ANALYSIS OF BER IN INTEROPERABILITY OF WI-FI (802.11A) AND WIMAX (802.16) USING CHANNEL CODING

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ABSTRACT

THIS PAPER STUDIES THE INTER-OPERABILITY PERFORMANCE ANALYSIS OF TWO WIRELESS STANDARDS WIMAX (802.16-2004) AND WI-FI (802.11A). EXTENSIVE SIMULATIONS ARE PERFORMED IN MATLAB IN ORDER TO PLOT BIT ERROR RATE (BER) AGAINST THE SIGNAL-TO-NOISE RATIO (SNR). THE BASIC AIM OF THIS THESIS IS TO ANALYZE THE PERFORMANCE WHEN INTEROPERABILITY IS CONSIDERED BETWEEN WIMAX AND WI-FI AND TO STUDY HOW VARIOUS CHANNEL CODING SCHEMES COULD BE FEASIBLE IN THIS RESPECT.

ANALYSIS HAS BEEN DONE BY STARTING CONSIDERING INDIVIDUAL STANDARDS 802.11A AS WELL AS FOR 802.16 AND THEN THE WHOLE SYSTEM IS CONSIDERED. THEORETICAL AND SIMULATED CURVES ARE PLOTTED FOR BER VS. SNR. CHANNEL CODING (CONVOLUTIONAL CODES (FOR WI-FI) AND FOR WIMAX (CONCATENATED REED SOLOMON-CONVOLUTIONAL CODING (RS-CC) CODING) HAS BEEN APPLIED SO AS TO MINIMIZE THE BER AND TO IMPROVE THE SYSTEM PERFORMANCE.

MOREOVER, SINCE THE CHANNEL CODING ADDS REDUNDANCY OF BITS FOR IMPROVEMENT OF BER THERE IS A NEED OF MORE BANDWIDTH IN THIS REGARD. HOWEVER, THERE ARE CASES IN WHICH LIMITED BANDWIDTH IS AVAILABLE SO IN THIS REGARD PUNCTURING OF THE CONVOLUTIONAL CODES IS DONE AND THE PERFORMANCE CAN BE ANALYZED BY LOOKING AT BOTH THE SIMULATION CURVES, ONE HAVING 'CODE RATE=1/2' AND THE OTHER WITH 'CODE RATE=2/3.'

KEYWORDS

Interoperability, WiMAX, wiFi, channel coding, performance analysis, AWGN channel, Rayleigh channel

1. INTRODUCTION

Globalization coupled with phenomenal improvement in communication means has brought a change that was a dream larger than life, hardly a decade ago. Now the times have changed, we are more toward the use of complication technologies to communicate efficiently; the researchers are attempting hard to find more and improved ways to achieve better communication technologies and the incredible data rates which one had ever dreamt of.

Thanks to the modern technology and the presences of large number of standard, researchers are working to make the inter-operability possible between different standards. Now to provide end to end coverage of data networks inter-operability has to be there. No matter what the back haul is based upon the end users should be facilitated with more and more benefits.

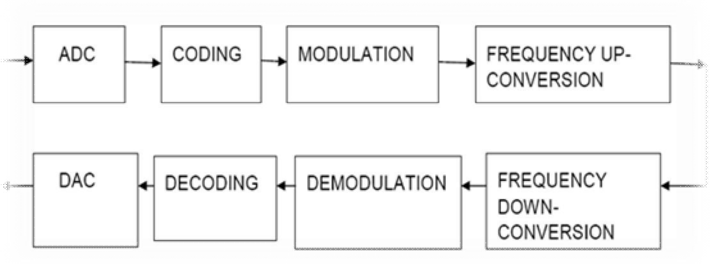
The overall paper novelty consisted of analyzing the performance in inter-operability of WiMAX (802.16) and Wi-Fi (802.11a).The effect of channel coding can also be seen and the improvement in Bit Error Rate can be noticed that fluctuates with coding rate also. The curves that are plotted show both the theoretical and the simulated BER for coding rate of CR=1/2 and coding rate of 2/3.

1.1 BASIC OBJECTIVE

The basic aim of this thesis is to provide an analysis of Bit Error Rate when the inter-operability factor is considered, like what is the effect on system performance when one standard of wireless communication is transformed to other .more over how the coding rate effects the bit error rate and to what extent the erroneous communication can be controlled. The channels to be considered here are Additive White Gaussian Noise as well as Ray-Leigh multipath fading channel.

2. 0 BASIC BLOCKS OF DIGITAL COMMUNICATION SYSTEM

Basic block diagram of a digital communication system is



[Fig 2.1]: Block diagram of a Basic Digital Communication System

2.1 BER – BIT ERROR RATE

Bit error rate is a method of assessing the digital wireless transmission and thus is a very good way of increasing the system integrity and even the robustness can be improved by calculating the bit error rate and if it is below a certain threshold, steps can be taken to improve it

Bit Error rate = Number of errors / Number of bits transmitted

2.2 CODING IN COMMUNICATION SYSTEM

The main aim of any system is to provide error free communication. The coding block of any communication system consists of two stages, first is the source encoder where the bits from the information source are compressed to reduce the bandwidth requirements and second stage is the channel encoder where controlled redundancy is built in the data stream to allow for detection and error correction. However this paper is mainly related to the channel coding part so the source coding description is skipped.

2.2.1 Channel Coding

Modern error correction coding is considered to have started with the work of Shannon in 1940’s [3]. Shannon’s seminal work proved that it is possible to send information across noisy channels up to a certain bit rate known as the channel capacity, such that the information is received practically error free. Different types of channel coding are as follows

2.2.1.1 Block Codes

Then the first error correction codes were developed by Hamming who described an operation which mapped sequences of bits into longer sequences [4].

2.1.2 Reed-Solomon Codes (RS-Codes)

The Reed-Solomon encoder takes a block of digital data and adds extra "redundant" bits. Errors occur during transmission or storage for a number of Reasons. The Reed- Solomon decoder processes each block and attempts to correct errors and recover the original data..

2.2.1.3 Convolutional Codes (CC-Codes)

The first convolution code was presented in 1955, by Elias [5]. The convolution code is one whose output bits are the result of a convolution of some convolution kernel. Convolution codes can be systematic or non-systematic. Systematic codes contain a portion of Input bits in output but the non-systematic codes do not contain any of the bits of input in output. In general, convolution codes have some desirable properties over block codes, most of all that they can be used in real-time applications where block buffering and latency is unacceptable.

Convolutional codes are commonly specified by three parameters; (n, k, and m)

Where:

n = number of output bits

k = number of input bits

m = number of memory registers

The quantity k/n called the code rate is a measure of the efficiency of the code.
Convolutional coding combined with trellis decoding is able to decode any coded message containing 't' errors in a block of m bits given the minimum free distance; Dm of the code follows the following equation

$$\boxed{D_m \leq 2t-1}$$

2.2.1.4 Punctured Convolutional Codes

For the special case of k = 1, the codes of rates ½, 1/3, ¼, 1/5, 1/7 are sometimes called mother codes [6]. We can combine these single bit input codes to produce punctured codes which give us code rates other than 1/n.

By using two rate ½ codes together, and then just not transmitting one of the output bits we can convert this rate ½ implementation into a 2/3 rate code. 2 bits come and 3 go out. This concept is called puncturing. On the receive side, dummy bits that do not affect the decoding metric are inserted in the appropriate places before decoding.

2.3 CHANNEL MODELS AND EFFECT OF NOISE ON COMMUNICATION SYSTEMS

The noise is present everywhere in a system. Noise can be any unwanted signal that is superimposed on the original signal and degrades its performance and hence makes it un-decodable at the receiver end. In this paper, I have considered two types of channel models

(i) AWGN Channel Model

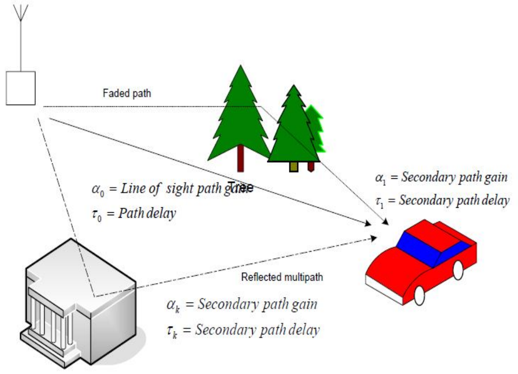
(ii) Ray-Leigh Fading channel model.

2.3.1 AWGN Channel Model

AWGN is a channel model which affects the communication system with linearly addition of white noise with a constant spectral density. This model does not account for fading, multipath, dispersion. [7]

2.3.2 RAY- LEIGH Fading Channel Model

The rapid fluctuation of the amplitude of a signal over a relatively small distance is referred to as fading. Interference between two or more versions of the transmitted signal can result in different propagation delays at the receiver and this is known as multipath.



[Fig 2.2]: Multipath scattering of the signal

3.0 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

OFDM is a combination of modulation and multiplexing. In OFDM the signal itself is first split into independent channels, modulated by data and then re-multiplexed to create the OFDM carrier [8]. OFDM is a special case of FDM.

[Fig 3.1]: All cargo on one truck vs. splitting the shipment in to more than one

This is how the ofdm works by splitting the main signal into small signal and then modulating each of the splitted signals by the sub carriers.

Because of the efficient ways of ofdm to avoid inter symbol interference and reducing the noise impact it is being adopted by Wi-Fi and WiMAX moreover it has become the choice for the upcoming communication standards like LTE and 4th generation of mobile system.

3.1 BASIC CONCEPT OF OFDM

OFDM basically belongs to a class of modulation scheme called multi-carrier modulation which works mainly by dividing a higher bit stream into many parallel lower bit rate streams

The spectrum of multi-carrier system does not allow the sub carriers to overlap and hence made the waste of precious bandwidth which is critical in many communication systems. However if we look at the spectrum of OFDM, overlapping is allowed and hence a lot of bandwidth is saved through this.

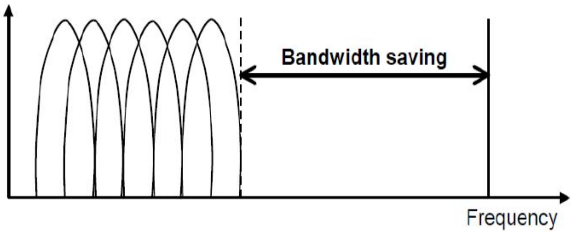


Fig [3.2]: SPECTRUM OF OFDM

3.2 PROS AND CONS OF OFDM

3.2.1 Advantages [11]

- Can easily adapt to severe channel conditions without complex equalization
- Robust against Inter symbol interference (ISI) and fading caused by multipath propagation.
- Efficient implementation using FFT.
- High spectral efficiency

3.2.2 Disadvantages [11]

- Sensitive to Doppler shift.
- Sensitive to frequency synchronization problems.
- High peak to average power ratio.

4.0 WIMAX (WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS) IEEE 802.16-2004

To accelerate the growth of broadband services and to make it wireless WiMAX standard was proposed which is capable of both providing the fixed wireless broadband as well as the mobile broadband services.

4.1 WiMAX Evolution

Basically there are three stages for the evolution of WiMAX first generation LOS broadband systems; second generation NLOS broadband system and third generation standard based broadband wireless systems

4.1.1 First Generation – LOS

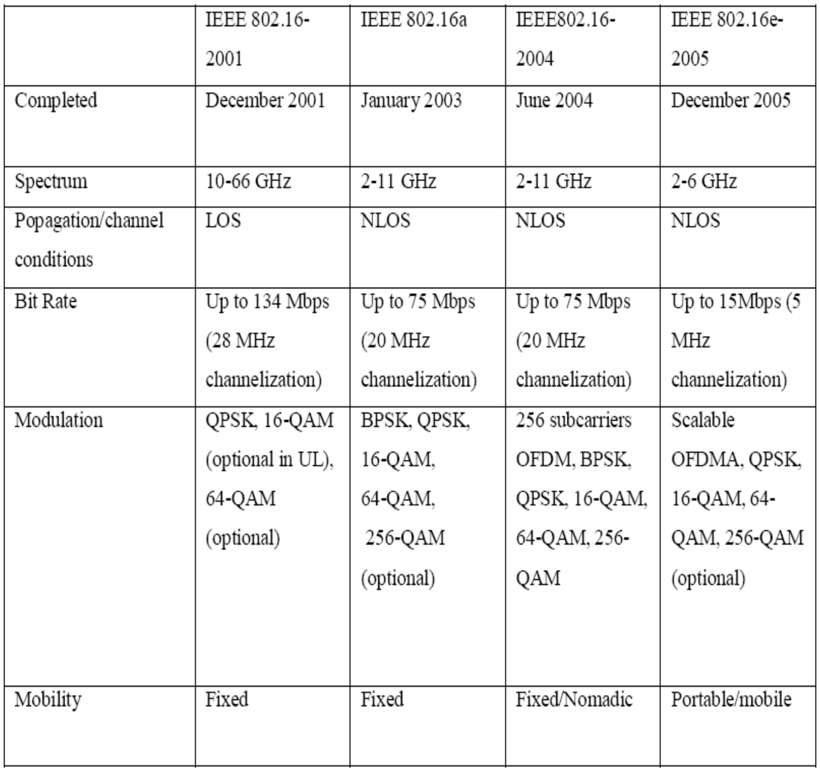
In the early period only Line of sight type broadband systems were available that uses high power transmitter to provide wirelessly the connection to the subscribers, covers distances of up to 35 miles.

4.1.2 Second Generation NON-LOS

The LOS broadband systems did not gain much popularity so the engineers and researchers came up with a new one that does not require line of sight. Cellular type of technique is used in this type of broadband. This type of system is capable of transmitting up to few megabits with the help of Orthogonal Frequency Division Multiplexing technique.

4.1.3 Third Generation Standard Based Broadband System

The IEEE formed a group by the name of 802.16 to develop a standard for wireless metropolitan area networks in 1998. The main motivation was to allow for inter-operability among different wireless equipments and to provide high speed connections to places that could not obtain fiber. In the beginning the 802.16 group focused on developing solutions in the 10-66 GHz band. Since the formation of this group a lot of work has been done to develop standards for both fixed and mobile broadband wireless access.



	IEEE 802.16-2001	IEEE 802.16a	IEEE802.16-2004	IEEE 802.16e-2005
Completed	December 2001	January 2003	June 2004	December 2005
Spectrum	10-66 GHz	2-11 GHz	2-11 GHz	2-6 GHz
Popagation/channel conditions	LOS	NLOS	NLOS	NLOS
Bit Rate	Up to 134 Mbps (28 MHz channelization)	Up to 75 Mbps (20 MHz channelization)	Up to 75 Mbps (20 MHz channelization)	Up to 15Mbps (5 MHz channelization)
Modulation	QPSK, 16-QAM (optional in UL), 64-QAM (optional)	BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)	256 subcarriers OFDM, BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM	Scalable OFDMA, QPSK, 16-QAM, 64-QAM, 256-QAM (optional)
Mobility	Fixed	Fixed	Fixed/Nomadic	Portable/mobile

[Table 4.1]: Summary of IEEE 802.16 standards [11]

4.2 IEEE 802.16-2004 Specifications:

The IEEE 802.16-2004 is known as ‘Fixed WiMAX’ and supports multiple physical specifications. Initially, 802.16 was developed to operate in LOS environments by using single carrier transmission but soon after this technologies like OFDM and OFDMA has been included in the standard to allow for the operation in NLOS conditions.

4.2.1 Frequency Spectrum

The IEEE 802.16-2004 which is commonly known as the standard for Fixed WiMAX operates in the band of 2GHz-11GHz. [13]

4.2.2 Bandwidth

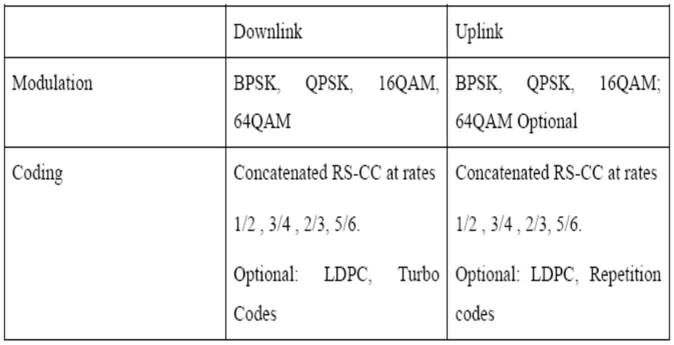
The bandwidth of the channel can be an integer multiple of 1.25MHz, 1.5MHz, 1.75MHZ and 2MHz.

4.2.3 Error Control

The standard defines a concatenated code with Reed-Solomon as the outer code and Convolutional code as the inner code. The Convolutional code is takes care of the individual bit errors while Reed-Solomon corrects burst errors at byte level. Some optional codes like turbo codes and LDPC codes etc can also be applied to lower the BER.

4.2.4 Modulation Technique

A variety of modulation techniques is supported by WiMAX that depend upon the channel condition and the bit rate required



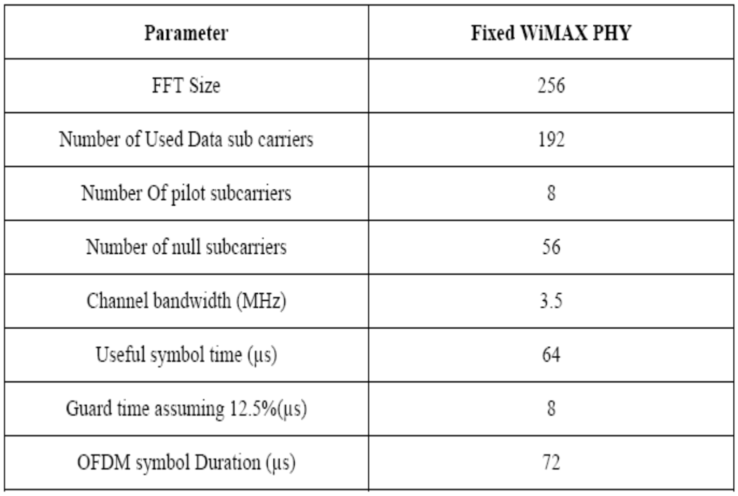
	Downlink	Uplink
Modulation	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM; 64QAM Optional
Coding	Concatenated RS-CC at rates 1/2 , 3/4 , 2/3, 5/6. Optional: LDPC, Turbo Codes	Concatenated RS-CC at rates 1/2 , 3/4 , 2/3, 5/6. Optional: LDPC, Repetition codes

Table [4.3] modulation schemes that are supported by 802.16-2004 [13]

4.2.5 OFDM Parameters

For the fixed WiMAX the number of subcarriers is 256 out of which 192 are used for data and 8 are used for pilots and the remaining are null subcarriers. Since the FFT size is fixed at 256 the spacing between the subcarriers varies with the channel bandwidth [11].

Some of the OFDM parameters are summarized in the table below



Parameter	Fixed WiMAX PHY
FFT Size	256
Number of Used Data sub carriers	192
Number Of pilot subcarriers	8
Number of null subcarriers	56
Channel bandwidth (MHz)	3.5
Useful symbol time (μs)	64
Guard time assuming 12.5%(μs)	8
OFDM symbol Duration (μs)	72

Table 4.4 OFDM parameters for WiMAX standard 802.16-2004 [13]

4.2.6 Encoding

Concatenated RS-CC encoder is used. The reed Solomon coding is derived from RS (N=255, k=239, T=8) using Galois Field GF [12].

Where;

N = Number of bytes after coding.

K= Number of bytes before Encoding

T= Number of bytes that can be corrected

After reed Solomon coding, Convolutional coding is performed on each RS block which has a coding rate of 1/2 and constraint length of 7 with generator polynomials 171_{OCT} and $133_{OCT.}$

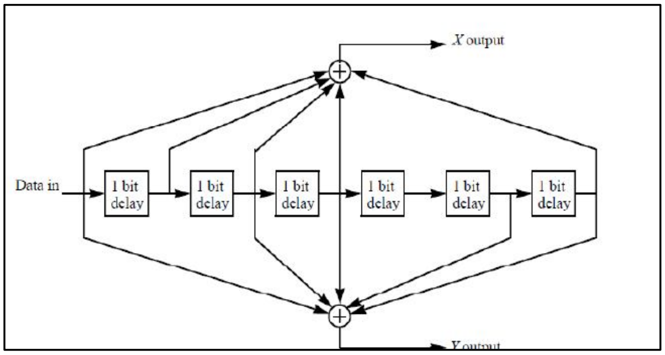


Fig [4.1]: Convolutional encoder CR=1/2 [13]

5. 0 WI-FI (WIRELESS FIDELITY) IEEE 802.11(A)

Wi-Fi stands for Wireless Fidelity this is basically a Wireless Local Area Network that is used to provide the interconnectivity wirelessly. It has gained popularity in companies even used for point to point link as it works on free ISM band. Railways, airport, cafes, restaurant where people are in need of wireless internet network it provides a feasible way for them to connect to the outer world.

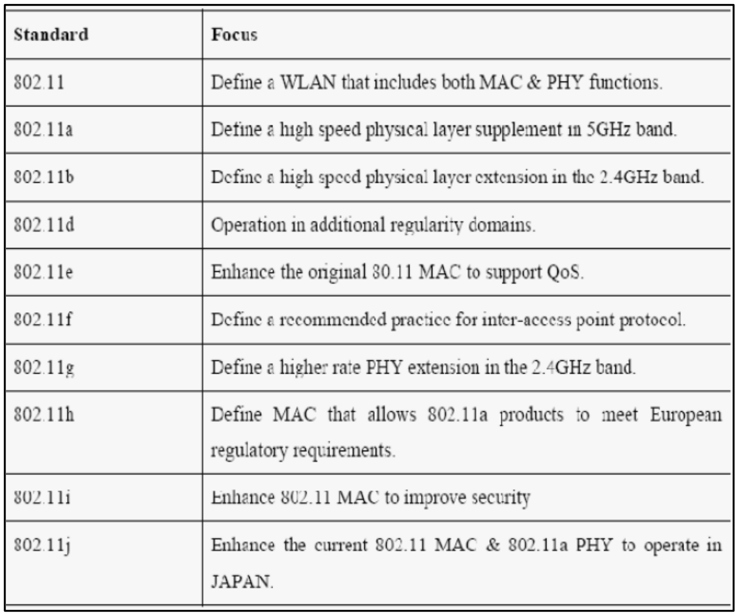
5.1 EVOLUTION

With the end of era of dialup and the merging of wired broadband services such as DSL and the emergence of laptops so people feel like there should be a wireless connection that can give an approximate speed of the wired but should be secured as well so IEEE established the 802.11 group. The number 802 refers to all the standards dealing with local and metropolitan area networks and the suffix 11 was assigned for WLANs. IEEE 802.11 cannot be thought of as a one standard but in reality it consists of many different standards. The first was the 802.11 standard and was intended to work in 2.45GHz band and provide a data rate of 1 and 2Mbit/s.

It soon became obvious that higher data rates were demanded and two sub-groups were formed in which one group 802.11a investigated OFDM and the other 802.11b attempted to retain the DSSS approach which was used in the original 802.11 standard. Additionally a number of further subgroups were formed which all were dealing with amendments or additions to the 802.11 standard.

5.2 Different standard of IEEE 802.11

Below is a table that summarizes different IEEE 802.11 standards and their main focuses:

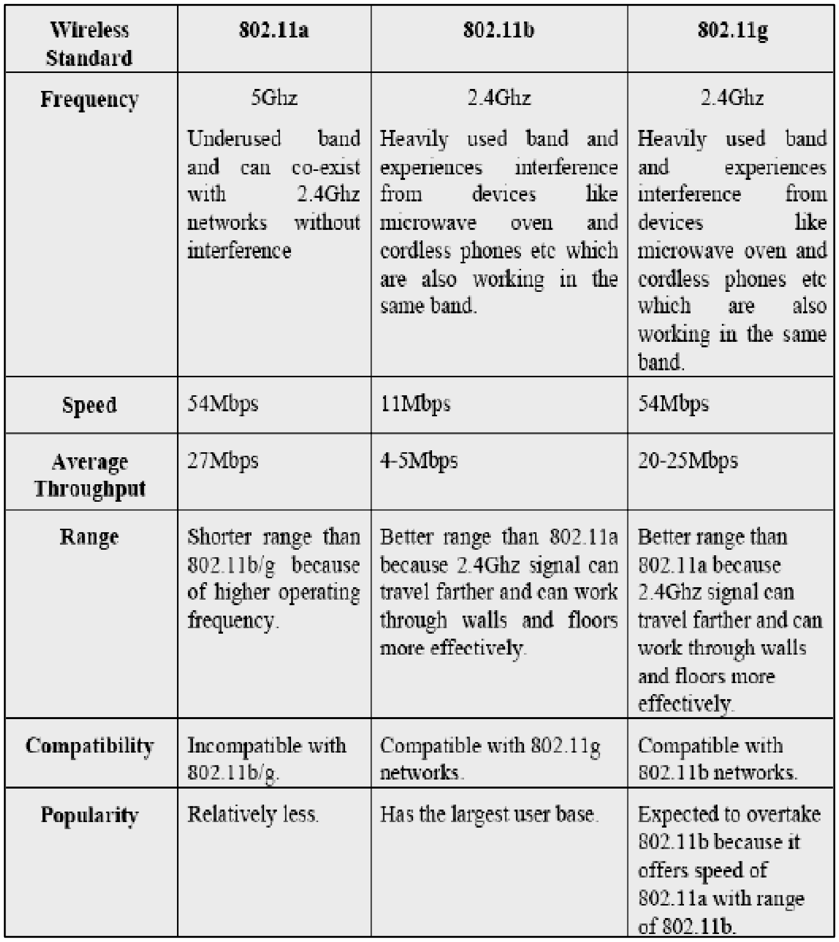


Standard	Focus
802.11	Define a WLAN that includes both MAC & PHY functions.
802.11a	Define a high speed physical layer supplement in 5GHz band.
802.11b	Define a high speed physical layer extension in the 2.4GHz band.
802.11d	Operation in additional regularity domains.
802.11e	Enhance the original 80.11 MAC to support QoS.
802.11f	Define a recommended practice for inter-access point protocol.
802.11g	Define a higher rate PHY extension in the 2.4GHz band.
802.11h	Define MAC that allows 802.11a products to meet European regulatory requirements.
802.11i	Enhance 802.11 MAC to improve security
802.11j	Enhance the current 802.11 MAC & 802.11a PHY to operate in JAPAN.

[Table 5.1]: 802.11 different standards [12]

5.3 Comparison of 802.11 standards

Different standards were derived from the original 802.11 IEEE standard. No one is best but depends upon the channel conditions, the distance and the interference issues. Below is a summary of the three most popular WLAN standards namely 802.11a, 802.11b and 802.11g, which are collectively known as WI-FI technologies



Wireless Standard	**802.11a**	**802.11b**	**802.11g**
Frequency	5Ghz Underused band and can co-exist with 2.4Ghz networks without interference	2.4Ghz Heavily used band and experiences interference from devices like microwave oven and cordless phones etc which are also working in the same band.	2.4Ghz Heavily used band and experiences interference from devices like microwave oven and cordless phones etc which are also working in the same band.
Speed	54Mbps	11Mbps	54Mbps
Average Throughput	27Mbps	4-5Mbps	20-25Mbps
Range	Shorter range than 802.11b/g because of higher operating frequency.	Better range than 802.11a because 2.4Ghz signal can travel farther and can work through walls and floors more effectively.	Better range than 802.11a because 2.4Ghz signal can travel farther and can work through walls and floors more effectively.
Compatibility	Incompatible with 802.11b/g.	Compatible with 802.11g networks.	Compatible with 802.11b networks.
Popularity	Relatively less.	Has the largest user base.	Expected to overtake 802.11b because it offers speed of 802.11a with range of 802.11b.

Table [5.2]: comparison of 802.11a, 802.11b and 802.11g [12]

5.4 IEEE 802.11(a) SPECIFICATIONS:

IEEE 802.11a operates in the 5GHz band and was established to avoid overcrowding in the 2.45GHz band and to provide data rates of up to 54Mbps by defining a physical layer based on orthogonal frequency division multiplexing.

5.3.1 Frequency Bands:

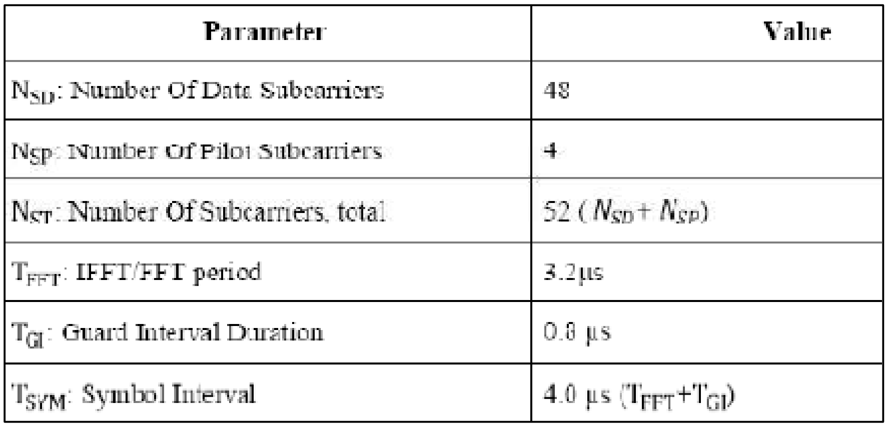
The radio frequency local area network system was initially aimed to work on 5.15-5.25, 5.25-5.35 and 5.725-5.825GHz called the Unlicensed National Information Structure (UNII) bands [13]. The transmit powers in the 5.15-5.25, 5.25-5.35 and 5.725-5.825Ghz are limited to 40, 200 and 800mW respectively.

5.3.2 Modulation and coding

IEEE 802.11a specifies OFDM as its modulations format so as to enable higher data rates. In 802.11a OFDM with 64 sub-carriers is specified. However, out of these 64 subcarriers only 52 are used to carry information and other are null carriers and are reserved for future uses. Out of the 52 sub-carriers, 48 are used for data and remaining for are used for pilots and these pilots should be BPSK modulated by a pseudorandom sequence to prevent spectral lines [13].

The 48 data subcarriers can be modulated using any of the schemes specified in the standard like BPSK, QPSK, 16-QAM or 64-QAM. For FEC, 802.11a uses a Convolutional encoder with a constraint length k = 7 and the permissible coding rates of 1/2, 2/3, 3/4 depending on the data rate required.

5.3.3 Timing Related Parameters:

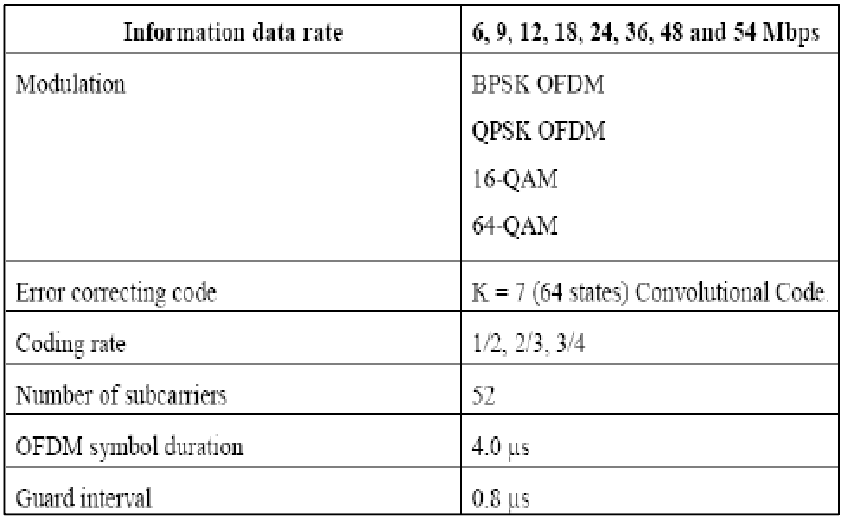


Parameter	Value
N_{SD}: Number Of Data Subcarriers	48
N_{SP}: Number Of Pilot Subcarriers	4
N_{ST}: Number Of Subcarriers, total	52 ($N_{SD}+N_{SP}$)
T_{FFT}: IFFT/FFT period	3.2μs
T_{GI}: Guard Interval Duration	0.8 μs
T_{SYM}: Symbol Interval	4.0 μs ($T_{FFT}+T_{GI}$)

Table [5.3] Timing related parameters [12]

5.3.4 OFDM Physical Layer Parameters

Below is the table containing the OFDM parameters:



Information data rate	6, 9, 12, 18, 24, 36, 48 and 54 Mbps
Modulation	BPSK OFDM QPSK OFDM 16-QAM 64-QAM
Error correcting code	K = 7 (64 states) Convolutional Code
Coding rate	1/2, 2/3, 3/4
Number of subcarriers	52
OFDM symbol duration	4.0 μs
Guard interval	0.8 μs

Table [5.4] OFDM parameters

5.3.5 Convolutional Encoder

The Convolutional encoder specified in the standard of 802.11a has a constraint length of k = 7 and generator polynomials of industry standard g0 = 133 and g1 = 171. The bit denoted as ‘A’ will be output from the encoder before the bit denoted as ‘B’. Decoding by viterbi algorithm is preferred [13]

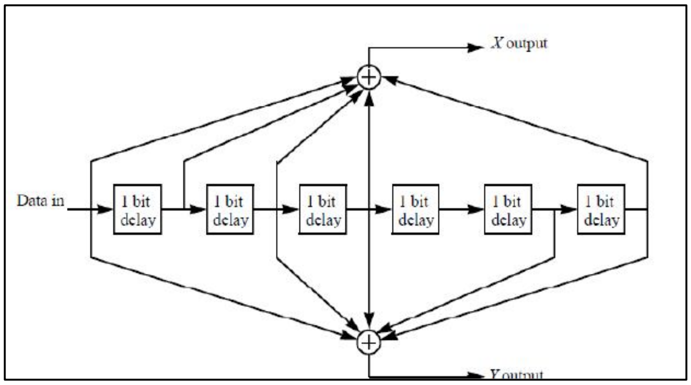


Fig [5.1]: Convolutional encoder CR=1/2

6.0 SIMULATION MODEL AND RESULTS

The main objective of this paper is to analyze how the channel coding(with puncturing bits and without puncturing bits) effects the performance and lowers the BER of Wi-Fi and WiMAX and in last when the inter-operatibility factor is considered what is the effect in overall performance of the system. The communication system designed takes into account all the mandatory blocks which are necessary in a complete design and the results are shown by plotting the bit error curves against multiple signals to noise ratio values. The physical layer parameters are in accordance with the IEEE standard 802.16-2004 for WiMAX and 802.11a for Wi-Fi. The whole system can be illustrated by the figure below:

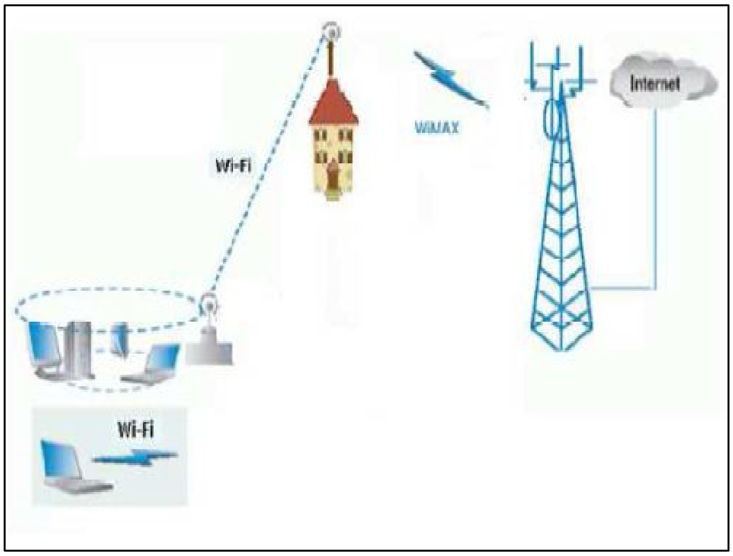


Fig [6.1]: THE OVERALL SYSTEM

6.1 SIMULATION

The overall system general block diagram can be represented as:

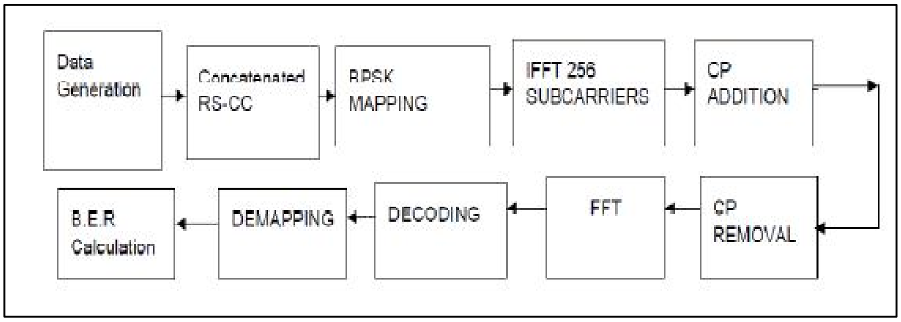


Fig [6.2]: General block diagram of the whole system

In the initial phase individual standards were simulated and graphs were plotted for their BER vs. SNR .As both the channel type Rayleigh and AWGN indices the noise differently so they have their different effect on the system because of the fading and reflected paths of signal are considered in Rayleigh channel model and after successful simulation of these blocks, they all were combined together into a complete design. The figure above is drawn according to the flow of the data assumed in the simulation; data conversion is achieved by zero padding when going from one standard to another.

6.2 SIMULATION OF INDIVIDUAL BLOCKS

Individual blocks are simulated separately and then they are merged to form the complete system.

6.2.1 WiMAX BLOCK SIMULATION

The WiMAX standard was simulated following the IEEE802.16 document which is the Standard for fixed WiMAX. The block diagram is drawn below:

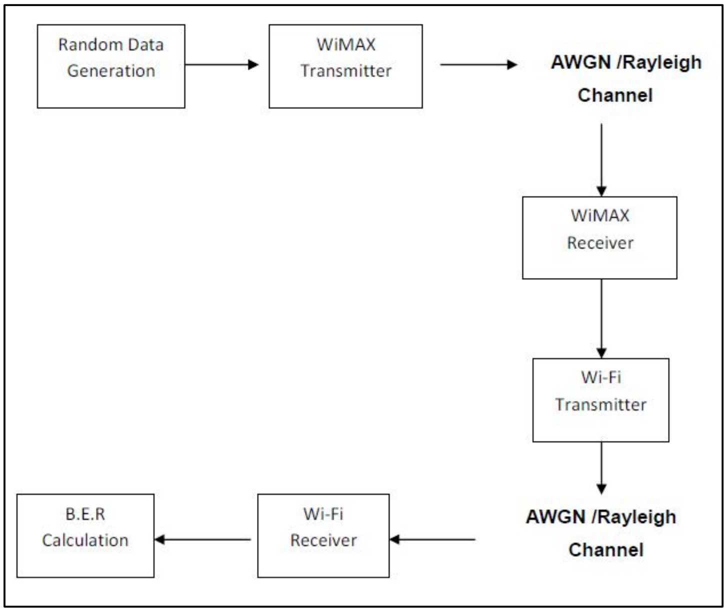


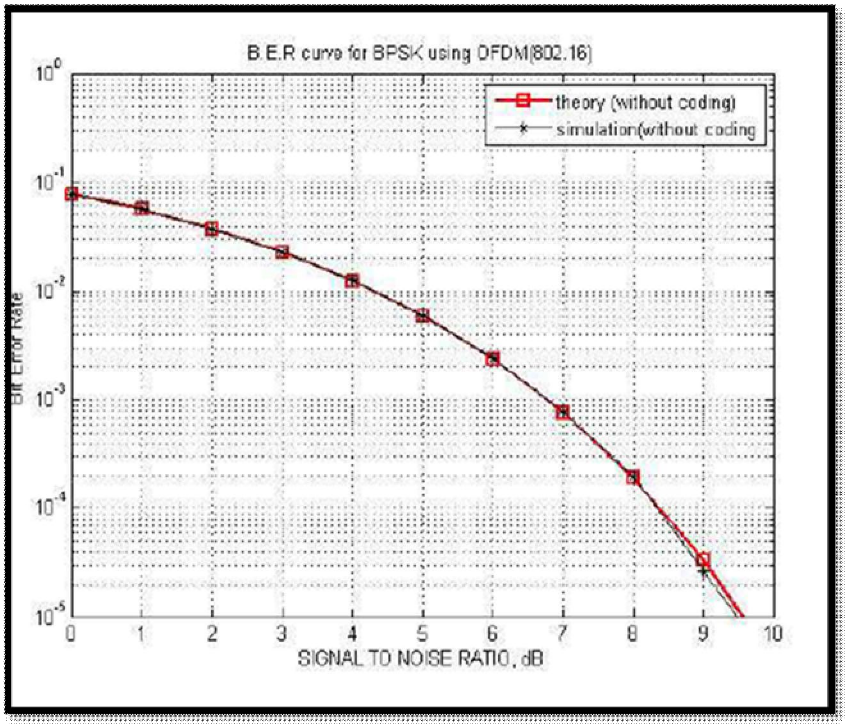
Fig [6.3]: WiMAX Block

The simulation of WiMAX block was performed following the steps given below

- Random bits generated with equal probability.
- Concatenated RS-CC with RS (N=255, k=239, T=8) using Galois Field GF (28) (standard 802.16-2004). With Reed Solomon as the outer code and Convolutional code of constraint length 7 and generator polynomials 171 and133 (standard 802.16-2004) as the inner code.
- Binary Phase Shift Keying BPSK mapping.
- Bits assigned to multiple OFDM data subcarriers (192 data subcarriers).
- Cyclic prefix addition (CP-addition).
- Multiple symbols concatenated.
- AWGN /Rayleigh.
- channel.(separate graphs for each).
- Removing cyclic prefix and taking out the desired subcarriers.
- De-mapping.
- Decoding (only For Coded OFDM).
- Bit errors calculation and plotting.

6.2.1.1 SIMULATION RESULTS

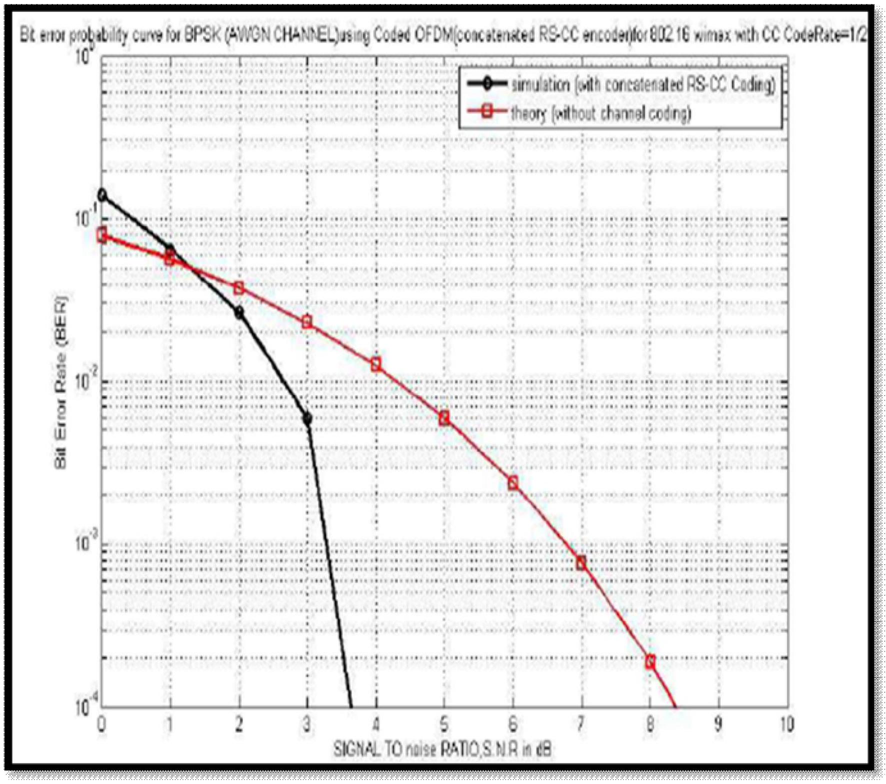
Considering AWGN channel



[Fig 6.4] B.E.R vs. SNR CURVE FOR WIMAX (AWGN CHANNEL) WITH NO CHANNEL CODING

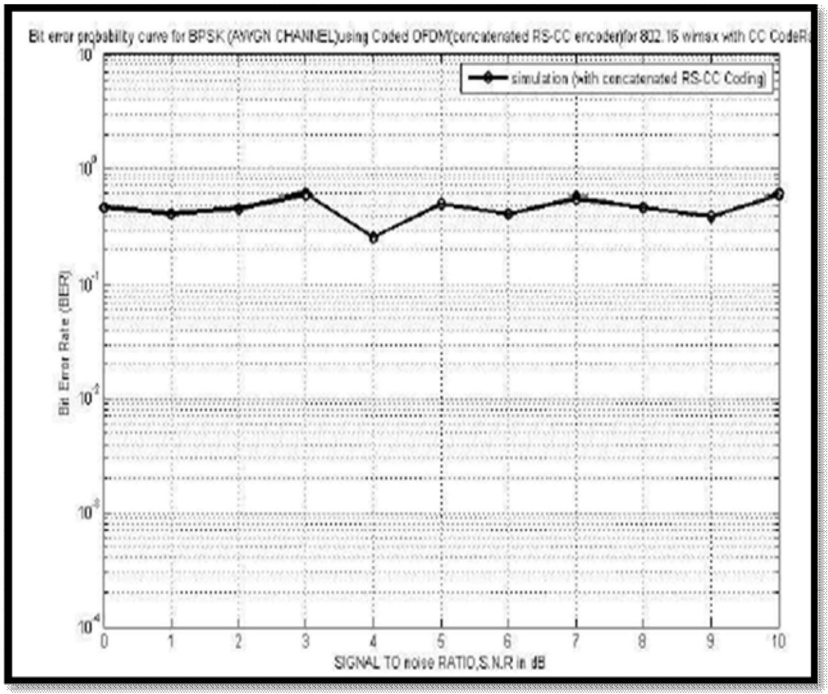
The heoretical B.E.R was calculated assuming no coding and the following equation of BPSK bit error rate:

$$\boxed{\mathrm{Pe} = 0.5 * erfc\left(sqrt\left(\frac{Eb}{No}\right)\right)}$$

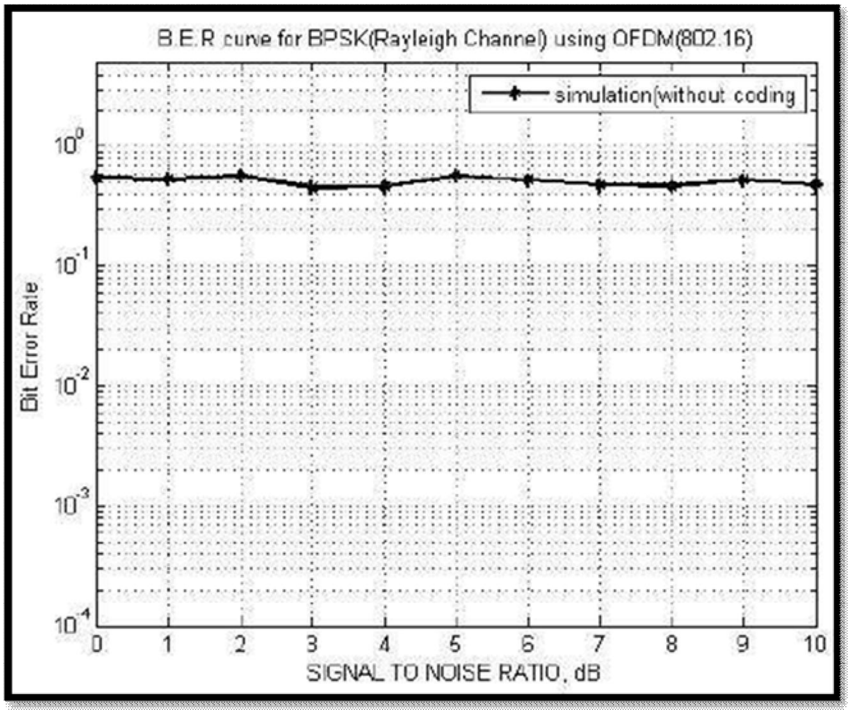


[Fig 6.5] B.E.R vs. SNR CURVE FOR WIMAX (AWGN CHANNEL) WITH CONCATENATED RS – CC CHANNEL CODING CR=1/2

*** Now Considering Rayleigh Channel ***



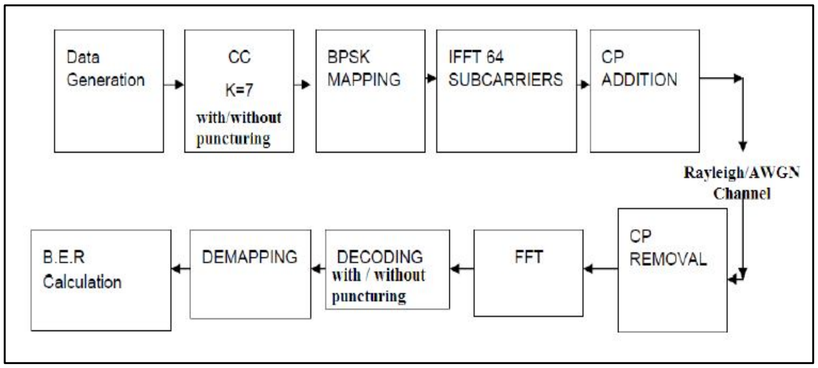
[Fig 6.6] B.E.R vs. SNR CURVE FOR WIMAX (RAYLEIGH CHANNEL) WITH CONCATENATED RS-CC CHANNEL CODING CR=1/2



[Fig 6.7] B.E.R vs. SNR CURVE FOR WIMAX (RAYLEIGH CHANNEL) WITH NO CHANNEL CODING

6.2.2 Wi-Fi BLOCK SIMULATION:

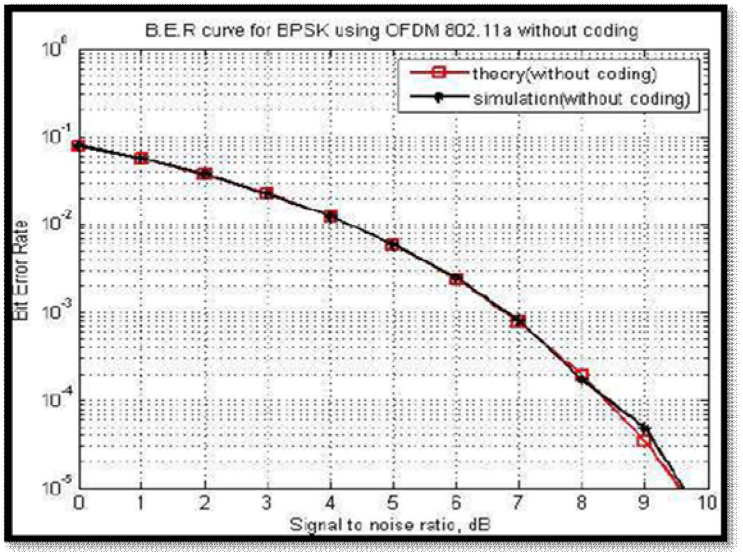
The Wi-Fi standard was simulated following the IEEE802.11a document. The block diagram is given below:



[Fig 6.8]: Block diagram of Wi-Fi 802.11a [12]

The simulation was performed following the steps give below

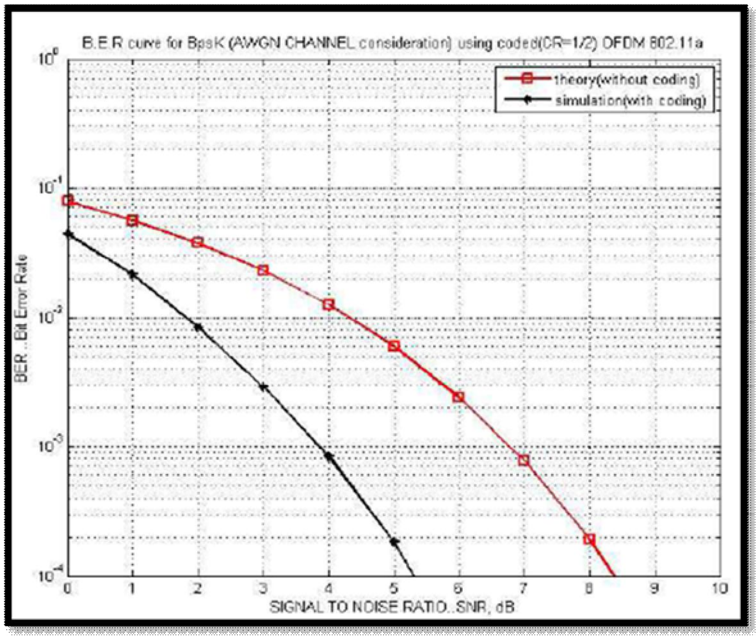
- Random bits generated with equal probability.
- Convolutional code of constraint length 7 and generator polynomials 171 OCT and 133OCT (standard IEEE 802.11a).CC applied with no puncturing CR=1/2 and then punctured for CR=2/3.
- BPSK mapping.
- Bits assigned to multiple OFDM data subcarriers (52 data sub-carriers).
- Cyclic prefix addition.
- Multiple symbols concatenated.
- AWGN channel/Rayleigh channel.
- Removing cyclic prefix and taking out the desired subcarriers.
- De mapping.
- □Decoding using Viterbi algorithm.
- Bit errors calculation and plotting



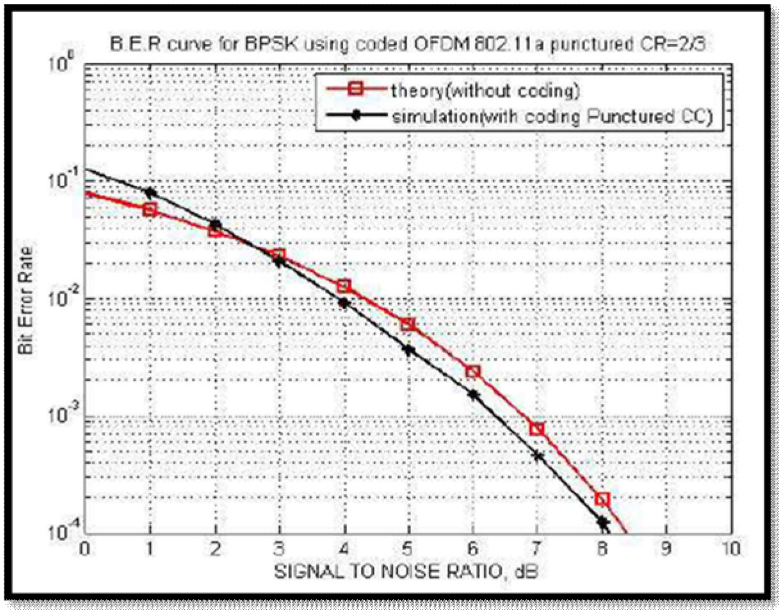
[Fig 6.9] B.E.R vs. SNR CURVE FOR WI-FI (AWGN CHANNEL) WITH NO CHANNEL CODING

The Theoretical B.E.R was calculated assuming no coding and the following equation of BPSK bit error rate

$$\boxed{Pe = 0.5 * erfc\left(sqrt\left(\frac{Eb}{No}\right)\right)}$$

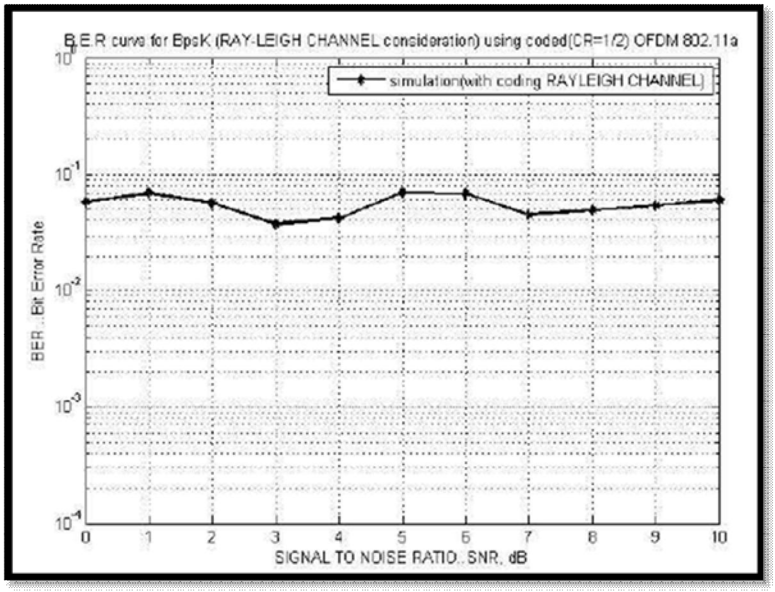


[Fig 6.10] B.E.R vs. SNR CURVE FOR WI-FI (AWGN CHANNEL) CONVOLUTIONAL CODING WITH NO PUNCTURING CODE RATE=1/2

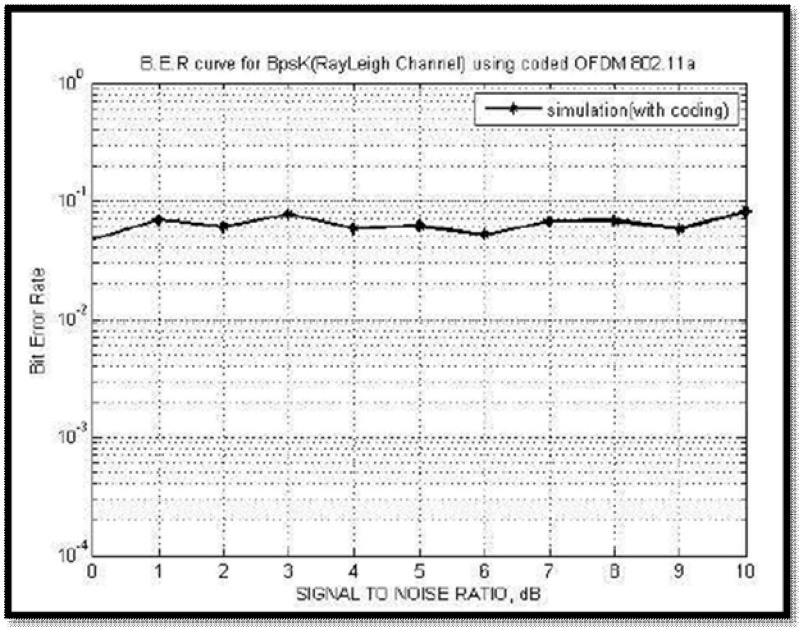


[Fig 6.11] B.E.R vs. SNR CURVE FOR WI-FI (AWGN CHANNEL) CONVOLUTIONAL CODING WITH PUNCTURING CODE RATE=2/3

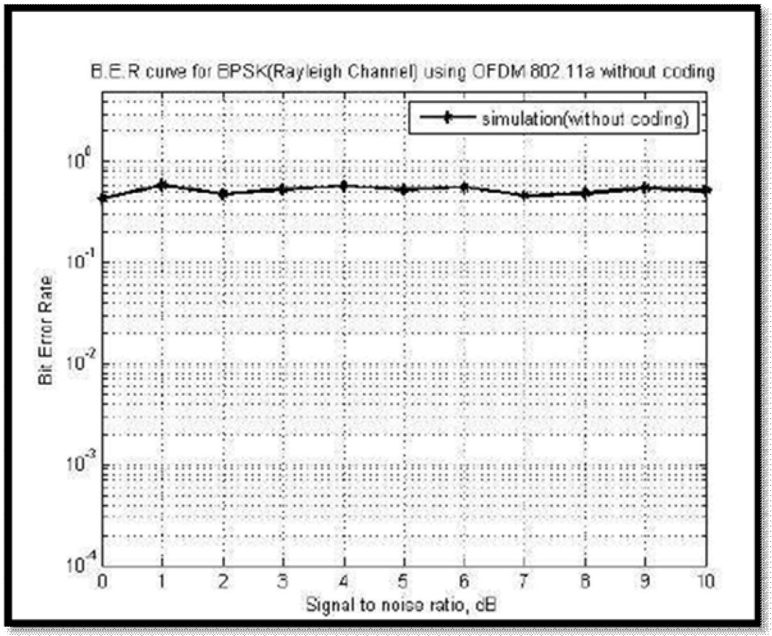
*** Considering Ray-Leigh Channel ***



[Fig 6.12] B.E.R vs. SNR CURVE FOR WI-FI (RAYLEIGH CHANNEL) CONVOLUTIONAL CODING WITH NO PUNCTURING CODE RATE=1/2



[Fig 6.13] B.E.R vs. SNR CURVE FOR WI-FI (RAYLEIGH CHANNEL) CONVOLUTIONAL CODING WITH PUNCTURING CODE RATE=2/3

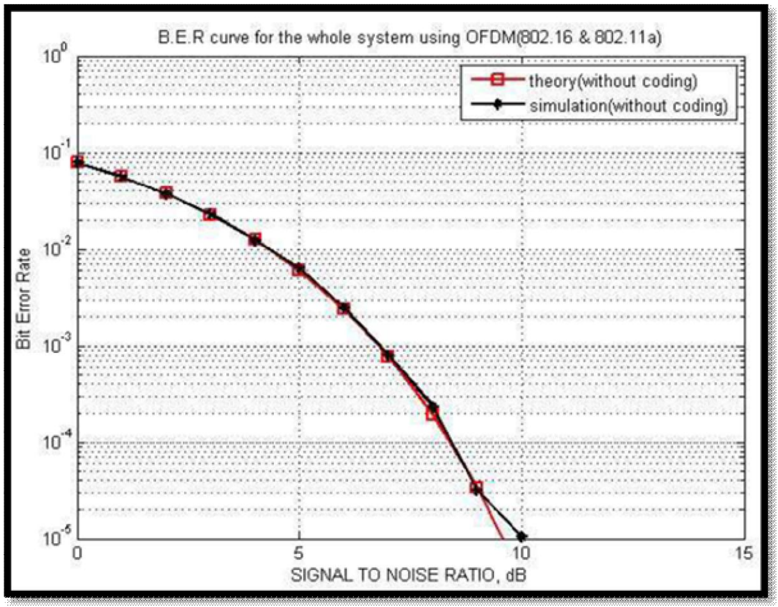


[Fig 6.14] B.E.R vs. SNR CURVE FOR WI-FI (RAYLEIGH CHANNEL) WITH NO CHANNEL CODING

6.2.3 Whole System Simulation

The simulation was performed following the steps give below:

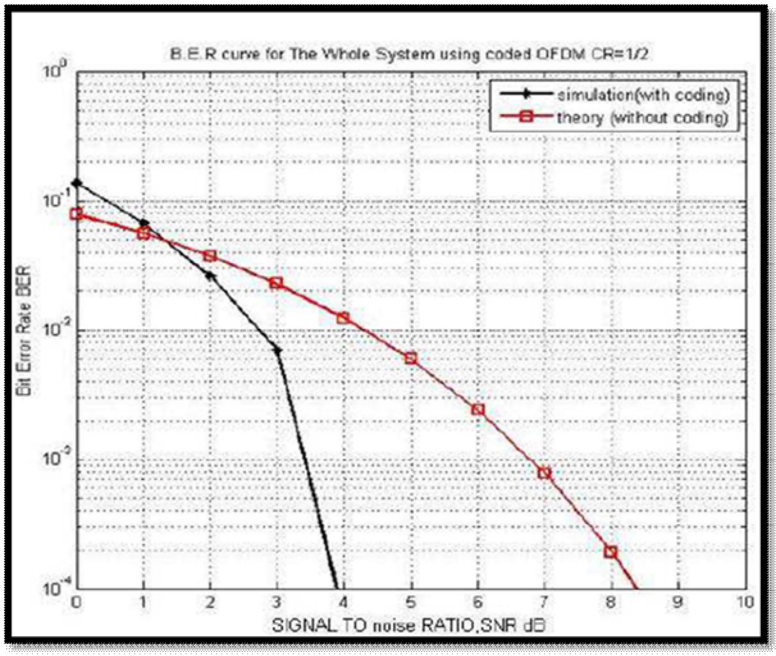
- Random bits generated with equal probability.
- Concatenated RS-CC with RS (N=255, k=239, T=8) using Galois Field GF (standard 802.16-2004). With Reed Solomon as the outer code and Convolutional code of constraint length 7 and generator polynomials 171OCT and133 OCT (standard 802.16-2004) as the inner code.
- BPSK mapping.
- Bits assigned to multiple OFDM data subcarriers (192 data subcarriers).
- Cyclic prefix addition.
- Multiple symbols concatenated.
- AWGN /Rayleigh channel.
- Removing cyclic prefix and taking out the desired subcarriers.
- De mapping.
- Decoding.
- Convolutional code of constraint length 7 and generator polynomials 171 OCT and 133OCT (standard IEEE 802.11a).CC applied with no puncturing CR=1/2 and then punctured for CR=2/3.
- BPSK mapping.
- Zero padding to make the bit stream equal to the multiple of 52 data subcarriers.
- Bits assigned to multiple OFDM data subcarriers (52 data subcarriers)
- Cyclic prefix addition.
- Multiple symbols concatenated.
- AWGN /Rayleigh channel.
- Removing cyclic prefix and taking out the desired subcarriers.
- Removing the padded zeros.
- De mapping.
- Decoding using Viterbi algorithm.
- Bit errors calculation and plotting.



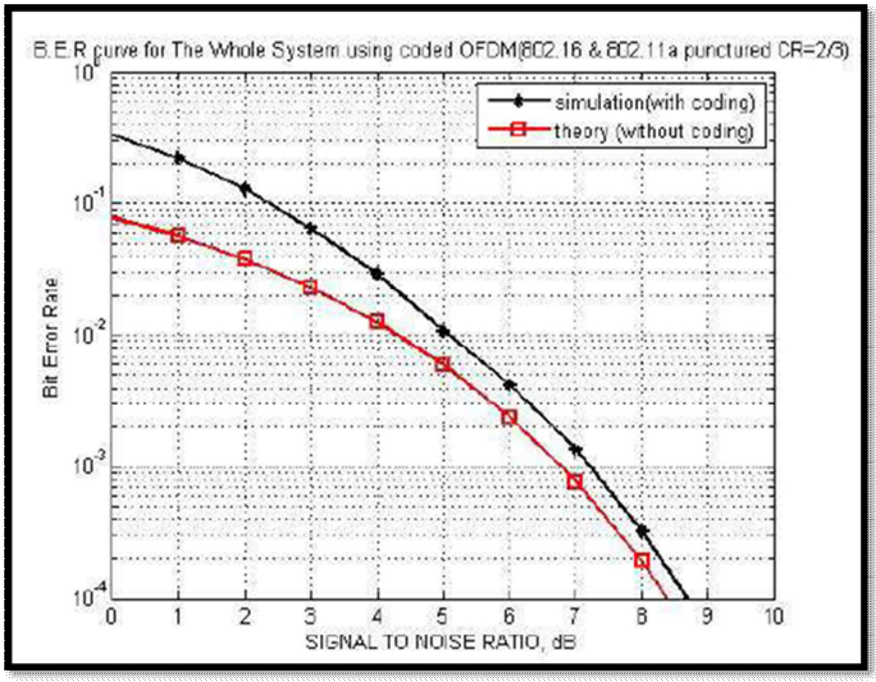
[Fig 6.15] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (AWGN CHANNEL) WITH NO CHANNEL CODING

The Theoretical B.E.R was calculated assuming no coding and the following equation of BPSK bit error rate:

$$\boxed{Pe = 0.5 * erfc\left(sqrt\left(\frac{Eb}{No}\right)\right)}$$

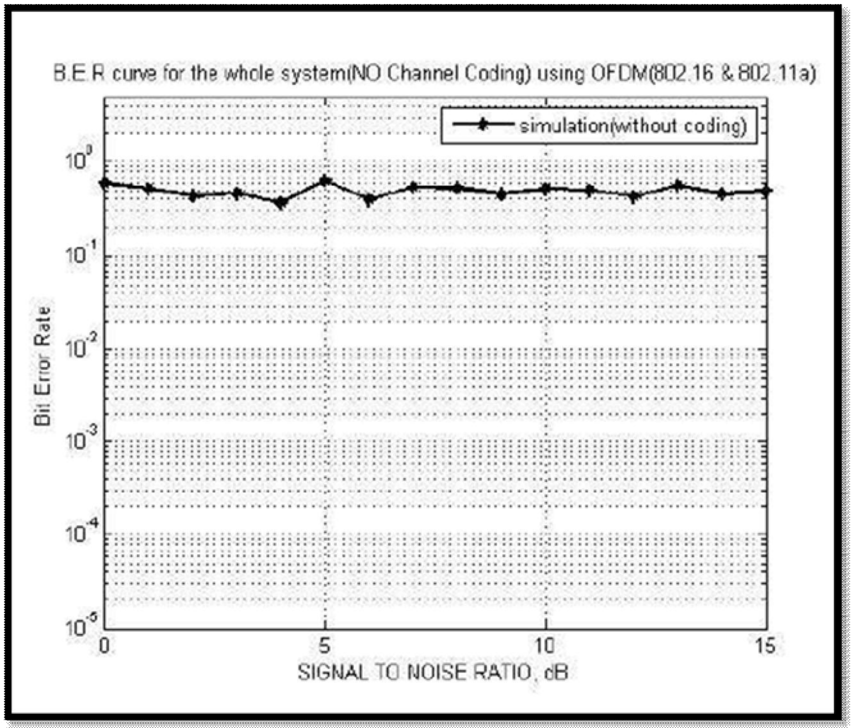


[Fig 6.16] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (AWGN CHANNEL) WITH CHANNEL CODING NO PUNCTURING CR=1/2

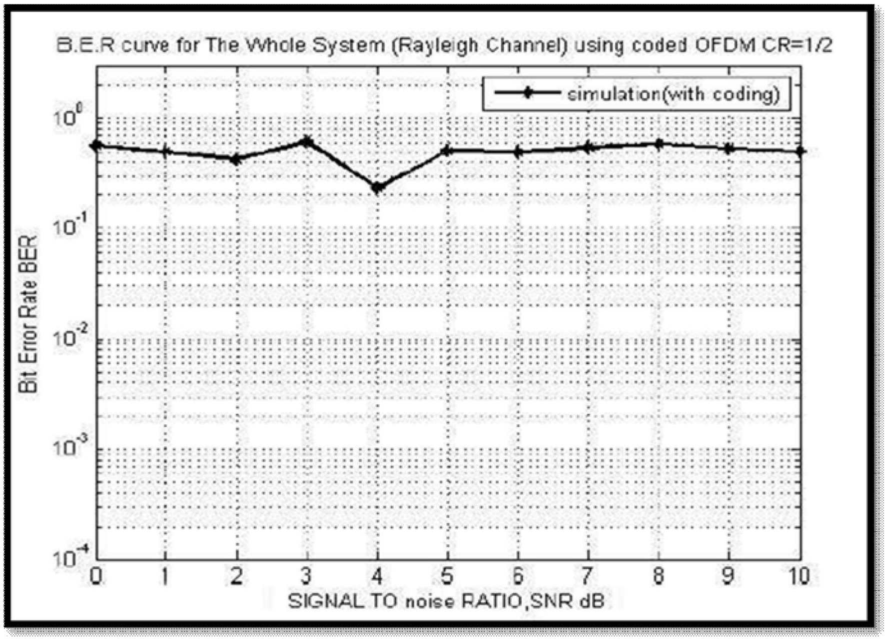


[Fig 6.17] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (AWGN CHANNEL) WITH PUNCTURED CHANNEL CODING CR=2/3

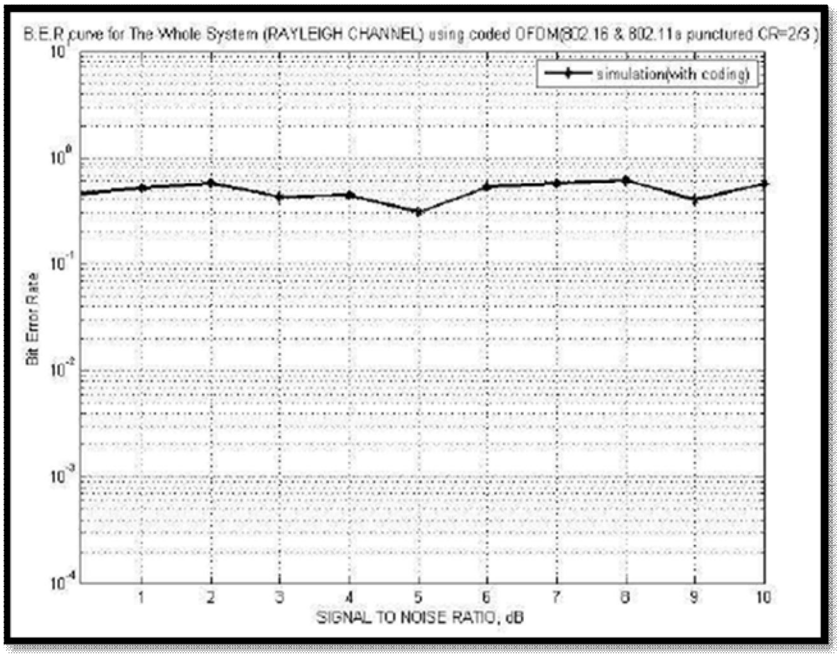
* Considering Ray-Leigh Channel *



[Fig 6.18] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (RAYLEIGH CHANNEL) WITH NO CHANNEL CODING



[Fig 6.19] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (RAYLEIGH CHANNEL) WITH CHANNEL CODING NO PUNCTURING CR=1/2



[Fig 6.20] B.E.R vs. SNR CURVE FOR WHOLE SYSTEM (RAYLEIGH CHANNEL) WITH PUNCTURED CHANNEL CODING CR=2/3

7.1 RESULTS AND CONCLUSION

From the graphs plotted we can clearly see how the channel coding improve the overall efficiency of the system even in the cases of low bandwidth system punctured channel coding is effective there. By performing the simulations, bit error rates (BER) were calculated at the receiver and observed to investigate how the system will perform under different signal to noise ratios. The individual blocks were plotted first and then the overall system was plotted for both AWGN and Rayleigh channel (which includes the fading effects also).These results can be used to analyze the performance of system when the inter-operability is considered between WiMAX and Wi-Fi.

7.2 FUTURE WORKS

The IEEE WiMAX standard (802.16) also support optional channel codlings like LDPC and Turbo coding, these coding can be implemented to improve the efficiency to a much more extent.

7.3 ANALYSIS OF THE RESULTS

In the simulation result section as shown in Fig 6.4, the theoretical BER of BPSK (WiMAX) for AWGN channel can be calculated by the function

$$\boxed{\mathrm{Pe} = 0.5 * erfc\left(sqrt\left(\frac{Eb}{No}\right)\right)}$$

This is basically used for comparison with the simulated results so that the improvement can be demonstrated. However, certain simplifying assumptions are made in the calculation of theoretical BER. AWGN is a static channel in which no fading as well as no multipath factors are considered. By implementing the channel coding on AWGN channel around 50% of the improvement has been seen overall. Uniform decrease in BER has also been noted after implementing the channel coding.

BIT ERROR RATE DECREASE WITH INCREASE IN SNR

↓BER ↑SNR

The standard of WiMAX specifies the use of RS-CC coding with optional Turbo and LDPC coding. When RS-CC coding is applied and AWGN channel is considered Fig 6.5 shows the improvement in the BER which is uniformly decreasing with the increase in SNR.

In Fig 6.6 when Rayleigh channel is considered which takes into account all the multipath losses and signal degradation due to distance and small as well as large scale propagations loss, simulation shows a little improvement in BER for WiMAX case but there is no uniform decrease in the BER as the SNR is improved. Another technique that is interleaving and de-interleaving should be implemented, especially to improve the BER in multipath and fading signal scenarios. As Rayleigh channel model considers multipath fading as well as reflections and other small scale as well as large scale signal fading so there is no uniform decrease in BER.

- Path Loss due to dissipation of energy: it depends on distance only
- Shadowing due to obstacles such as buildings, trees, walls is caused by absorption, reflection, scattering.
- Self-Interference due to Multipath.

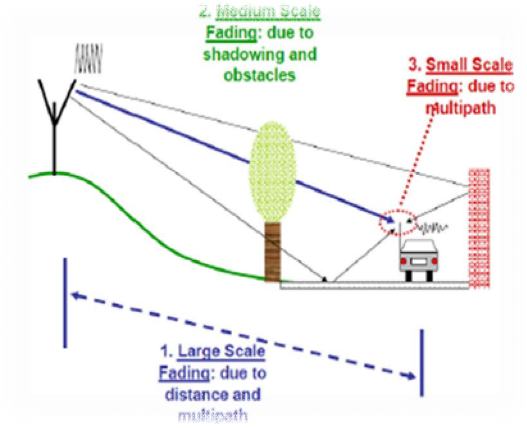


Fig [7.1] Signal losses due to three effects

As specified in Table 4.3, WiMAX standard specifies use of optional codes for further improvement of the BER. However, these optional codes are not implemented in this thesis. Further analysis can be done by implementing optional modern codes like Turbo or LDPC that are predictable to show better performance as the results using RS-CC in Rayleigh channel is not up to the satisfactory mark and still more improvement to decrease the Bit Error Rate.

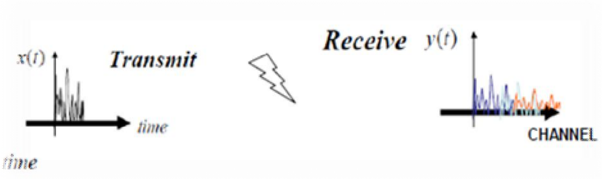


Fig [7.2] Practical reception of signal due to multipath, shadowing, reflection and refraction factors.

The affect of interleaving and de-interleaving in multipath is that if a single symbol gets corrupted so it won't be possible to recover the whole symbol by coding schemes so interleaving helps a lot in improving the BER as shuffling the bits of different symbols so less chances of getting lost of the whole symbol bits.

Moreover, in this thesis I have considered only Viterbi hard decoding decision for decoding the encoded signal. Hard-decision and soft-decision decoding are based on the type of quantization used on the received bits. Hard-decision decoding uses 1-bit quantization on the received samples. Soft-decision decoding uses multi-bit quantization (e.g. 3 bits/sample) on the received sample values.

When the Wi-Fi part is considered and coding is applied (AWGN channel, Fig 6.11) around 50% improvements is seen.

Channel coding adds redundancy of bits thus compromising the throughput of the system. If we are low in the available bandwidth we can change the Coding Rate, for example in Fig 6.12 puncturing is used; 2 bits are going as an input and we get 3 bits as output thus puncturing 1 bit. For the previous case we were getting 4 bits out of 2 bits as input for CR=1/2. But this code puncturing lowers the Error correction performance as depicted by the simulation result in Fig 6.12. The simulation result is a bit higher compared to theoretical because of neglecting certain factors in theoretical function.

When Rayleigh channel is considered for WiFi transmission and comparison is made between the un-coded and coded transmission of data in Wi-Fi scenario. A bit more improvement as compared with the WiMAX Rayleigh simulation result has been found as shown in Fig 6.13 and Fig 6.14 the BER has been reduced from 100 to 10-1

In the end when the overall system is considered and interoperability factor is there between WiMAX and Wi-Fi there is much improvement in BER because of the Channel coding effect in AWGN as well as in Rayleigh channel as shown in Fig 6.18 and Fig 6.19.

For more analysis different modulation schemes can be applied also as well as the modern channel coding schemes with built-in interleaving / de-interleaving function should be applied also. This is outside the scope of thesis and will be considered in future research.

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