modulation techniques permit high data rates within fixed bandwidth straints. A convenient set of signals for M-ary PSK is

$$\varphi_i(t) = A\cos(w_c t + \theta_i), \qquad 0 < t \leq T_s \qquad (1.3)$$

ere the M phase angles are

$$\theta_i = 0, \frac{2\pi}{M}, \ldots, \frac{2\pi(M-1)}{M}. \qquad (1.4)$$

equiprobable ones and zeros the PSD for M-ary PSK is

$$S_\varphi(\omega) = A^2 T_s Sa^2\left[(\omega - \omega_c)\frac{T_s}{2}\right] \qquad (1.5)$$

e symbols in this case are of duration T_s, so the information (or bit) rate T_b satisfies,

$$T_S = T_b \log_2 M \qquad (1.6)$$

e potential bandwidth efficiency of M-ary PSK can be shown to be

$$\frac{f_b}{B} = \log_2 M \text{ bps/Hz} \qquad (1.7)$$

ignal constellation diagram for the case of M=8 are shown below:

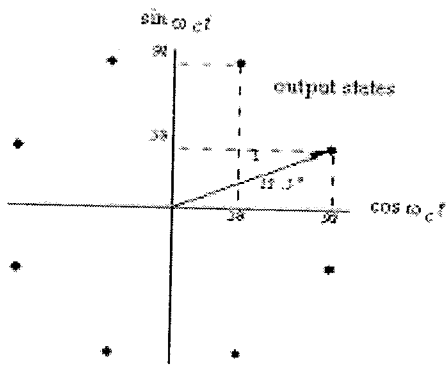


Figure 1.2 Constellation diagram for 8-PSK

All signals have the same energy E_s over the interval (0, T_s), and each signal is correctly odulated at the receiver if the phase is within $\pm\pi / M$ of the correct phase θ_i. No information ntained in the energy of the signal. A probability of error calculation involves analysing the ved phase at the receiver (in the presence of noise), and comparing it to the actual phases. xact solution is difficult to compute, but for $P_\epsilon < 10^{-3}$ an approximate probability of making nbol error is

$$P_\epsilon \approx 2\text{erfc}\sqrt{\frac{2E_s}{\eta}\sin^2\frac{\pi}{M}} \qquad M > 2 \qquad (1.8)$$

ı Gray code is used, then the corresponding bit error is approximately

$$P_{be} \approx P_{\epsilon} / \log_2 M \quad (1.9)$$

Stremler provides a table of the SNR requirements of M-ary PSK for fixed error rates. e results indicate that for QPSK (M = 4) has definite advantages over coherent PSK (M = 2) - bandwidth efficiency is doubled for only about a 0.3dB increase in SNR. For higher-rate ısmissions in band limited channels the choice M = 8 is often used. Values of M > 8 are lom used due to excessive power requirements.

M-ary PSK requires more complex equipment than BPSK signaling. Carrier recovery is more complicated. The requirement that the carrier be recovered can be mitigated by using a nparison between the phases of two successive symbols. This leads to M-ary Differential K, and is in principle similar to DPSK (which is differential PSK for M = 2).

large SNR the probability of error is

$$P_{\epsilon} \approx 2\,\mathrm{erfc}\sqrt{\frac{2E_s}{\eta}\sin^2\frac{\pi}{\sqrt{2M}}} \quad (1.10)$$

s differential detection increases the power requirements by the factor

$$\Gamma = \frac{\sin^2 \pi/M}{\sin^2\left(\pi/\sqrt{2M}\right)} \quad (1.11)$$

M=4, the increase is required power is about 2.5dB, which may be justified by the saving in oment complexity.

?.3 Binary Phase-Shift Keying

BPSK (also sometimes called Phase Reversal Keying or 2PSK) is the simplest form of ase shift keying. It uses two phases which are separated by 180° and so can also be termed 'SK. It does not particularly matter exactly where the constellation points are positioned, and he figure 1.3 they are shown on the real axis, at 0° and 180°. This modulation is the most ust of all the PSKs since it takes the highest level of noise or distortion to make the nodulator reach an incorrect decision. It is, however, only able to modulate at 1 bit/symbol l so is unsuitable for high data-rate applications when bandwidth is limited.

In the presence of an arbitrary phase-shift introduced by the communications channel, the nodulator is unable to tell which constellation point is which. As a result, the data is often erentially encoded prior to modulation.

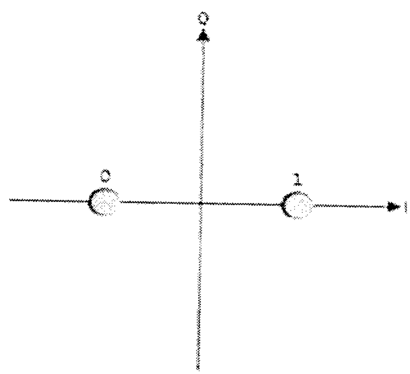


Figure 1.3 Constellation diagram for BPSK

APPLICATIONS OF VARIOUS MODULATION TECHNIQUES

- The wireless LAN standard, IEEE 802.11b, uses a variety of different PSKs depending on the data-rate required. At the basic-rate of 1 Mbit/s, it uses DBPSK.
  To provide the extended-rate of 2 Mbit/s, DQPSK is used. In reaching 5.5 Mbit/s and the full-rate of 11 Mbit/s, QPSK is employed, but has to be coupled with complementary code keying. The higher-speed wireless LAN standard, IEEE 802.11g-2003 has eight data rates: 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s.

- The 6 and 9 Mbit/s modes use OFDM modulation where each sub-carrier is BPSK modulated. The 12 and 18 Mbit/s modes use OFDM with QPSK. The fastest four modes use OFDM with forms of quadrature amplitude modulation.
- Because of its simplicity BPSK is appropriate for low-cost passive transmitters, and is used in RFID standards such as ISO/IEC 14443 which has been adopted for biometric passports, credit cards such as American Express's Express Pay, and many other applications.
- Bluetooth 2 will use π / 4-DQPSK at its lower rate (2 Mbit/s) and 8-DPSK at its higher rate (3 Mbit/s) when the link between the two devices is sufficiently robust.
- Bluetooth 1 modulates with Gaussian minimum-shift keying, a binary scheme, so either modulation choice in version 2 will yield a higher data-rate.

CHAPTER 2

BIT INTERLEAVED CODED MODULATION

ı CODED MODULATION

This section presents the use of coded signals for bandwidth-constrained channels. For :h channels, the digital communication system is designed to use bandwidth-efficient ıltilevel amplitude and phase modulation, such as PAM, PSK, DPSK, or QAM, and operates the region where R/W > 1. When coding is applied to the bandwidth-constrained channel, a formance gain is desired without expanding the signal bandwidth. This goal can be achieved increasing the number of signals over the corresponding uncoded system to compensate for redundancy introduced by the code.

If the modulation is treated as a separate operation independent of the encoding, the use very powerful codes (large-constraint-length convolutional codes or large-block-length block es) is required to offset the loss and provide some significant code gain. On the other hand, if modulation is an integral part of the encoding process and is designed in conjunction with the e to increase the minimum Euclidean distance between pair of coded signals, the loss from expansion of the signal set is easily overcome and a significant coding gain is achieved with tively simple codes [5]. The key to this integrated modulation and coding approach is to ise an effective method for mapping the coded bits into signal points such that the minimum lidean distance is maximized.

BICM

One of the most important objectives in the design of digital communication systems is efficient utilization of the available bandwidth. BICM introduced in [6], has been shown to eve large coding gain for bandwidth efficient transmission over different communication nels [7]. BICM, which consists of a coding, bit-wise interleaving and constellation mapping, first proposed by Zehavi. Studies show that BICM is much better than Trellis Coded an TCM under AWGN channel. Li et al. [8] , proposed iterative decoding with soft feedback : BICM over additive AWGN channel.

This decoder is suboptimal and non-iterative, but offers a very good performance and it is eresting from practical perspective due to its low implementation complexity. Caire *et al.* [9] ther elaborated on Zehavi's decoder and, under the assumption of an infinite length erleaver, proposed and analyzed a BICM model as a set of parallel independent binary-input tput symmetric channels. Based on the data processing theorem, Caire et al. [10] showed that BICM mutual information cannot be larger than that of CM. However surprisingly a priori, y found that the cutoff rate of BICM might exceed that of CM [11].

The building blocks of BICM system model is given in Figure 2.1: 1) encoder 2) erleaver 3) modulator, modeled by a labeling map and a signal set, i.e., a finite set of points in complex N-dimensional Euclidean space C^N 4) stationary finite-memory vector channel ose transition Probability Density Function as defined in (2.1) may depend on a vector ameter θ.

$$p_\theta(b/a): a, b \in c^N \qquad (2.1)$$

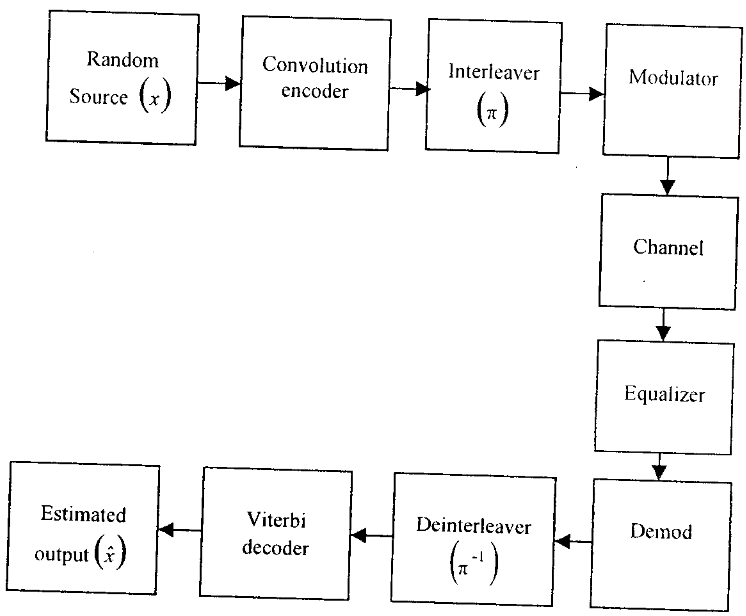


Figure 2.1 System model of BICM

Demodulator, in the present scenario plays the role of a branch metric computer 6) branch etric deinterleaver 7) decoder. The remaining of this section is devoted to a detailed description these blocks for CM and BICM.

Consider a vector channel characterized by a family of transition probability density nctions is given by (2.2).

$$p_\theta(b/a) : \theta \in c^{N'} ; a, b \in c^{N} \qquad (2.2)$$

rameterized by a complex-valued vector θ representing the channel state. θ is assumed to be of lependent of the channel input a, and that, conditionally on the sequence θ', the channel is moryless which is given by (2.3).

$$p_{\theta'}(b'/a') = \prod_k p_{\theta'}(b_k/a_k) \qquad (2.3)$$

Moreover, θ' is assumed to be a stationary, finite memory random process. More cisely, an integer $V \geq 0$ such that, for all r-tuples $V < k_1 < \ldots < k_r$ and for all n-tuples $j_1 < \ldots \leq 0$ is assumed, the sequences $(\theta_{k1}, \ldots, \theta_{kr})$ and $(\theta_{j1}, \ldots, \theta_{jn})$ are statistically independent.

By this model, a large number of typical communication channels such as the AWGN nnel (θ =constant), with constant or random phase (θ is the residual phase due to imperfect ier phase recovery) and frequency nonselective slow fading channels (θ describes the tiplicative fading process) is represented. However, the model cannot take into account Inter ibol Interference, or frequency selectivity in fading channels since, in these cases, the nnel state depends on the input sequence. A CM scheme can be viewed as the concatenation 1 encoder C for a code defined over a label alphabet A with an N-dimensional memoryless ulator over a signal set $X \in C^N$ [12], [13]. Assuming A and X are finite and $|A| = |X| = M$. transmitted code sequence $C' \in C$ is mapped onto the signal sequence a by the (one-to-one) ing map, $A \rightarrow X$ acting component wise.

l Interleaver

Interleaving is a simple yet powerful technique that can be used to enable a random error cting code to perform burst error correction. It is a tool that can be used in digital nunications systems to enhance the random error correcting capabilities of block codes such

Convolutional codes, Reed-Solomon codes etc., to the point that they can be effective in a rst noise environment. The interleaver subsystem rearranges the encoded symbols over ltiple code blocks. This effectively spreads out long burst noise sequences so they appear to decoder as independent random symbol errors or shorter more manageable burst errors. The ount of error protection based on the length of the noise bursts determines the span length or oth of interleaving required.

Interleaving can be classified as either periodic or pseudo-random. The periodic erleaver orders the data in a repeating sequence of bytes. Block interleaving is an example of iodic interleaving. These interleavers accept symbols in blocks and perform identical mutations over each block of data. One way of accomplishing this is by taking the input data writing the symbols by rows into a matrix with *i* rows and *n* columns and then reading the a out of the matrix by columns. This is referred to as a (n,i) block interleaver. Pseudo-random erleavers rearrange the data in a pseudo-random sequence. Periodic interleaving is more nmonly invoked because it is more easily accomplished in hardware.

If the code C is designed for the correct random error, it may be convenient to introduce a ibol interleaver π between the encoder and the mapper μ. In this work, assuming that π is an l interleaver (i.e., with infinite depth and completely random). Thus, the interleaving/ terleaving blocks can be excluded from consideration, provided that the sequence is ϑ' ependent and identically distributed, and hence, characterized by its first order PDF.

In general, BICM can be obtained by concatenating an encoder for a binary code C, with N-dimensional memoryless modulator over a signal set as defined in (2.4), through a bit leaver π and a one-to-one binary labeling map as given in (2.5).

$$x \subseteq c^N \text{ of size } |x|=M=2^m \quad (2.4)$$

$$\mu : \{0,1\}^m \rightarrow x \quad (2.5)$$

The code sequence is first interleaved by π. Next, the interleaved sequence $\pi(c')$ is broken subsequences of m bits each, which is mapped onto signals in x. Finally, the resulting signal uence x' is transmitted over the vector channel. The bit interleaver can be seen as a one-to- correspondence $\pi : k \to (k', i)$, where k denotes the time ordering of the coded bits c_k, k', otes the time ordering of the signals $x_{k'}$ transmitted over the vector channel, and indicates the ition of the bit in the label of $x_{k'}$. Here, ideal bit interleaving is assumed.

RESULTS AND DISCUSSIONS

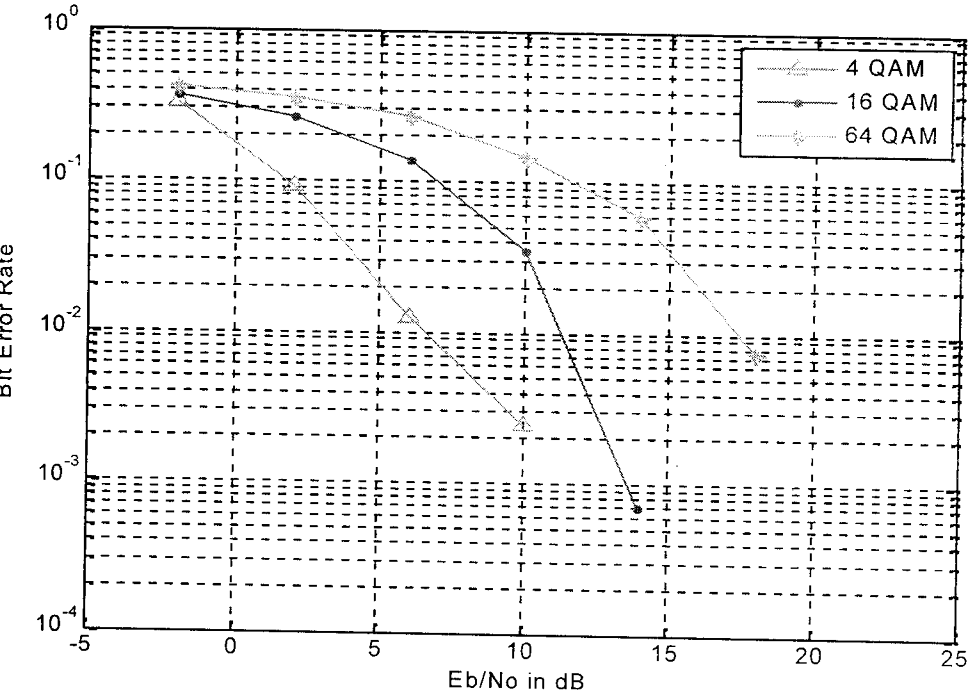


Figure 2.2 BER performance of M-QAM CM through AWGN

Table 2.1 M-QAM CM through AWGN

BER at 10^{-2} for M-QAM	SNR value (dB)
	AWGN
4	6.5
16	11
64	17.5

BER performance of M-QAM with Coded Modulation (without interleaver) through GN channel is performed. The number of transmitted bits is 4200 with the code rate=1/2. length=3. As the M-ary increases it yields poor performance. For M=64, the increase in ed power is about 11 dB when compared to M=4.

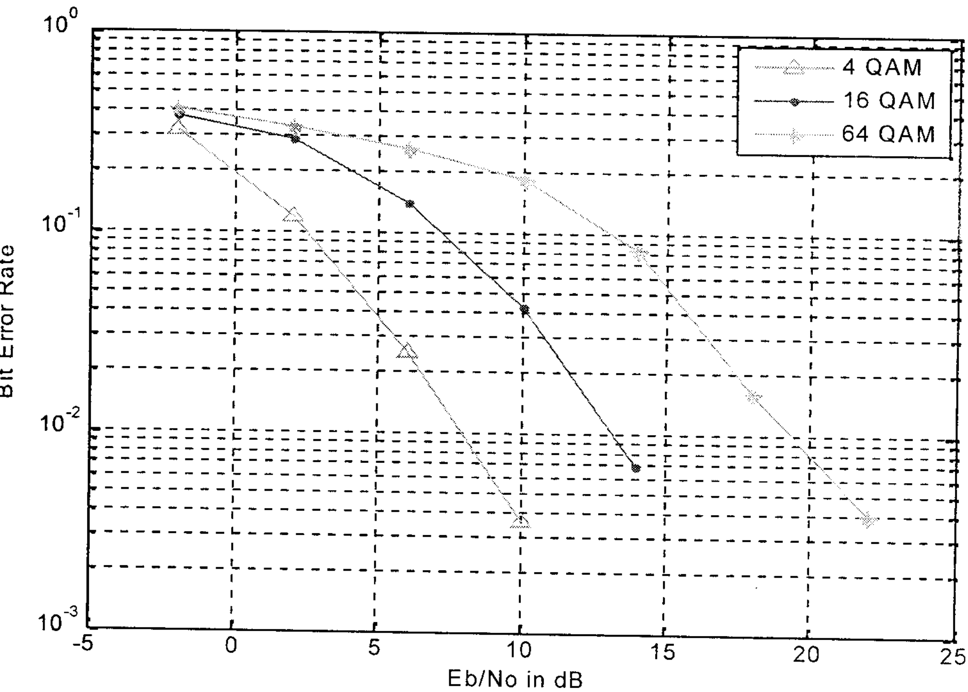


Figure 2.3 BER performance of M-QAM CM through Rayleigh

Table 2.2 M-QAM with CM through Rayleigh

BER at 10^{-2} for M-QAM	SNR value (dB)
	Rayleigh
4	8
16	13
64	19

BER performance of M-QAM with Coded Modulation (without interleaver) through eigh channel is performed. The number of transmitted bits is 4200 with the code rate=1/2, length=3. As the M-ary increases it yields poor performance. For M=16, the increase in red power is about 5 dB when compared to M=4.

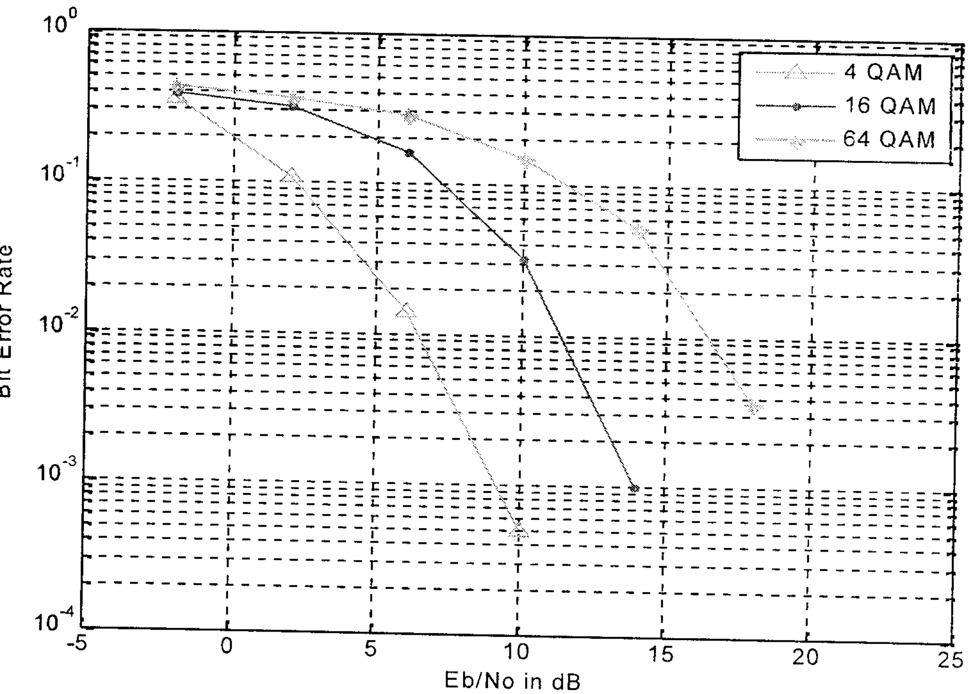


Figure 2.4 BER performance of M-QAM BICM through AWGN

Table 2.3 M-QAM BICM through AWGN

BER at 10^{-2} for M-QAM	SNR value (dB)
	AWGN
4	6.5
16	11.5
64	16.5

BER performance of M-QAM with Bit Interleaved Coded Modulation (with interleaver) gh AWGN channel is performed. The number of transmitted bits is 4200 with the code /2, code length=3. As the M-ary increases it yields poor performance. For M=64, the se in required power is about 10 dB when compared to M=4.

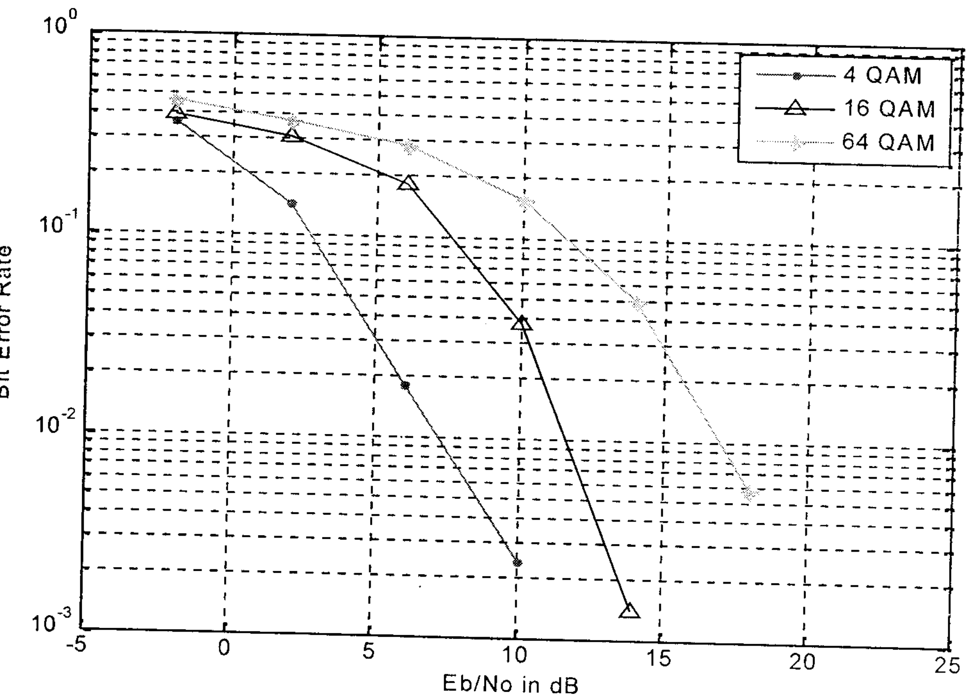


Figure 2.5 BER performance of M-QAM BICM through Rayleigh

Table 2.4 M-QAM BICM through Rayleigh

BER at 10^{-2} for M-QAM	SNR value (dB)
	Rayleigh
4	7
16	11.5
64	17

BER performance of M-QAM with Bit Interleaved Coded Modulation (with interleaver) h Rayleigh channel is performed. The number of transmitted bits is 4200 with the code /2, code length=3. As the M-ary increases, it yields poor performance. For M=16, the se in required power is about 4.5 dB when compared to M=4.

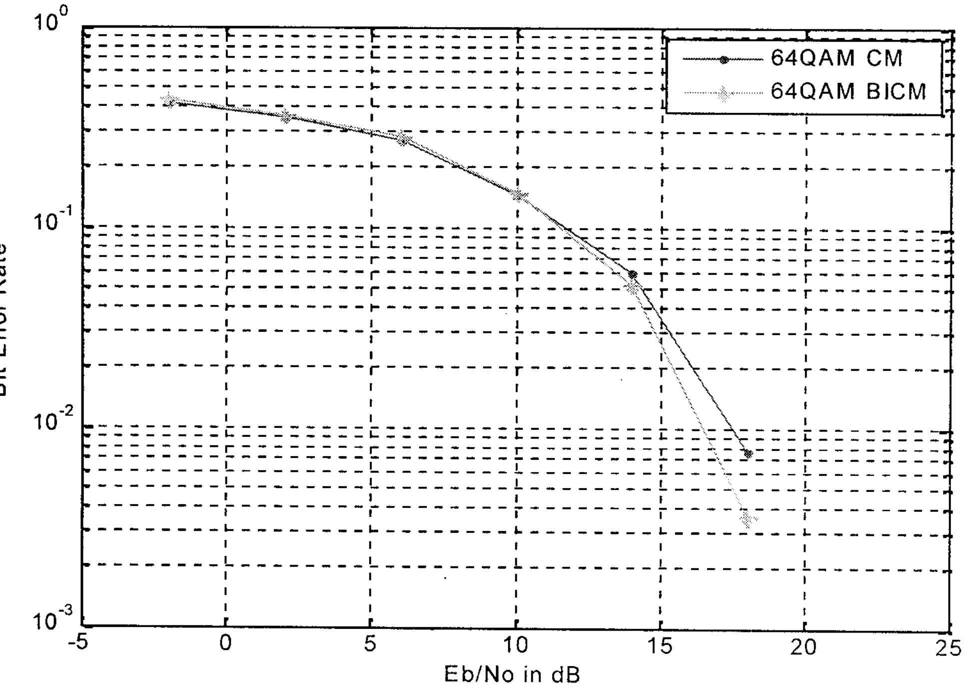


Figure 2.6 BER performance of 64QAM with CM and BICM through AWGN

Table 2.5 64QAM with CM and BICM through AWGN

BER at 10^{-2} with AWGN	SNR value (dB)	
	CM	BICM
64 QAM	17.5	16.5

BER performance of 64-QAM with Coded Modulation (without interleaver) and Bit
.eaved Coded Modulation (with interleaver) through AWGN channel is performed. The
)er of transmitted bits is 4200 with the code rate=1/2, code length=3. After interleaver is
luced to eliminate the robust errors, the code gain achieved by BICM is 1 dB when
)ared to CM.

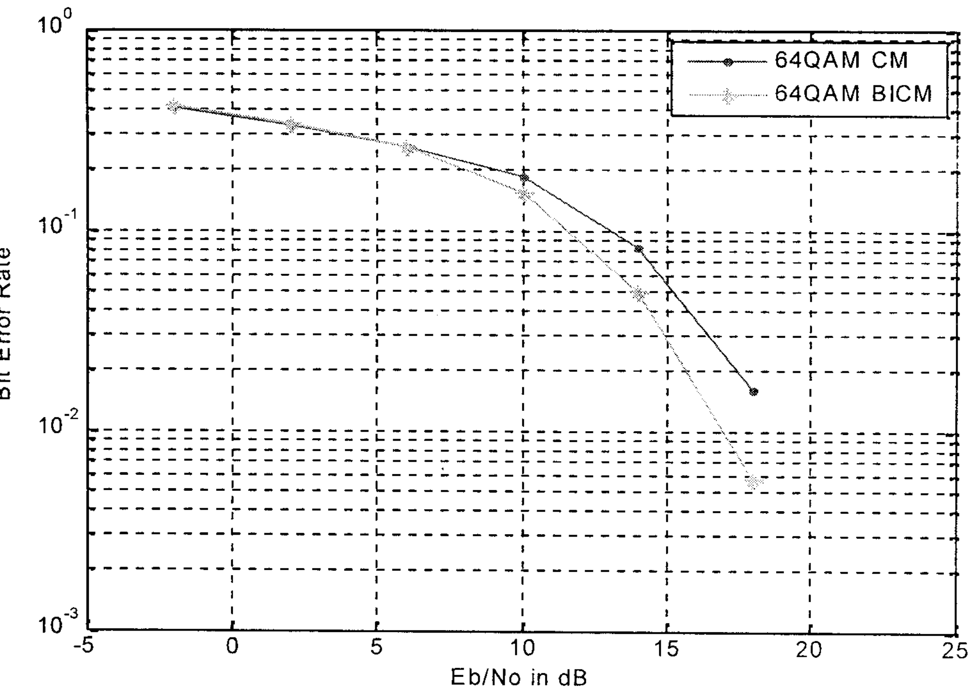


Figure 2.7 BER performance of 64QAM with CM and BICM through Rayleigh

Table 2.6 64QAM with CM and BICM through Rayleigh

BER at $10^{-1.8}$ with Rayleigh	SNR value (dB)	
	CM	BICM
64 QAM	16	18

BER performance of 64-QAM with Coded Modulation (without interleaver) and Bit leaved Coded Modulation (with interleaver) through Rayleigh channel is performed. The ber of transmitted bits is 4200 with the code rate=1/2, code length=3. After interleaver is duced to eliminate the robust errors, the code gain achieved by BICM is 2 dB when pared to CM. From the result it's concluded that, BICM is robust against fading channels as gain achieved for Rayleigh is 2 dB than AWGN which is 1 dB.

CHAPTER 3

BIT INTERLEAVED CODED MODULATION - ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

INTRODUCTION TO OFDM

Orthogonal Frequency Division Multiplexing is a modulation technique for European dards such as the Digital Audio Broadcasting and the Digital Video Broadcasting Systems. uch it has received much attention and has been proposed for many applications, including l area networks and personal communication systems. OFDM is a type of multichannel ulation that divides a given channel into many parallel sub channels or subcarriers, so that iple symbols are sent in parallel.

Multiuser systems that use OFDM must be extended with a proper multiple-access me as single carrier transmission systems. Compared to single carrier systems, OFDM is a atile modulation scheme for multiple access systems in that it intrinsically facilitates both -division multiple access and frequency-division (subcarrier-division) multiple access. M also has some drawbacks, because OFDM divides a given spectral allotment into many ow subcarriers each with inherently small carrier spacing, it is sensitive to carrier frequency s. Furthermore, to preserve the Orthogonality between subcarriers, the amplifiers need to be r.

PRINCIPLES OF OFDM

OFDM is a block transmission technique. In the baseband, complex-valued data symbols ulate a large number of tightly grouped carrier waveforms. The transmitted OFDM signal iplexes several low-rate data streams-each data stream is associated with a given subcarrier.

The main advantage of this concept is in a radio environment, each of that data streams riences an almost flat fading channel. In slowly fading channels, the ISI and ICI within an

)M symbol can be avoided with a small loss of transmission energy using the concept of ic prefix.

CONCEPTS OF OFDM

- A type of multi-carrier modulation
- Single high-rate bit stream is converted to low-rate N parallel bit streams
- Each parallel bit stream is modulated on one of N sub-carriers
- Each sub-carrier can be modulated differently, e.g. QAM, QPSK or BPSK
- To achieve high bandwidth efficiency, the spectrum of the sub-carriers are closely spaced and overlapped
- Nulls in each sub-carrier's spectrum land at the center of all other sub-carriers (orthogonal)

BASIC CONCEPTS OF OFDM SIGNALS

1 Orthogonality

The sub-carrier frequencies are chosen so that they are orthogonal to each other. This ns that cross-talk between the sub-carriers is not possible and hence inter-carrier guard bands not required. The Orthogonality allows:

- Simultaneous transmission on numerous sub-carriers in a tight frequency band without interference from each other
- High spectral efficiency, near the Nyquist rate
- Simpler transmitter and receiver design
- Efficient modulator and demodulator implementation using the FFT algorithm

However, in order to maintain Orthogonality, very accurate frequency synchronization is iired between the receiver and transmitter. If the frequency deviates, the sub-carriers would remain orthogonal causing inter-carrier interference. Figure 3.1 shows the six sub-carriers ch are orthogonal to each other.

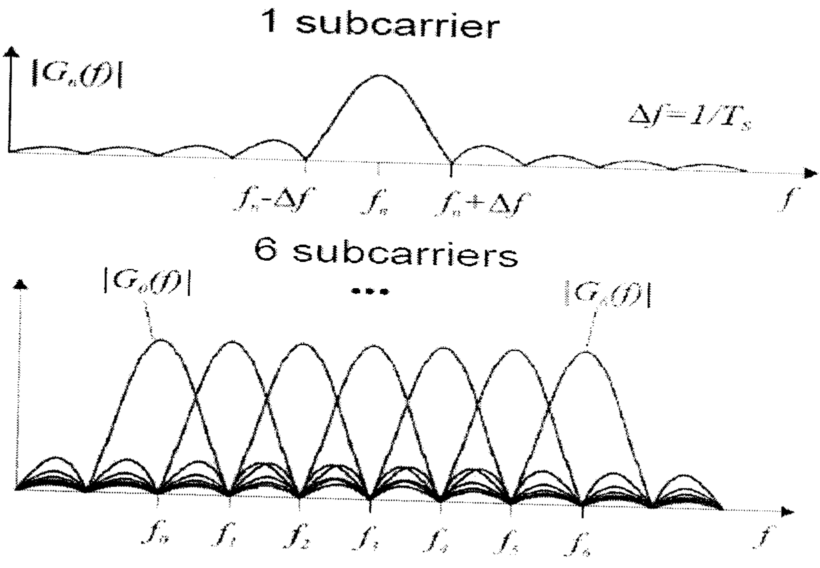


Figure 3.1 Orthogonality of Sub Carriers

2 Guard Interval

OFDM transmits a number of low-rate streams in parallel instead of a single high-rate m. Lower symbol rate modulation means the symbol duration is comparatively longer and it asible to insert a guard interval between OFDM symbols.

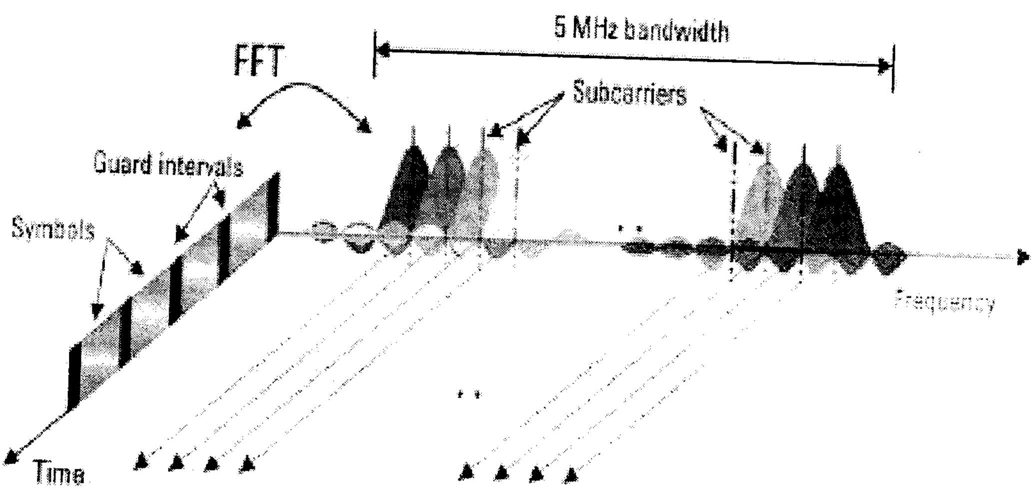


Figure 3.2 Guard Interval between OFDM symbols

The presence of this guard interval makes the system resilient to multipath components
helps to eliminate inter-symbol interference. The guard interval also eliminates the need for se-shaping filter and reduces the sensitivity to time synchronization problems.

.3 Cyclic Prefix

The cyclic prefix is transmitted during the guard interval and it consists of the end of the DM symbol copied into the guard interval. The cyclic prefix is transmitted followed by the DM symbol. Cyclic prefix Insertion is shown in below Figure 3.3.

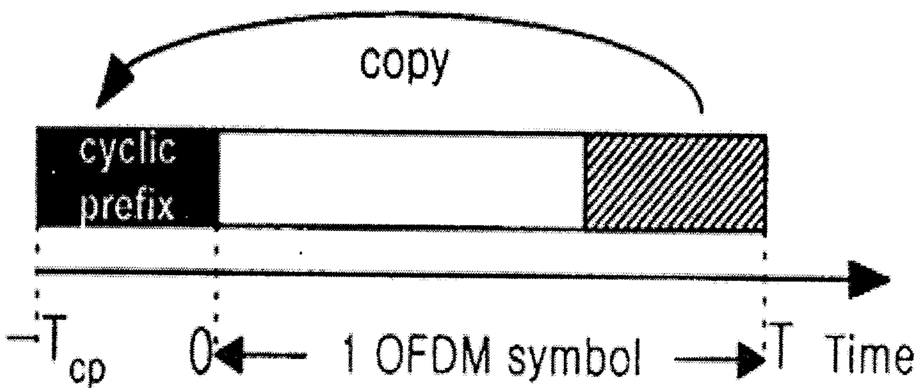


Figure 3.3 Insertion of Cyclic Prefix

The reason for the cyclic prefix being a copy of the OFDM symbol's tail is so that the iver will integrate over an integer number of sinusoidal cycles for each of the multi-path ponents when it performs OFDM demodulation with the FFT. The disadvantage of using a ic extension is a less available bandwidth for the real data transmission. In most ronments, the length of the Guard interval is equal to a quarter symbol duration. This is a le compromise between the less bandwidth efficiency and the better performance due to ferences.

.4 Channel Estimation

In the receiver, the channel needs to be equalized so that the transmitted information can correctly interpreted. For this to be possible, the channel must be known. Since the channel stantly changes due to movement of both the mobile unit and the surroundings, the channel not be known once and for all. The channel has to be re-estimated every once in a while. So ed pilots are used to estimate the channel. These are data that are known to the receiver. ce the system should also transmit unknown data, pilots cannot be transmitted continuously

- Pilots are placed in different, strategic places in the time frequency grid
- The other values have to be interpolated from the known values by Simple linear interpolation, MMSE estimation, FIR estimation

5 Pilot Carriers

Some of the sub-carriers in OFDM symbols may carry pilot signals for the measurement hannel conditions. Pilot signals may also be used for frequency (to avoid ICI) and time (to d ISI) synchronization. Pilots are used to track the residual phase error if present after uency correction. Without this correction, the constellation points start rotating either -ve angle. It is very much sensitive at higher constellation. If phase θ is estimated from s, then it is corrected by multiplying the received signal exp (-j*2*pi*θ) before demapping.

Channel Coding and Interleaving

OFDM is invariably used in conjunction with channel coding (forward error correction). lmost always uses frequency and/or time interleaving. Frequency interleaving ensures that it errors that would result from those subcarriers in the faded part of the bandwidth are d out in the bit-stream rather than being concentrated. This increases resistance to ency-selective channel conditions. Similarly, time interleaving ensures that bits that are ally close together in the bit-stream are transmitted far apart in time, thus mitigating st severe fading as would happen when travelling at high speed. Common types of error ction coding used with OFDM-based systems are convolution coding, Reed-Solomon ing and turbo coding. Error correction coding is employed in the receiver to correct any rs that result from environmental effects.

OFDM PARAMETERS

When designing an OFDM system, a number of different parameters have to be sidered

3.5.1 *Subcarrier bandwidth*

- The subcarrier bandwidth (or spacing) is affected by cost of cyclic prefix
- A small spacing leads to long symbol duration hence less cost of cyclic prefix i.e. Doppler spread
- A small bandwidth leads to high relative doppler spread. thus sensitivity to movement
- The system designer has to trade off these contradicting demands depending on the system

  – How mobile is the system?

  – What data rates are needed?

3.5.2 *Number of subcarriers*

- When the subcarrier separation is decided the number of subcarriers can be calculated – If the system has a limited bandwidth this will give the maximum number of subcarriers
- Some slack is needed to ensure low enough out-of-band transmission – If instead a certain throughput is needed, the number of subcarriers can be calculated based on constellation and coding
- This will then set the total bandwidth of the system

3.5.3 *Length of cyclic prefix*

- The cyclic prefix should be long enough to ensure orthogonality of the system – Multipath spread has to be considered
- Longer transmission distances normally call for longer CPs – However at long distances, e.g. at cell edges, other effects may limit the performance and therefore it is possible to allow a system which is not completely orthogonal everywhere
- Some systems support multiple cyclic prefix lengths to handle different environments

6 OFDM ADVANTAGES

- OFDM is spectrally efficient
  - IFFT/FFT operation ensures that sub-carriers do not interfere with each other
- OFDM has an inherent robustness against narrowband interference
  - Narrowband interference will affect at most a couple of sub channels
  - Information from the affected sub channels can be erased and recovered via the forward error correction codes
- Equalization is very simple compared to Single-Carrier systems
- OFDM has excellent robustness in multi-path environments
  - Cyclic prefix preserves orthogonality between sub-carriers
  - Cyclic prefix allows the receiver to capture multi-path energy more efficiently
- Ability to comply with world-wide regulations:
  - Bands and tones can be dynamically turned on/off to comply with changing regulations
- Coexistence with current and future systems:
  - Bands and tones can be dynamically turned on/off for enhanced coexistence with the other devices.

OFDM DRAWBACKS

High sensitivity Inter Channel Interference

OFDM is sensitive to frequency, clock and phase offset

The OFDM time-domain signal has a relatively large peak-to-average ratio

- tends to reduce the power efficiency of the RF amplifier
- non-linear amplification destroys the orthogonality of the OFDM signal and introduced out-of-band radiation

BICM-OFDM

The block diagram of the BICM-OFDM system under investigation is shown in Fig.3.4.

transmitter side, the system uses convolution encoder and interleaves the data and th nbol mapping is done. Later, OFDM concept is introduced and analyzed under Additive ite Gaussian Noise and frequency non-selective, slow fading channel. In the receiver side, the nals are equalized and undo all the steps done at the transmitter side.

The system main modules are described below:

irce generator:

The transmitted information bits are generated using Bernoulli binary generator.

innel Coding:

Channel coding is composed of Forward Error Correction (FEC) and interleaving.

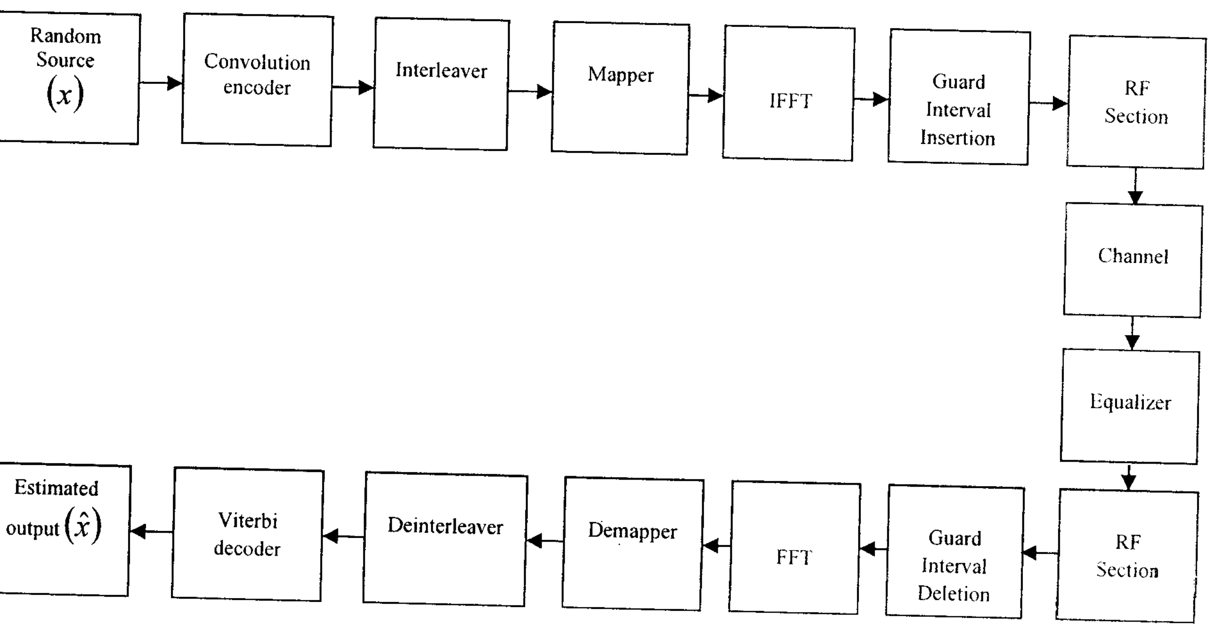


Figure 3.4 BICM-OFDM System model

For FEC, Convolutional Code (CC) encoder is used, which is the only mandatory coding ne according to the IEEE 802.16e-2005 specifications. The CC uses the code rate of /2, memory m = 6 convolutional encoder with generator matrix G (D) = (1 + D + D2 + D3 1 + D2 + D3 + D5 + D6). To decode, the Viterbi algorithm is used with original rate 1/2 erleaving:

The code sequence $\bar{c}$ is first interleaved by π, denoted as $\pi(\bar{c})$. One of the most important ectives in the design of digital communication systems is the efficient utilization of the ilable bandwidth. BICM introduced in [7], has been shown to achieve large coding gain for dwidth efficient transmission over different communication channels.

dulation:

After bit interleaving, the data bits are entered serially to the constellation mapper. The em support M-QAM (Quadrature Amplitude Modulation) and M-PSK (Phase Shift Keying).

)M:

3locks involved in OFDM Transmission are

- IFFT - for centering the carrier frequency
- Guard Interval Insertion- to perfectly eliminate ISI
- RF Section - for frequency selection

Being an open sensitive design, the reception block is the inverse of OFDM transmission. ɔgonal Frequency Division Multiplexing sometimes called multicarrier or discrete multi- modulation is used for digital TV in Japan, Europe and Australia. In [14] OFDM, being d spectrum by nature, uses a number of carriers, which are spectrally distributed at precise encies, for data transmission. Orthogonality is provided by this spectrum spacing which nts demodulator interference with other frequencies. OFDM offers a number of benefits esiliency to Radio Frequency (RF) interference, high spectral efficiency and lower ɔath distortion. The increasing need for high speed mobile data transmission is a byproduct recent advancements in the digital wireless communication [15]. As power is the biggest

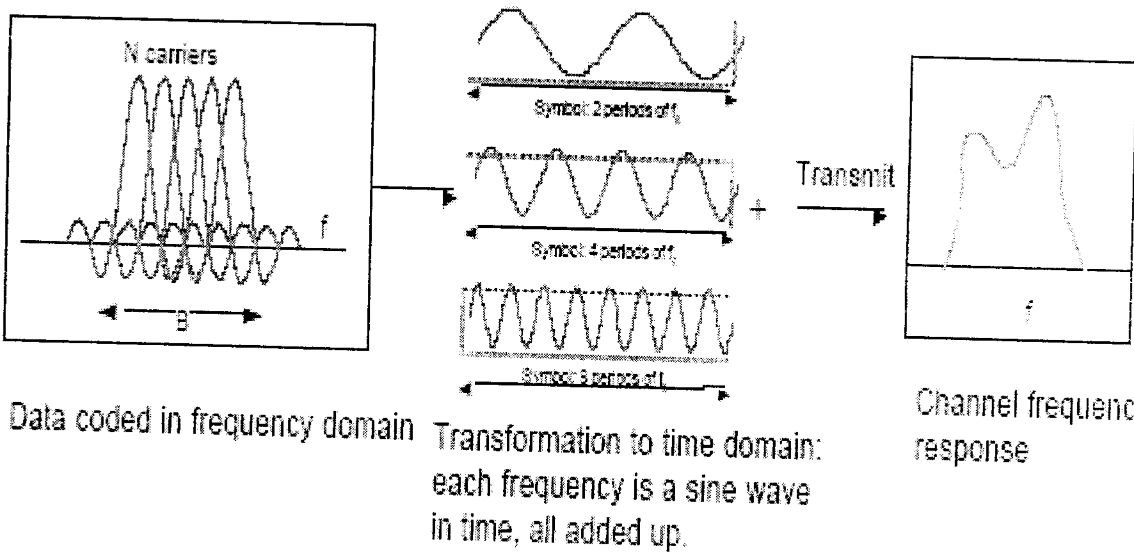


Figure 3.5 OFDM Modulation

ern in most of the wireless communication, OFDM has feasibly gained its high processing er at economical cost in comparison with existing wireless technologies like 4G.

CHAPTER SUMMARY

A correctly designed OFDM system can be decoupled into a number of single carrier systems

- This makes OFDM, an attractive choice for new systems
- However this comes at a price of wasted power and bandwidth for the cyclic prefix
- It also requires channel coding to avoid information loss due to frequency fading

It is important to know at what conditions the system is designed for different environment and different system parameters

The channel needs to be known in order to extract the information

- In OFDM, correlation between different subcarriers and time instances can be used in order to estimate the channel
- The pilots must not be available on all subcarriers

- In multi user systems, OFDM can be used as an access method where the frequency spectrum is divided between the users.
    - This is an advanced type of FDMA that uses the orthogonality of the OFDM subcarriers
    - To make this possible in the uplink, OFDMA, certain care has to be taken to ensure that the information from different units reaches the base station at approximately the same time (within the cyclic prefix) and same power

.10 RESULTS AND DISCUSSIONS

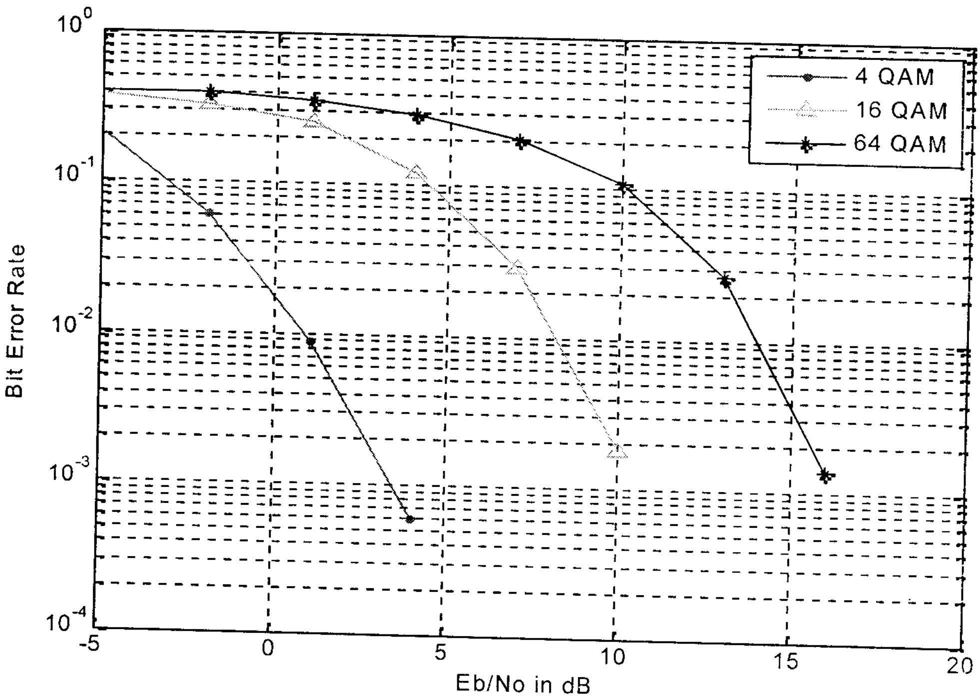


Figure 3.6 BER performance of M-QAM with BICM-OFDM through AWGN

Table 3.1 M-QAM with BICM-OFDM through AWGN

BER at 10^{-2} for M-QAM	SNR value (dB)
	AWGN
4	1
16	8
64	14

BER performance of M-QAM with BICM-OFDM through AWGN channel is performed. number of sub-carriers considered is 1705, with the FFT/IFFT length of 4096, code =1/2, code length=3. As the M-ary increases it yields poor performance. For M=64, the ease in required power is about 13 dB when compared to M=4.

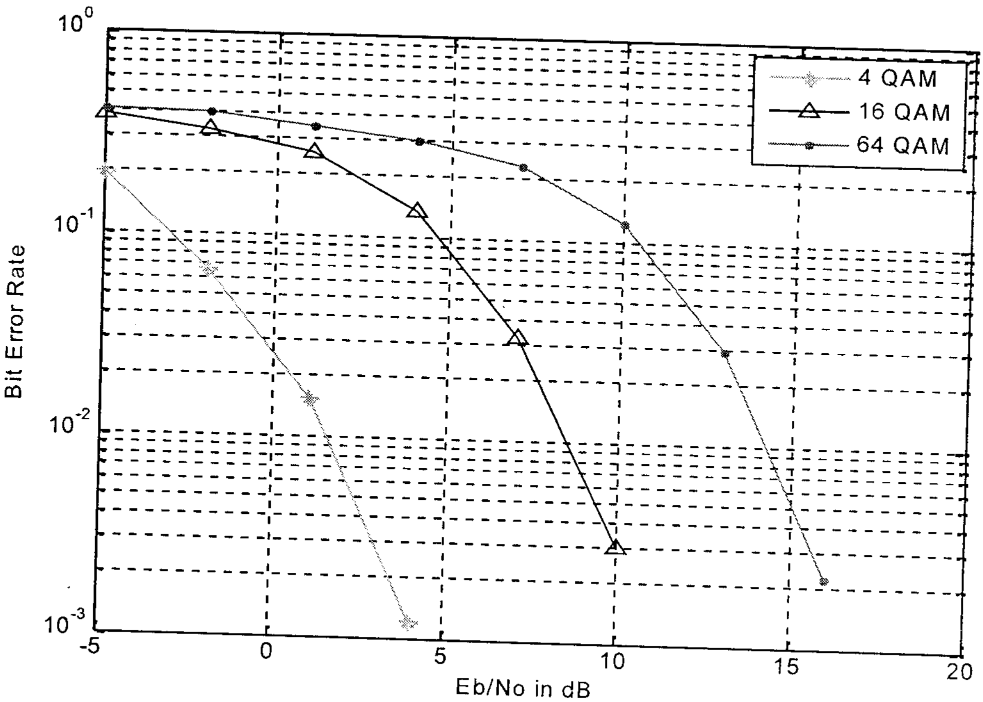
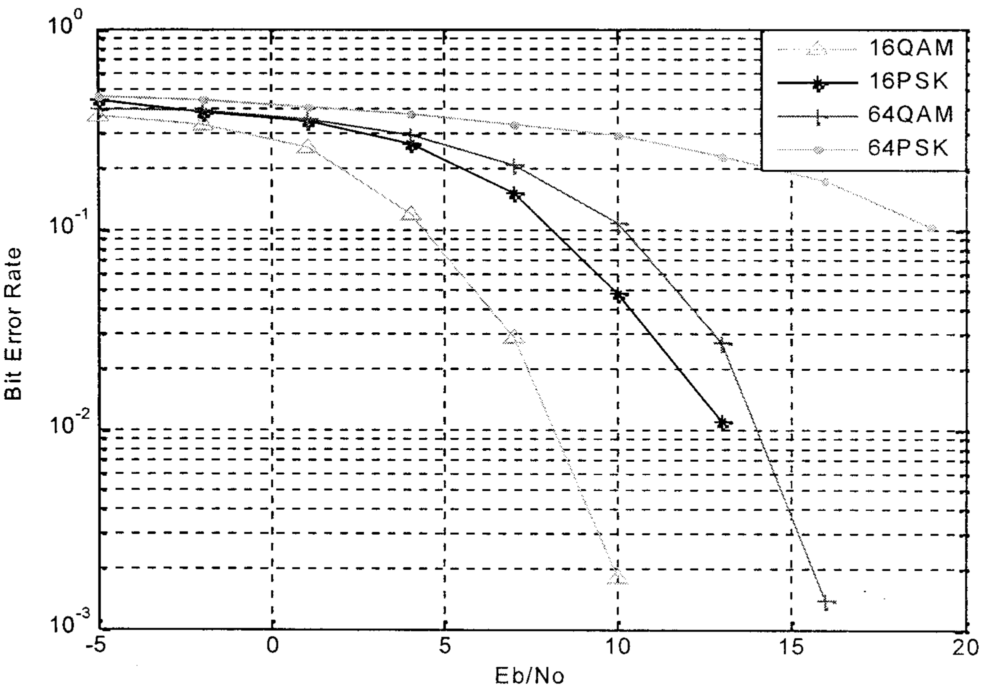


Figure 3.7 BER performance of M-QAM with BICM-OFDM through Rayleigh

Table 3.2 M-QAM with BICM-OFDM through Rayleigh

BER at 10^{-2} for M-QAM	SNR value (dB)
	Rayleigh
4	1.5
16	8.5
64	14

BER performance of M-QAM with BICM-OFDM through Rayleigh channel is ...rmed. The number of sub-carriers considered is 1705, with the FFT/IFFT length of 4096, rate=1/2, code length=3. As the M-ary increases it yields poor performance. For M=16, the ...ase in required power is about 7 dB when compared to M=4.



igure 3.8 BER performance of MQAM and MPSK with BICM-OFDM through AWGN

Table 3.3 MQAM and MPSK with BICM-OFDM through AWGN

SNR at 10 dB with AWGN	BER value	
	QAM	PSK
16	$10^{-1.27}$	$10^{-1.32}$
64	$10^{-0.97}$	$10^{-0.53}$

BER performance of M-QAM and M-PSK with BICM-OFDM through AWGN channel erformed. The number of sub-carriers considered is 1705, with the FFT/IFFT length of 4096, le rate=1/2, code length=3. For M=16, the difference in BER value at 10 dB SNR of QAM l PSK is $10^{-0.05}$. From the result it's concluded that QAM yields better performance than PSK.

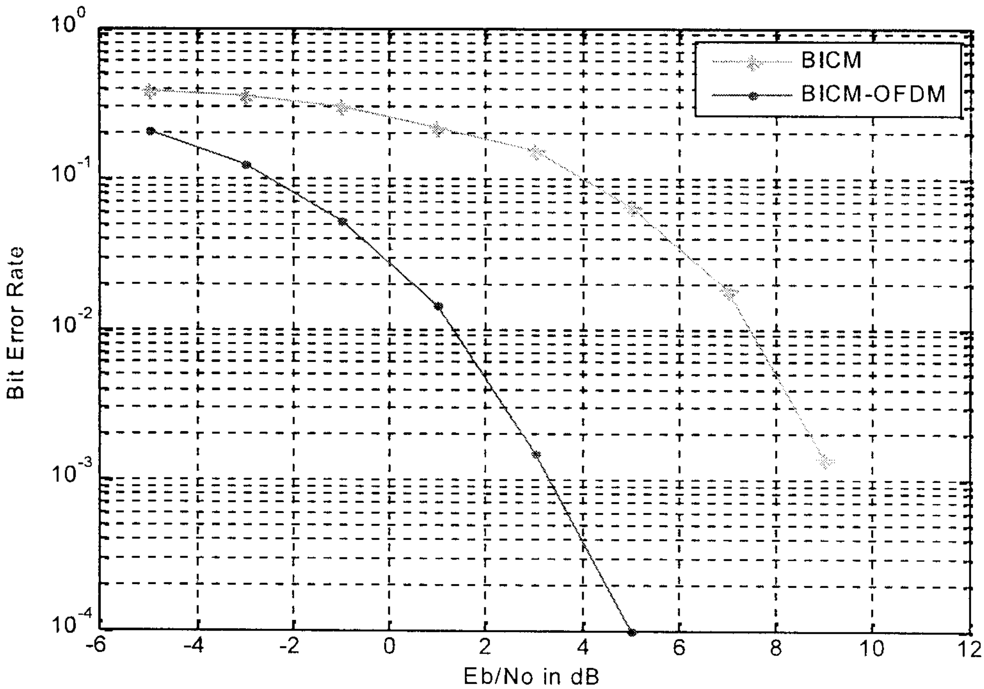
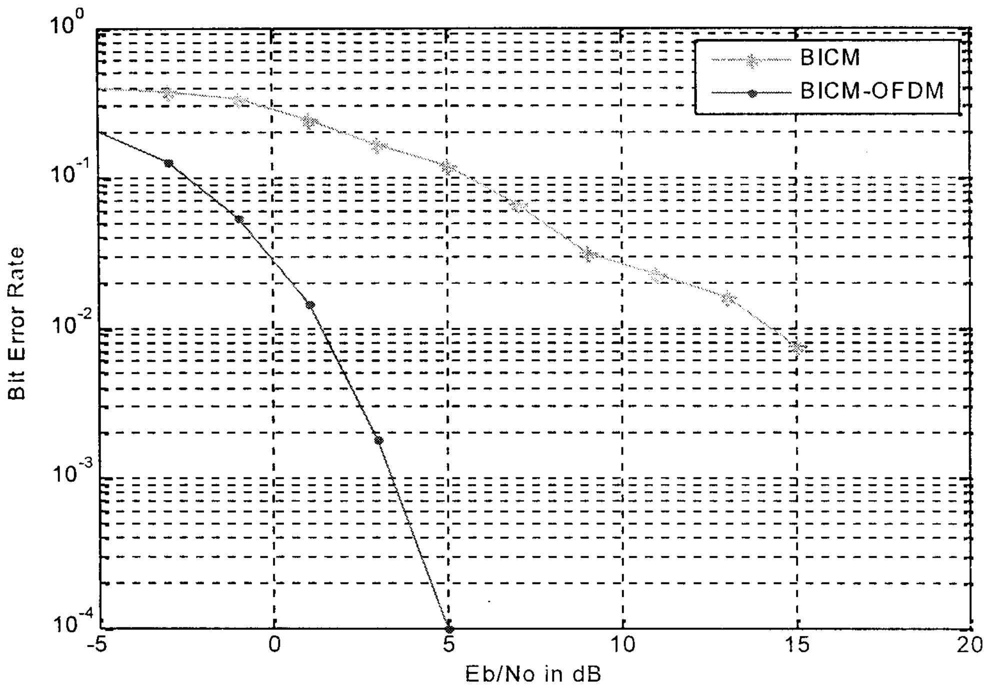


Figure 3.9 BER performance of 4QAM with BICM and BICM-OFDM through AWGN

Table 3.4 4QAM with BICM and BICM-OFDM through AWGN

BER value for 4 QAM with AWGN	SNR value (dB)	
	BICM	BICM-OFDM
10^{-2}	7.5	1.3

Comparison of BICM and BICM-OFDM for 4-QAM is analyzed over AWGN channel. e number of transmitted bits is 4200 with the code rate=1/2, code length=3. At BER of 10^{-2}, increase in required power for BICM is about 6.2 dB when compared to BICM-OFDM. So concluded that, BICM-OFDM gives better performance by achieving high code gain.

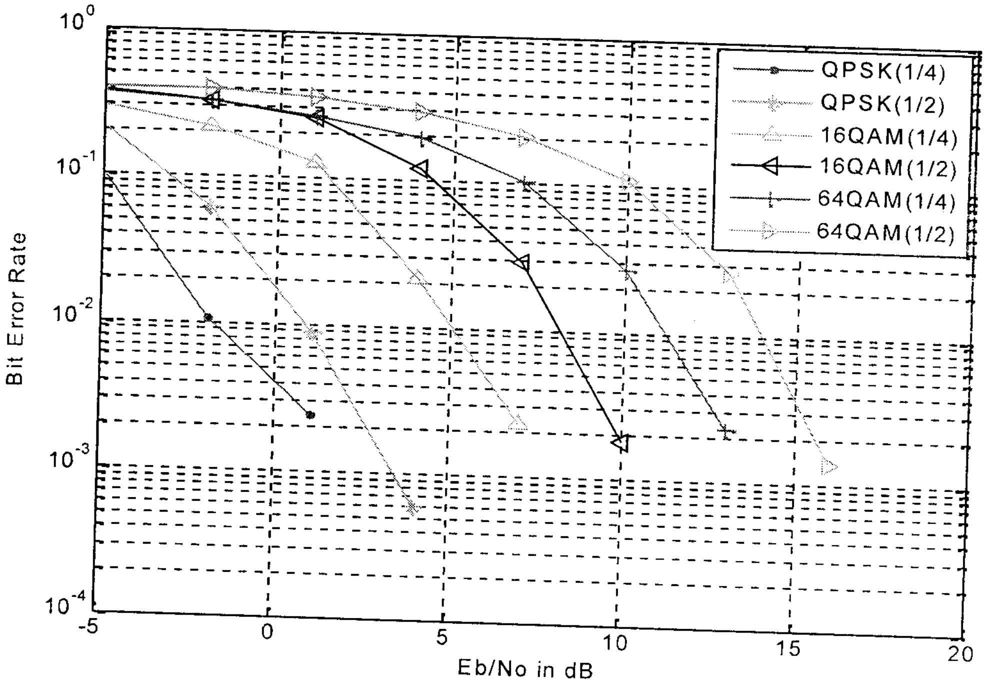


igure 3.10 BER performance of 4QAM with BICM and BICM-OFDM through Rayleigh

Table 3.4 4QAM with BICM and BICM-OFDM through Rayleigh

BER value for 4 QAM with Rayleigh	SNR value (dB)	
	BICM	BICM-OFDM
10^{-2}	14	1

Comparison of BICM and BICM-OFDM for 4-QAM is analyzed over Rayleigh Fading annel. The number of transmitted bits is 4200 with the code rate=1/2, code length=3. At BER 10^{-2}, the increase in required power for BICM is about 13 dB when compared to BICM-FDM. So it's concluded that, BICM-OFDM gives better performance by achieving high code in.

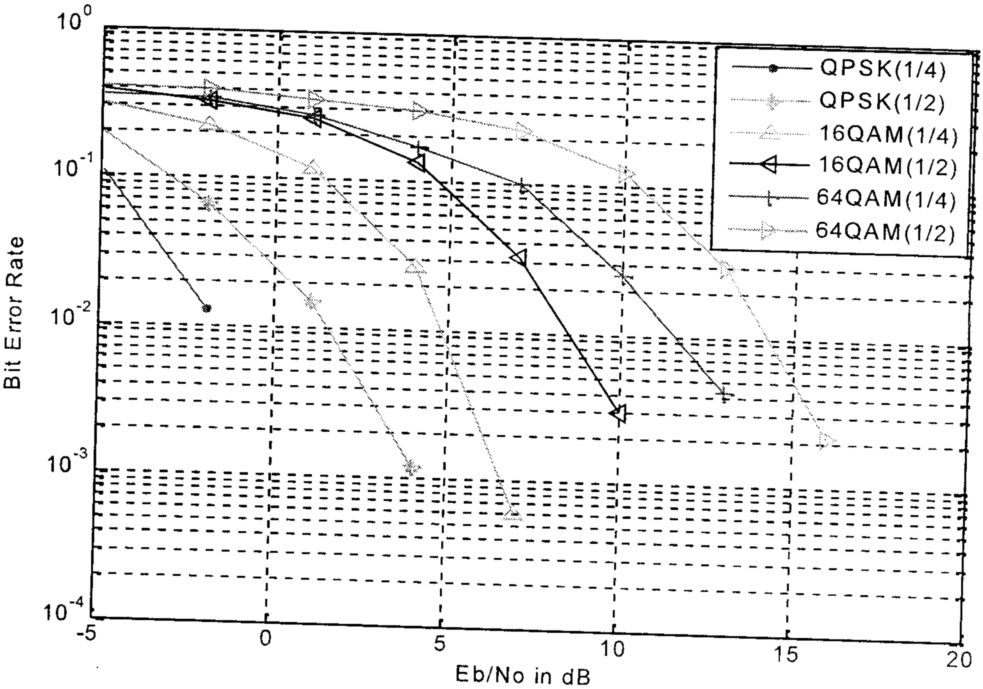


igure 3.12 BER performance of M-QAM BICM-OFDM through AWGN with different code rates

Table 3.6 M-QAM BICM-OFDM through AWGN with diff code rates

Modulation	SNR value (dB) at BER of 10^{-2}
	AWGN
16QAM(1/4)	5
16QAM(1/2)	8
64QAM(1/4)	11
64QAM(1/2)	14

Comparison of M-QAM BICM-OFDM with different code rates like ½, ¼ through GN is analyzed. For the same code rate, a lower modulation scheme provide better rmance with less E_b/N_o and for the same modulation scheme with lower code rate provides r performance.



igure 3.12 BER performance of M-QAM BICM-OFDM through Rayleigh with different code rates

Table 3.7 M-QAM BICM-OFDM through Rayleigh with diff code rates

Modulation	SNR value (dB) at BER of 10^{-2}
	Rayleigh
16QAM(1/4)	5
16QAM(1/2)	8.5
64QAM(1/4)	12
64QAM(1/2)	14

Comparison of M-QAM BICM-OFDM with different code rates like ½, ¼ through eigh Fading channel is analyzed. For the same code rate, a lower modulation scheme de better performance with less E_b/N_o and for the same modulation scheme with lower code provides better performance.

CHAPTER 4

CONCATENATED BICM-OFDM SYSTEM

PROPOSED SYSTEM MODEL

A block diagram of the proposed concatenation scheme of BICM-OFDM system is cribed in this Section. The proposed mixed codes block explanation is given below, other ck details can be referred in previous section.

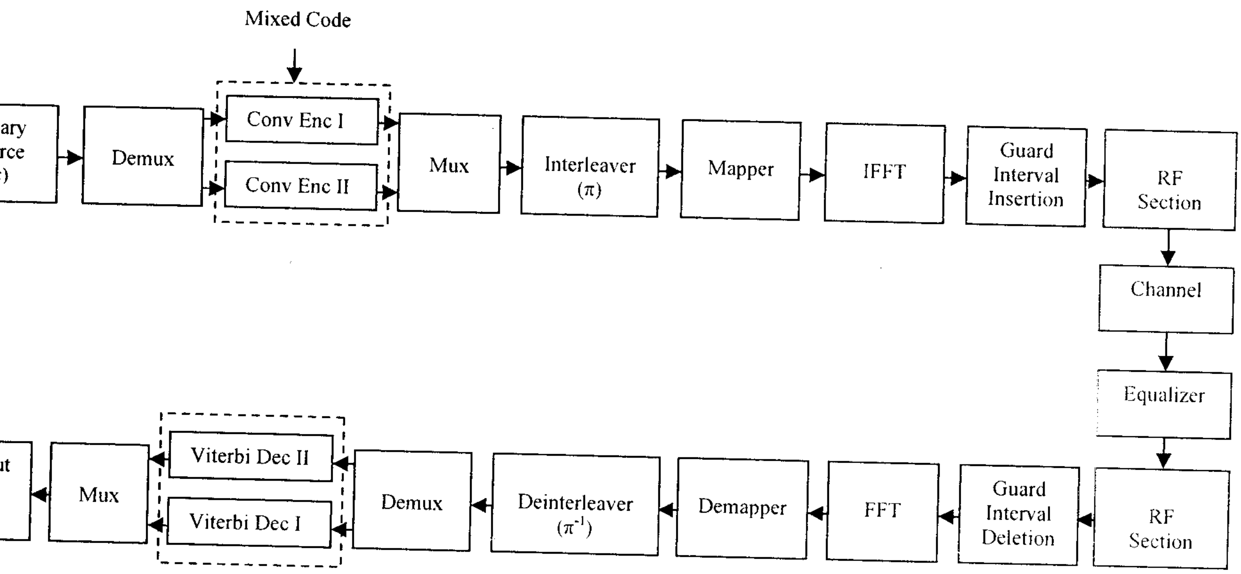
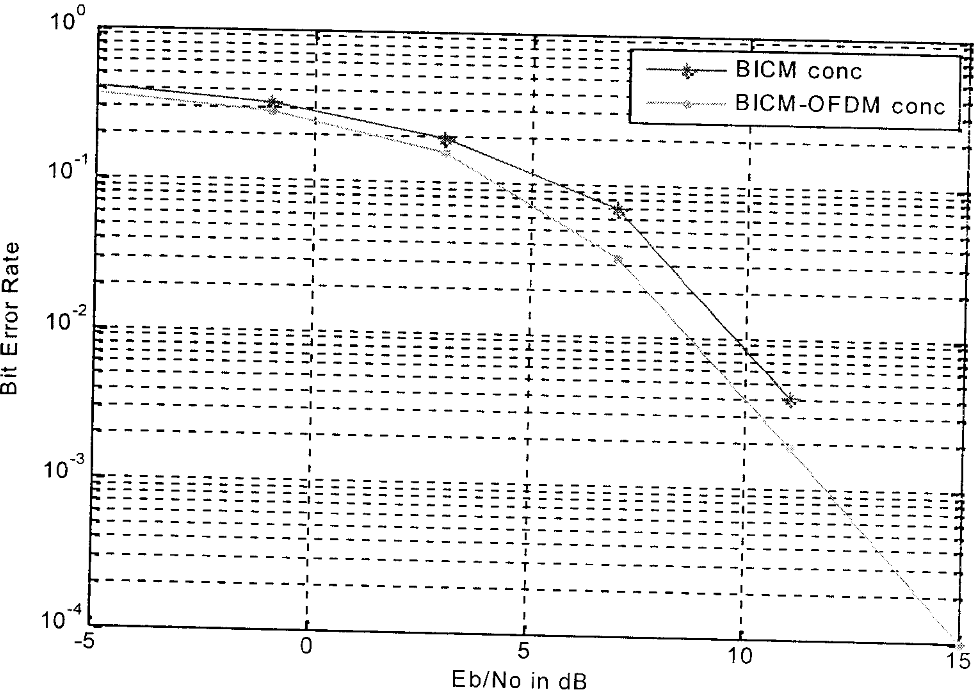


Figure 4.1 The Proposed BICM-OFDM Concatenation Scheme

For FEC, Convolution code encoder, which is the only mandatory coding scheme, is used 6]. First, a binary information block x of length L_x is divided into two binary sequences x_I x_{II} of lengths L_I and L_{II} respectively, using a demultiplexer. Each sequence x_i $i \in \{I, II\}$ is led by a suitable rate- k_i/n_i binary encoder c_i into a coded sequence $\bar{c}_i$. These binary lers could be simple convolutional or repetition codes. Coded sequences $\bar{c}_I$ and $\bar{c}_{II}$ are then ly combined by a multiplexer to create a coded sequence $\bar{c}$. The mixed code provides a le structure to control the convergence of the system.

If the length of the code L_x is divided equally then it is equally concatenated system, if ngth of the code L_x is divided unequally then it is

' RESULTS AND DISCUSSIONS

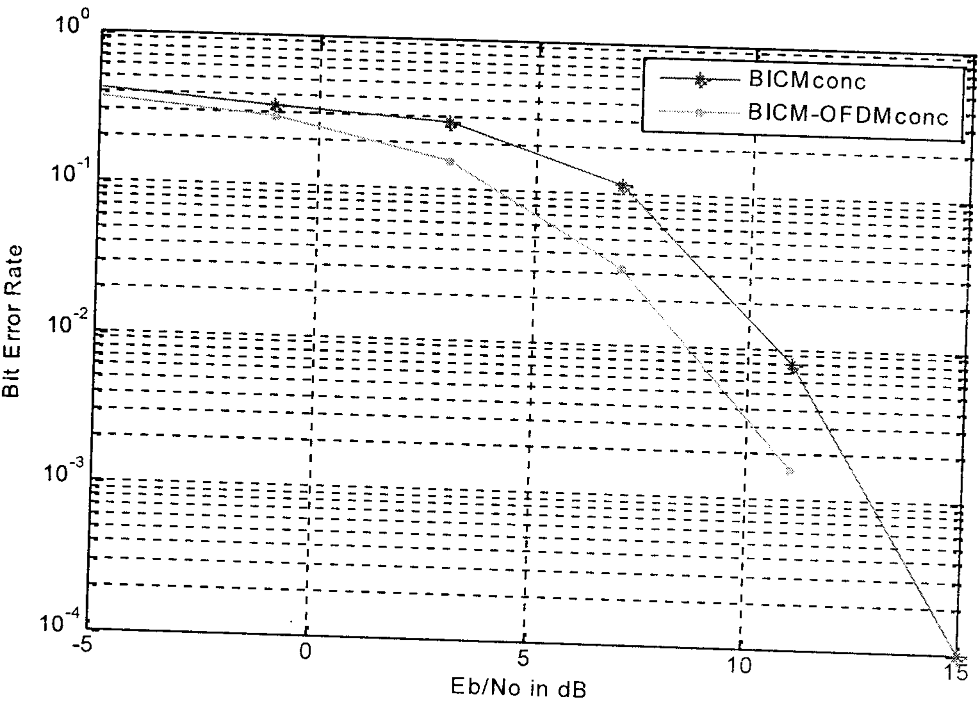


'igure 4.2 BER performance of 8QAM with BICM conc, BICM-OFDM conc through AWGN

Table 4.1 8QAM with different schemes through AWGN

BER value for 8 QAM with AWGN	SNR value (dB)	
	BICM Concatenated	BICM-OFDM Concatenated
10^{-2}	9.7	8.7

Comparison of BICM Concatenated and BICM-OFDM Concatenated for 8-QAM is zed over AWGN channel. The number of transmitted bits is 4200 with the code rate=1/2, length=3. At BER of 10^{-2}, the increase in required power for BICM-OFDM Concatenated is 1 dB when compared to BICM Concatenated scheme. So it's concluded that, proposed atenated BICM-OFDM scheme gives better performance by achieving high code gain.

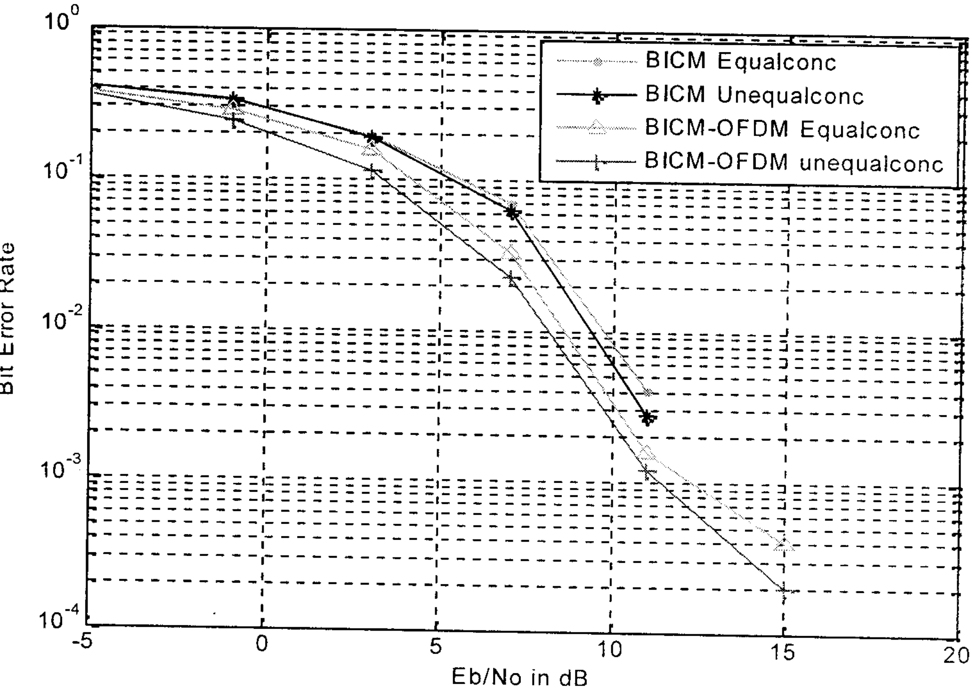


igure 4.3 BER performance of 8QAM with BICM conc, BICM-OFDM conc through Rayleigh

Table 4.2 8QAM with different schemes through Rayleigh

BER value for 8 QAM with Rayleigh	SNR value (dB)	
	BICM Concatenated	BICM-OFDM Concatenated
10^{-2}	10.7	8.5

Comparison of BICM Concatenated and BICM-OFDM Concatenated for 8-QAM is zed over Rayleigh Fading channel. The number of transmitted bits is 4200 with the code /2, code length=3. At BER of 10^{-2}, the increase in required power for BICM-OFDM tenated is about 2.2 dB when compared to BICM Concatenated scheme. So it's concluded roposed Concatenated BICM-OFDM scheme gives better performance over Rayleigh by ing high code gain 2.2 dB than AWGN which gives 1 dB.

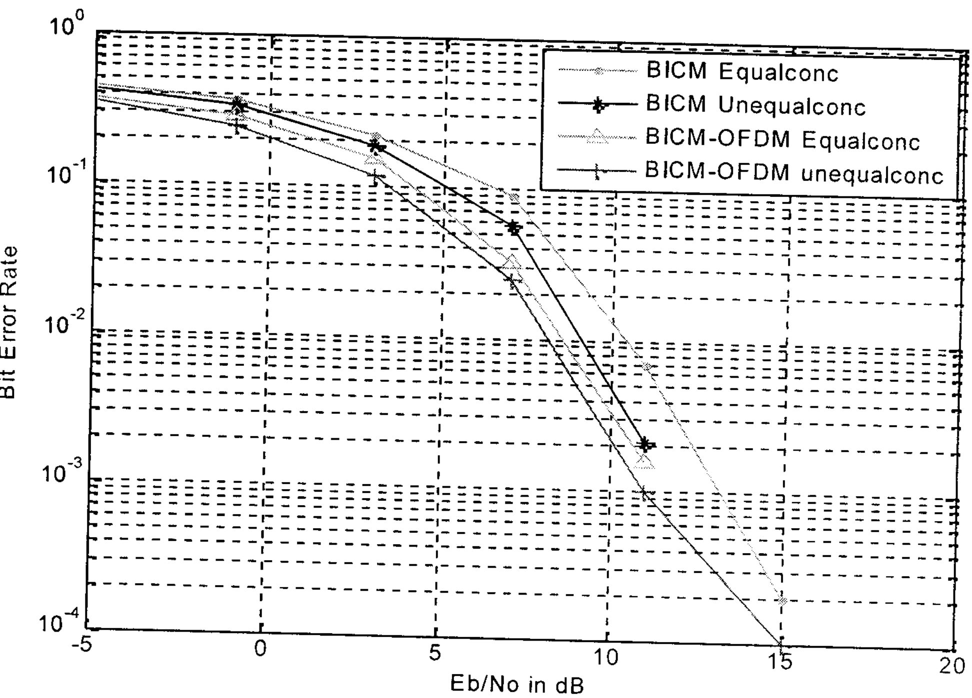


gure 4.4 BER performance of 8QAM with BICM equal, unequal conc, BICM-OFDM equal, unequal conc through AWGN

Table 4.3 8QAM with different schemes through AWGN

BER at 10^{-2} dB for 8 QAM	SNR value (dB) AWGN
BICM equal conc	9.8
BICM unequal conc	9.4
BICM-OFDM equal conc	8.6
BICM-OFDM unequal conc	8.1

BER performance of BICM equally, unequally concatenated and BICM-OFDM equally, ually concatenated for 8-QAM is analyzed over AWGN channel. The number of transmitted s 4200 with the code rate=1/2, code length=3. At BER of 10^{-2}, the increase in required r for BICM equally concatenated is about 1.7 dB when compared to BICM-OFDM unequal tenated code.



gure 4.5 BER performance of 8QAM with BICM equal, unequal conc, BICM-OFDM Equal, unequal conc through Rayleigh

Table 4.4 8QAM with different schemes through Rayleigh

BER at 10^{-2} dB for 8 QAM	SNR value (dB)
	Rayleigh
BICM equal conc	10.4
BICM unequal conc	9.1
BICM-OFDM equal conc	8.62
BICM-OFDM unequal conc	8.12

BER performance of BICM equally, unequally concatenated and BICM-OFDM equally, ally concatenated for 8-QAM is analyzed over Rayleigh channel. The number of nitted bits is 4200 with the code rate=1/2, code length=3. From the inference it's concluded he code gain achieved by BICM-OFDM unequal concatenation is 2.3 dB when compared CM equally concatenated code.

CHAPTER 5

CONCATENATED BIT INTERLEAVED CODED MODULATION-ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS

INTRODUCTION TO OFDMA

Mobile communication has gone through generations of evolution to bring enhanced and ue-added features and services to consumers. Second generation (2G), 2.5G, and third eration (3G) standards of mobile systems are being deployed while efforts are ongoing ard the development and standardization of beyond 3G (B3G) systems and, ultimately, to the h talk about fourth generation (4G) [16].

Researchers are currently developing frameworks for future 4G networks. Different arch programs, such as Mobile VCE, MIRAI, and DOCOMO, have their own visions on 4G ures and implementations. Some key features (mainly from the users' point of view) of 4G orks are stated as follows [17]:

- High usability: anytime, anywhere, and with any technology
- Support for multimedia services at low transmission cost
- Personalization
- Integrated services

For satisfying this demand, one of the main issues is to choose a multiple access ology for efficient share of the available scarce bandwidth among a large number of users, h can offer higher data rate and cope with the harsh mobile environment. The main ntages of OFDM over other communication modes are that it solves the problem of Inter ool Interference, has high bandwidth efficiency, scalable to high data rates, flexible ulation scheme which can be made adaptive, good at minimizing the effects of time rsion, no requirement of channel equalization, no need for phase lock of the local oscillators Besides, OFDM is easier to implement than code division multiple accesses by small anies, as CDMA networks need more experienced engineers.

An OFDMA symbol consists of a number of carriers equal to the size of the Fourier nsform. The OFDMA symbols are constructed from data, pilot, and null carriers:

:a carriers: for data transmission.

ot carriers: the magnitude and phase of these carriers are known to the receiver and they are d for channel estimation.

ll carriers: there is no transmitted energy on these carriers to enable the signal to naturally ay and prevent leakage of energy into adjacent channels.

To support multiple accessing, the data subcarriers are divided into groups that make up channels. The subcarriers that make up a sub channel are distributed across all of the lable carriers. Particular users are allocated a number of different sub channels to send and ive data. Fig.5.1 shows OFDMA frequency description.

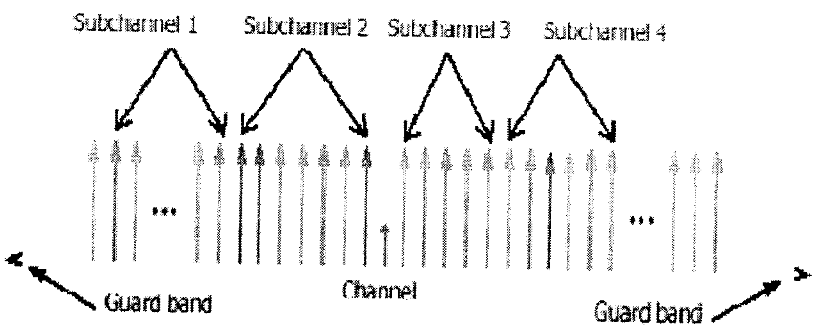


Figure 5.1 OFDMA Frequency Description

CONCATENATED BICM-OFDMA SYSTEM MODEL

The block diagram of the proposed concatenation scheme of BICM-OFDMA system r investigation is shown in Fig.5.2. At the transmitter side, the system uses concatenated s (Mixed codes) and interleaves the data. Next the data bits are entered serially to the ellation mapper.

DMA modulation:

At the input of the Inverse Fast Fourier Transform, for e.g., data selector was used to n OFDMA symbols which consist of 1024 carriers. This OFDMA symbols constructed from) data sub-carriers, 120 pilot carriers, 183 guard sub-carriers and one DC sub sub-carrier used center frequency. Before transmitting the OFDMA symbols, cyclic prefix is added to mitigate effect of the multipath. Before the data being transmitted, OFDM symbols are converted n parallel to serial.

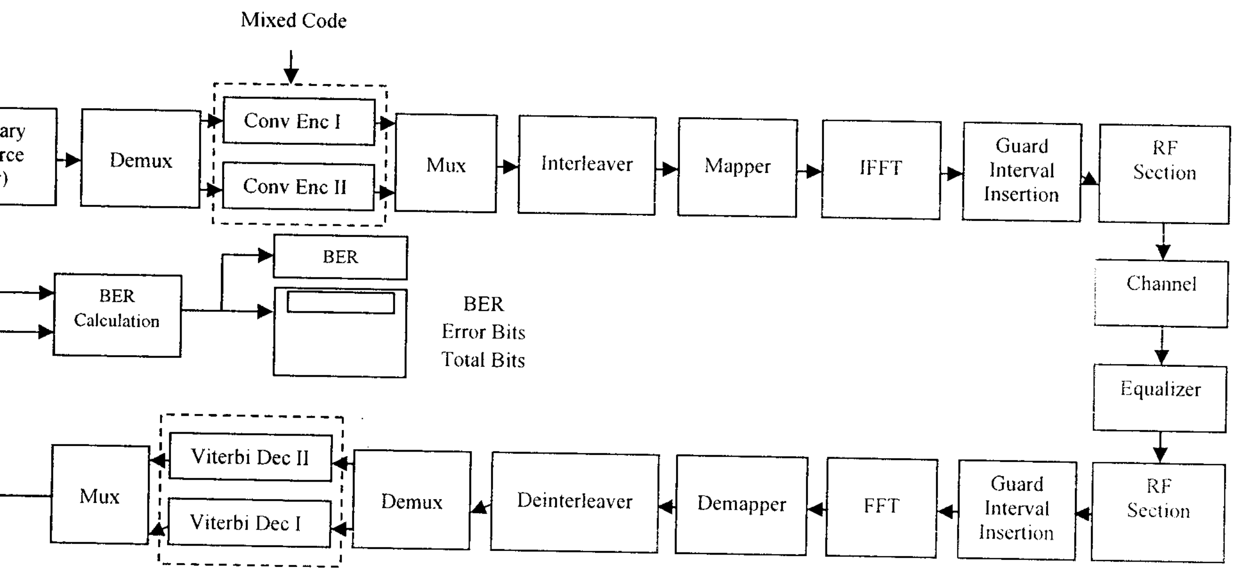


Figure 5.2 The Proposed Concatenated scheme of BICM-OFDMA System

eiver side:

At the receiver side, undo all steps which are done at the transmitter. At first, data are verted from serial to parallel. After that, we extract the data subcarriers and pilots from the)MA symbol.

calculation:

The BER is calculated using Communication tool box-Error Rate Calculation tool box.

3 RESULTS AND DISCUSSIONS

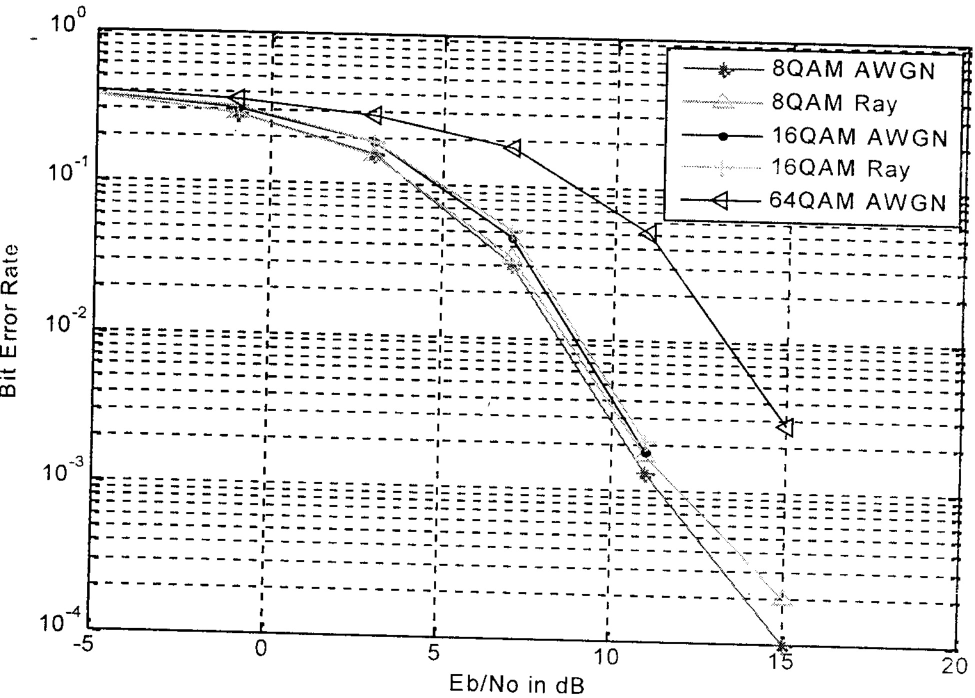


Figure 5.3 BER performance of M-QAM with BICM-OFDMA conc through AWGN and Rayleigh

Table 5.1 M-QAM with BICM-OFDMA Conc through AWGN and Rayleigh

BER at 10^{-2} for M-QAM with AWGN and Rayleigh	SNR value (dB)
8 QAM Awgn	8.5
8 QAM Rayleigh	9
64 QAM Awgn	13

BER performance of M-QAM with BICM-OFDMA through AWGN and Rayleigh channel is performed. The number of sub-carriers considered is 1705, with the FFT/IFFT length 4096, code rate=1/2, code length=3, users=6. As the M-ary increases it yields poor performance. For M=64 QAM, the increase in required power is about 4.5 dB when compared to 8 QAM through AWGN.

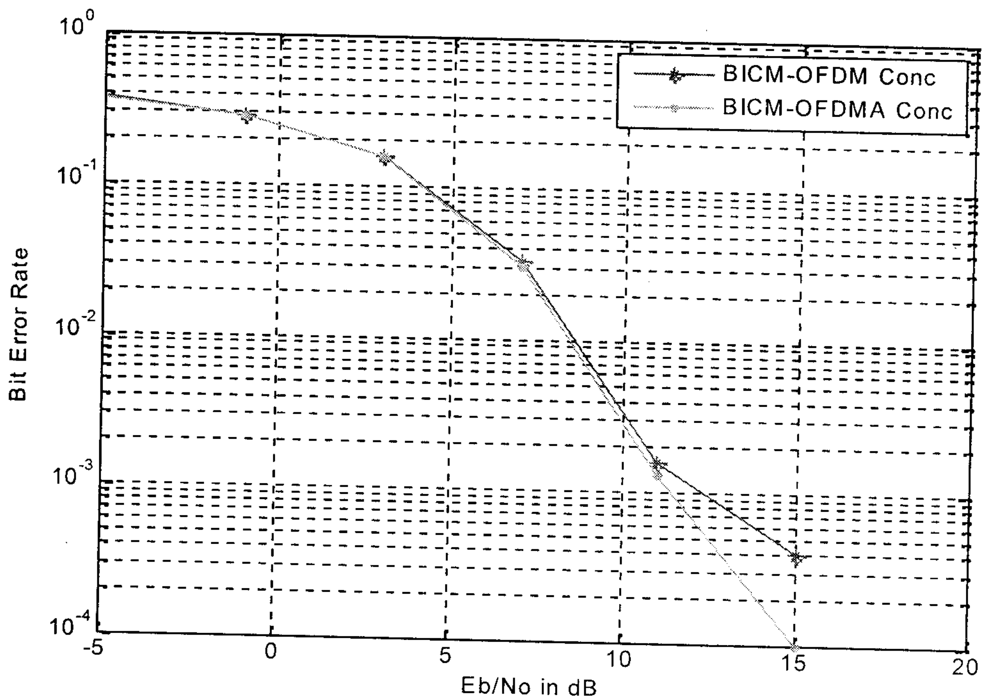


Figure 5.4 BER performance of 8QAM with BICM-OFDM Conc, BICM-OFDMA Conc through AWGN

Table 5.2 8QAM with BICM-OFDM Conc, BICM-OFDMA Conc through AWGN

BER value for 8 QAM with AWGN	SNR value (dB)	
	BICM-OFDM Conc	BICM-OFDMA Conc
$10^{-3.4}$	15	12.8

Comparison of BICM-OFDM Concatenated and BICM-OFDM Concatenated for 8-QAM analyzed over AWGN. The number of sub-carriers considered is 1705, with the FFT/IFFT gth of 4096, code rate=1/2, code length=3, users=6. At BER of $10^{-3.4}$, the increase in required wer for BICM-OFDM Concatenated (equal) is about 2.2 dB when compared to BICM-DMA Concatenated (equal). So it's concluded that, BICM-OFDMA gives better performance achieving high code gain

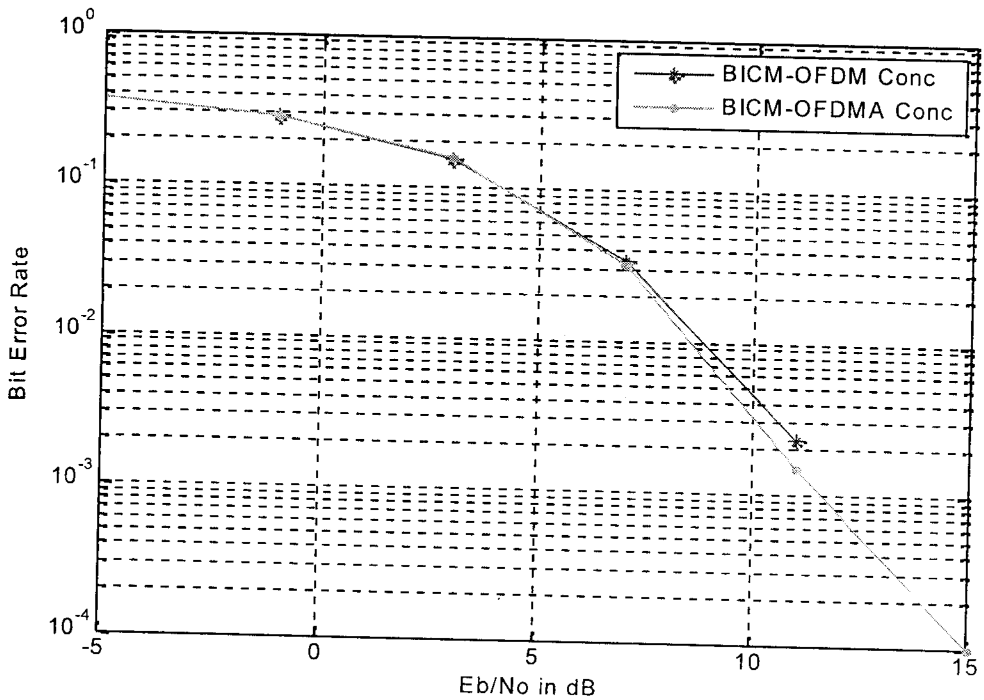


Figure 5.5 BER performance of 8QAM with BICM-OFDM Conc, BICM-OFDMA Conc through Rayleigh

Table 5.3 8QAM with BICM-OFDM Conc, BICM-OFDMA Conc through Rayleigh

BER value for 8 QAM with Rayleigh	SNR value (dB)	
	BICM-OFDM Conc	BICM-OFDMA Conc
$10^{-2.5}$	10.5	10

Comparison of BICM-OFDM Concatenated and BICM-OFDM Concatenated for 8-QAM analyzed over AWGN. The number of sub-carriers considered is 1705, with the FFT/IFFT gth of 4096, code rate=1/2, code length=3, users=6. At BER of $10^{-2.5}$, the increase in required ver for BICM-OFDM Concatenated (equal) is about 0.5 dB when compared to BICM-DMA Concatenated (equal). So it's concluded that, BICM-OFDMA gives better performance achieving high code gain.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

The proposed Concatenated BICM-OFDM system has been simulated and analyzed over AWGN and frequency non-selective, slow fading channel. The analysis and numerical results hows that, BICM method can provide better result for fading channel. And also, the impact of ignaling schemes like QAM and PSK is examined. It is observed that, the Concatenated BICM-OFDM outperforms CM, BICM and BICM-OFDM schemes in fading channel. From the mulation results, it is inferred that proposed BICM-OFDM with unequally concatenated codes nproves the performance over Rayleigh Fading Channel with high code gain. The proposed ystem simulated with different modulation and coding schemes. The BER vs E_b/N_o curves were sed to compare the performance of different modulation and coding scheme under AWGN and ding channel. It is observed that the lower modulation and coding scheme provides better rformance. Finally, the implemented system focus on the mandatory physical layer aspects of FDMA defined by The IEEE 802.16 standards. In OFDM, an advanced scheme known as FDMA, in which different users are allowed to use different subsets of the subcarriers. From simulation results, it is concluded that the proposed Concatenated BICM-OFDM with equally concatenated outperforms CM, BICM and BICM-OFDM schemes in fading channel h high code gain.

While it comes with many optional PHY layer features, which can be implemented to her improve the performance. The optional Block Turbo Coding (BTC) can be implemented enhance the performance of FEC. Also, here are several areas that warrant further estigation. In particular, the additional performance benefits provided by advanced antenna niques (e.g., MIMO, STC, and AAS) are of particular interest for IEEE 802.16e systems.

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e certify that Dr/Prof/Mr/Ms R. PADMASHINI affiliated to KUMARAGURU COLLEGE OF TECHNOLOGY has presented a paper on ERFORMANCE ANALYSIS OF BICM - OFDM SYSTEM at the IEEE-EDS sponsored ternational Conference on Nanoelectronics (ICONE-2011) organized by the epartment of Electronics and Communication Engineering during 24-26 Feb 2011.

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