Performance Evaluation of Fixed WiMax Physical Layer under High Fading Channels

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Declaration

I declare that this thesis entitled “Performance Evaluation of IEEE 802.16D OFDM Physical Layer under High Fading Channels with Diversity Transmission and Receiving Techniques” is an outcome of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

Signature ……………

Shanar H. Askar

Date:

Acknowledgement

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Abstract

A radio channel characteristic modelling is essential in every network planning. This project deals with the performance of WiMax networks in an outdoor environment while using fading channel models. The radio channels characteristics are analyzed by simulations have been done using Matlab programming.

Stanford University Interim (SUI) Channels set was proposed to simulate the fixed broadband wireless access channel environments where IEEE 802.16d is to be deployed. It has six channel models that are grouped into three categories according to three typical different outdoor Terrains, in order to give a comprehensive study of fading channels on the overall performance of the system, WiMax system has been tested under SUI channels that modified into account for 30^o directional antennas, with 90% cell coverage and with 99.9% reliability in its geographical covered area. Furthermore, in order to combat the fading which occurs in urban areas and improve the capacity and the throughput of the system, multiples antennas at both ends of communication link are used, the transmission gain obtained when using multiple antennas instead of only a single antenna. Space-time coding and maximum ratio combining for more than one transmit and receive antenna is implemented to allow performance investigations in various MIMO scenarios. It has been concluded that uses multiple antennas at the receiver offers a significant improvement of 3 dB of gain in the channel SNR.

This thesis also contain implementation of all compulsory features of the WiMax OFDM physical layer specified in IEEE 802.16-2004 using Matlab coding. In order to combat the temporal variations in quality on a multipath fading channel, an adaptive modulation technique is used. This technique employs multiple modulation schemes to instantaneously adapt to the variations in the channel SNR, thus maximizing the system throughput and improving BER performance. WiMax transceiver has been tested with and without encoding and studied the effect of encoding on multipath channel. Testing the system with flexible channel bandwidth has been part of this thesis. Finally it has been explained in this thesis the affect of increasing the size of cyclic prefix on overall performance of WiMax system.

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Abbreviations and Acronyms

3G	Third Generations
4G	Fourth Generations
AAS	Adaptive Antenna System
AMC	Adaptive Modulation and Coding
AP	Access Point
ARQ	Automatic repeat request
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
BTC	Block Turbo Coding
BWA	Broadband Wireless Applications
CC	Convolutional Coding
CDMA	Code Division Multiple Access
C/I	Carrier to Interference
CIR	Channel Impulse Response
CP	Cyclic Prefix
CPE	Customer-premises equipment
CTC	Convolutional Turbo Coding
DB	Decibels
DFS	Dynamic Frequency Selection
DL	Downlink
DLL	Dynamic Link Libraries
DSL	Digital Subscriber Line
DFT	Discrete Fourier Transform
DoD	Direction of Departure
DoI	Direction of Arrival
FDD	Frequency Division Duplexing
FDDI	Fibber Distributed Data Interface

FDM	Frequency Division Multiplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
EM	Electromagnetic
GF	Galois Field
GSM	Global System for Mobile Communication
HSDPA	High Speed Downlink Packet Access
ICI	Inter-Carrier Interference
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
LAN	Local Area Network
LLC	Logical Link Control
LoS	Line of Sight
LS	Least Squares
MAC	Medium Access Control
MAN	Metropolitan Area Network
MEA	Multi-element Antenna
MIB	Management information Base
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Simple-Output
MMDS	Multichannel Multipoint Distribution Service
MRC	Maximum Ratio Combining
MS	Mobile Station
NLoS	Non Line of Sight
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open System Interconnection
PAM	Pulse Amplitude Modulation
PAN	Personal Area Network

PDA	Personal Digital Assistant
pdf	Probability Density Function
PDP	Power Delay Profile
PHY	Physical Layer
PL	Path Loose
PMP	Point to Multipoint
PAPR	Peak to Average Power Ratio
PRBS	Pseudo-Random Binary Sequence
PSD	Power Spectral Density
PSK	Phase Shift Keying
PTP	Point to Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RF	Radio Frequency
RMS	Root Mean Square
RS	Reed-Solomon
SC	Single Carrier
SDMA	Space Division Multiple Access
SIMO	Single-Input Multiple-Output
SINR	Signal-to-Interference-plus-Noise Ratio
SISO	Single-Input Single-Output
SNR	Signal-to-Noise Ratio
SS	Subscriber Station
STBC	Space-Time Block Coding
STC	Space-Time Coding
SUI	Stanford University Interm
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over IP

WAN	Wireless Area Network
Wi-Fi	Wireless-Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network

Chapter 1: Introduction

The telecommunication industry is changing, with a demand for a greater range of services, such as video conferences, or applications with multimedia contents. The increased reliance on computer networking and the Internet has resulted in a wider demand for connectivity to be provided "anywhere, anytime", leading to a rise in the requirements for higher capacity and high reliability broadband wireless telecommunication systems.

Broadband availability brings high performance connectivity to over a billion users' worldwide, thus developing new wireless broadband standards and technologies that will rapidly span wireless coverage. Wireless digital communications are an emerging field that has experienced a spectacular expansion during the last several years. Moreover, the huge uptake rate of mobile phone technology, Wireless Local Area Network (WLAN) and the exponential growth of Internet have resulted in an increased demand for new methods of obtaining high capacity wireless networks [1].

WiMax (Worldwide Interoperability for Microwave Access) is a promising technology which can offer high speed data, voice and video service to the customer end, which is presently, dominated by the cable and digital subscriber line (DSL) technologies. WiMax allows for an efficient use of bandwidth in a wide frequency range, and can be used as a last mile solution for broadband internet access. The biggest advantage of Broadband wireless application (BWA) over its wired competitors is its increased capacity and ease of deployment.

Additionally, WiMax represents a serious competitor to 3G (Third Generation) cellular systems as high speed mobile data applications achieves with the 802.16e specification.

This chapter provides a brief introduction to the motivation behind this work and its objective have been discussed as well, then it sails through scope and methodology of this thesis, and then it gives a brief comparison between WiMax and 3G technologies. At last the structure of the document would be provided.

1.0 Motivation

DSL/cable technologies require telephone/cable lines to be laid over long distances to serve customers. In countries such as India, Mexico or Brazil, the potential for broadband access is extremely high, taking into account the trend of Internet requirements. However, the penetration of DSL/cable is not as high, mainly due to a lack of reliable infrastructure, cables or backbone switching equipment. A viable complement to DSL/cable based service is WiMax or wireless broadband, which connects users to the Internet, even in places where the infrastructure might not be as developed. At first glance, WiMax would seem similar to 3G cellular technologies, since both these networks can transmit data and voice, but by design, cellular 3G is voice-centric while WiMax is data-centric. WiMax can achieve data rates up to 75Mbps and a theoretical 30 mile reach[2], however, in typical deployment scenarios, data rates fall with increasing reach. Geographically WiMax is flexible and can improve yield due to wiring/labour cost savings.

1.1 Amis and Objectives

This thesis aims to give a detailed insight into various fading channel modelling and multipath effect simulation, the objective of this thesis is to implement and simulate mandatory and optional features of the Institute of Electrical and Electronics Engineers IEEE 802.16 OFDM physical layer including adaptive transmission and receiving scheme Multiple-Input Multiple-Output (MIMO) using Matlab coding, in order to have better understanding of the standard and the system performance. This involves sailing through simulation, the various Physical Layer (PHY) modulations, some coding techniques and nominal bandwidth of the system in the form of Bit Error Rate (BER) under variant fading channel models. Then to learn about the WiMax and to understand about the technologies behind WiMax that makes it capable of in non-line-of-sight transmission.

1.2 Scope

SUI channel models consist of six channels SUI (1- 6). Every model is different from the other. The user decides which model can be used based on the terrain type of the area under study. The classification is done in such a way that, the terrain is classified into three types and every type is given two SUI models that suitable for it.

The project requires to learn in detail and understand about the properties of WiMax focusing more on how WiMax works in a non-line of sight situation and also to have knowledge of different SUI models, propagation models and fading channel modelling.

Matlab programming simulation used to simulate the performance of the system. Different parameters of the transmitter, receiver and the channel can be varied and the output can be verified for every set of inputs. The simulation results are available in terms of the received power spectrum, BER performance. Multiple-input multiple-output (MIMO) multipath fading channels based on the IEEE 802.16 channel models for fixed wireless applications have been also simulated. Two transmit antennas and one or two receive antennas are used and the calculated of throughput in each case using the MIMO multipath fading channel and the rounded Doppler spectrum objects has been considered.

1.3 Contribution

This thesis contributes to knowledge by giving a detailed insight into various propagation models, analyses various aspects of IEEE 802.16d and focuses on their implications on the performance of communication. Stanford University Interim (SUI) Channel serial was proposed to simulate the fixed broadband wireless access channel environments where IEEE 802.16d is to be deployed. In this thesis a set of 6 typical channels were implemented for three different terrain types and simulated, WiMax system has been tested under SUI channels that modified in to account for 30^o directional antennas, with 90% cell coverage and with 99.9% reliability in its geographical covered area. These six SUI channels can be use for development and testing technologies suitable for fixed broadband wireless applications; they divided into three categories, category A for Urban area, category B for sub-urban area, and category C for rural areas. Different channel models and scenarios are applied for the system so the fading phenomenon could be studied.

One objective of the thesis was to evaluate the performance of the system as well as to obtain a more accurate understanding of the operation of WiMax system in high fading environment and to implement the system mandatory and optional features. Furthermore, in order to combat the fading and improve the capacity and the throughput of the system, multiples antennas at both ends of communication link are used. The transmission gain obtained when using multiple antennas instead of only a single antenna. It has been concluded that uses multiple antennas at the receiver offers a significant improvement of 3 Decibels (dB) of gain in the channel SNR. Space-time coding and maximum ratio combining for more than one transmit and receive antenna is implemented to allow performance investigations in various MIMO scenarios. In order to combat the temporal variations in quality on a multipath fading channel, an adaptive modulation technique is used. This technique employs multiple modulation schemes to instantaneously adapt to the variations in the channel SNR, thus maximizing the system throughput and improving BER performance. Simulating the fixed OFDM IEEE 802.16d physical layer under different combinations of digital modulation (BPSK (Binary Phase Shift Keying), QPSK(Quadrature Phase Shift Keying), 4-QAM (Quadrature Amplitude Modulation) and 16-QAM) was part of this study.

This thesis also contains implementation of compulsory features of the WiMax OFDM physical layer specified using Matlab coding. WiMax transceiver has been tested with and without encoding and studied the effect of encoding on multipath channel. Testing system with flexible channel bandwidth has been done. At the end clarification of the affect of increasing the size of cyclic prefix on overall performance of WiMax system has been concluded.

1.4 Methodology

An in-depth analysis of the capabilities of the IEEE 802.16 standard devices is presented. This study is based on 802.16-2004 models implemented in Matlab2008 using m- files. Simulation is the methodology used to explore the PHY layer performance by using a Windows XP-Service Pack3 Operating System installed on Intel Core 2Quad CPU, 2.40GHz, and 3GB of RAM. The Performance assessment method was mainly focused on the effect of modulation and cyclic prefix on the PHY layer and some optional features of 802.16-2004. The overall system performance was also evaluated under different fading channels circumstances.

1.5 Comparison between WiMax and 3G

Table 1.1 gives brief comparison between major wireless systems: the second-generation cellular system Global System for Mobile Communication (GSM), in its Enhanced Data Rate for GSM Evolution (EDGE) Enhanced Data Rates for GSM Evolution, 3G Universal Mobile

Telecommunications System (UMTS), WiFi in its two variants. 802.11b (the original WiFi) and 80.11a (including Orthogonal Frequency Division Multiplexing (OFDM) transmission), and WiMax.

	Operating frequency	Licensed	One channel (frequency carrier) bandwidth	Number of users per channel	Range
GSM/EDGE	0.9 GHz, 1.8 GHz, other	Yes	200 kHz	2 to 8	35, km (often less)
UMTS	1.9 GHz	Yes	5 MHz	Many (order of magnitude: 25); data rate decreases	5 km (up to, often less)
WiFi (11b)	2.4 GHz	No	5 MHz	1 (at a given instant)	100 m
WiFi (11a)	5 GHz	No	20 MHz	1 (at a given instant)	100 m
WiMax	2.3 GHz, 2.5 GHz, 3.5 GHz, 5.8 GHz, other	Licensed and unlicensed bands are defined	3.5 MHz, 7 MHz, 10 MHz, other	Many (100, …)	20 km (outdoor CPE)

Table 1.1: Basic comparison between major wireless systems [3]

In order to compare with cellular 3G networks, just Mobile WiMax is considered, since Fixed WiMax represents a marketplace completely different from 3G.

1.5.1 Advantages of the 3G Cellular System

WiMax uses higher frequencies than Cellular 3G, which primarily operates in the 1.8 GHz range. Received power decreases when frequency increases and wireless system transmitted powers are often limited due to environmental and authoritarian requirements. WiMax ranges are globally smaller than 3G ranges. This is the case for outdoor and indoor equipments. on the other hand, the cell range parameter is often not the most limiting one in high-density zones, where the main part of a mobile operator market is located. 3G is already here, its equipment including the high-data rate High-Speed Downlink Packet Access (HSDPA) networks and products are already used, since 2005 in some countries. Internationally, 3G has a field advance of two to three years with regard to WiMax. Will it be enough for 3G to occupy a predominant market share?

The WiMax spectrum changes from one country to another. For example, a WiMax user taking equipment from country A to country B would probably have to use a different WiMax frequency to meet up with operator's frequency of country B. On the other hand, making multi-frequency mobile equipment, for a reduced cost, is now becoming more and easier for manufacturers. Some countries have restrictions on WiMax frequency use, i.e. WiMax operators can be forbidden to deploy mobility by the regulator.

1.5.2 Advantages of the (Mobile) WiMax System

WiMax is a very open system as frequently, many algorithms are left for the seller, which opens the door to optimisation, and connections between different business units operating on different parts of the network (core network, radio access network. services providers, etc.), possibly in the same country, are made easy. This is probably a benefit, but perhaps it might create some interoperability problems in the first few years?

The WiMax PHYsical Layer is based on OFDM, a transmission technique known to have relatively high spectrum-use efficiency (with regard to SC (CDMA) Single Carrier Code Division Multiple Access). There are plans to upgrade 3G by including OFDM and MIMO in it. This evolution is called for the moment LTE (Long-Term Evolution). This gives a time advance for WiMax in the implementation of OFDM.

WiMax is an all- Internet Protocol (IP) technology. This is not the case for the 3G system where many intermediate protocols made for the first versions of 3G are not all-IP. However, development of 3G should provide end-to-end IP (or all-IP). WiMax has a strong support of some industry giants, such as Intel, Samsung, KT and many others. Taking into account all these comments, it is very difficult to decide between the two systems. On the other hand, it could be said that there is a place for both of these two technologies, depending on the market, the country and the application … at least for a few years to come!

In any case, both WLAN and cellular mobile applications are being extensively expanded to fulfil the demand for wireless access. However, they experience several difficulties for reaching a complete mobile broadband access, bounded by factors such as bandwidth, infrastructure costs and coverage area.

On one hand, Wireless-Fidelity (Wi-Fi) provides a high data rate, but only on a short range of distances and with a slow movement of the user. On the other hand, UMTS offers larger ranges and vehicular mobility, but instead, it provides lower data rates, and requires high investments for its deployment. WiMax tries to balance this situation. As shown in Figure 1.1 it fills the gap between Wi-Fi and UMTS, thus providing vehicular mobility (included in IEEE 802.16e), and high service areas and data rates.

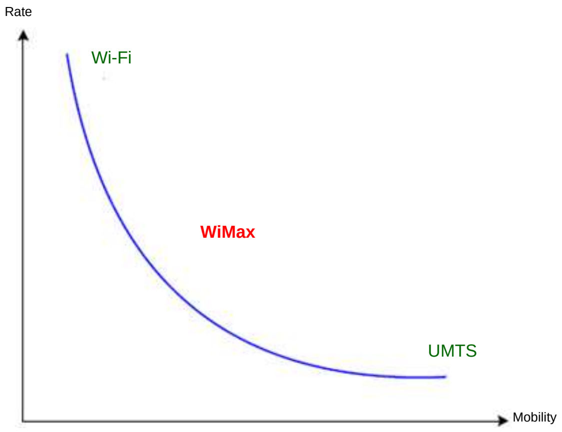


Figure 1.1: WiMax fills the gap between Wi-Fi and UMTS [3].

Therefore, WiMax will complement Wi-Fi and UMTS in some of the possible scenarios where these systems are not sufficiently developed, i.e. they face several problems in the deployment and they do not offer enough capacity to serve all potential users, WiMax would be able to compete with Wi-Fi and UMTS also in other possible scenarios, where, in general, the costs in the deployment, maintenance, or just the supply of the service would not be commercial.

1.6 Thesis Structure

This thesis consists of six main chapters as is shows below:

The first chapter consists of a general Introduction, the scope and objective of the project, in additionally contain comparison between WiMax and 3G technologies and also the flow of this thesis.

Chapter 2 is an overview about WiMax. The chapter discusses in detail about the capabilities, WiMax technologies, modulation and features of WiMax.

Chapter 3 for developing new and more effective wireless telecommunication system, wide knowledge of propagation channel is needed, so this chapter will be about studies the electromagnetic wave propagation and the losses encountered by the wave on its journey to the receiver after its transmission from the transmitter. It discovers different high fading propagation channels as well.

Chapter 4: This chapter will be all about one of the best optional feature of 802.16 standard, which is the diversity of transmission and receiving. Chapter four starts by giving a brief description about the MIMO transmission and basics of MIMO channels, then it goes through Shannon’s Law, the end in this chapter will be about Space-Time Coding (STC), Alamouti concept and maximaum ratio combining (MRC).

Chapter 5: This chapter is all about the simulation, in order to implement and test the mandatory and the optional features of WiMax, This chapter has been divided into six cases, each case deal with different aspect of this new technology. Case one is about implementing variant combinations of MIMO channel including (MIMO, MISO, SIMO, SISO) Using M-file and plot the result then find the throughput for each scenario. Case two is about implementing modified Stanford University Interim channels between the transmitter and the receiver, to find out in depth the effect of multipath propagation and the fading channels on radio propagations. Third case of this chapter is about simulation WiMax system in which all the modulations are used (BPSK, QPSK, 16QAM, 64QAM) as it mentioned in the standard. Forth case in simulation chapter is about studying the effect of variant cyclic prefix then explaining which one is optimal to combat the effect of multipath and high fading channels in propagation environments. In case five another optional feature of WiMax PHY layer has been considered, which is bandwidth flexibility, and then simulation of system with variant values of the nominal BW also has been implemented. The last case is case Six, and in this case the simulation with and without encoding of the signal has been implemented, to find out the affect of encoding on the received signals quality.

Chapter 6: Ends up with conclusion for this project. This chapter also have proposal for future works.

Chapter 2: IEEE 802.16: Evolution and Architecture

2.0 Introduction to Broadband Wireless Access

Since the final decades of the twentieth century, data networks have known gradually increasing success. After the setting up of fixed Internet networks in many places all over the planet and for their now vast extension, they require is now becoming more significant for wireless access.

The basic physical laws that make radio possible are known as Maxwell's equations, identified by James Clerk Maxwell in 1864, when the Maxwell equations showed that the transmission of information could be achieved without the need for a wire. Few years later, experimentations such as those of Marconi proved that wireless transmission may be a reality and for rather long distances. Through the twentieth century, great electronic and propagation discoveries and inventions gave way to several wireless transmission systems.

The Bell Labs proposed the cellular concept in the 1970s, a magic idea that allowed the coverage of a zone as large as needed using a fixed frequency bandwidth. Since then, many wireless technologies had large utilization, the most successful until now being GSM, the Global System for Mobile communication, initially European second generation cellular system. GSM is a technology mainly used for voice transmission in adding to low-speed data transmission such as the Short Message Service (SMS).

The GSM has evolution that is already used in several countries. These evolutions are destined to facilitate relatively high-speed data communication in GSM-based networks. The most important evolutions are:

GPRS (General Packet Radio Service), the packet-switched evolution of GSM; EDGE (Enhanced Data rates for GSM Evolution), which includes link or digital modulation efficiency edition, i.e. adaptation of transmission properties to the (quickly varying) radio channel state.

In addition to GSM, third-generation (3G) cellular systems, originally European and Japanese UMTS (Universal Mobile Telecommunication System) technology and originally American Code Division Multiple Access (cdma2000) technology, are already deployed and are promising wireless communication systems. Cellular systems have to cover wide areas, as large as countries [4]. An extra approach is to use wireless access networks, which were initially proposed for Local Area Networks (LANs) but can also be used for wide area networks.

2.1 Different Types of Data Networks

A large number of wireless transmission technologies exist, other systems still being under design. These technologies can be distributed over different network families, based on a network scale. In Figure 2.1, a now-classical representation (sometimes called the ‘eggs figure’) is shown of wireless network categories, with the most famous technologies for each type of network [5] .

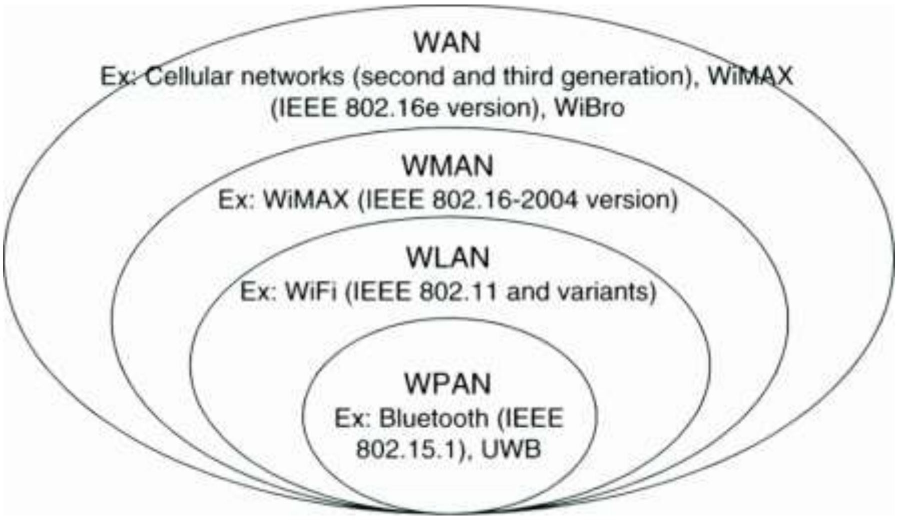


Figure 2.1: Illustration of network types [5]

A Personal Area Network (PAN) is a (generally wireless) it's a network that provides wireless connectivity over distances of up to 10m or so. Although some WPAN technologies may have a greater reach or less . Data network used for communication among data devices close to one person. Examples of WPAN technologies are UWB and Bluetooth.

A Local Area Network (LAN) is a data network type used for communication among data devices: computer, telephones, printer and personal digital assistants (PDAs). This network covers a relatively small area, like a home, an office or a small campus (or part of a campus). The range of a LAN is of the order of 100 metres. The most (by far) presently used LANs are Ethernet (fixed LAN) and WiFi (Wireless LAN, or WLAN) [5].

A Metropolitan Area Network (MAN) is a data network type that covers up to several kilometres, typically a large site or a city. For instance, a university may have a MAN that joins together many of its LANs situated around the site, each LAN being of the order of half a square kilometre. Then from this MAN the university could have several links to other MANs that make up a Wireless Area Network (WAN) [5]. Examples of MAN technologies are FDDI

(Fiber-Distributed Data Interface) and Ethernet-based MAN. Fixed WiMax can be considered as a Wireless MAN (WMAN).

A Wide Area Network (WAN) [5] is a data network covering a wide geographical area, as big as the Planet. WANs are based on the connection of LANs, WAN consists of a number of interconnected switching nodes; these connections are made using leased lines and circuit-switched. The most (by far) at the moment used WAN is the Internet network. Other examples are 3G and mobile WiMax networks, which are Wireless WANs. The WANs often have much smaller data rates than LANs (consider, for example, the Internet and Ethernet), WANs use when reach is the most important aspect of your solution, and speed is less significant.

Reach is important if you are providing wireless solutions to the public at large, for example, or you want to give your employees wireless access to your corporate data, whether they are in the office, across town, out of town, or (in some cases) in other countries.

2.2 WiMax Topologies

The IEEE 802.16 standard defines two possible network topologies. In figure 2.2 Point to Multipoint (PMP) topology and Mesh topologies is in Figure 2.3[5].

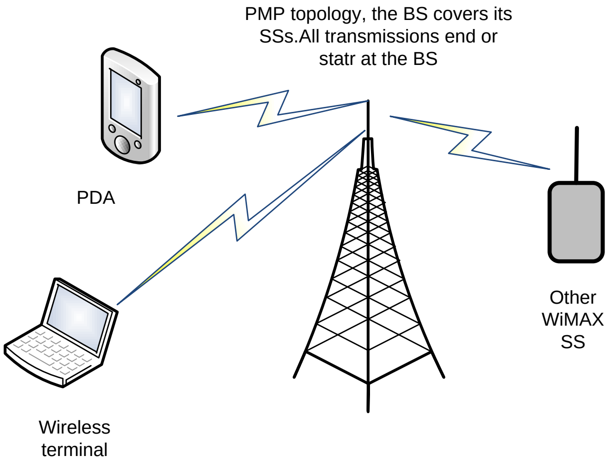


Figure 2.2: Point to Multipoint (PMP) topology

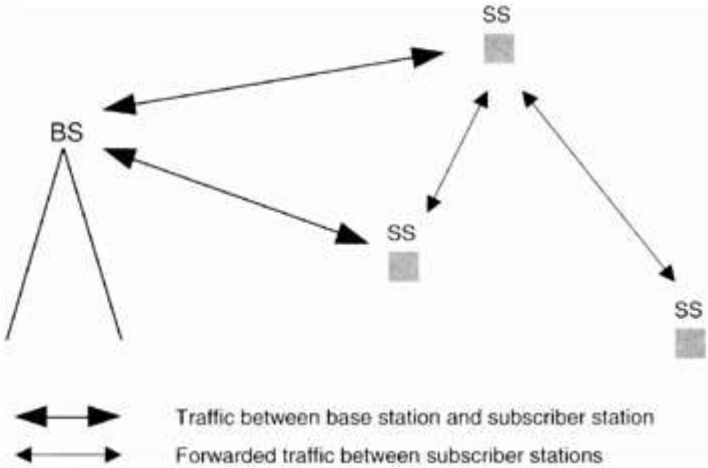


Figure 2.3: Mesh topology [5]

The main difference between the two modes is the following: in the Point to multi Point (PMP) mode, traffic may take place only between a Base Station (BS) and its Subscriber Station SSs, while in the Mesh mode the traffic can be routed through other SSs until the Base Station (BS) and can even take place only between SSs. PMP is a centralised topology where the BS is the centre of the system while in Mesh topology it is not. The elements of a Mesh network are called nodes, e.g. a Mesh SS is a node.

First WiMax network deployments are planned to follow mainly PMP topology. Mesh topology is not yet part of a WiMax certification profile (September 2006) [6,7]. It has been reported that some manufacturers are planning to include the Mesh feature in their products, even before Mesh is in a certification profile.

In Mesh topology, each station can create its own communication with any other station in the network and it’s then not restricted to communicate only with the BS. Thus, a major advantage of the Mesh mode is that the reach of a BS can be much greater, depending on the number of hops, until the most distant SS. On the other hand, using the mesh mode brings up the now thoroughly studied research topic of ad hoc (no fixed infrastructure) networks routing.

When it authorized to a Mesh network, a candidate SS node receives a 16-bit Node ID (IDentifier) upon a request to an SS identified as the Mesh BS. The Node ID is the basis of node identification. The Node ID is transferred in the Mesh sub header of a generic Medium Access Control (MAC) frame in both uni-cast and broadcast messages.

2.3 WiMax Standards

WiMax standards are the operational descriptions, products and tests that allow manufactures to produce devices that reliably operate and can work with devices produced by other manufactures, WiMax standards developments is overseen by the institute of Electrical and Electronics Engineers(IEEE). The IEEE 802.16 standard was firstly designed to address communications with direct visibility in the frequency band from 10 to 66 GHz [8].

Due to the fact that non-line-of-sight transmissions are difficult when communicating at high frequencies, the amendment 802.16a was specified for working in a lower frequency band, between 2 and 11 GHz. The IEEE 802.16d specification is a variation of the fixed standard (IEEE 802.16a) with the main advantage of optimizing the power consumption of the mobile devices. The last revision of this specification is better known as IEEE 802.16-2004. On the other hand, the IEEE 802.16e standard is an amendment to the 802.16-2004 base specification with the aim of targeting the mobile market by adding portability [9].

WiMax standard-based products are designed to work not only with IEEE 802.16-2004 but also with the IEEE 802.16e specification. While the 802.16-2004 is primarily intended for stationary transmission, the 802.16e is oriented to both stationary and mobile deployments [8].

Initial WiMax 802.16 standard was developed to provide high-speed data communication for licensed fixed applications at microwave frequency (10-66 GHz). Shortly after the development of the initial 802.16 standard, several versions were created to apply for different types of services and to operate in lower frequency (2-11 GHz) [8].

The 802.16a specification was created to allow WiMax to operate in 2-11 GHz bandwidth range, this was followed by the 802.16c specification which contained profiles for 10-66 GHz system. Development on an 802.16d specification was started to define profiles for 2-11 GHz range, eventually all of the variations (802.16a, 802.16c and 802.16d) were merged back together into a single 802.16 specification (802.16-2004)[9], and this specification has been selected for our simulation profile.

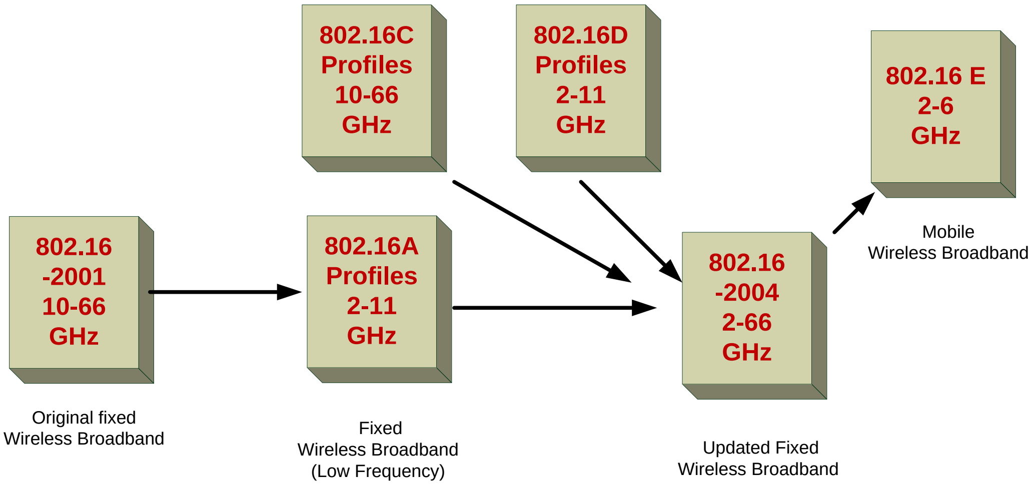


Figure: 2.4 Wireless Broadband 802.16 Evolution

In figure 2.4, it can be seen how 902.16 wireless broadband systems have been evolved over time. This diagram shows the original 802.16 specification offered fixed wireless broadband service at 10-66 GHz. To provide fixed wireless broadband service in the range 2-11 GHz, 802.16a specification was created. Additional variations of the original 802.16 specification were created until in 2004, these specifications were merged all together back into a single 802.16-2004 specification. This figure shows that since the 802.16-2004 specification was released, 802.16e addendum was approved that ads mobility to the 802.16 WiMax system.

Table 2.1 Shows summaries of some of the 802.16 WiMax Standards, it's also shows that the main 802.16 standard is 802.16-2004 which updates The original 802.16-2001 specification by merging the 802.16a, 802.16c and 802.16d amendments. The 802.16e specification adds mobility feature like hand over capabilities to the 802.16-2004 specification. This table also shows that other standards have been created to allow for the setup and management of WiMax system including 802.16f (management information base (MIB)) and 802.16.2 (co-existence).

Standard	Covers	Notes
802.16-2004	Main 802.16 Standerd	Updates the original 802.16 by merging the 802.16a, 802.16c and 802.16d amendments
802.16f-2005	Addendum to 802.16 for Management Information Base(MIB)	
802.16e	Addendum that ads mobility to 802.16	Mobile operation up to 6 GHz, Released in 2006
802.16c0-2002	Profile for 10-66 GHz	Updated by 802.16-2004
802.16a-2003	Addendum that added 2-11 GHz capability to 802.16	Updated by 802.16-2004
802.16d	System Profile for 2-11 GHz	Development discontinued
802.16.2	Co-existence of wired and wireless broadband	
802.16-2001	Original WiMax standard 10-66 GHz	Updated by 802.16-2004

Table 2.1: WiMax Standards [3]

WiMax standard defines the air interface for the IEEE 802.16-2004 specification working in the frequency band 2-11 GHz. This air interface includes the definition of the medium access control (MAC) and the physical (PHY) layers.

2.4 WiMax's Protocol Layers

The IEEE 802.16 Broadband Wireless Access (BWA) network standard applies what it calls Open Systems Interconnection (OSI) network reference seven-layer model, also called the OSI seven-layer model. This model is very often used to describe the different aspects of a network technology. It starts from the Application Layer, or Layer 7, at the top and ends with the Physical (PHY) Layer, or Layer 1, at the bottom.

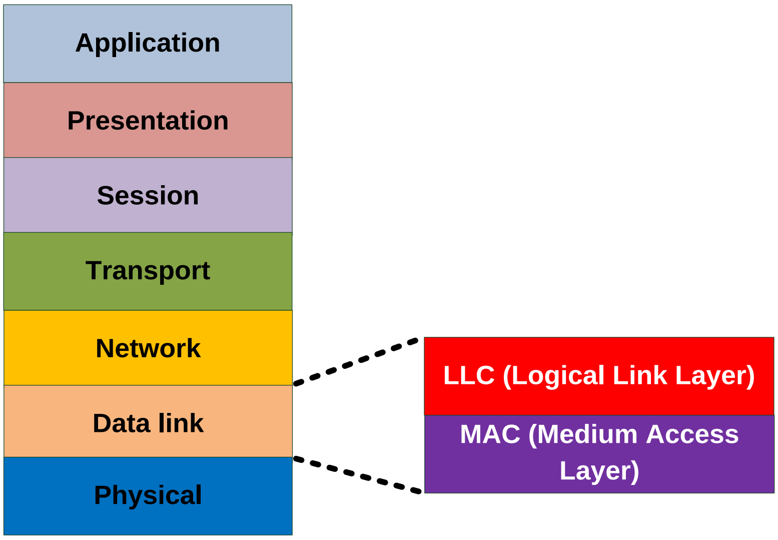


Figure 2.5: The seven-layer OSI model for networks. In WiMax/802.16

The OSI model separates the functions of different protocols into a series of layers, each layer using only the functions of the layer below and exporting data to the layer above. For example, the IP (Internet Protocol) is in Layer 3, or the network layer. Typically only the lower layers are implemented in hardware while the higher layers are implemented in software [7].

The two lowest layers are then the Physical (PHY) Layer, or Layer 1, and the Data Link Layer, or Layer 2. IEEE 802 splits the OSI Data Link Layer into two sub-layers named Logical Link Control (LLC) and Media Access Control (MAC). The PHY layer creates the physical connection between the two communicating entities (the peer entities), [7] while the MAC layer is responsible for the establishment and maintenance of the connection (multiple access, scheduling, etc.).

The IEEE 802.16 standard specifies the air interface of a fixed BWA system supporting multimedia services. The MAC Layer supports a primarily point to-multipoint (PMP) architecture, with an optional mesh topology. The MAC Layer is structured to support many physical layers (PHY) specified in the same standard. In fact, only two of them are used in WiMax.

2.5 Medium Access Control (MAC) layer

Some functions are associated with providing service to subscribers. They include transmitting data in frames and controlling the access to the shared wireless medium. The medium access control (MAC) layer, which is situated above the physical layer, groups the mentioned functions.

The original MAC is enhanced to accommodate multiple physical layer specifications and services, addressing the needs for different environments. It is generally designed to work with point-to-multipoint topology networks, with a base station controlling independent sectors simultaneously. Access and bandwidth allocation algorithms must be able to accommodate hundreds of terminals per channel, with terminals that may be shared by multiple end users. Therefore, the MAC protocol defines how and when a base station (BS) or a subscriber station (SS) may initiate the transmission on the channel.

In the downstream direction there is only one transmitter, and the MAC protocol is quite simple using Time Division Multiplexing (TDM) to multiplex the data. However, in the upstream direction, where multiple SSs compete for accessing to the medium, the MAC protocol applies a time division multiple access (TDMA) technique, thus providing an efficient use of the bandwidth. The services required by the multiple users are varied, including voice and data, Internet protocol (IP) connectivity, and voice over IP (VoIP). In order to support this variety of services, the MAC layer must accommodate both continuous and bursty traffic, adapting the data velocities and delays to the needs of each service. Additionally, mechanisms in the MAC provide for differentiated quality of service (QoS) supporting the needs of various applications.

Issues of transport efficiency are also addressed. Both modulation and coding schemes are specified in a burst profile that is adjusted adaptively for each burst to each subscriber station, making the use of bandwidth efficient, providing maximum data rates, and improving the capacity of the system. The request-grant mechanism is designed to be scalable, efficient, and self correcting, allowing the system a scalability from one to hundreds of users.

Another feature that improves the transmission performance is the automatic repeat request (ARQ) as well as the support for mesh topology rather than only point-to-multipoint network architectures. The possibility of working with mesh topologies allows direct communication between SSs, enhancing this way the scalability of the system. The standard also supports automatic power control, and security and encryption mechanisms. Further information about the MAC features can be found in [8]and [10]

2.6 Physical (PHY) Layer

The physical layer performs the conversation of data to a physical medium (such as copper, optic or radio) transmission and coordinates the transmission and reception of these physical signals. The physical layer receives data for transmission from an upper layer and converts it into physical format suitable for transmission through a network (such as frames and bursts). An upper layer provides the physical layer with the necessary data and control (example maximum packet size) to allow conversion to a format suitable for transmit ion on a specific network type and transmission line.

The IEEE 802.16-2004 standard defines three different PHY layers that can be used in conjunction with the MAC layer to provide a reliable end-to-end link. These PHY specifications are:

- A single carrier (SC) modulated air interface.
- A 256-point Fast Fourier Transform (FFT) OFDM7 multiplexing scheme.
- A 2048-point FFT Orthogonal Frequency Division Multiple Access (OFDMA) scheme.

While the SC air interface is used for line-of-sight (LoS) transmissions, the two OFDM-based systems are more suitable for non line-of-sight (NLoS) operations due to the simplicity of the equalization process for multicarrier signals. The fixed WiMax standard defines profiles using the 256-point FFT OFDM PHY layer specification. Furthermore, fixed WiMax systems provide up to 5 km of service area allowing transmissions with a maximum data rate up to 70 Mbps in a 20 MHz channel bandwidth, and offer the users a broadband connectivity without needing a direct line-of-sight to the base station [11].

The main features of the mentioned fixed WiMax are detailed next:

- Support of both time and frequency division duplexing formats, Frequency Division Duplexing, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD), allowing the system to be adapted to the regulations in different countries.
- Use of an OFDM modulation scheme, which allows the transmission of multiple signals using different subcarriers simultaneously. Because the OFDM waveform is composed of multiple narrowband orthogonal carriers, selective fading is localized to a subset of carriers that are relatively easy to equalize.

Designing of an adaptive modulation and coding mechanism that depends on channel and interference conditions. It adjusts the modulation method almost instantaneously for optimum data transfer, thus making a most efficient use of the bandwidth.

Robust Forward Error Correction (FEC) techniques, used to detect and correct errors in order to improve throughput. The FEC scheme is implemented with a Reed- Solomon encoder concatenated with a convolutional one, and followed by an interleaver. Optional support of block turbo coding (BTC) and convolutional turbo coding (CTC) can be implemented.

Design of a dynamic frequency selection (DFS) mechanism to minimize interferences. Use of flexible channel bandwidths, comprised from 1.25 to 28 MHz [9], thus providing the necessary flexibility to operate in many different frequency bands with varying channel requirements around the world. This flexibility facilitates transmissions over longer ranges and from different types of subscriber platforms. In addition, it is also crucial for cell planning, especially in the licensed spectrum. Optional supports of both transmit and receive diversity to enhance performance in fading environments through spatial diversity, and to allowing the system to increase capacity. The transmitter implements space-time coding (STC) to provide transmit source independence, reducing the fade margin requirement, and combating interference. The receiver, however, uses maximum ratio combining (MRC) techniques to improve the availability of the system. Optional support of smart antennas, beams can steer their focus to a particular direction or directions always pointing at the receiver, and consequently, avoiding interference between adjacent channels, and increasing the spectral density and the SNR. There are two basic types of smart antennas, those with multiple beams (directional antennas), and those known as adaptive antenna systems (AAS). The first ones can use either a fixed number of beams choosing the most suitable for the transmission or a steering beam to the desired antenna. The second type works with multi-element antennas with a varying beam pattern. These smart antennas are becoming a good alternative for BWA deployments .

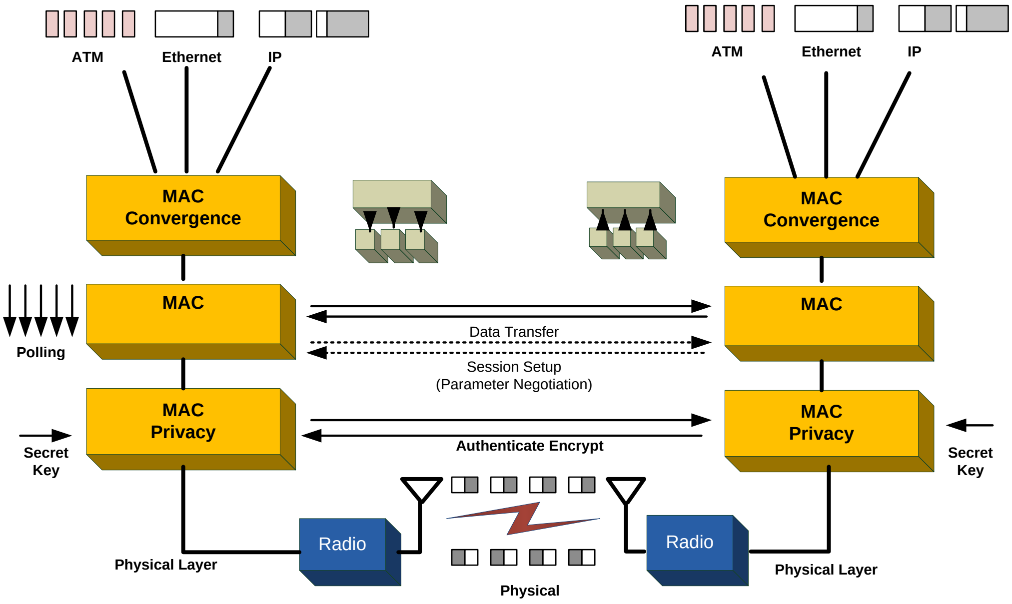


Figure 2.6 WiMax Protocol Layer

Figure 2.6 Shows that WiMax composed of 4 primary layers. The physical layer is responsible for converting bits of information into radio bursts. MAC security layer is responsible for identifying the users authentication and keeping the information private (encrypting). The MAC layer is responsible for requesting access and coordinating the flow of information. The MAC convergence layer is used to adapt WiMax system to other systems such as Ethernet [9].

The mobile WiMax (IEEE 802.16e) 12 uses the 2048-point FFT OFDMA PHY specification. It provides a service area coverage from 1.6 to 5 km, allowing transmission rates of 5 Mbps in a 5 MHz channel bandwidth, and with a user maximum speed below 100 km/h. It presents the same features as those of the fixed WiMax specification that have been already mentioned. However, other features such as handoffs and power-saving mechanisms are added to offer a reliable communication [12], [13].

2.7 Supported Band of Frequency

The IEEE 802.16 supported licensed and unlicensed bands of interest are as follows:

a) 10-66GHz licensed band

In this frequency band, due to shorter wave length, line of sight operation is required and as a result the effect of multipath propagation is ignored. The standard promises to provide data rates up to 120 Mb/s in this frequency band [14]. The abundant availability of bandwidth is also another reason to operate in this frequency range. Unlike the lower frequency ranges where frequency bands are often less than 100MHz wide, most frequency bands above 20GHz can provide several hundred megahertz of bandwidth [15]. Additionally, channels within these bands are typically 25 or 28 MHz wide [14].

b) 2-11GHz licensed and licensed exempt

In this frequency bands, both licensed and licensed exempt bands are addressed. Extra physical functionality supports have been introduced to operate in Near Line of Sight (LoS) and None Line of Sight (NLoS) environment and to mitigate the effect of multipath propagation. In fact, many of the IEEE 802.16 PHY's most valuable capabilities are found in this frequency range. Operation in licensed exempt band experiences extra interference and coexistence issue. The PHY and MAC address mechanism like dynamic frequency selection (DFS) to detect and avoid interference (for licensed exempt band)[11]. Though service provision in this frequency band is highly depends on design goals, vendors typically cite target aggregate data rates of up to 70Mb/s in a 14 MHz channel [16].

2.8 IEEE 802.16 PHY interface variants

WiMax system variants are the types of radio interference that WiMax can use to provide wireless broadband service. WiMax variants include Wireless MAN-SC, Wireless MAN-OFDM, Wireless-OFDMA and Wireless Human.

a) Wireless MAN-SC

Wireless MAN single carrier is a licensed version that operates in the 10-66 GHz spectrum frequency and permits data transmission speeds up to 120 Mbps per Radio Frequency (RF) carrier.

b) Wireless MAN-SCa

Wireless MAN single carrier version is a licensed version that operates in the 2-11 GHz spectrum frequency and permits data transmission speed up to 120 Mbps per RF carrier. It’s because of operation at low frequency where multipath transmissions may occur. The wireless MAN-SC system includes the capability of equalizing (adjusting) the received signal to compensate for distortion occurs from multi-path.

c) Wireless MAN-OFDM

Wireless MAN orthogonal frequency division multiplexing is a licensed version that operates in the 2-11GHz frequency spectrum and divides the data signal into up to 256 sub-carriers.

d) Wireless MAN –OFDMA

Wireless MAN orthogonal frequency division multiple access is a licensed version that operates in the 2-11GHz frequency spectrum and divides the data signals into transferred on to up to 2048 sub-carriers. The OFDMA system allows for the dynamic assignment of sub-carriers (multiple access) to specific sub-scriber stations.

e) Wireless HUMAN

Wireless HUMAN is air interference (radio part) is designed to operate on unlicensed radio channels (primarily 5 to 6 GHz). Wireless Human includes dynamic frequency selection (DFS) to allow the system to automatically select RF channel frequencies.

Air Interference	Frequency band	Duplexing	Primary Use
Wireless MAN-SC	10-66 GHz	FDD & TDD	PTP
Wireless MAN-SCa	2-11 GHz	FDD&TDD	PTP
Wireless MAN-OFDM	2-11 GHz	FDD & TDD	PTMP
Wireless MAN-OFDMA	2-11 GHz	FDD& TDD	PTMP
Wireless-HUMAN	5-6 GHz (unlicensed)	TDD	PTMP

Table 2.2: WiMax System Types [9]

Table 2.2 shows the different RF types that can be used for the 802.16 system. This table shows that some versions of WiMax system are single carrier and others sub-divide the carrier into multiple independently controlled channels. This table also shows that WiMax frequency bands range from 2GHz to 66 GHz.

2.9 Single Carrier (SC) versus Multi-carrier

The carrier signal always has higher frequency and mostly a single tone cosine signal. Modulation schemes are classified according to which property of carrier changed by data signal and whether they are analogue or digital. But regardless of these entire if they are using a single tone, like in inherited old systems they called ‘Single Carrier’ modulation and consequently single carrier communication system. Figure 2.7 shows a single carrier signal spectrum.

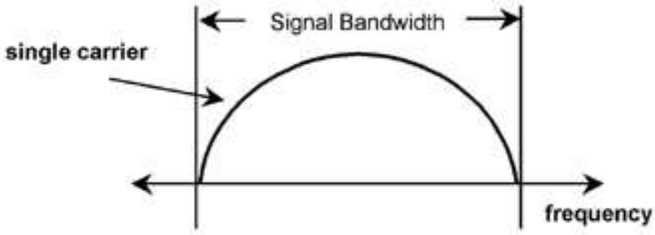


Figure 2.7 Single Carrier Power Spectrum

If more than one user wanted to share such system to communicate with others they will need a technique called Multiplexing to relay using of resources.

In the other hand ‘Multicarrier’ systems are existed. As it can be understood from name in such modulation techniques and systems more than one frequency carriers are used to modulate information signal. The carrier signals could be generated individually but in most cases they are generated from same source to ensure of frequency synchronization and orthogonality.

Multicarrier systems are more immune to multipath fading, both frequency and time synchronization errors and narrow band noise. All these properties in addition to saving in guard band and lower latency and higher data rate make multicarrier systems more favourite for future communication systems [17].

The use of OFDM increases the data capacity and, consequently, the bandwidth efficiency with regard to classical Single Carrier (SC) transmission. This is done by having carriers very close to each other but still avoiding interference because of the orthogonal nature of these carriers. Therefore, OFDM presents a relatively high spectral efficiency. This is greater than the values often given for CDMA (Code Division Multiple Access) used for 3G, although this is not a definitive assumption as it depends greatly on the environment and other system parameters, the OFDM transmission technique and its use in OFDM and OFDMA physical layers of WiMax will be describe later in this chapter.

2.10 WiMax Technologies

Some of the key technologies used in WiMax system include orthogonal frequency division multiplexing, frequency reuse, adaptive modulation, diversity transmission and adaptive antennas.

2.10.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is the most well-known multicarrier technique that can be considered both a modulation and a multiplexing method. It divides the spectrum to many subcarriers to modulate them with lower data rate streams. It uses available spectrum much more efficient than conventional single carrier modulation schemes. This efficiency comes from putting the subcarriers closer together or actually inserting them inside each other in a way to make their spectrum orthogonal to each other [18]. Orthogonality means that each subcarrier's spectrum has a null value in its adjacent subcarriers peak value and so on (Figure 2.8). The orthogonality makes the spectrum efficiency of OFDM 50% superior over traditional modulation schemes [17].

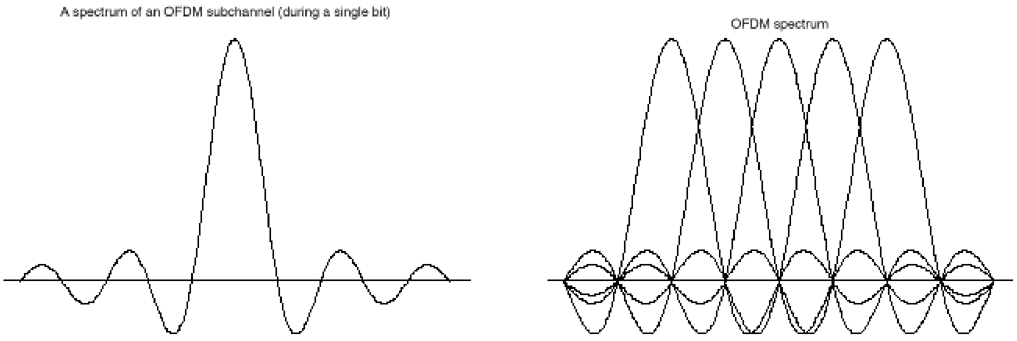


Figure 2.8 OFDM Signal Spectrums [18]

The baseband modulation techniques are still available in OFDM and after mapping of data individually, the subcarrier generated by a Discrete Fourier Transform block to make sure of orthogonality and load data on them. This makes the synchronization easier and avoids frequency offsets. The figure 2.8 shows a general discrete domain OFDM system.

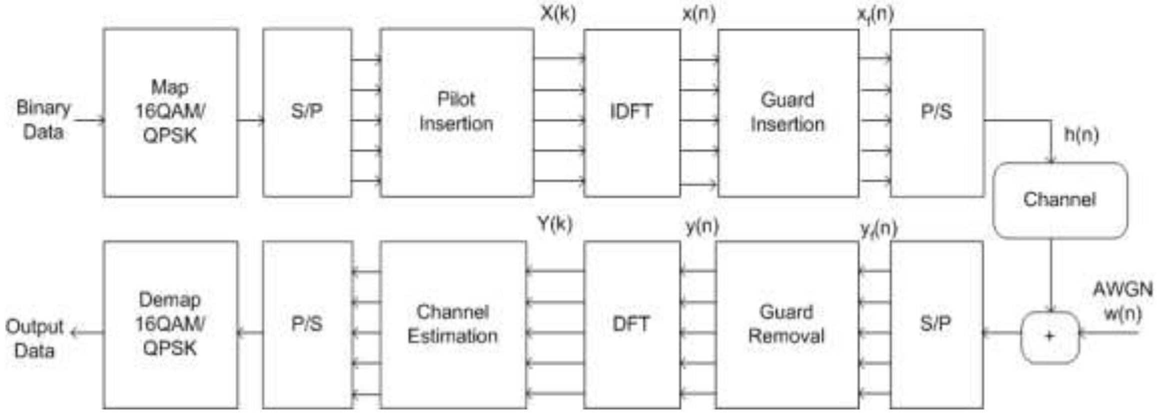


Figure 2.9 General OFDM Transceiver [19]

The following stages are obvious and form main parts of OFDM transmitter:

Mapper: As soon as user data is ready to transmit and comes through higher layers of system and arrives in physical layer, it will be mapped to its appropriate available states of baseband modulation like Phase Shift Keying (PSK) or QAM. The available constellation points are determined from modulation order that itself pre-determined by system design or adaptively changes based on receiver feedback according to channel condition.

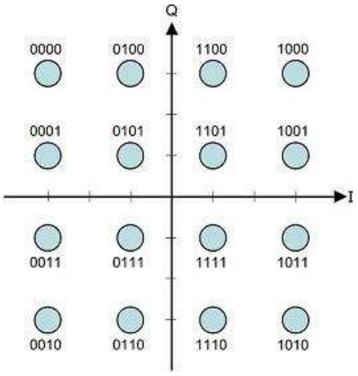


Figure 2.10 16-QAM constellation map [20]

Each state in constellation map represents a group of data bits. There are different methods to assign the bits to states. Figure 2.10 demonstrates a 16-QAM constellation map with 16 states as it could be find out from name which a group of 4 information bits assigned to each state in simple binary order.

Inverse Fast Fourier Transform (IFFT): Inverse Fast Fourier Transform that is used for its simplicity and accuracy is the main block of any multicarrier system including OFDM. It can be imagined as many parallel local oscillators that work exactly on adjacent “Orthogonal” frequencies. This orthogonality can be considered main feature of OFDM modulation that guarantees the avoidance of interference between adjacent subcarriers.

This block converts frequency domain states from mapped signals to their related time domain signal with orthogonal spectrum on modulated subcarriers. FFT/IFFT is a computationally efficient form of Discrete Fourier Transform which works by decomposition of mathematical approach of Discrete Fourier Transform (DFT) to several lower order transformations and reducing the computational complexity. It converts frequency domain symbols to their time domain samples.

GI/CP Guard Interval Insertion: In OFDM there is no need for guard band frequencies due to time domain effect of channel by existence of IFFT and FFT but instead the consecutive symbols may interfere with followed ones due to channel delay spread. To avoid these phenomena a time guard interval inserted between two successive symbols coming from IFFT stage. This block is our stage of interest and covered in more detail later in this dissertation.

Then signal passes through a Digital to Analogue converter and converted to continuous time signal, then up converted to specified frequency and loaded to required part of spectrum and transmitted to channel.

In the channel signal will be attenuated, distorted, faded and induced by noise and interference. Different environments affect signal in different forms but all does one thing, all degrade the signal quality in a way that makes further processing in receiver to compensate such declination necessary. The channel part is very important in any communication system thence it covered in more detail in next case.

At the receiving part the antenna/s gather required amount of power from channel to form received signal. After some amplification and purification it will be down converted to baseband and then sampled by an Analogue to Digital converter. Then it applied to following main stages:

a) GI/CP removal: In this stage the added guard intervals are removed from OFDM symbols. This will cancel the effect of induced interference from delayed replicas of preceding symbols and reduce ISI.

b) FFT: Fast Fourier Transform that inverses the effect of IFFT and returns the frequency domain samples which represent modulation states. In fact the FFT and IFFT do same thing, because Fast Fourier Transform is implemented using a linear algorithm and works in both direction in the same way. The ‘Inverse’ prefix just used to acknowledge the frequency to time transformation at the transmitter and makes no change in real.

c) Equalizer: To compensate the channel effects the receiver contains one more important part. It actually encloses two subparts, Estimator and Equalizer. The receiver estimates the channel impulse response by using pre-known values called pilots or non-pilot algorithms and then tries to compensate it by applying reverse effect to the signal. This part is also covered later in channel's case.

d) De-mapper: Finally samples goes through a demodulation block and translated to real data. This Case does the inverse of modulation and performed in same order. But the difference is that the received states of signal suffering from random noise effects that are existed even after equalization also the fading effects company the signal due to non-perfect channel estimation.

2.10.2 Advantages and Disadvantages of OFDM

All the advantages from using OFDM technology have been sorted in these points [21]:

ADVANTAGES:

- Makes efficient use of the spectrum by allowing overlap.
- By dividing the channel into narrowband flat fading sub-channels, OFDM is more resistant to frequency selective fading than single carrier systems are.
- Eliminates ISI and Inter-Carrier Interference (ICI) through use of a cyclic prefix.
- Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel.
- Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
- OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.

- Is less sensitive to sample timing offsets than single carrier systems are.
- Provides good protection against co-channel interference.

Also OFDM has some drawbacks which can be conceder below,

DISADVANTAGES:

- The OFDM signal has a noise like amplitude with a very large dynamic range, therefore it requires RF power amplifiers with a high peak to average power ratio.
- It is more sensitive to carrier frequency offset and drift than single carrier systems are due to leakage of the DFT.

2.10.3 Orthogonal Frequency Multiple Access (OFDMA)

Orthogonal frequency division multiple access is a process of dividing a radio carrier channel into several independent sub-carrier channels that are shared between simultaneous users of the radio carrier. When a mobile radio communicates with an OFDMA system it’s dynamically assigned a specific sub-carrier channel or group of sub-carrier channels within the radio carrier, by allowing several users to use different sub-carrier channels, OFDMA system increase their ability to serve multiple users and the OFDMA system may dynamically allocated varying amounts of transmission bandwidth based on how many sub-carrier channels have been assigned to each user.

OFDMA distributes subcarriers among users so all users can transmit and receive at the same time within a single channel on what are called sub-channels. What’s more, subcarrier-group sub-channels can be matched to each user to provide the best performance, meaning the least problems with fading and interference based on the location and propagation characteristics of each user.

Figure 2.11 describe how the WiMax system allows more than one simultaneous user per radio channel through the use of orthogonal frequency division multiple access. This example shows how WiMax channel can be divided to multiple sub-carriers and that the sub-carriers can be dynamically assigned to multiple users who are sharing a radio carrier signal. This example also shows that the data rates that are provided to each user can vary based on the number of subscribers that are assigned to each user.

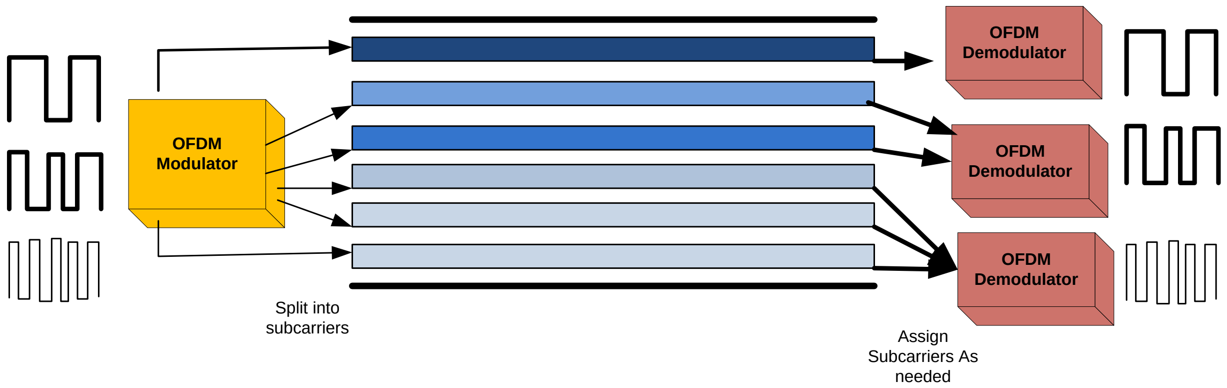


Figure 2.11 Orthogonal Frequency Divisions Multiple Accesses (OFDMA) [9]

2.10.4 Frequency Reuse

In the cellular concept, frequencies allocated to the service are re-used in a regular pattern of areas, called 'cells', each covered by one base station. In mobile-telephone nets these cells are usually hexagonal. In radio broadcasting, a similar concept has been developed based on rhombic cells.

To ensure that the mutual interference between users remains below a harmful level, adjacent cells use different frequencies. In fact, a set of C different frequencies {f1, ..., fC} are used for each cluster of C adjacent cells. Cluster patterns and the corresponding frequencies are re-used in a regular pattern over the entire service area.

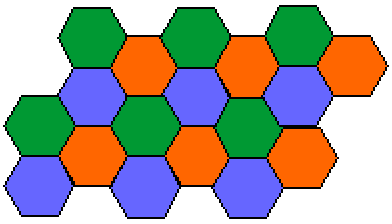


Figure 2.12 Frequency reuse plan for C = 3, with hexagonal cells. (i=1, j =1) [22]

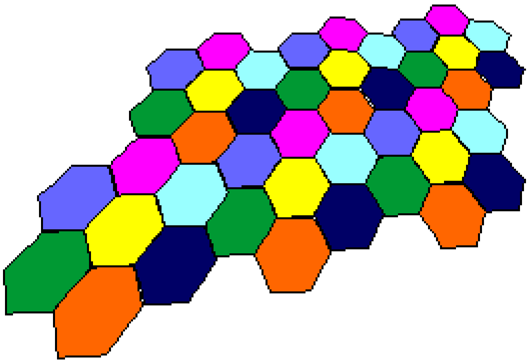


Figure 2.13 Frequency reuse plan for C = 7 (i=2, j =1)[22]

Frequency reuse is the process of using the same radio frequencies on radio transmitter sites within a geographic aria that are separated by sufficient distance to cause minimal interference with each other. Frequency reuse allows for a dramatic increase in the number of customer that can be served within a geographic area on a limited amount of radio spectrum (limited number of radio channels). The WiMax system can use frequency reuse which allows WiMax system operators to reuse the same frequency at different cell sites within their system operating area.

The number of times a frequency can be reused is determined by the amount of interference a radio channel can tolerate from nearby transmitters that are operating on the same frequency. Carrier to interference (C/I) level is the amount of interference level from all unwanted interfering signals in comparison to the desired carrier signals. The C/I ratio is commonly expressed in dB, different types can tolerate different levels of interference depends on the modulation type and error protection system. The typical C/I ratio for narrowband mobile systems ranges from 9 dB (GSM) to 20 dB (Analog cellar). WiMax systems can be much more tolerant to interference levels (Probably less than 3 dB C/I) when OFDM and adaptive antenna systems are used [9].

WiMax system may also reuse frequencies through the use of cell sectoring, which is a process of dividing a geographic region (such as radio coverage) where the initial geographic area (example cell site coverage area) is divided into smaller coverage areas (sectors) by using focusing equipment (Directional antenna).

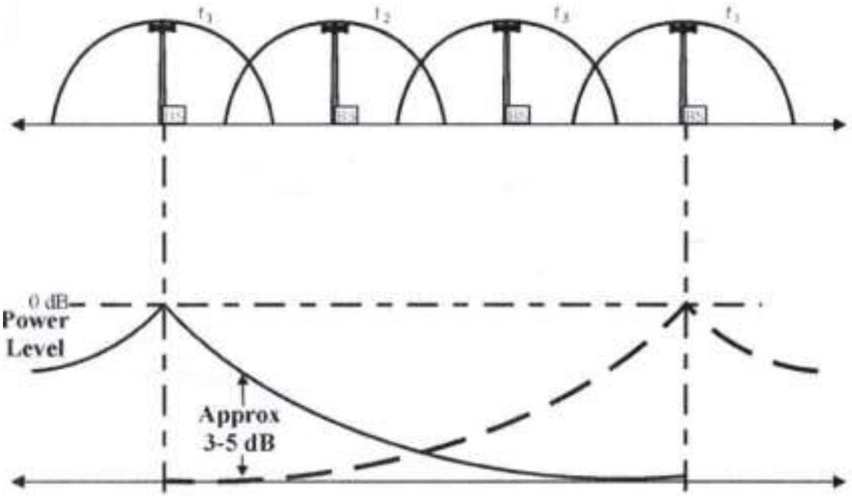


Figure 2.14 WiMax Frequency Reuse [9]

Figure 2.14 shows how radio channels (frequencies) in a WiMax communication system can be reused in towers that have enough distance between them. This example shows that radio channel signal strength decreases exponentially with distance. As a result, mobile radios that are far enough apart can use the same radio channel frequency with minimal interference.

2.10.5 Digital Modulations

Modulation is the process of changing the amplitude, frequency or phase of a radio frequency carrier signal (a carrier) to change with the information signal (such as voice or data). Four modulations are supported by the IEEE 802.16 standard: BPSK, QPSK, 16-QAM and 64-

QAM. In this case the modulations used in the OFDM and OFDMA PHYsical layers are introduced with a short description for each.

As for all modern communication systems, WiMax/802.16 uses digital modulation. The now well-known principle of a digital modulation is to modulate an analogue signal with a digital sequence in order to transfer this digital sequence over a given medium, fiber, radio link, etc. (see Figure 2.15). This has great advantages with regard to classical analogue modulation: better resistance to noise, use of high-performance digital communication and coding algorithms, etc.

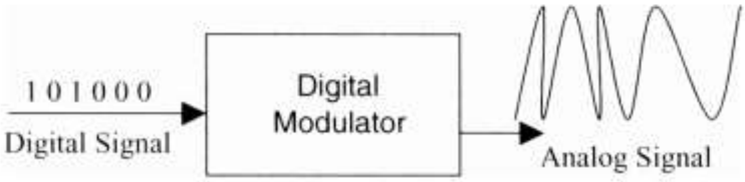


Figure 2.15: Digital modulation principle

2.15 Binary Phase Shift Keying (BPSK)

The BPSK is a binary digital modulation process; i.e. one modulation symbol is one bit. This gives high immunity against noise and interference and a extremely robust modulation. A digital phase modulation, which is the case for BPSK modulation, uses phase variation to encode bits: each modulation symbol is equivalent to one phase. The phase of the BPSK modulated signal is π or -−π according to the value of the data bit. A frequently used illustration for digital modulation is the constellation. Figure 2.16 shows the BPSK constellation; the values that the signal phase can take are 0 or π [5].

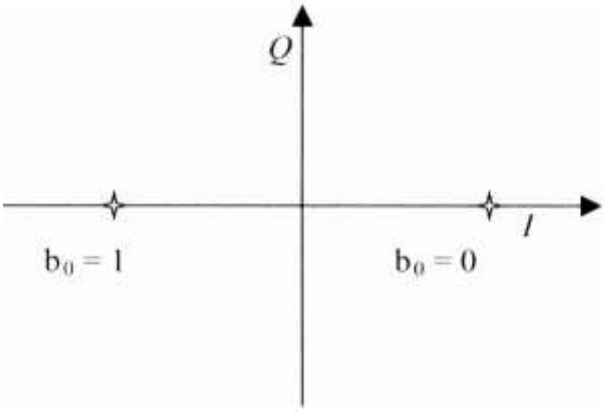


Figure 2.16: The BPSK

2.10.4.2 Quadrature Phase Shift Keying (QPSK)

When a higher spectral efficiency modulation is needed, i.e. more b/s/Hz, greater modulation symbols can be used. For example, QPSK considers two-bit modulation symbols. QPSK is a type of modulation that uses 4 different phase shifts of a radio carrier signal to represent the digital information signal. These shifts are represented typically as +/- 45 and +/- 135 degrees.

Many variants of QPSK can be used but QPSK always has a four-point constellation (see Figure 2.17). The decision at the receiver, e.g. between symbol ‘00’ and symbol ‘01’, is less easy than a decision between ‘0’ and ‘1’. The QPSK modulation is therefore less noise resistant than BPSK as it has a smaller immunity against interference [5]. A well-known digital communication principle must be kept in mind: ‘A greater data symbol modulation is more spectrum efficient but also less robust.’

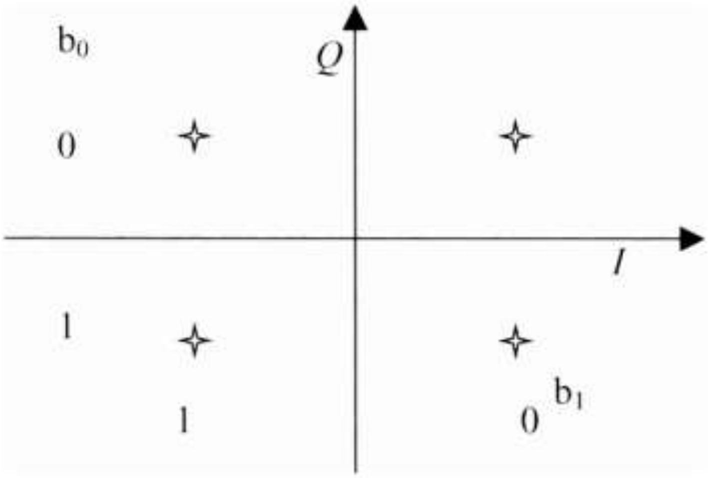


Figure 2.17: Example of a QPSK constellation

2.10.4.3 Quadrature Amplitude Modulation (QAM): 16-QAM and 64-QAM

QAM is a combination of amplitude modulation (changing the amplitude or voltage of a sine wave to convey information) together with phase modulation.

The QAM changes the amplitudes of two sinusoidal carriers depending on the digital sequence that have got to be transmitted; the two carriers being out of phase of +π/2, this amplitude modulation is called quadrature. It should be mentioned that according to digital communication theory, QAM-4 and QPSK are the same modulation (considering complex data symbols). Both 16-QAM (4 bits/modulation symbol) and 64-QAM (6 bits/modulation symbol) modulations are included in the IEEE 802.16 standard. The 64-QAM is the most efficient modulation of 802.16 (see Figure 2.18). Indeed, 6 bits are transmitted with each modulation symbol [5].

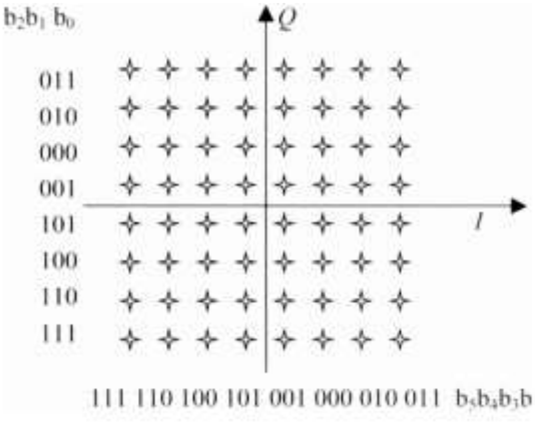


Figure 2.18: A 64-QAM constellation

The 64-QAM modulation is optional in some cases [5]:

- license-exempt bands, when the OFDM PHYsical Layer is used
- for OFDMA PHY, yet the Mobile WiMax profiles indicates that 64-QAM is mandatory in the downlink.

2.10.5 Link Adaptation

Adaptive modulation is the process off dynamically adjusting the modulation type of a communication channel based on specific criteria like interference or data transmission rate.

Having more than one modulation has a great advantage; link adaptation can be used. The principle is rather simple: when the radio link is good, use a high-level modulation; when the radio link is awful, use a low-level, but also robust, modulation. Figure 2.19 shows this principle, illustrating the fact that the radio channel is better when an SS is close to the BS. Another dimension is added to this figure when the coding rate is also changed [8].

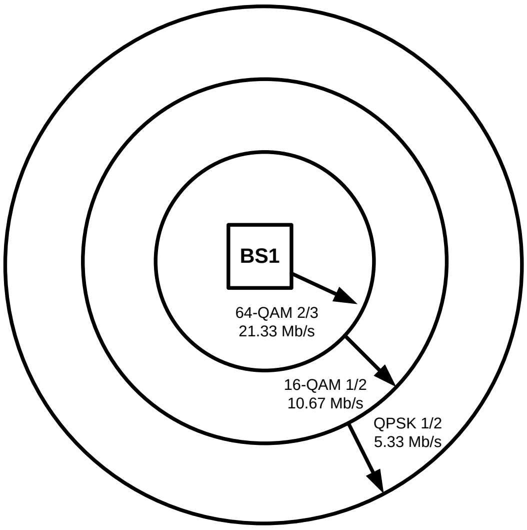


Figure 2.19: link adaptation [8]

2.10.6 Diversity Transmission

Diversity transmission is the process of using two or more signals to carry the same information source between a transmitter and a receiver. Diversity transmission can use the physical separation of antenna elements (spatial diversity) the use of multiple wavelengths (frequency diversity) and the shifting of time (time diversity), It can help overcome the effects of fading, outages, and circuit failures. When using diversity transmission and reception, the amount of received signal improvement depends on the independence of the fading characteristics of the signal as well as circuit outages and failures.

There are different types of diversity in communication system; they are going to be explained bravely:

Transmission Diversity: Transmission diversity is the process of sending two or more signals from the same information source so a receiver can select or combine the signals to produce a received signal that is better quality than is possible with a single transmitted signal.

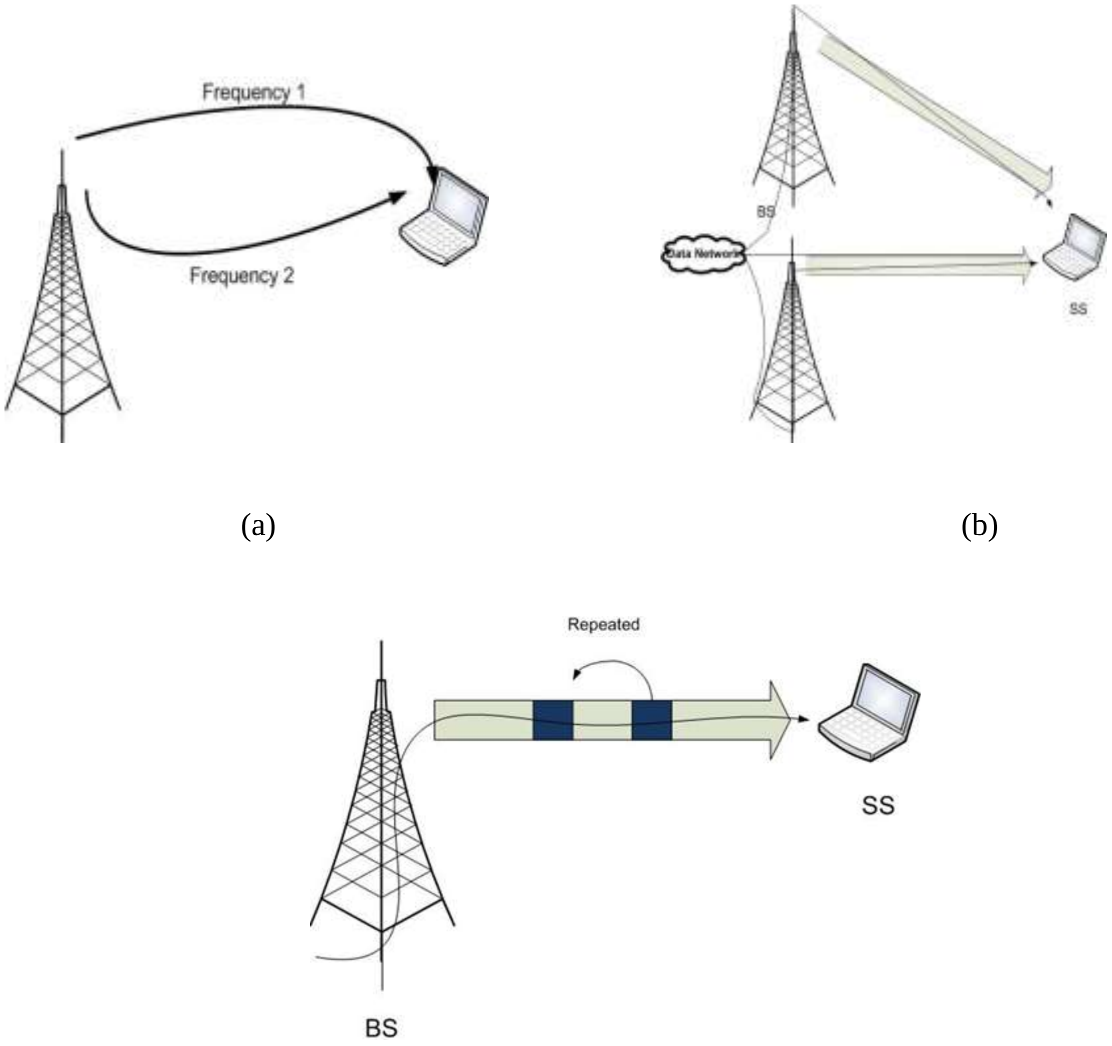
Receive Diversity: is the use of two antennas at receiver side that are physical separated vertically or horizontally that can be used to select or combine a received signal to yield a stronger signal quality level for communication.

Frequency Diversity: Frequency diversity is the process of receiving a radio signal on multiple channels (different frequencies) or over a wide radio channel (wide frequency band) to reduce the effects of radio signal distortions (such as signal fading) that occur on one frequency components but do not occur on another frequency component.

Time diversity: it's the process of sending the same signal or components of a signal through a communication channel where the same signal is transmitted or received at different times. The reception of two or more of the same signal with time diversity may be used to compare, recover, or add to the overall quality of the received signal.

Spatial Diversity: Spatial diversity is a method of transmission and or reception employed to minimize the effects of fading by the simultaneous use of two or more antennas spaced a number of wavelengths apart. Antenna diversity is a form of spatial diversity that improves the reception of a radio signal by using the signals from two or more antennas to minimize the effects of radio signal fading or distortion.

Space time coding is the adding of time information to transmission carriers to allow diversity operation by identifying and processing multiple carriers of the same signal that may arrive at different times and or from different locations [9], figure 2.20 illustrates different types of diversity.



(a) (b)

(c)

Figure 2.20 Different types of diversity transmission and reception
(a) Frequency Diversity (b) Spatial Diversity (c) Time Diversity

2.10.7 Adaptive Antenna System (AAS)

An Adaptive Antenna System (AAS) can focus its transmit energy to the direction of a receiver. While receiver can focus to the direction of the transmitting device. The technique used in AAS is known as beamforming or beamsteering or beamshaping [9]. It works by adjusting the width and the angle of the antenna radiation pattern (a.k.a. the beam).

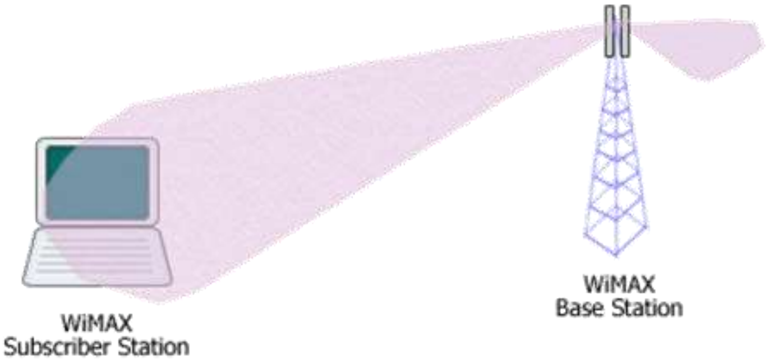


Figure 2.21: WiMax BS with AAS beamforming capability

Combined with multiple antennas in the Base Station (BS), AAS can be used to serve multiple Subscriber Stations (SSs) with higher throughput. A technique known as SDMA (Space Division Multiple Access) is employed here where multiple SSs that are separated (in space) can transmit and receive at the same time over the same sub-channel.

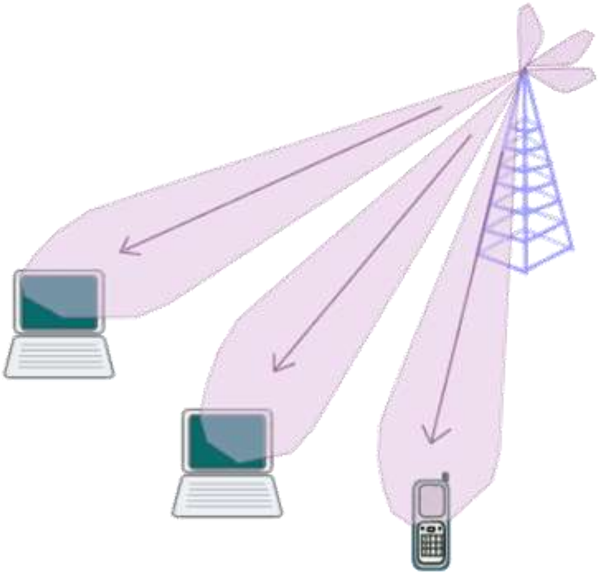


Figure 2.22: WiMax BS with multiple antennas and AAS

AAS and multiple antennas combined in the BS can increase per user data rate.

AAS also eliminates interference to and from other SSs and other sources by steering the nulls to the direction of interferers. AAS is an optional feature in WiMax and not included in WiMax certification. But due to its effectiveness in improving performance and coverage especially in Mobile WiMax case, many vendors integrate AAS capability into their products.

2.11 Channel Coding

The radio link is a quickly varying link, often suffering from great interference. Channel coding, whose main tasks are to prevent and to correct the transmission errors of wireless systems, must have a very good performance in order to maintain high data rates. The 802.16 channel coding chain is composed of three steps [9]:

- Randomizer
- Forward Error Correction (FEC)
- Interleaving

They are applied in this order at transmission. The corresponding operations at the receiver are applied in reverse order.

2.12 Randomization

Randomization is the process of rearranging data components in a serial bit sequence to statistically approximate a random sequence.

The WiMax system uses pseudo-random binary sequence (PRBS) randomization process to be sure that there are no long sequences of bits that would cause a high peak to average power ratio (PAPR). PAPR is comparison of the peak power detected over a period of sample time to the average power level that occurs over the same time period [8]. A high PAPR would require the use of s more linear RF amplifier assembly increasing cost and decreasing power conversion efficiency (short battery life).

2.13 Forward Error Correction (FEC)

Error correction code are additional information elements (codes) that are sent along with an information data signal that can be used to detect and possibly correct errors that occur during the transmission and storage of the media. The 802.16 system can use a variety of error coding methods including Reed Soloman coding [9], Convolution coding (optional) and block turbo code (optional).

2.14 Interleaving

Interleaving is used to protect the transmission against long sequences of consecutive errors, which are very difficult to correct. These long sequences of error may affect a lot of bits in a row and can then cause many transmitted burst losses. The use of interleaving greatly increases the ability of error protection codes to correct for burst errors [9].

The 802.16 system uses interleaving to map data onto non-adjacent sub-carriers to overcome the effect of frequency selective (multi-path) distortion.

2.15 Puncturing process

Puncturing is the process of systematically deleting bits from the output stream of a low-rate encoder in order to reduce the amount of data to be transmitted, thus forming a high-rate code. The bits are deleted according to a perforation matrix, where a "zero" means a discarded bit. The process of puncturing is used to create the variable coding ratesneeded to provide various error protection levels to the users of the system. The different rates that can be used are rate 1/2, rate 2/3, rate 3/4, and rate 5/6 [5]. The puncturing vectors for these rates are given in Table 2.3.

Rate	**Puncture Vector**
1/2	[1]
2/3	[1 1 1 0]
3/4	[1 1 0 1 1 0]
5/6	[1 1 0 1 1 0 0 1 1 0]

Table 2.3 Puncture vectors for different convolution coding rates

2.16 Pilot Symbols

Each signal is divided into frames and each frame consists of a plurality of blocks. A pilot signal block is inserted into each frame of each signal before transmission. The pilot signal blocks are inserted in a time staggered fashion, spread though out the frame. The pilot symbols are time-staggered using an arbitrary algorithm for the pilot symbol insertion. This enables each receiver to perform more accurate, continuous channel estimation and results in a reduced Bit Error Rate (BER) and an improved Quality of Service (QoS) [16].

Pilot symbols can be used to perform frequency offset compensation at the receiver. Additionally, as recent results showed [23], they can be used for channel estimation in fast time-varying channels. Pilot symbols allocate specific subcarriers in all OFDM data symbols. These pilots are obtained by a pseudo-random binary sequence (PRBS) generator that is based on the polynomial $x11 + x9 + 1$. They are, moreover, 2-PAM pulse amplitude modulated. This kind of mapping is given by the operations $1 - 2wk$ and $1 - 2wk$, where wk is the sequence produced by the PRBS generator, and wk denotes the binary inversion.

The indices represent the subcarrier numbers where the pilots are going to be inserted:

$$p\text{-}88 = p\text{-}38 = p63 = p88 = 1 - 2wk,$$
$$p\text{-}63 = p\text{-}13 = p13 = p38 = 1 - 2wk.$$

The initialization sequences for the PRBS generator vary depending on the direction of transmission, i.e. the downlink or the uplink. A sequence of all "ones" is used in the downlink while a sequence of alternated "ones" and "zeros", being the first bit equal to "one", is used in the uplink.

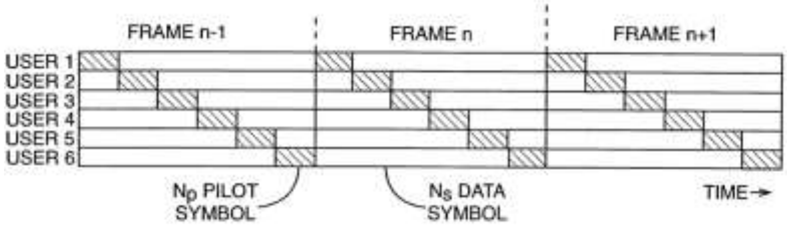


Figure 2.23: Pilot symbols insertion [3]

2.17 Assembler

WiMax specifications for the 256-point FFT OFDM PHY layer define three types of subcarriers; data, pilot and null, as shown in figure 2.24. 200 of the total 256 subcarriers are used for data and pilot subcarriers, eight of which are pilots permanently spaced throughout the OFDM spectrum. The remaining 192 active carriers take up the data subcarriers. The rest of the potential carriers are nulled and set aside for guard bands and removal of the center frequency subcarrier.

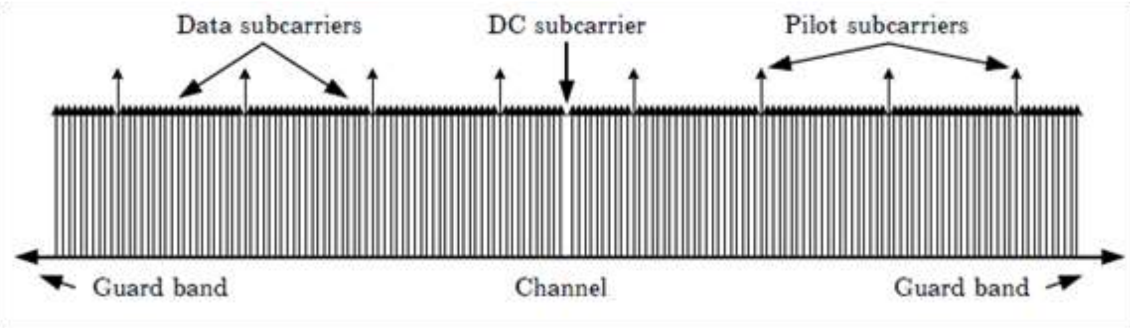


Figure 2.24: OFDM frequency description [3]

In order to construct an OFDM symbol, a process to rearrange these carriers is needed. With this purpose, the assembler block is inserted in the simulator.

It performs this operation in two steps by first inserting the pilot tones and the zero DC subcarrier between data with a process of vertical concatenation, and then appending the training symbols at the beginning of each burst in a horizontal way, as shown in Figure 2.25. It is shown that while the first step performs a concatenation in the frequency domain, the second step does it in the time domain [24].

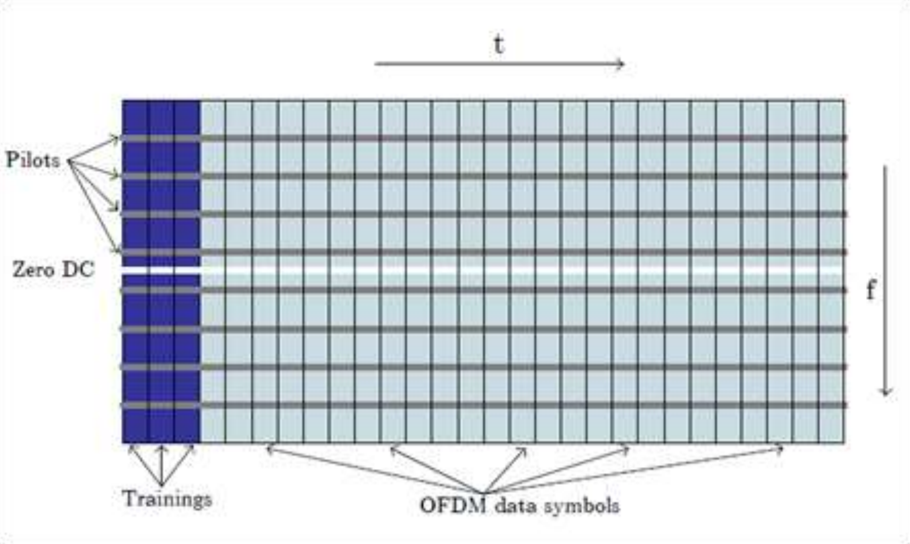


Figure 2.25: OFDM burst structure obtained after assembling [3]

Matlab allows only positive indices, and so, a shift on these index values is needed in the simulator.

2.18 The Guard Interval and Cyclic Prefix

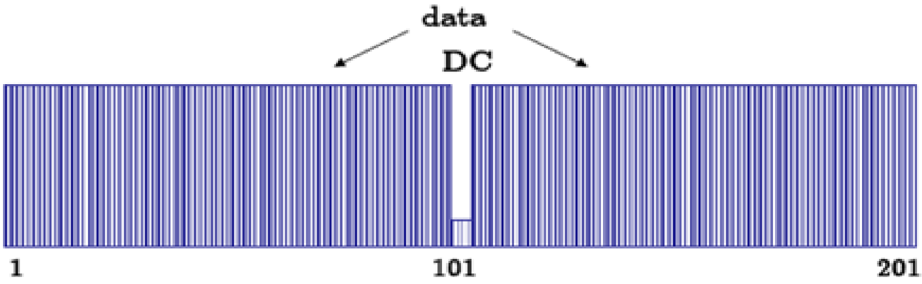


Figure 2.26: Structure composed with data, pilots and zero DC subcarriers [3]

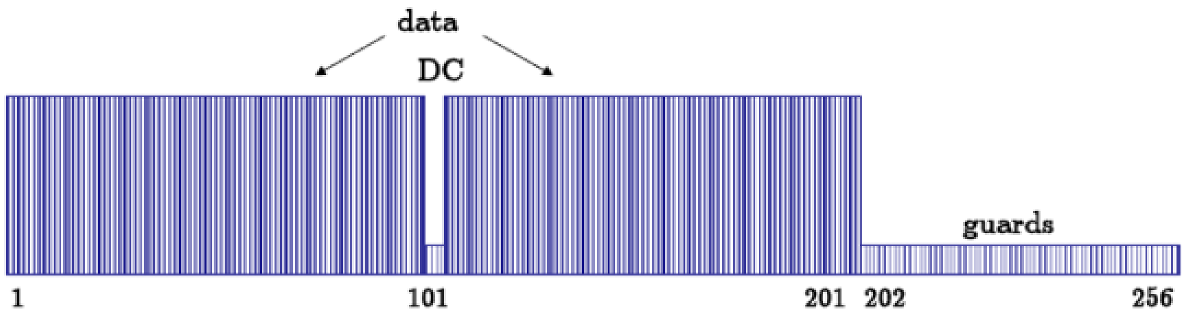


Figure 2.27: Structure after appending the guard bands [3]

Figure 2.26 and Figure 2.27 shows the structure of the subcarriers before and after appending the guard bands. The interference makes the situation for channel estimation and compensation for fading channels worse. In order to make equalization as simple as it's possible in OFDM, as it has been mentioned earlier a Guard Interval introduced to capture the delayed symbols replicas and prevent them from interfering the subsequent one. The OFDM physical layer of the IEEE 802.16-2004 standard specifies that transmission must be performed using 256 frequency subcarriers. The total amount of subcarriers to be used is determined by the number of points needed to perform the IFFT.

After the assembling process described in case 2.6, only 201 of the total 256 subcarriers are used. The remaining 55 carriers that are zero subcarriers appended at the end of the cited structure, act as guard bands with the purpose to enable the naturally decay of the signal. This guard bands are used to decrease emissions in adjacent frequency channels.

The addition of a cyclic prefix to each symbol solves both Inter-Symbol-Interference (ISI) and Inter-Channel-Interference (ICI). By having this buffer of essentially junk data in the front, the convolution of the impulse response with the signal at the end of a symbol does not affect any of the actual data at the beginning of the next symbol, creating a cyclically extended guard interval where each OFDM symbol is preceded by a periodic extension of the signal itself. This guard interval, that is actually a copy of the last portion of the data symbol, is known as the cyclic prefix (CP).

After the time-domain signal passes through the channel, it is broken back into the parallel symbols and the prefix is simply discarded, Figure 2.28 shows one time-domain symbol with the cyclic prefix.

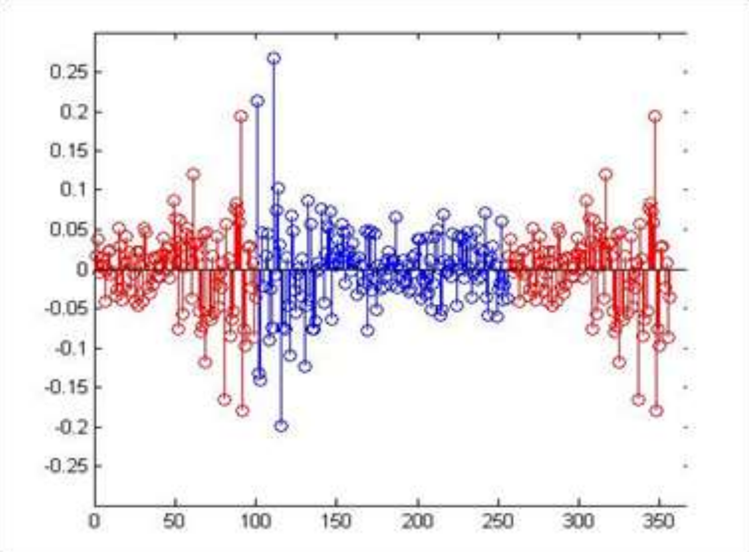


Figure 2.28: One time-domain symbol with the cyclic prefix and last L elements shown in red [25]

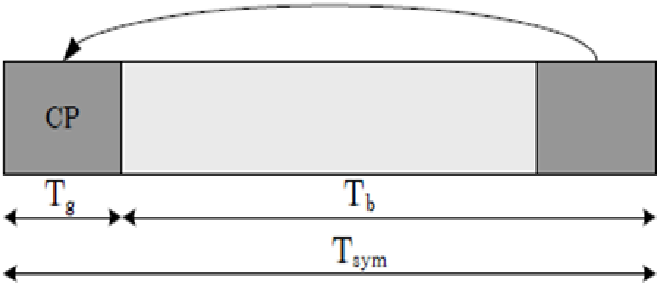


Figure 2.29: OFDM symbol with the cyclic prefix [3].

Figure 2.29 depicts one way to perform the cited long symbol period, creating a cyclically extended guard interval where each OFDM symbol is preceded by a periodic extension of the signal itself. This guard interval, that is actually a copy of the last portion of the data symbol, is known as the cyclic prefix (CP). Copying the end of a symbol and appending it to the start results in a longer symbol time. Thus, the total length of the symbol is:

$$\mathrm{Tsym} = \mathrm{Tb} + \mathrm{Tg} \qquad (2.1)$$

In equation (2.1), Tsym is the OFDM symbol time, Tb is the useful symbol time, and Tg represents the CP time.The parameter G defines the ratio of the CP length to the useful symbol time. When eliminating ISI, it has to be taken into account that the CP must be longer than the dispersion of the channel. Moreover, it should be as small as possible since it costs energy to the transmitter. For these reasons, G is usually less than 1/4:

$$G=\frac{Tg}{Tb}. \qquad (2.2)$$

2.19 IFFT and FFT

The IFFT is used to produce a time domain signal, as the symbols obtained after modulation can be considered the amplitudes of a certain range of sinusoids. This means that each of the discrete samples before applying the IFFT algorithm corresponds to an individual subcarrier. Besides ensuring the orthogonality of the OFDM subcarriers, the IFFT represents also a rapid way for modulating these subcarriers in parallel, and thus, the use of multiple modulators and demodulators, which spend a lot of time and resources to perform this operation, is avoided. Before doing the IFFT operation in the simulator, the subcarriers are rearranged. Figure 2.27 shows the subcarrier structure that enters the IFFT block after performing the cited rearrangement [24]. As seen in the following figure, zero subcarriers are kept in the centre of the structure.

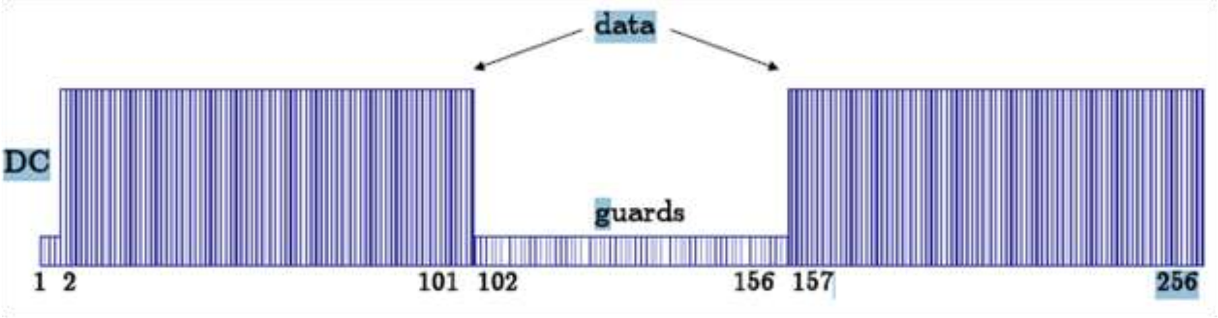


Figure 2.30: Rearrangement performed before realizing the IFFT operation [3]

The IFFT algorithm represents a rapid way for modulating a group of subcarriers in parallel. Either the FFT or the IFFT are a linear pair of processes, and that’s why FFT is necessary to convert the signal again to the frequency domain[1].

Chapter 3: Wireless Channel

3.1 Introduction to Wave Propagation

One would think, then, that a thorough understanding of these principles is a relatively simple task. For the electrical engineer or the individual with a natural curiosity for the unknown, it is indeed a simple task. Most technicians, however, tend to view wave propagation as something complex and confusing. This attitude undoubtedly stems from the fact that wave propagation is an invisible force that cannot be detected by the sense of sight or touch. Understanding wave propagation requires the use of the imagination to visualize the associated concepts and how they are used in practical application.

3.2 Components of the Electromagnetic Wave

An electromagnetic wave consists of two primary components an electric field and a magnetic field. The electric field results from the force of voltage, and the magnetic field results from the flow of current. Although electromagnetic fields that are radiated are commonly considered to be waves, under certain circumstances their behaviour makes them appear to have some of the properties of particles. In general, however, it is easier to picture electromagnetic radiation in space as horizontal and vertical lines of force oriented at right angles to each other. These lines of force are made up of an electric field and a magnetic field, which together make up the electromagnetic field in space.

3.3 Free Space Propagation

The free space propagation model assumes a transmit antenna and a receive antenna to be located in an otherwise empty environment. Neither absorbing obstacles nor reflecting surfaces are considered. In particular, the influence of the earth surface is assumed to be entirely absent.

For propagation distances d much larger than the antenna size, the far field of the electromagnetic wave dominates all other components. It has been allowed to model the radiating antenna as a point source with negligible physical dimensions. In such case, the energy radiated by an omni-directional antenna is spread over the surface of a sphere. This allows the designers to analyze the effect of distance on the received signal power.

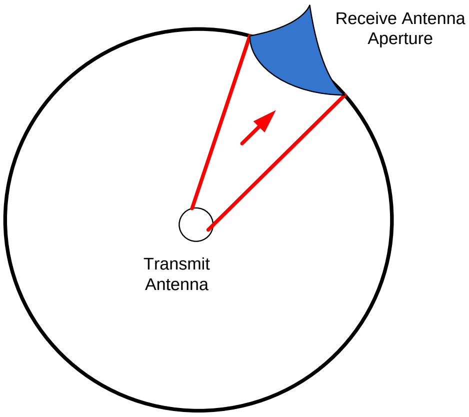


Figure 3.1: Transmit antenna modelled as a point source

3.4 Radio Propagation

Radio propagation is the process of transferring a radio signal from one point to another point. It’s may involve a direct wave (space wave) or a wave that travels along the surface (a surface wave). Radio propagation characteristics typically vary based on the medium of transmission and the frequency of radio transmission. WiMax system may operate as a line of sight, or not line of sight. 802.16 systems are designed with a radio link budget. A link budget is the maximum amount of signal losses that may occur between the transmitter and receiver to achieve an adequate signal quality level. The link budget typically includes cable losses, antenna conversion efficiency, propagation path loss and the fade margin [9]. Radio propagation describes how radio waves behave when they are transmitted, or are propagated from one point on the Earth to another [26] . Like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering [27].

3.5 Reflection

Reflection is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated. Common examples include the reflection of light, sound and water waves. The law of reflection says that for specular reflection, the angle at which the wave is incident on the surface equals to the angle at which it is reflected. There are two types of reflection [29]:

- Specular reflection from smooth surfaces.
- Reflections (Scattering) from rough surfaces.

3.6 Specular Reflection

Specular reflection is the mirror-like reflection of light (or sometimes other kinds of wave) from a surface, in which light from a single incoming direction (a ray) is reflected into a single outgoing direction. Such behaviour is described by the law of reflection, which states that the direction of incoming light (the incident ray), and the direction of outgoing light reflected (the reflected ray) make the same angle with respect to the surface normal, thus the angle of incidence equals the angle of reflection; mathematically this is $\theta i = \theta r$.

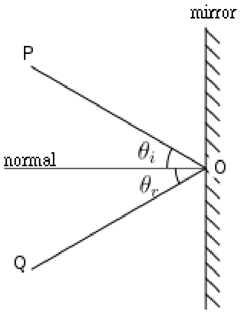


Figure 3.2: Diagram of specular reflection [28]

Figure 3.3: Reflections on still water are an example of specular reflection [28]

3.7 Reflections from Rough Surfaces

The reflections from rough surfaces are termed non-specular reflections. In general the resulting reflection from a real surface will be a combination of specular and non-specular reflections as shown in Figure 3.4.

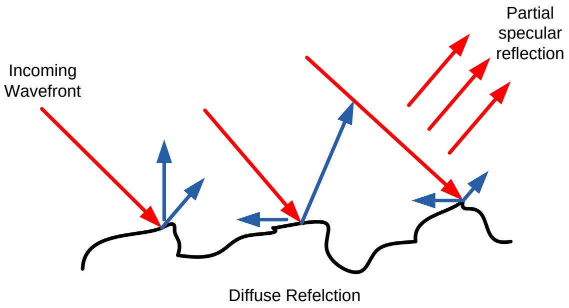


Figure 3.4 - Reflections from Rough Surfaces

But how is a rough surface defined? The relative smoothness of surface depends on:

- Wavelength
- Angle of incidence

The degree of roughness is given by the Rayleigh criterion:

$$hR \geq \frac{\gamma}{8 \sin \gamma 0} \tag{3.1}$$

where h_R is the difference in the maximum and minimum surface variations;
γ^0 is the angle between the incident ray and the surface.

3.8 Refraction

Refraction is the change in direction of a wave due to a change in its speed. This is most commonly observed when a wave passes from one medium to another at an angle. Refraction of light is the most commonly observed phenomenon, but any type of wave can refract when it interacts with a medium, for example when sound waves pass from one medium into another or when water waves move into water of a different depth [29].

3.9 Diffraction

Diffraction refers to various phenomena which occur when a wave encounters an obstacle. It is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings. Diffraction is an important wave propagation mechanism which can occur to any propagating wave in wireless communications. Diffraction only happens when an object partially blocks the path of a propagating wave [11].

3.10 Wedge Diffraction

In city propagating environments, diffracting wedges are considered a very important feature. Wedge diffraction occurs at the corner of buildings, at the edge of walls where they intersect roofs, and at the junction of walls with the ground or street. The picture below depicts what happens to a wave under wedge diffraction [29].

The wedge diffraction scheme, although highly computational, is used to find the diffraction attenuation for an obstructed interference path over a rooftop edge or the parapet of a building. Moreover, experimental results have demonstrated the validity of the wedge diffraction calculation in predicting signal levels on a certain path obstructed by a building corner.

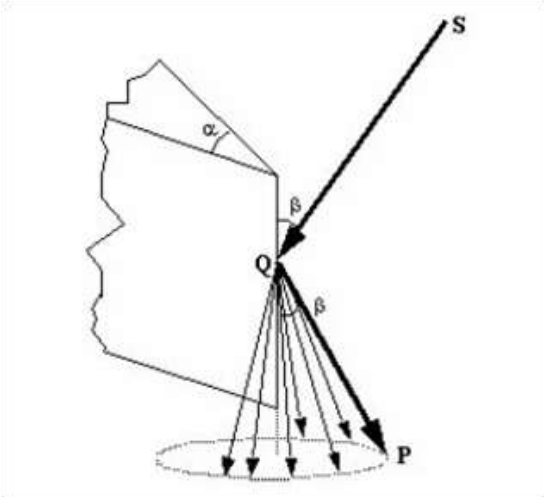


Figure 3.5: Wedge diffraction [29]

3.11 Knife-Edge Diffraction

When shadowing is caused by a single object such as a hill or mountain, the attenuation caused by diffraction can be estimated by treating the obstructing as a diffracting knife edge. This is simplest of diffraction models, and the diffraction loss in this case can be estimated using classical Fresnel solution for the field behind a knife edge (also called a half plane)[29] . Knife-edge diffraction is a special case of the wedge diffraction and it has been used to estimate the effects of blocking obstacles and terrain for cellular telecommunications.

3.12 Scattering

Scattering is a general physical process where some forms of radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which they pass [30].

The actual received signal in a mobile radio environment is often stronger than what is predicted by reflection and diffraction models alone [29]. This is because when a radio wave impinges on a rough surface, the reflected energy is spread out in all directions due to scattering. Objects such as lamp posts and trees tend to scatter in all directions, thereby providing additional radio energy at a receiver.

3.13 Polarization

Polarization is a property of certain types of waves that describes the orientation of their oscillations. Electromagnetic waves such as light exhibit polarization; acoustic waves (sound waves) in a gas or liquid do not have polarization because the direction of vibration and direction of propagation are the same [31].

3.14 Line of Sight (LOS)

Line of sight is a direct path in a wireless communication system that does not have any significant obstructions. 802.16 systems that operate in the 10-66 GHz range are LOS systems.

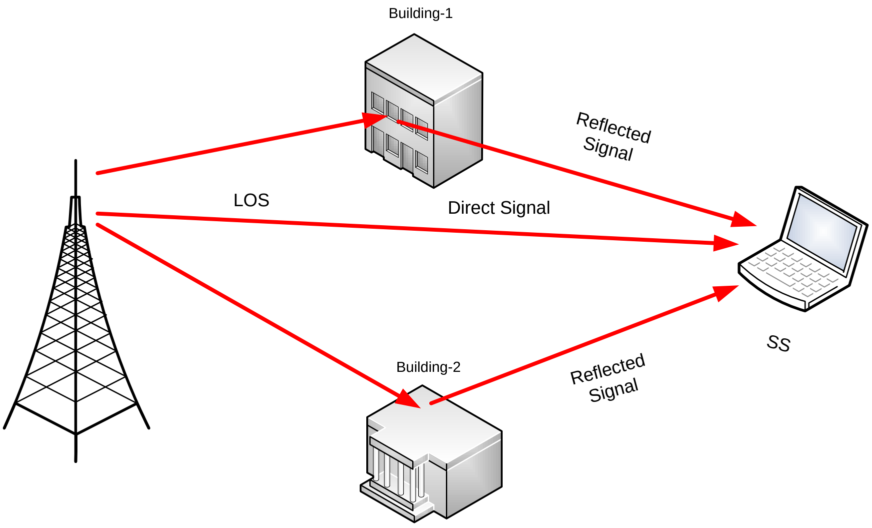


Figure 3.6: Line of sight wave propagation

3.15 Non Line of Sight (NLOS)

Not line of sight is a wireless communication system that does not have a direct path between the transmitter and receiver. NLOS system can use optical or radio signals for transmission. 802.16 system that operate in 2-11 GHz is a not line of sight system.

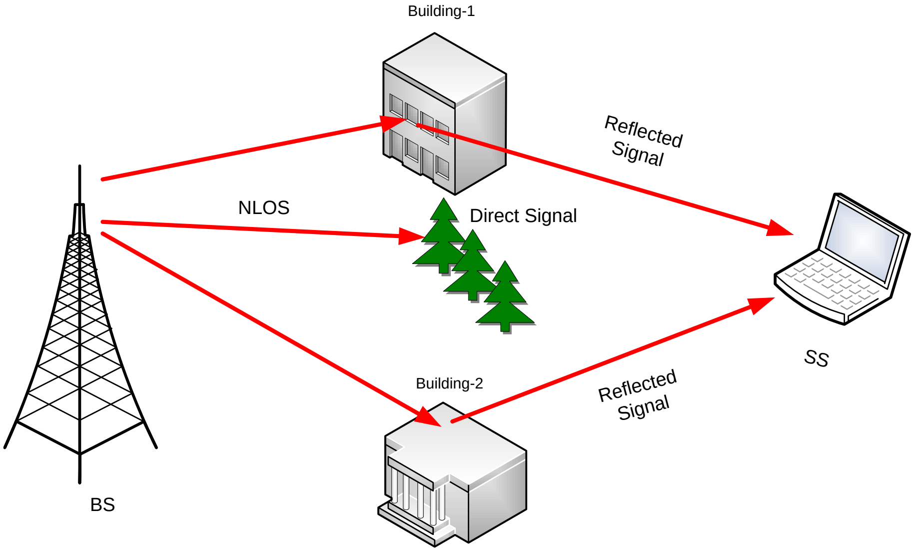


Figure 3.7: Not Line of Sight wave propagation

3.16 Multipath Propagation

Multipath radio signal propagation occurs on all terrestrial radio links. The radio signals not only travel by the direct line of sight path, but as the transmitted signal does not leave the transmitting antenna in only the direction of the receiver, but over a range of angles even when a directive antenna is used. As a result, the transmitted signals spread out from the transmitter and they will reach other objects: hills, buildings reflective surfaces such as the ground, water, etc. The signals may reflect of a variety of surfaces and reach the receiving antenna via paths other than the direct line of sight path.

The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading [22], with standard statistical distribution known as the Rayleigh distribution. Rayleigh fading, with a strong line of sight content is said to have a Rician distribution, or to be Rician fading.

3.17 Fading Channel Description

In a realistic wireless radio environment, a single received signal is composed of a number of scattered waves, caused by the reflection and diffraction of the original transmitted signal by objects in the surrounding geographical area.

These multipath waves are combined at the receiver to give a resultant signal that can widely vary in amplitude and phase. Physical factors influencing the characteristics of the fading experienced by the transmitter are multipath propagation, mobility of the reflecting objects and scatterers, and the relative motion between the transmitter and the receiver.

The presence of reflecting objects and scatterers in the wireless channel causes a constant change in the propagation environment. This changing environment alters the signal energy in amplitude, phase, and time, and as a result, multipath propagation occurs causing signal fading.

The transmitted signal arrives at the receiver via multiple propagation paths, each of which has an associated time delay. Because the received signal is spread in time due to the multipath scatterers at different delays, the channel is said to be time dispersive. The difference between the largest and the smallest among these delays defines the maximum delay spread.

On the other hand, when the receiver and the transmitter are in relative motion, the received signal is subject to a constant frequency shift, called the Doppler shift. Therefore, as it occurs in the time domain, the Doppler spread is defined as the difference between the largest and the smallest among these frequency shifts [29],

$$f_d = f_M \ \mathrm{COS}\,\vartheta \qquad (3.2)$$

where:

- $f_M = fcv/c$ is the maximum Doppler shift,
- v is the vehicle speed,
- fc is the carrier frequency,
- c is the speed of light, and
- α is the arrival angle of the received signal component.

Furthermore, a time-varying Doppler shift is induced on each multipath component if the reflecting objects and scatterers in the propagation channel are in motion, causing frequency dispersion.

3.18 Multipath Fading

Signals are received in a terrestrial environment, i.e. where reflections are present and signals arrive at the receiver from the transmitter via a diversity of paths. The overall signal received is the sum of all the signals appearing at the antenna. Sometimes these will be in phase with the main signal and will add to it, increasing its power. At other times they will interfere with each other. This will result in the overall signal strength being reduced.

Sometimes would be changes in the relative path lengths. This could result from either the transmitter or receiver moving, or any of the objects that provides a reflective surface moving. This would changes in the phases of the signals arriving at the receiver, and in turn this will result in the signal strength varying. It is this that causes the fading that is present on several signals.

It can also be found that the interference may be flat, i.e. applied to all frequencies equally across a given channel, or it may be selective, i.e. applying to more to some frequencies across a channel than others.

3.19 Interference Caused by Multipath Propagation

Multipath propagation can give rise to interference that can reduce the signal to noise ratio and increases bit error rates for digital signals. One cause of a degradation of the signal quality is the multipath fading already described. However there are other ways in which multipath propagation can degrade the signal and affect its integrity [29].

One of the ways which is particularly obvious when driving in a car and listening to an FM radio, at certain points the signal will become distorted and appear to break up. This arises from the fact that the signal is frequency modulated and at any given time, the frequency of the received signal provides the instantaneous voltage for the audio output. If multipath propagation occurs, then two or more signals will appear at the receiver. One is the direct or line of sight signal, and another is a reflected signal. As these will arrive at different times because of the different path lengths, they will have different frequencies, caused by the fact that the two signals have been transmitted by the transmitter at slightly different times.

Accordingly when the two signals are received together, distortion can arise if they have similar signal strength levels.

3.20 Types of Small-Scale Fading

In this case, it has been demonstrated that the type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters (such as bandwidth, symbol period, etc.) and the channel parameters (such as rms delay spread and Doppler spread), different transmitted signals will undergo different types of fading. The time dispersion and frequency dispersion mechanisms in a mobile radio channel lead to four possible distinct effects, which are manifested depending on the nature of the transmitted signal, the channel, and the velocity. While multipath delay spread leads to time dispersion and frequency selective fading, Doppler spread leads to frequency dispersion and time selective fading [29]. The two propagation mechanisms are independent of one another. Figure 3.8 shows a tree of the four different types of fading.

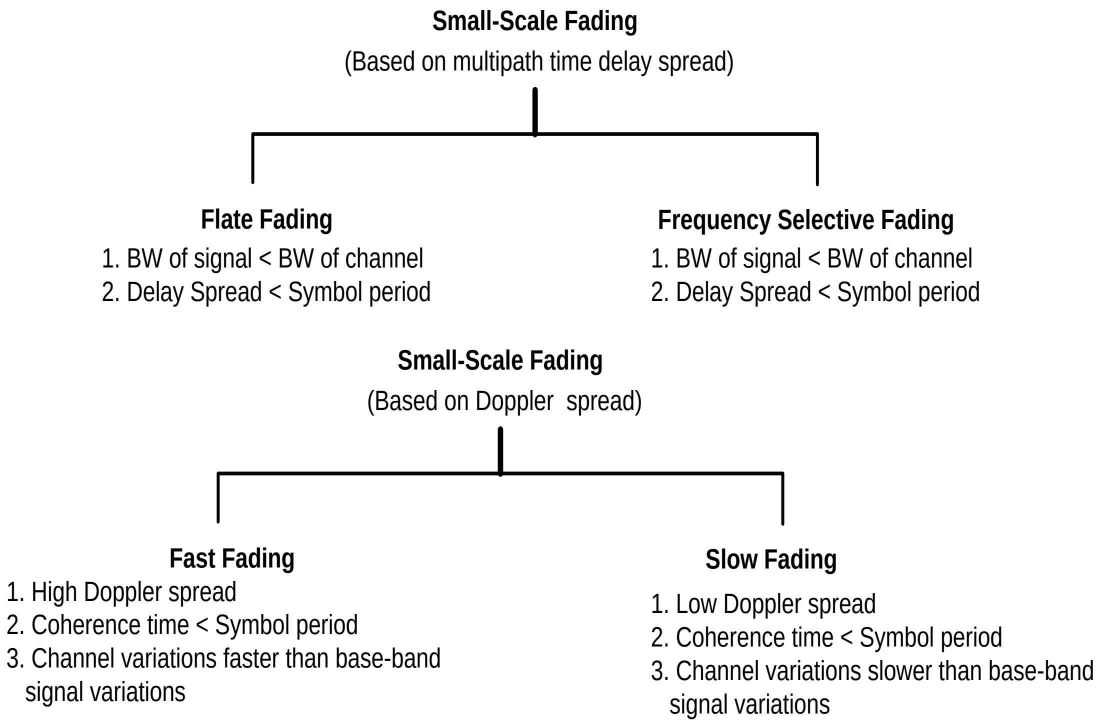


Figure 3.8 Tree of the four different types of fading [29].

3.21 Delay Spread and Doppler Spread

As previously explained, two manifestations of the channel time variations are the delay spread and the Doppler spread. Depending on their values, the signal transmitted through the channel will undergo flat or frequency selective fading. On one hand, the delay spread is a measure of the spread in time over which the multipath signals arrive. It is a measure of the time dispersion of a channel, and is very important in determining how fast the symbol rate can be in digital communications. One of the most widely used measurement for characterizing the delay spread of a multipath channel is the rms delay spread α_T. Furthermore, the inverse of the delay spread defines the coherence bandwidth. On the other hand, the Doppler spread, Bd, is a measure of the spectral broadening caused by the time rate of change of the multipath components due to the relative motion between transmitter and receiver [29]. Depending on how rapidly the multipath components change, the channel may be classified either as a fast or a slow fading channel. Inversely proportional to one another are the Doppler spread and the coherence time. The coherence time, T_{coh}, is the time domain dual of Doppler spread and is used to characterize the time-varying nature of the frequency depressiveness of the channel in the time domain. It is a statistical measure of the time duration over which the channel impulse response is essentially invariant quantifying the similarity of the channel response at different times.

3.22 Selective and Flat Fading

Multipath fading can affect radio communications channels in two main ways. This can give the way in which the effects of the multipath fading are mitigated.

3.22.1 Flat fading

This form of multipath fading affects all the frequencies across a given channel either equally or almost equally. When flat multipath fading is experienced, the signal will just change in amplitude, rising and falling over a period of time, or with movement from one position to another [29].

3.22.2 Selective Fading

Selective fading occurs when the multipath fading affects different frequencies across the channel to different degrees. It will mean that the phases and amplitudes of the signal will vary across the channel. Sometimes relatively deep nulls may be experienced, and this can give rise to some reception problems. Simply maintaining the overall amplitude of the received signal will not overcome the effects of selective fading, and some form of equalization may be needed. Some digital signal formats, e.g. OFDM are able to spread the data over a wide channel so that only a portion of the data is lost by any nulls. This can be reconstructing using forward error correction techniques and in this way it can mitigate the effects of selective multipath fading [29].

Selective multipath fading occurs because even though the path length will be change by the same physical length (e.g. the same number of metres, yards, miles, etc) this represents a different proportion of a wavelength. Accordingly the phase will change across the bandwidth used. Selective multipath fading is also experienced at higher frequencies, and with high data rate signals becoming commonplace wider bandwidths are needed. As a result nulls and peaks may occur across the bandwidth of a signal.

3.23 Rayleigh and Ricean Fading Models

Rayleigh fading is the name given to the form of fading that is often experienced in an environment where there is a large number of reflections present. The Rayleigh fading model uses a statistical approach to analyses the propagation, and can be used in a number of environments.

The Rayleigh fading model is particularly useful in scenarios where the signal may be considered to be scattered between the transmitter and receiver. In this form of scenario there is no single signal path that dominates and a statistical approach is required to the analysis of the overall nature of the radio communications channel.

Wireless channels can be characterized with tap coefficients that are complex valued Gaussian random variables. A channel model where there are only non line-of-sight communications is characterized by a Rayleigh distribution [29]. On the contrary, if dominating paths are present, the channel coefficients are modeled by a Ricean distribution. As already mentioned, a

Rayleigh distribution is normally used to model NLoS communications. It is statistically characterized by fading amplitude α (t), modelled with a Rayleigh probability distribution, which has zero-mean Gaussian components. Furthermore, the phase, ø(t), is uniformly distributed over the interval (0, 2 pie). The fading amplitude is described by the probability density function (pdf)[32]

$$f_{\mathrm{Ray}}(a)\begin{cases} \frac{a}{\sigma^2}\exp(-\frac{\mathrm{a}^2}{2\sigma^2}) & \text{if a}\geq 0 \\ & \text{if a}<0 \end{cases} \tag{3.3}$$

On the other hand, when the components of (t) are Gaussian with nonzero mean values and the phase is also non-zero mean, the amplitude is characterized statistically by the Rice probability distribution. In this case, the channel presents multipath propagation with some dominating paths, i.e. representing a major part of the channel energy. The pdf of the Ricean fading amplitude is given by:

$$f_{\mathrm{Rice}}(a)\begin{cases} \frac{a}{\sigma^2}\exp(-\frac{\mathrm{a}^2+p^2}{2\sigma^2})\ \mathrm{I}_0\frac{\mathrm{a}\rho}{\sigma^2}\left(\frac{1}{\mathrm{n}}\right)^{\mathrm{n}} & \text{if a}\geq 0 \\ & \text{if a}<0 \end{cases} \tag{3.4}$$

Where the parameter P^2 represents the power of the received non-fading signal component, and I_0 is the modified Bessel function of first kind and order zero. The Ricean distribution is usually expressed with the K-factor defined as the ratio of the power of the deterministic signal to the variance of the multipath component [33]:

$$K = \frac{\rho^2}{2\sigma^2} \tag{3.5}$$

If K approaches zero, then the Rice distribution degenerates is a Rayleigh distribution. Thus, when P has values near to 0, K is prone to – ∞ dB, and since the dominant path decreases in amplitude, the Rice distribution becomes a Rayleigh distribution. Furthermore, if K approaches infinity, one path will contain the whole channel energy, corresponding to a LoS scenario.

3.24 Channel Models

Channel models are fundamental tools for designing any fixed broadband wireless communication system. It basically predicts what will happen to the transmitted signal while in transit to the receiver. According to [33] these models are divided into three basic classifications: theoretical, empirical, and physical.

3.24.1 Theoretical Models

These models are based on some theoretical assumptions about the propagation environment. Theoretical models are not suitable for planning communications systems to serve a particular area because there is no way to relate the parameters of these models to physical parameters of any particular propagation environment. They do not directly use information about any specific environment, thus it can be useful for analytical studies of the behaviour of communication systems under a wide variety of channel response circumstances [29]. An example of a theoretical model is the “tapped delay line” model in which densely spaced delays and multiplying constants and tap-to-tap correlation coefficients are determined on the basis of measurements or some theoretical interpretation of how the propagation environment affects the signal.

3.24.2 Empirical Models

Empirical models are based on observations or measurements. Measurements are typically done in the field to measure path loss, delay spread, or other channel characteristics. Empirical models are widely used in mobile radio and cellular system engineering. Many cellular operators have ongoing measurements or drive-test programs that collect measurements of signal level, call quality, and network performance which are then used to refine empirical propagation models used in the system-planning tool [34]. Parameters included in empirical models are distance, frequency, base antenna height, and number of buildings.

3.24.3 Physical Models

Physical models are the most widely used propagation models for fixed broadband wireless systems. They rely on the basic ideology of physics rather than statistical outcomes from experiments to find the Electromagnetic (EM) field at a point. Databases of terrain elevations, clutter heights, atmospheric refractivity conditions, and rain intensity rates are all used in the design process. Physical models may or may not be site specific. Non site specific models uses physical principles of EM wave propagation to predict signal levels in a generic environment in order to develop some simple relationships between the characteristics of that environment. On the other hand, when particular elements of the propagation environment between the transmitter and receiver are considered, the modal is considered site specific. An example of a physical model is the “Ray-tracing” model. However, if there is an incomplete or insufficiently refined description of the propagation environment [37], Ray-tracing does not provide a complete and accurate calculation of the field at all locations in the environment.

3.25 Hata Model for Suburban Areas

Hata Model for Urban Areas, also known as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used radio frequency propagation model for predicting the behaviour of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures [34]. This model also has two more varieties for transmission in Suburban Areas and Open Areas.

Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. And is a function of transmission frequency and the average path loss in urban areas. This particular version of Hata model is applicable to the transmissions just out of the cities and on rural areas where man-made structures are there but not so high and dense as in the cities. To be more precise, this model is suitable where buildings exist, but the mobile station does not have a significant variation of its height. This model is suited for both point-to-point and broadcast transmissions and frequency of operation form 150 MHz to 1500 GHz, mobile Station Antenna Height: between 1 m and 10 m, Base station Antenna Height: between 30 m and 200 m and Link distance: between 1 km and 20 km [11].

Hata Model for Suburban Areas is formulated as

$$L_{SU} = L_U - 2\left(log + \frac{f}{28}\right)^2 - 5.4 \qquad (3.6)$$

Where,
L_{SU} = Path loss in suburban areas. (dB)
$_{LU}$ = Average Path loss in urban areas. (dB)
f = Frequency of Transmission. (MHz).

3.26 Fixed Wireless Applications Channel Models

An important requirement for assessing technology for Broadband Fixed Wireless applications is to have an accurate description of the wireless channel. Channel models are heavily dependent upon the radio architecture. For example, in first generation systems, a super-cell or “single-stick” architecture is used where the Base Station (BS) and the subscriber station are in Line-of-Sight (LOS) condition and the system uses a single cell with no co-channel interference. For second generation systems a scalable multi-cell architecture with Non-Line-of-Sight (NLOS) conditions becomes necessary [35]. In this document a set of propagation models applicable to the multi-cell architecture is presented. Typically, the scenario is as follows:

- Cells are < 10 km in radius, variety of terrain and tree density types
- Under-the-eave/window or rooftop installed directional antennas (2 – 10 m) at the receiver
- 15 - 40 m BTS antennas
- High cell coverage requirement (80-90%)

The wireless channel is characterized by:

- Path loss (including shadowing)
- Multipath delay spread
- Fading characteristics
- Doppler spread
- Co-channel and adjacent channel interference [35]

It is to be noted that these parameters are random and only a statistical characterization is possible, the mean and variance of parameters are specified. The above propagation model parameters depend upon terrain, tree density, antenna height and beam width, wind speed, and season (time of the year).

3.27 Suburban Path Loss Model

The most widely used path loss model for signal strength prediction and simulation in macro-cellular environments is the Hata-Okumura model [36, 37]. This model is valid for the 500-1500 MHz frequency range, receiver distances greater than 1 km from the base station, and base station antenna heights greater than 30 m. There exists an elaboration on the Hata-Okumura model that extends the frequency range up to 2GHz [38]. It was found that these models are not suitable for lower base station antenna heights, and hilly or moderate-to-heavy wooded terrain. To correct for these limitations, a model presented in [39] has been proposed.

The model covers three most common terrain categories found across the United States. However, other sub-categories and different terrain types can be found around the world.

The extensive experimental data was collected by AT&T Wireless Services across the United States in 95 existing microcells at 1.9 GHz. For a given close-in distance d0, the median path loss (PL in dB) is given by

$$PL = A + 10\,\gamma{=}\log_{10}(d/d_0) + s \qquad \text{for } d > d_0 \qquad (3.7)$$

Where $A = 20 \log_{10}(4\,\pi\, d_0 / \lambda)$ (λ being the wavelength in m), γ=is the path-loss exponent with $\gamma= (a - b\, h_b + c / h_b)$ for hb between 10 m and 80 m (h_b is the height of the base station in m), d0 = 100m and a, b, c are constants dependent on the terrain category given in [39] and reproduced in table 3.1.

Model parameter	Terrain Type A	Terrain Type B	Terrain Type C
A	4.6	4	3.6
B	0.0075	0.0065	0.005
C	12.6	17.1	20

Table 3.1 Constants dependent on the terrain category [12]

The shadowing effect is represented by s, which follows lognormal distribution. The typical value of the standard deviation for s is between 8.2 and 10.6 dB, depending on the terrain/tree density type [39].

3.28 Receive Antenna Height and Frequency Correction Terms

The above path loss model is based on the frequencies close to 2 GHz, and for receiver antenna heights close to 2 m. In order to use the model for other frequencies and for receive antenna heights between 2 m and 10 m, correction terms have to be included. The path loss model (in dB) with the correction terms would be

$$PL_{modified} = PL + \Delta PL_f + \Delta PL_h \qquad (3.8)$$

Where PL is the path loss given in [39], ΔPL_f (in dB) is the frequency correction term [40, 41]given by

$$\Delta PL_f = 6 \log (f / 2000) \qquad (3.9)$$

Where f is the frequency in MHz, and ΔPL_h (in dB) is the receive antenna height correction term given by

$$\Delta PL_h = - 10.8 \log (h / 2); \qquad \text{for Categories A and B} \qquad (3.10)$$

$$\Delta PL_h = - 20 \log (h / 2); \qquad \text{for Category C} \qquad (3.11)$$

Where h is the receive antenna height between 2 m and 10 m.

3.29 Urban (Alternative Flat Suburban) Path Loss Model

In [42], it was shown that the Cost 231 Walfish-Ikegami (W-I) model [43] matches extensive experimental data for flat suburban and urban areas with uniform building height. It has been also found that the model presented in the previous case for the Category C (flat terrain, light tree density) is in a good agreement with the Cost 231 W-I model for suburban areas, providing continuity between the two proposed models.

In Figure 3.9, the authors compares a number of published path loss models for suburban morphology with an empirical model based on drive tests in the Dallas-Fort Worth area [44]. The Cost 231 Walfisch-Ikegami model was used with the following parameter settings;

Frequency = 1.9 GHz

Mobile Height = 2 m

Base Height = 30 m

Building spacing = 50 m

Street width = 30 m

Street orientation= 90°

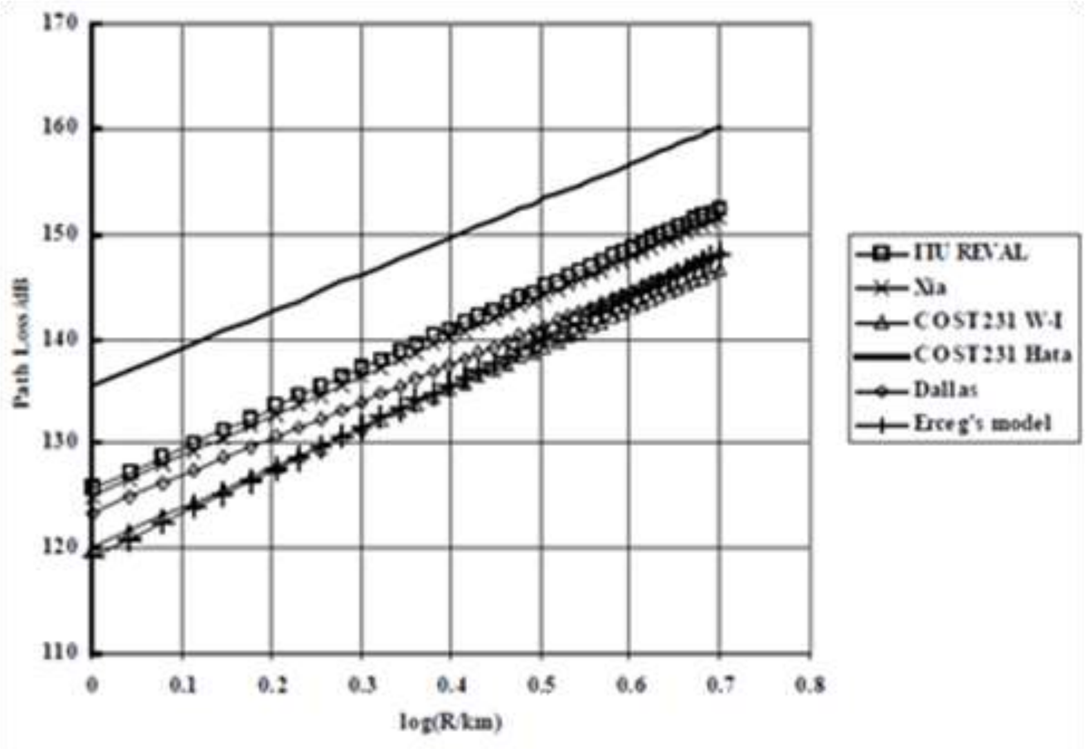


Figure 3.9 Comparison of suburban path loss models [35]

It has also been found that the Cost 231 W-I model agrees well with measured results for urban areas, provided the appropriate building spacing and rooftop heights are used. It can therefore be used for both suburban and urban areas, and can allow for variations of these general categories between and within different countries [44]. Flat terrain models in conjunction with terrain diffraction modelling for hilly areas can be used in computer based propagation tools that use digital terrain databases.

3.30 Multipath Delay Profile

Due to the scattering environment, the channel has a multipath delay profile. For directive antennas, the delay profile can be represented by a spike-plus-exponential shape [45]. It is characterized by τ_{rms} (RMS delay spread of the entire delay profile) which is defined as

$$\tau^2_{rms} = \Sigma_j P_j \tau^2_j - (\tau_{avg})^2 \qquad (3.12)$$

$\tau_{avg} = \Sigma_j P_j \tau_j$ (3.13)

Where,

τ_j is the delay of the j th delay component of the profile and P_j is given by

P_j = (power in the j th delay component) / (total power in all components).

The delay profile has been modelled using a spike-plus-exponential shape given by

3.31 RMS Delay Spread

A delay spread model was proposed in [46] based on a large body of published reports. It was found that the rms delay spread follows lognormal distribution and that the median of this distribution grows as some power of distance. The model was developed for rural, suburban, urban, and mountainous environments. The model is of the following form

$$\tau_{rms} = T_1 d^{\varepsilon} y \qquad (3.14)$$

Where τ_{rms} is the rms delay spread, d is the distance in km, T_1 is the median value of τ_{rms} at d = 1 km, ε is an exponent that lies between 0.5-1.0, and y is a lognormal variety. The model parameters and their values can be found in Table III of [46]. However, these results are valid only for Omni-directional antennas. To account for antenna directivity, results reported in [45, 47] can be used. It was shown that 32^o and 10^o directive antennas reduce the median τ RMS values for Omni-directional antennas by factors of 2.3 and 2.6, respectively.

Depending on the terrain, distances, antenna directivity and other factors, the RMS delay spread values can span from very small values (tens of nanoseconds) to large values (microseconds).

3.32 Fade Distribution, K-Factor

The narrow band received signal fading can be characterized by a Ricean distribution. The key parameter of this distribution is the K-factor, defined as the ratio of the “fixed” component power and the “scatter” component power. In [48], an empirical model was derived from a 1.9 GHz experimental data set collected in typical suburban environments for transmitter antenna heights of approximately 20 m. In [49], an excellent agreement with the model was reported using an independent set of experimental data collected in San Francisco Bay Area at 2.4 GHz and similar antenna heights. The narrowband K-factor distribution was found to be lognormal, with the median as a simple function of season, antenna height, antenna beam width, and distance. The standard deviation was found to be approximately 8 dB. The model presented in [48] is as follows:

$$K = F_s F_h F_b K_o d^{\gamma} u \qquad (3.15)$$

Where,

F_s is a seasonal factor, $F_s = 1.0$ in summer (leaves); 2.5 in winter (no leaves)

F_h is the receive antenna height factor, $F_h = (h/3)^{0.46}$; (h is the receive antenna height in meters)

F_b is the beam width factor, $F_b = (b/17^{)-0.62}$; (b in degrees)

K_o and γ are regression coefficients, $K_o = 10$; $\gamma = -0.5$

u is a lognormal variable which has zero dB mean and a std. deviation of 8.0 dB.

Using this model, one can observe that the K-factor decreases as the distance increases and as antenna beam width increases. K-factors that meet the requirement of 90% of all locations within 99.9% reliability of geographical signal have been considered. The calculation of K-factors for this scenario is rather complex since it also involves path loss, delay spread, antenna correlation (if applicable), specific modem characteristics, and other parameters that influence system performance. However, the approximate value can be obtain as follow: First selection of 90% of the users with the highest K-factors over the cell area has been considered. Then the approximate value obtained by selecting the minimum K-factor within the set. For a typical deployment scenario this value of K-factor can be close or equal to 0 [35]. Figure 3.10 shows fading cumulative distribution functions (CDFs) for various K factors.

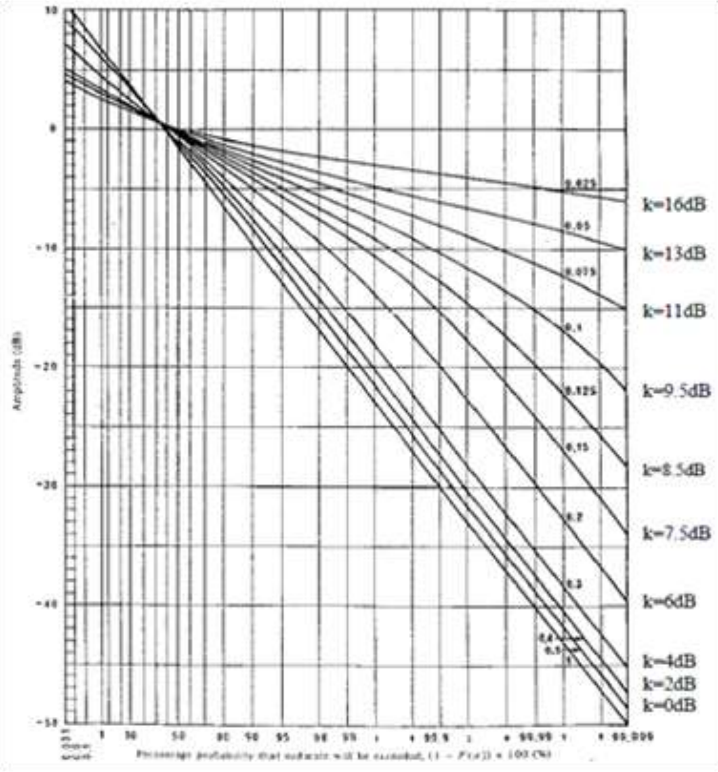


Figure 3.10 Rician fading distributions [35]

3.33 Co-Channel Interference

C/I calculations use a path loss model that accounts for median path loss and lognormal fading, but not for 'fast' temporal fading. In the example shown in figure 3.11, a particular reuse pattern has been simulated with r^2 or r^3 signal strength distance dependency, with apparently better C/I for the latter. However, for non-LOS cases, temporal fading requires us to allow for a fade margin. The value of this margin depends on the Ricean K-factor of the fading, the QoS required and the use of any fade mitigation measures in the system.

Two ways of allowing for the fade margin then arise; either the C/I cdf is shifted left as shown below or the C/I required for a non-fading channel is increased by the fade margin. For example, if QPSK requires a C/I of 14 dB without fading, this becomes 24 dB with a fade margin of 10 dB.

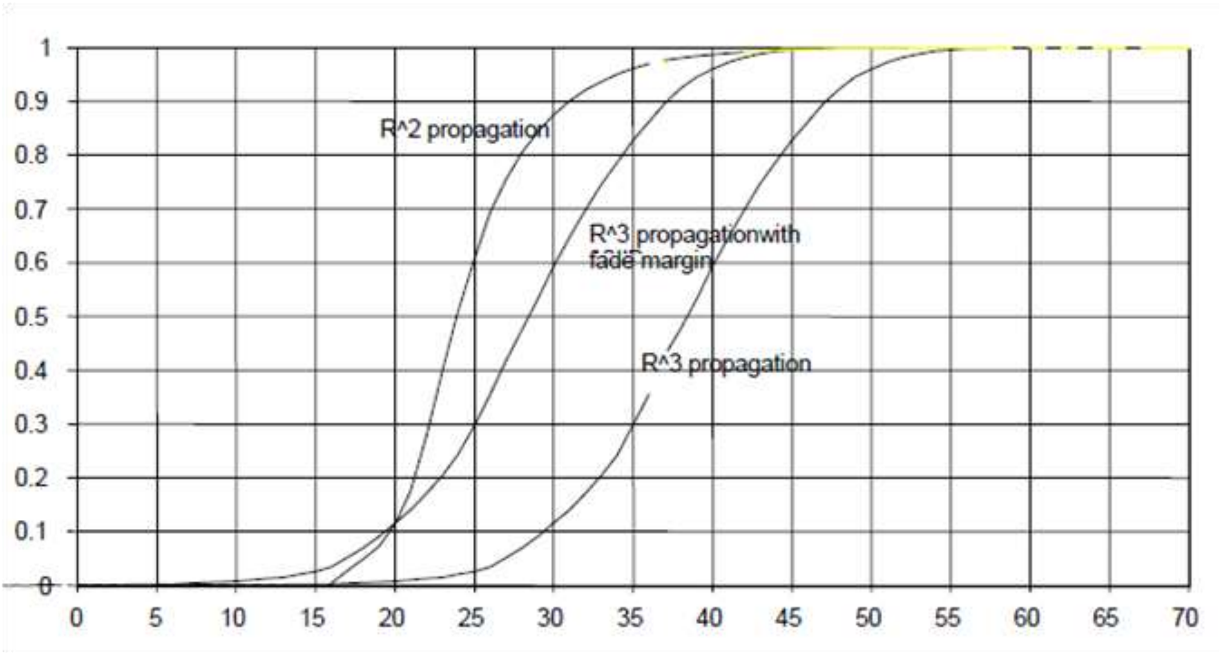


Figure 3.11 Effects of fade margin on C/I distributions [35]

Chapter 4: MIMO Transmission

4.1Introduction

For developing new and more effective wireless telecommunication systems, wide knowledge of the propagation channel is needed. Channel measurements can be used in acquiring measurement data of different kind of wireless propagation channels, such as SISO (Single Input Single Output) and MIMO (Multiple Input Multiple Output) channels, indoor and outdoor channels, and channels with different cell sizes. Using parameter estimation methods, various multi-path properties of the propagating waves, such as Direction of Departure (DoD), Direction of Arrival (DoA), delay and polarization can be extracted from the measurement data, and the acquired channel information can be used in developing new channel models. Measurement data can also be used in testing existing channel models or in testing and developing new signal processing algorithms.

Applying multiple antennas at both ends of a communication system can not only greatly improve the capacity and the throughput of a wireless link in flat-fading but also in frequency-selective fading channels, especially when the environment provides rich scattering.

Multiple-input multiple-output systems, also known as MIMO, have MEA (Multi-Element Antenna) arrays at both transmit and receive sides. High data rates are achieved when implementing such structures without increasing, neither the bandwidth nor the total transmission power. Additionally, the use of multiple antennas at both transmitter and receiver provides a diversity advantage, that means a significant increase in capacity, i.e. improvement in SNR and hence in BER at the receiver [50].

This chapter presents the theoretical background of the MIMO channel, Space-time coding (STC) as well as the maximum ratio combining (MRC) technique are presented as the solutions implemented to perform the MIMO transmission and reception, respectively.

During the last few years the wireless access networks, e.g. WLAN and WiMax have become more and more popular and this kind of networks can be found from many places, e.g. airport terminals, shopping malls or cafeterias usually have one or several networks of this kind. As the MIMO products become more popular and more common, and as the deployment of the base stations becomes more dense, the need to understand the effects of multi-link interference becomes more important. For this purpose, measurements of MIMO propagation channel in multi-link scenarios are needed.

4.2 MIMO Basics

One of the core ideas behind MIMO wireless systems space-time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, i.e. the use of multiple antennas located at different points. Accordingly MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless.

To take advantage of this in a MIMO wireless system, the transmitted data must be encoded using what is termed a space-time code to allow the receiver to extract the fundamental transmitted data from the received signals [51].

The codes used for MIMO wireless systems vary according to a number of parameters. Some codes, known as "space-time diversity codes" are optimised for what is termed the diversity order. These optimise the signal to noise ratio, and the codes used define the performance gain that can be achieved and obviously the more gain that is achieved, the more processing power is required. Other MIMO codes are used for spatial multiplexing and improve the channel capacity. Although both schemes are of considerable interest, it is the spatial multiplexing that is of considerable interest in many applications where bandwidth is limited; figure 4.1 shows different configurations for MIMO system.

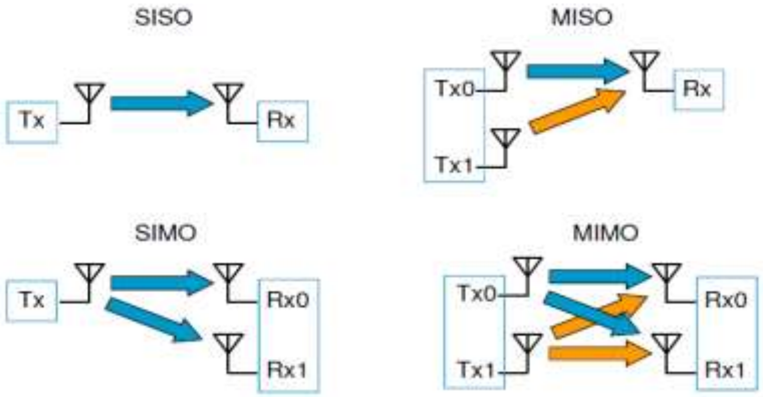


Figure 4.1: Multiple Antenna Configurations

4.3 MIMO overview

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

It is found between a transmitter and a receiver; the signal can take many paths. Additionally by moving the antennas even a small distance the paths used will change. The variety of paths available occurs as a result of the number of objects that appear to the side or even in the direct path between the transmitter and receiver. Previously these multiple paths only served to introduce interference. By using MIMO, these additional paths can be used to increase the capacity of a link.

Orthogonal Frequency Division Multiplexing (OFDM) is one of the most promising physical layer technologies for high data rate wireless communications due to its robustness to frequency selective fading, high spectral efficiency, and low computational complexity. OFDM can be used in conjunction with a Multiple-Input Multiple-Output (MIMO) transceiver to increase the diversity gain and/or the system capacity by exploiting spatial domain. Because the OFDM system effectively provides numerous parallel narrowband channels, MIMO-OFDM is considered a key technology in emerging high-data rate systems such as 4G, IEEE 802.16, and IEEE 802.16, figure 4.2 illustrates MIMO system.

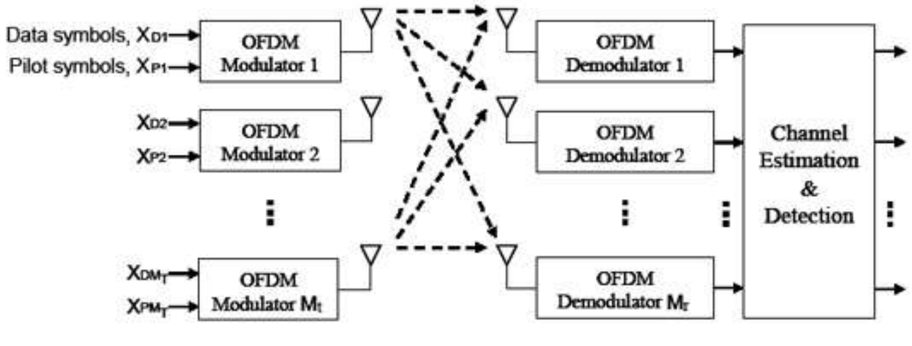


Figure 4.2 MIMO System[3]

MIMO communication uses multiple antennas at both the transmitter and receiver to exploit the spatial domain for spatial multiplexing and/or spatial diversity.

Spatial multiplexing has been generally used to increase the capacity of a MIMO link by transmitting independent data streams in the same time slot and frequency band simultaneously from each transmit antenna, and differentiating multiple data streams at the receiver using channel information about each propagation path.

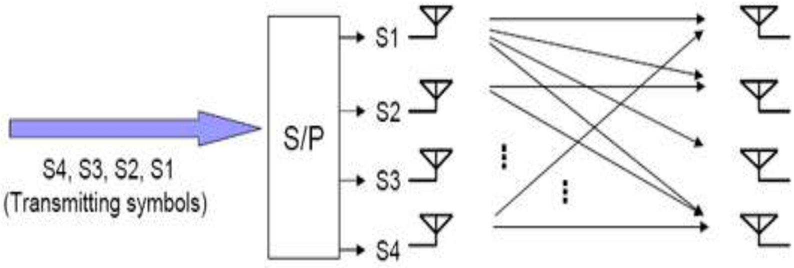


Figure 4.3 Spatial Diversity [3]

Figure 4.3 and 4.4 illustrate spatial multiplexing, the purpose of spatial diversity is to increase the diversity order of a MIMO link to mitigate fading by coding a signal across space and time so that a receiver could receive the replicas of the signal and combine those received signals constructively to achieve a diversity gain.

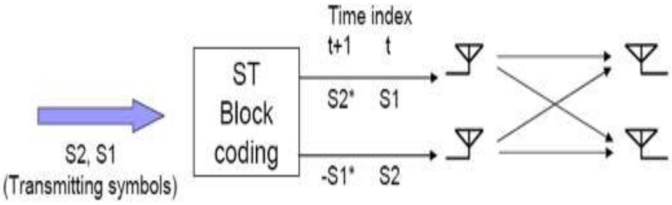


Figure 4.4: Spatial diversity for MIMO system using two antennas at each side [3]

4.4 Shannon's Theorem and MIMO

As with many areas of science, there a theoretical boundary, beyond which it is not possible to proceed. This is true for the amount of data that can be passed along a specific channel in the presence of noise. The law that governs this called Shannon's Law, named after the man who formulated it. This is particularly important because MIMO wireless technology provides a method not of breaking the law, but increasing data rates beyond those possible on a single channel without its use [51].

Shannon's law defines the maximum rate at which error free data can be transmitted over a given bandwidth in the presence of noise. It is usually expressed in the form:

$$C = W \log_2(1 + S/N) \qquad (4.1)$$

Where C is the channel capacity in bits per second, W is the bandwidth in Hertz, and S/N is the SNR (Signal to Noise Ratio). From this it can be seen that there is an ultimate limit on the capacity of a channel with a given bandwidth. However before this point is reached, the capacity is also limited by the signal to noise ratio of the received signal.

In view of these limits many decisions need to be made about the way in which a transmission is made. The modulation scheme can play a major part in this. The channel capacity can be increased by using higher order modulation schemes, but these require a better signal to noise ratio than the lower order modulation schemes. Thus a balance exists between the data rate and the allowable error rate, signal to noise ratio and power that can be transmitted [51].

While some improvements can be made in terms of optimising the modulation scheme and improving the signal to noise ratio, these improvements are not always easy or cheap and they are invariably a compromise, balancing the various factors involved. It is therefore necessary to look at other ways of improving the data throughput for individual channels. MIMO is one way in which wireless communications can be improved and as a result it is receiving a considerable degree of interest.

4.5 MIMO Channel Model

For a communication with multiple transmissions the signals are indexed with a time-discrete index as y (t) = Hs(t)+n(t). The channel can even be considered time-varying, where it may be denoted as H(t).

Figure 4.5 depicts a MIMO scenario with NT transmit antennas and NR receive antennas. The signals at the transmit antenna array are denoted by vector s(t) = [s1(t), s2(t), ..., sNT(t)]^T, and similarly, the signals at the receiver are y(t) = [y1(t), y2(t), ..., yNR(t)]^T, where $(\cdot)^T$ denotes transposition, and $s_m(t)$ and $y_m(t)$ are the signals at the *m*-th transmit antenna port and at the *m*-the receive antenna port, respectively.

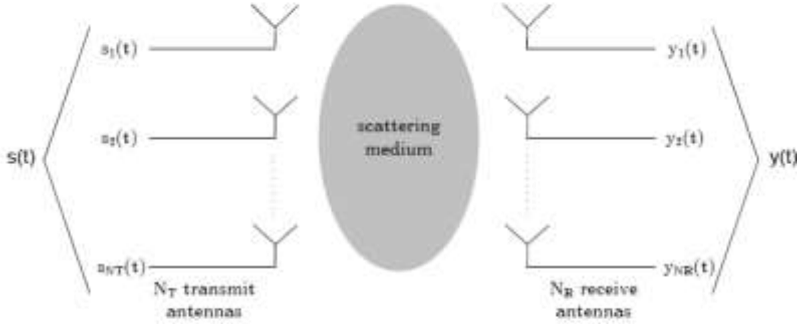


Figure 4.5: A MIMO channel model in a scattering environment **[3]**

$$\mathbf{H} = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1N_T} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2N_T} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{N_R1} & \alpha_{N_R2} & \cdots & \alpha_{N_RN_T} \end{pmatrix} \qquad (4.2)$$

The connection between transmitter and receiver can be expressed as: transmitter to antenna n at the receiver. Moreover, the path gains are correlated depending on the propagation environment, the polarization of the antenna elements, and the spacing between them. The relation between the vectors s(t) and y(t) can be expressed as

$$y(t) = H(t)s(t). \qquad (4.3)$$

In order to take the channel correlation into account, which has a strong impact on the achievable performance of the system; two different spatial channel models are considered.

4.6 Space-Time Coding

A space–time code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a good enough state to allow reliable decoding.

Space-time coding (STC) is an efficient approach to exploit the enormous diversity offered by the MIMO. It is used to obtain gains due to spatial diversity via multiple transmit and receive antennas. Moreover, a diversity gain proportional to the number of antennas at both transmit and receive sides can be achieved. One popular representation of these codes is the Alamouti schemes for two transmit antennas [52].

STC techniques are used to improve the performance of MIMO systems. Their central issue is the exploitation of multipath effects in order to achieve very high spectral efficiencies. With this purpose, the principal aim of the space-time coding lies in the design of two-dimensional signal matrices to be transmitted during a specified time period on a number of antennas. Thus, it introduces redundancy in space through the addition of multiple antennas, and redundancy in time through channel coding, enabling us to exploit diversity in the spatial dimension, as well as a obtaining a coding gain. Therefore, the transmit diversity plays an integral role in the STC design.

4.7 The Alamouti concept

Alamouti [53,54] introduced a very simple scheme of space-time block coding (STBC) allowing transmissions from two antennas with the same data rate as on a single antenna, but increasing the diversity at the receiver from one to two in a flat fading channel. As shown in figure 4.6 the Alamouti algorithm uses the space and the time domain to encode data, increasing the performance of the system by coding the signals over the different transmitter branches. Thus, the Alamouti code achieves diversity two with full data rate as it transmits two symbols in two time intervals.

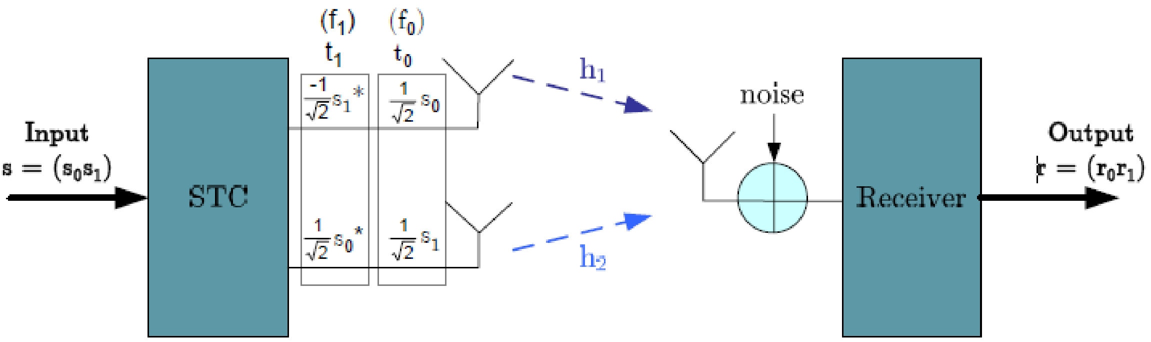


Figure 4.6; Alamouti scheme [17]

In the first time slot, transmit antennas Tx1 and Tx2 are sending symbols s_0 and s_1, respectively. In the next time slot, symbols $-s_1^*$ and s_0^* are sent, where $(\cdot)^*$ denotes complex conjugation. Each symbol is multiplied by a factor of a squared root of two in order to achieve a transmitted average power of one in each time step. Furthermore, it is supposed that the channel, which has transmission coefficients *h1* and *h2*, remains constant and frequency flat over the two consecutive time steps.

The received vector, r, is formed by stacking two consecutive received data samples in time, resulting in

$$\mathrm{r} = \frac{1}{\sqrt{2}}\,\mathrm{Sh} + \mathrm{n} \qquad (4.4)$$

Where $r = [r_0, r_1]^T$ represents the received vector, $h = [h_1, h_2]^T$ is the complex channel vector, $n = [n_0, n_1]^T$ is the noise at the receiver, and S defines the STC:

$$\mathrm{S} = \begin{pmatrix} s_0 & s_1 \\ {s^*}_1 & -{s^*}_0 \end{pmatrix} \qquad (4.5)$$

The vector equation in this Equation can be read explicitly as

$$r_{0=}\ \frac{1}{\sqrt{2}} s_0\, h_1 \ +\ \frac{1}{\sqrt{2}} s_1\, h_2\ + n_0 \qquad (4.6)$$

$$r_{1=}\ \frac{-1}{\sqrt{2}} s_1^*h_1 \ +\ \frac{1}{\sqrt{2}} s_0^*h_2\ + n_1 \qquad (4.7)$$

At the receiver, the vector y of the received signal is formed according to y = [r_0, r_1]^T, which is equivalent to

$$r_{0=}\ \frac{1}{\sqrt{2}}s_0\, h_1 + \frac{1}{\sqrt{2}}s_1\, h_2 + n_0 \tag{4.8}$$

$$r_1^* = \frac{1}{\sqrt{2}}s_0\, h_2^* + \frac{1}{\sqrt{2}}s_2\, h_0^* + n_1^* \tag{4.9}$$

These both equations can be rewritten in a matrix system as specified in this Equation:

$$\begin{pmatrix} r_0 \\ r_1^* \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} s_0 \\ s_1 \end{pmatrix} + \begin{pmatrix} n_0 \\ n_1^* \end{pmatrix} \tag{4.10}$$

The short notation for this is the following:

$$y = \frac{1}{\sqrt{2}}\ \mathbf{H}_v s + \tilde{n} \tag{4.11}$$

Where ñ represents the new noise vector obtained after the conjugation of the second equation, ñ = $[n_0, n_1^*]^T$.

The resulting virtual (2 × 2) channel matrix, H_, is orthogonal, i.e.

$$\mathrm{H}_v^{\mathrm{H}}\mathbf{H}_v = \mathbf{H}_v\mathrm{H}_v^{\mathrm{H}} - h^2\, \mathbf{H}_2 \tag{4.12}$$

where $(\cdot)^H$ represents the hermitian operation, I_2 is the 2×2 identity matrix, and h^2 is the power gain of the channel, with $h^2 = |h_1|^2 + |h_2|^2$. Due to this orthogonality, the Alamouti scheme decouples the Multiple-Input Simple-Output (MISO) channel into two virtually independent channels with channel gain h2 and diversity d = 2 [24].

The mentioned channel gain is deduced from Equation 4.13, which specifies that transmitted symbols can be estimated at the receiver as the result of multiplying the received signals by the hermitian of the virtual channel matrix. After performing the corresponding operations it results in a signal with a gain of h^2 plus some modified noise:

$$\hat{\mathrm{s}} = \mathrm{H}_v^{\mathrm{H}}\,\mathrm{y} = \frac{1}{\sqrt{2}}\, h^2\mathrm{s} + \mathrm{H}_v^{\mathrm{H}}\tilde{n} \tag{4.13}$$

4.8 Maximum Radio Combining

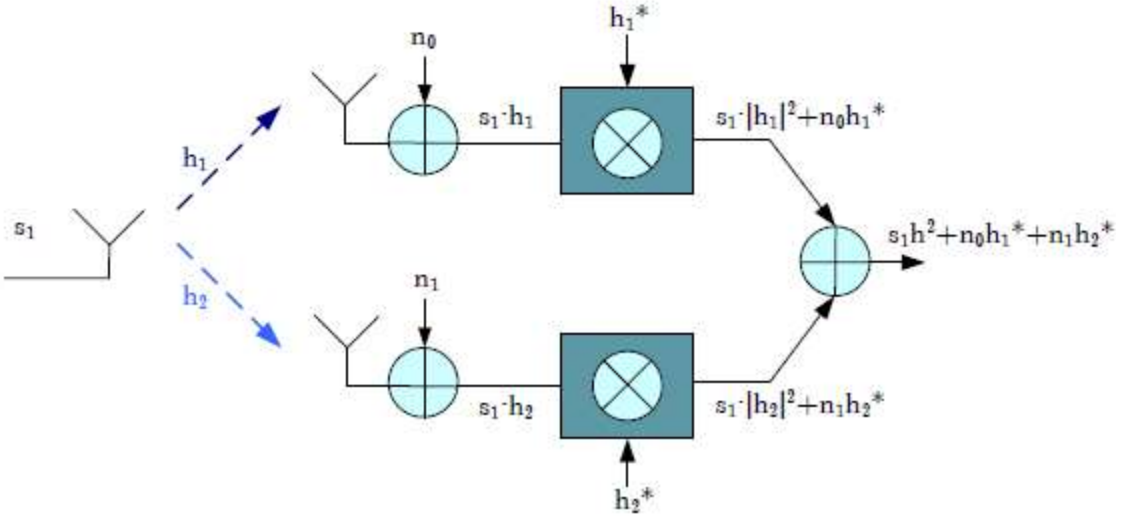


Figure 4.7: A system using two antennas in reception [17]

Maximum Ratio Combining (MRC) [23] is a special form of diversity where multiple replicas of the same signal, received over different diversity branches, are combined in order to maximize the instantaneous SNR at the combined output. Before summing the signals of every receive branch the symbols on all receive antennas are weighted. The weight factor corresponds with the complex conjugated channel coefficient of each receive branch. The signal received on each antenna is given by

$$yi = his + ni; \quad i = 1, 2, \ldots., NR, \tag{4.14}$$

Where h_i and n_i are the channel coefficients and the noise experienced by antenna i, respectively, s is the transmitted signal, and N_R is the number of receive antennas. Moreover, it is considered that the antennas are sufficiently spaced from each other and the channel coefficients, affected by fading, can be assumed to be independent.

The weighted combination for the input antennas to be taken into account is expressed as follows:

$$y = \sum_{i=1}^{N_R} \beta_i \, y_i = s \ \sum_{i=1}^{N_R} \beta_i \, h_i + \sum_{i=1}^{N_R} \beta_i \, n_i \qquad (4.15)$$

From this combination, the SNR of the channel is given by

$$\mathrm{SNR}\left(h_1, h_2, \cdots, h_{N_R}\right) = \frac{\mathrm{E}\left|s \sum_{i=1}^{N_R} \beta_i h_i\right|^2}{\mathrm{E}\left| \ \sum_{i=1}^{N_R} \beta_i n_i\right|^2} = \frac{\left|s \sum_{i=1}^{N_R} \beta_i h_i\right|^2}{\sum_{i=1}^{N_R} |\beta_i|^2} \qquad (4.16)$$

Applying the Cauchy-Schwartz inequality [39], it is straightforward to verify that $\beta_i = h_i^*$ maximizes the SNR. Replacing this value in Equation 4.16, the maximal SNR yields

$$\mathrm{SNR}\left(h_1, h_2, \cdots, h_{N_R}\right) = \ \mathrm{SNR} \sum_{i=1}^{N_R} |h_i| \qquad (4.17)$$

The process [24]described above is shown in Figure 4.7, where an example of a receiver with dual antenna diversity is depicted. The signal is sent over a channel with transmission coefficients h1 and h2, and reaches both receive antennas with some added noise. Then, the process consists of multiplying the signal in each receive branch by the corresponding conjugated channel coefficient, and at the end, the signals from both branches are summed.

It can be appreciated that the received signal is very similar to the one obtained with the Alamouti scheme in Equation 4.13 as the same gain in the signal is achieved, as well as some modified noise. However, better performance is obtained with this scheme as only one symbol is transmitted in one time interval and the unity average transmit power is already achieved in each interval. Therefore, the resultant signal is not multiplied by the factor $\frac{1}{\sqrt{X}}$ as in the Alamouti scheme, and consequently, a gain of 3 dB in power is obtained.

Chapter 5: Simulation and Analysis

5.1 Introduction

In this chapter, simulation results will be presented along with the underlying assumptions. The goal is to evaluate the performance of the system as well as to obtain a more accurate understanding of the operation of the WiMax system and to implement the system mandatory and optional features like Adaptive transmission under fading channels condition. Comparisons between simulation results obtained with different simulation parameters, some discussions about the use of these different parameters and options are given with the purpose of offering a complete view on the better way of performance of the transmission.

Different scenarios for fixed OFDM 802.16 have been done. Furthermore, the transmission gain obtained when using multiple antennas instead of only a single antenna at one or both ends of the transmission link is also examined. The different channel models and scenarios are applied in different simulations so that the fading phenomenon can be studied. To end, results when activating the Adaptive Modulation and Coding (AMC) mechanism are offered, thus showing the mentioned increase in spectral efficiency and data throughput as it shown in figure 5.6 and 5.7, these cases are listed below:

- Case1: WiMax simulation with Transmitter and receiver Diversity
- Case 2 WiMax system Simulation with fading channels SUI (1 al 6) plus Additive White Gaussian Noise (AWGN)
- Case 3: WiMax system simulation in which all the modulations are used (BPSK, QPSK, 16QAM and 64QAM)
- Case 4: WiMax system Simulation with variant size of the cyclic prefix (1/4, 1/8, 1/16, 1/32)
- Case 5:WiMax simulation with different values of the nominal BW of the system
- Case 6: Realize the simulation WITH and WITHOUT encoding of the bits and study the difference

5.1 Simulation Initializations

The common assumptions are to most of the simulations parameters are as follows: the simulation is carried out for downlink transmissions at a carrier frequency of 3.5 GHz and with variant channel bandwidth variant between (1.25- 28) MHz's. The length of the cyclic prefix is defined by G = ¼ which is the highest cyclic prefix as it is defined in the standard, because of fading channels and the frame duration is specified to be 2.5 msec, and the standard coding technique is used with rate of ½ for BPSK and QPSK, 16QAM and with coding rate 2/3 with 64QAM. Thus, only changes performed on these assumptions will be mentioned from now on.

5.2 Case 1: WiMax simulation with Transmitter and receiver Diversity

IEEE 802.16 Channel Models with MIMO implementation

In this case, simulation of multiple-input multiple-output (MIMO) multipath fading channels based on the IEEE 802.16 channel models for fixed wireless applications has been implemented. Two transmit antennas and one receive antennas are used, and then illustration the effect of using diversity at receiver side has been achieved, to get more understanding and to make whole picture clear about the MIMO channels. The demo uses the MIMO multipath fading channel and the rounded Doppler spectrum objects.

5.2.1 Simulation Model

In order to validate the proposed work, the simulation scenario is focused in a link budget with 30^o directional antennas and a Multi input single output transmission scheme (MISO). The cyclic prefix per symbol rate is 1/4. For the sake of simplicity, coding technique rate ½ has been used and ideal channel estimation is considered at the receiver. Moreover, the rest of parameters defined in the PHY layer are taken from and shown in Table 5.1.

There are two types of OFDM parameters (primitive and derived) that characterize OFDM symbol completely. The later can be derived from the former one because of fixed relation between them. In our MATLAB implementation of the physical layer, the primitive parameters are specified as ´OFDM_ params´ and primitive parameters are calculated as ´IEEE802.16 paparams´ which can be accessed globally. The used OFDM Parameters are listed below:

Type	Parameters	Value
Primitive	Nominal Channel Bandwidth, BW	3.5 MHz
	Number of Used Subcarrier, Nused	192
	Sampling Factor, n	8/7
	Ratio of Guard time to useful symbol time, G	1/4
Derived	NFFT(smallest power of 2 greater than Nused)	256
	Sampling Frequency, Fs	Floor(n.BW/8000) X 8000
	Subcarrier Spacing, Δf	Fs/NFFT
	Useful Symbol Time, Tb	1/ Δf
	CP Time, Tg	G.Tb
	OFDM Symbol Time, Ts	Tb+Tg
	Sampling Time	Tb/NFFT

Table 5.1: Shows simulation parameters for case-1

The IEEE 802.16 channel models for fixed wireless applications are proposed for scenarios where the cell radius is less than 10 km, the directional antennas at the receiver are installed under-the-rooftop/windows or on the rooftop, and the base station (BS) antennas are 15 to 40 m in height. The channel models comprise a set of path loss models including shadowing (suburban, urban) and a multipath fading model, which describes the multipath delay profile, the K-factor distribution, and the Doppler spectrum. The antenna gain reduction factor, due to the use of directional antennas, is also characterized. Each modified SUI channel model has three taps. Each tap is characterized by a relative delay (with respect to the first path delay), a relative power, a Rician K-factor, and a maximum Doppler shift.

Relative powers are specified for each channel model for a 30^o directional antenna. Furthermore, for each relative power, a K-factor for 90% cell coverage has been considered for simulations. Hence, each of the 6 modified SUI channel models comprises parameters for four distinct scenarios. Each modified SUI channel model is further assigned an antenna correlation, defined as the envelope correlation coefficient between signals received at different antenna elements. The simulation sampling rate is specified and kept the same for the remainder of the scenarios. The input to the channel simulator is oversampled by a factor of four. The channel model has three paths: the first path is Rician while the remaining two are Rayleigh. Each path has a rounded Doppler spectrum for its diffuse component: the parameters are as specified in the default Doppler rounded object while different maximum Doppler shifts are specified for each path in [57]. Maximum value of the Doppler shifts for all paths have been used.

It has to be mention that the simulation sampling rate is specified, and kept the same for the remainder of the demo. The input to the channel simulator is oversampled by a factor of four, the Input symbol rate is$10x10^3$ and the modulation type is BFSK.

5.2.2 Results and Discussion

The construction of MIMO channel object according to the modified SUI-5 channel model, for a directional antenna (30^0) and 90% cell coverage with 99.9% reliability has been made.

The channel model has 3 paths: the first path is Rician while the remaining two are Rayleigh. Each path has a rounded Doppler spectrum for its diffuse component: the parameters are as specified in the default doppler.rounded object. While different maximum Doppler shifts are specified for each path. Maximum value of the Doppler shifts for all paths have been used. 2 transmit antennas and 1 receive antenna are applied. The correlation coefficient between the two signals on each path is taken equal to the antenna correlation.

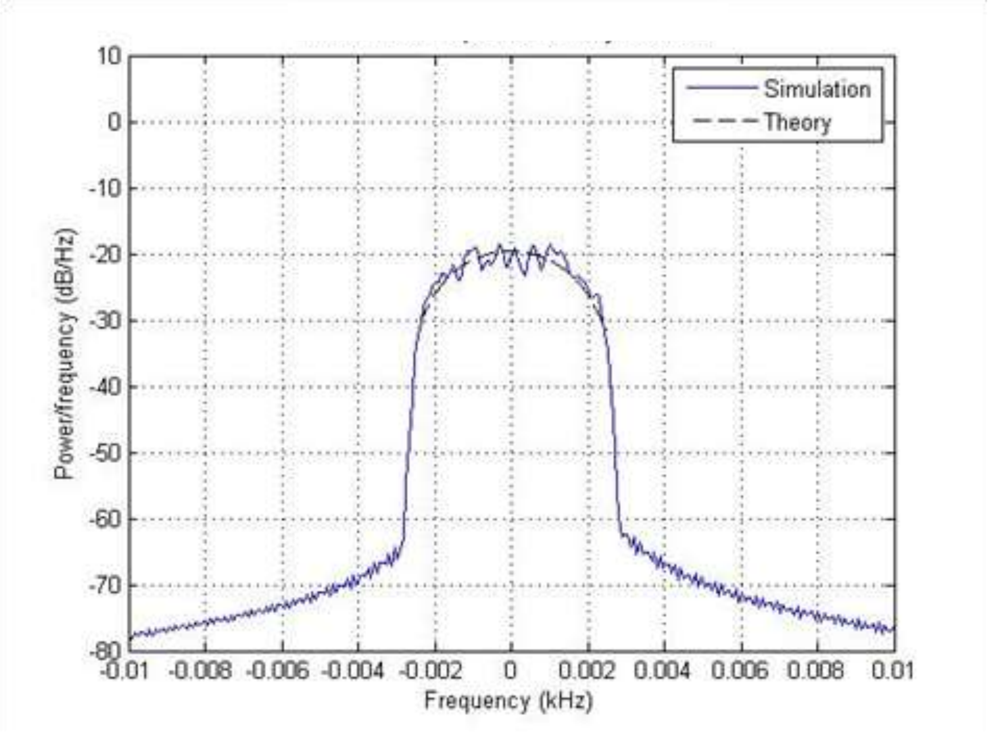


Figure 5.1: The Doppler spectrum of the 1st link of the 2nd path is estimated from the complex path gains and plotted under SUI 5 channel condition

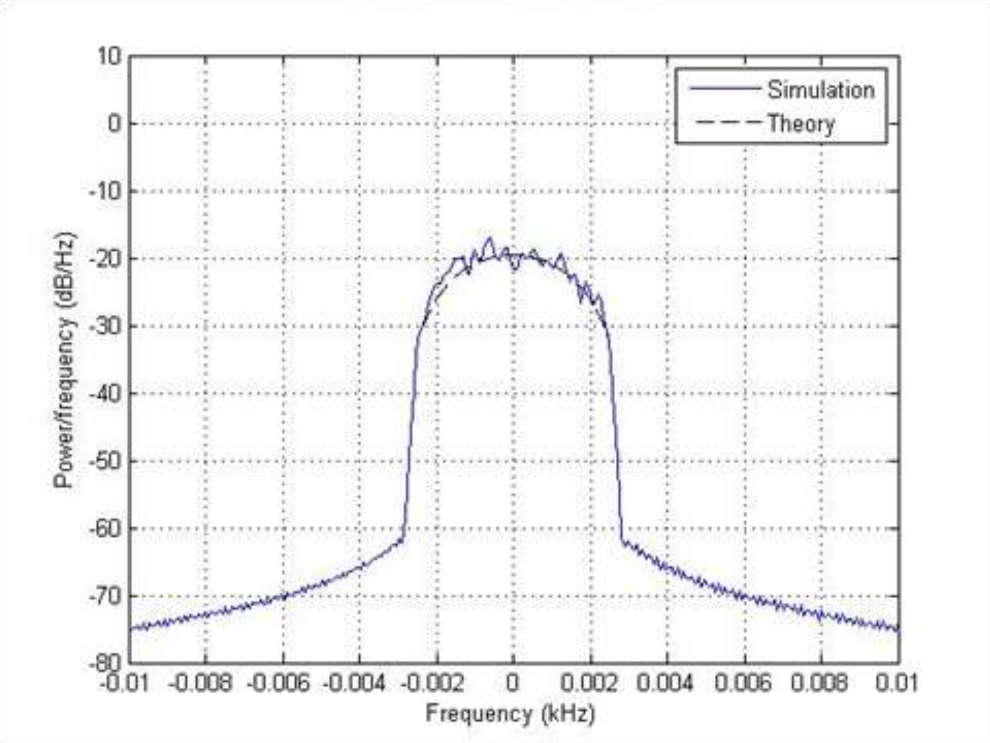


Figure 5.2: The Doppler spectrum for the 2nd link of the 2nd path is also estimated and compared to the theoretical spectrum under high terrain condition (SUI 5)

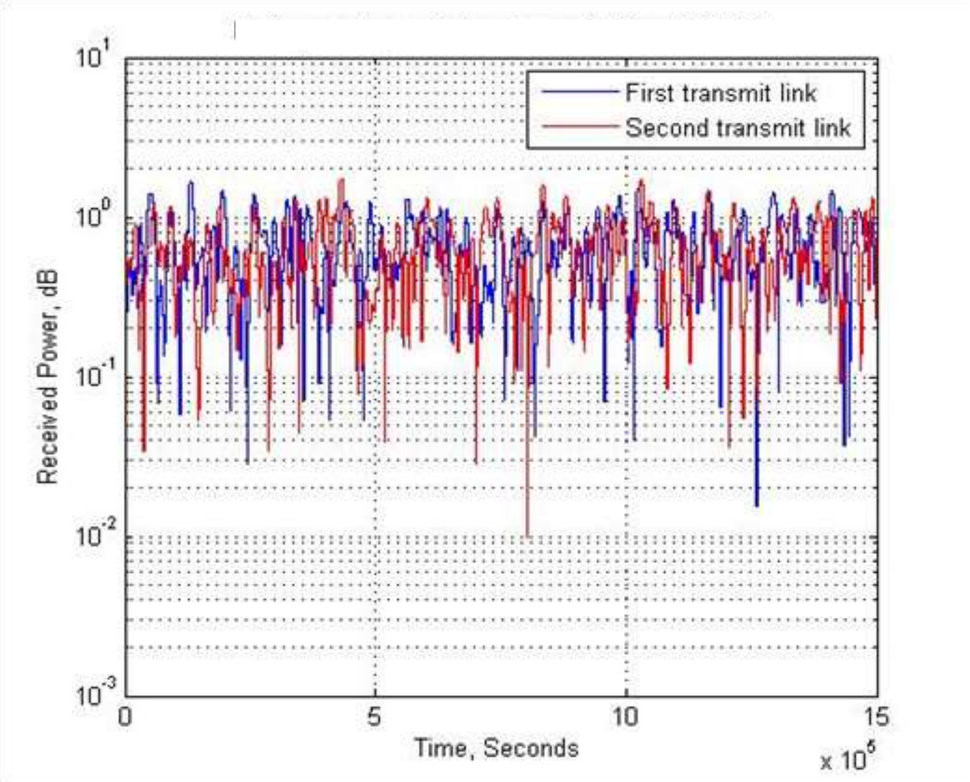


Figure 5.3: Fading envelopes for two transmitted links of path 1

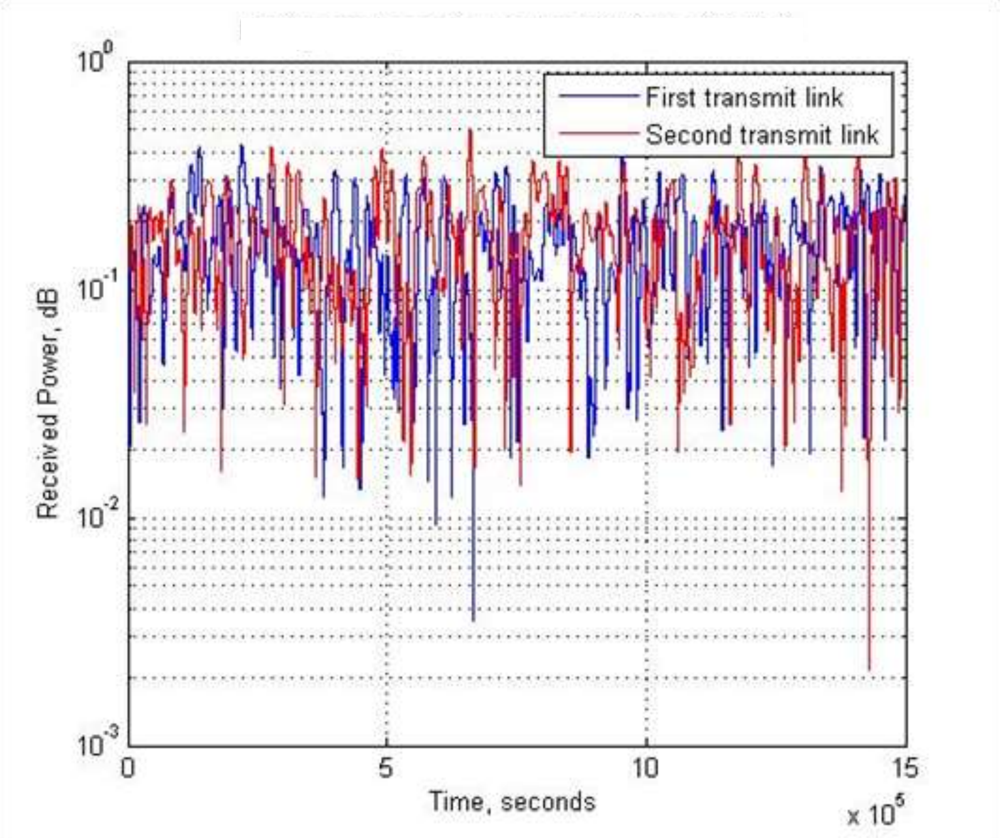


Figure 5.4: Fading envelopes for two transmitted links of path 2

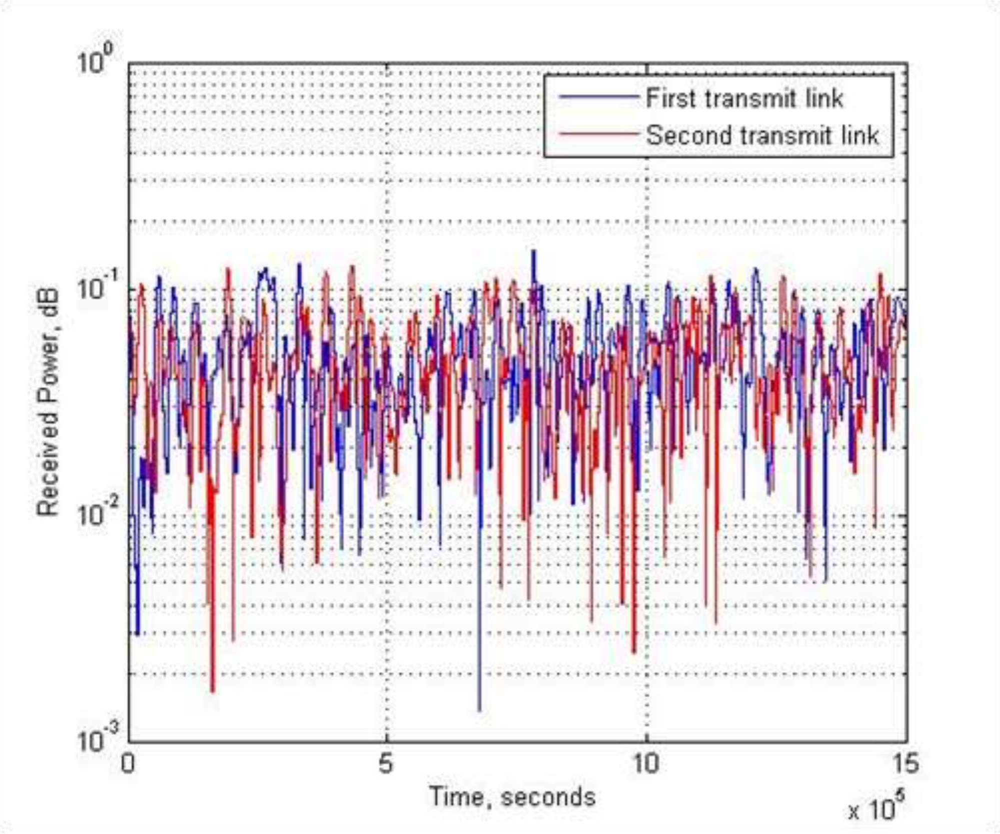


Figure 5.5: Fading envelopes for two transmitted links of path 3

The Doppler spectrum of the 1st link of the 2nd path is estimated from the complex path gains and plotted in Figure 5.1. After each frame is processed, the channel is not reset, this is necessary to preserve continuity across frames.

The Doppler spectrum for the 2nd link of the 2nd path is also estimated and compared to the theoretical spectrum under high terrain condition (SUI 5) in Figure 5.2. The theoretical rounded Doppler spectrum doesn’t overlay to estimated Doppler spectrum. Almost observes little fit between both signals, and that’s because the channels are for highly Terrain with moderate to heavy trees densities (Category A), and that’s mean high fading effect in the transmission medium. The situation same for Figure 5.2 for the same reason and a good fit observation between both simulated and theoretical signals haven't been achieved.

Fading envelope waveform of both transmitted links has been plotted, as it seen in Figure 5.3, 5.4 and 5.5 for path1, 2 and 3 respectively. It has been noticed there is no correlation between both transmitted links for all paths (1, 2 &3), the channel condition change rapidly and the channel fading is so fast which it means low temporal correlation and short coherence time.

This part was about estimated the power spectral density (PSD) for an urban area channel. PSD describes how the power of a signal or time series is distributed with frequency using Welch's modified periodogram method of spectral estimation. The goal of spectral density estimation is to estimate the spectral density of a random signal from a sequence of time samples.

6.2.3 SISO, SIMO, MISO, and MIMO systems implementation

Results obtained when using more than one antenna either at the transmitter or at the receiver, or at both ends of the communication link, are discussed in this case. As in the results for only one antenna, the common assumptions to all of the simulations are:

- f_c=3.5 GHz
- BW=20 MHz
- G=1/32
- Tframe=2.5 msec

Furthermore, a perfect knowledge of the channel coefficients and a SUI3 fading channel model are used. As it known, wireless channels key problem is fading. In order to combat this fading and improve the capacity and the throughput of the system, multiple antennas at both ends of the communication link are used. This case analyzes the enhancement achieved with such structures, making a comparison of the performance of not only systems with multiple transmit but also multiple receive antennas.

Figure 5.6 and 5.7 illustrates; the performance of the system drastically improves with a diversity system in place, the slope of the BER curves is an indicator of the degree of diversity that has been achieved. The degree of diversity is defined as the performance improvement in BER, in terms of power of ten, for a 10 dB higher SNR. As can be observed, the curve for the 1 x 1 system improves its error probability with a factor 10, i.e. power of 1 for a 10 dB rise in SNR. In this case, the degree of diversity is said to be equal to one, i.e. no diversity at all. However, when simulating with a 1 x 2 or a 2 x 1 system, which have diversity order of two, better performance is achieved equally, the degree of diversity achieved with the 2 x 2 system is of order four. Therefore, it can be concluded that the degree of diversity is equal to N_TN_R, being N_T and N_R the number of transmit and receive antennas, respectively. In addition, it is shown that although both 1 x 2 and 2 x 1 achieve the same degree of diversity, the system that uses multiple antennas at the receiver offers a significant improvement of 3 dB of gain in the channel SNR. This gain is deducted from the formula of the received signal when using the MRC (Maximum Ratio Combiner) and the Alamouti scheme. As only one symbol is transmitted at one time interval with the MRC algorithm, the unity average transmits power is already achieved in each time interval.

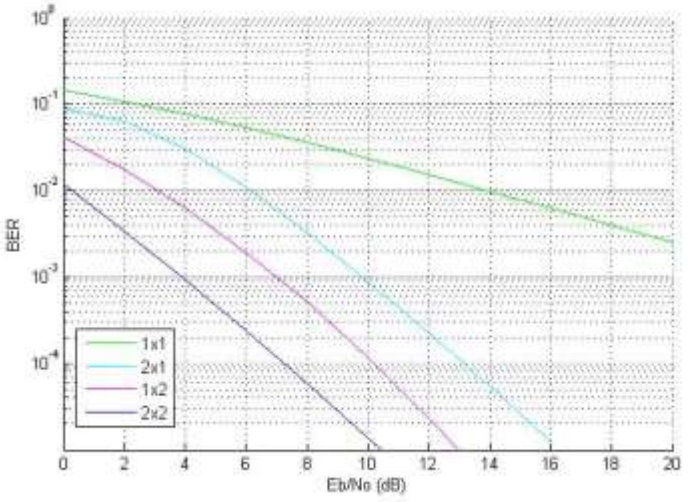


Figure 5.6: Comparison between different degrees of diversity

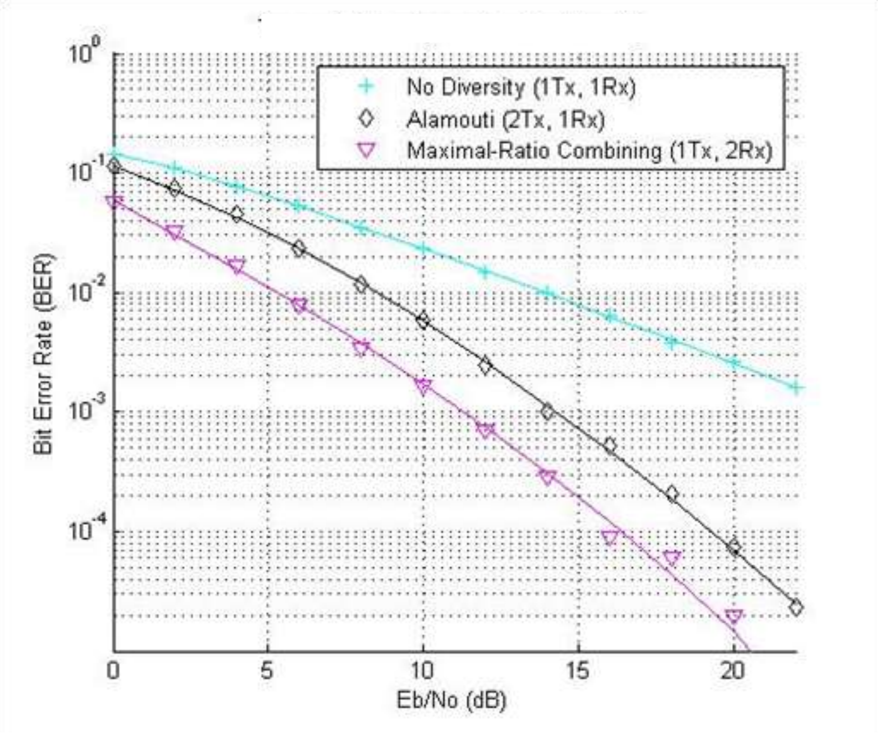


Figure 5.7 Transmitter vs. Receiver diversity

The throughput of the system is analyzed next; Figure 5.8 Explains that the higher the diversity order the more improvement in throughput is achieves.

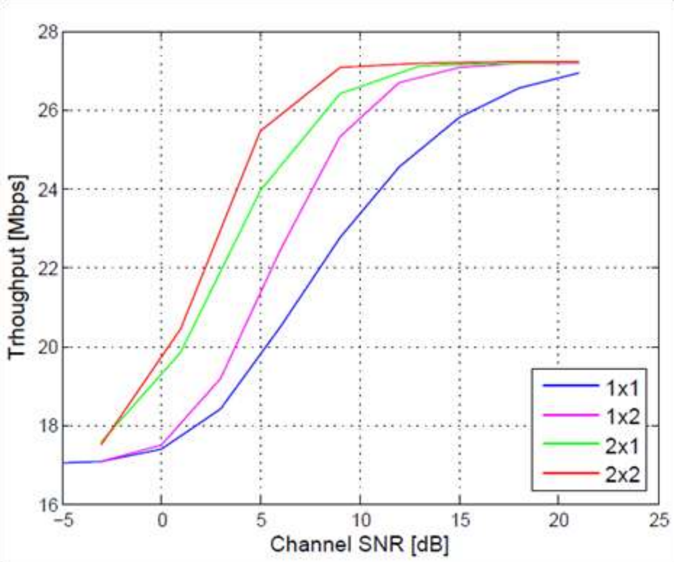


Figure 5.8: Throughput of the system using diversity schemes

5.3 Case 2 WiMax system Simulation with fading channels SUI (1 al 6) plus AWGN

Stanford University Interim (SUI) Channel Models

One of the most important issues in the design implementation and operation of land mobile system is the knowledge of the received signal and its fluctuations. Propagation models take into account the type of the environment and the materials.

As it mentioned before the wireless channel is characterized by:

- Path loss (including shadowing)
- Multipath delay spread
- Fading characteristics
- Doppler spread
- Co-channel and adjacent channel interference

Channel models described above provide the basis for specifying channels for a given scenario. It is obvious that there are many possible combinations of parameters to obtain such channel descriptions. A set of 6 typical channels was selected for the three terrain types that are typical of the continental US [58]. These channels divided into three categories (A, B &C), category A for Urban area with high tree density, category B for sub-urban area with moderate to heavy tree density and category C for rural area with light tree density. In this case SUI channels models that we modified to account for 30^o directional antennas have been presented. These models can be used for simulations, design, development and testing of technologies suitable for fixed broadband wireless applications

The parametric view of the SUI channels is summarized in the following tables below,

Terrain Type	SUI Channels Categories
C	SUI-1, SUI-2
B	SUI-3, SUI-4
A	SUI-5, SUI-6

Table 5.2 SUI channels categories

Doppler	Low delay spread	Moderate delay spread	High delay spread
Low	SUI-3		SUI-5
High		SUI-4	SUI-6

Table 5.3 K-Factor: Low

Doppler	Low delay spread	Moderate delay spread	High delay spread
Low	SUI-1,2		
High			

Table 5.4 K-Factor: High

The generic structure for the SUI Channel model is given below in Figure 5.9

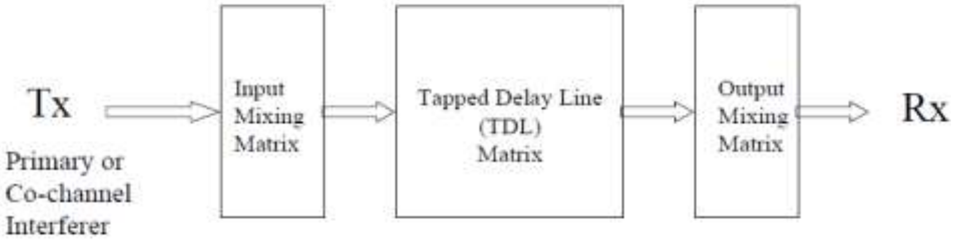


Figure 5.9: Shows the generic structure for the SUI Channel model [57]

The above structure is general for Multiple Input Multiple Output (MIMO) channels which is fits our purpose her and includes other configurations like Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) as subsets. The SUI channel structure is the same for the primary and interfering signals.

Input Mixing Matrix: This part models correlation between input signals if multiple transmitting antennas are used.

Tapped Delay Line Matrix: This part models the multipath fading of the channel. The multipath fading is modelled as a tapped-delay line with 3 taps with non-uniform delays. The gain associated with each tap is characterized by a distribution (Ricean with a K-factor > 0, or Rayleigh with K-factor = 0) and the maximum Doppler frequency.

Output Mixing Matrix: This part models the correlation between output signals if multiple receiving antennas are used.

Using the above general structure of the SUI Channel and assuming the following scenario, six SUI channels are constructed (Appendix A) which are representative of the real channels.

5.3.1 Scenario for modified SUI Channels

The following parameters have been applied to initialize SUI channels:

-Cell size: 7 km.

- BTS antenna height: 30 m.

- Receive antenna height: 6 m.

- BTS antenna beamwidth: 120^o

-Receive Antenna beamwidth: directional Antenna $(30)^o$

- Vertical Polarization only applied.

- 90% cell coverage with 99.9% reliability at each location covered.

For 30^o antenna beamwidth, 2.3 times smaller RMS delay spread is used when compared to an omni-directional antenna RMS delay spread [10]. Consequently, the 2nd tap power is attenuated an additional 6 dB and the 3rd tap power is attenuated an additional 12 dB (effect of antenna pattern, delays remain the same). Both theoretical and measurement-base propagation models indicate the average received signal power decreases logarithmically with distance, whether outdoor or indoor radio channels are considered.

5.3.2 Simulation Model

In order to validate the proposed work, the simulation scenario is focused in a link budget with 30^o directional antennas and a Multi input single output transmission scheme (MISO). The cyclic prefix per symbol rate is 1/32. For the sake of simplicity ideal channel estimation is also considered at the receiver, and the standard coding technique is used with rate of ½ for BPSK, QPSK and with 3/4 for 16QAM. Moreover, the rest of simulation parameters are in table 5.5 below:

Type	Parameters	Value
Primitive	Nominal Channel Bandwidth, BW	28,24 MHz
	Number of Used Subcarrier, Nused	192
	Sampling Factor, n	8/7
	Ratio of Guard time to useful symbol time, G	1/32
Derived	NFFT(smallest power of 2 greater than Nused)	256
	Sampling Frequency, Fs	Floor(n.BW/8000) X 8000
	Subcarrier Spacing, Δf	Fs/NFFT
	Useful Symbol Time, Tb	1/ Δf
	CP Time, Tg	G.Tb
	OFDM Symbol Time, Ts	Tb+Tg
	Sampling Time	Tb/NFFT

Table 5.5: Shows Simulation parameters for case2

The IEEE 802.16 channel models for fixed wireless applications are proposed for scenarios where the cell radius is less than 10 km, the directional antennas at the receiver are installed under-the-rooftop/windows or on the rooftop, and the base station (BS) antennas are 15 to 40 m in height. The channel models comprise a set of path loss models including shadowing (suburban, urban) and a multipath fading model, which describes the multipath delay profile, the K-factor distribution, and the Doppler spectrum. The antenna gain reduction factor, due to the use of directional antennas, is also characterized. Each modified SUI channel model has three taps. Each tap is characterized By a relative delay (with respect to the first path delay), a relative power, a Rician K-factor, and a maximum Doppler shift. Relative powers are specified for channel model with 30^o directional antenna, Furthermore, a K-factor for 90% cell coverage, illustrated in (Appendix A). Each modified SUI channel model is further assigned an antenna correlation, defined as the envelope correlation coefficient between signals received at different antenna elements. The simulation sampling rate is specified and kept the same for the remainder of the scenarios. The input to the channel simulator is oversampled by a factor of four. The channel model has 3 paths: the first path is Rician while the remaining two are Rayleigh. Each path has a rounded Doppler spectrum for its diffuse component; Maximum value of the Doppler shifts for all paths has been used.

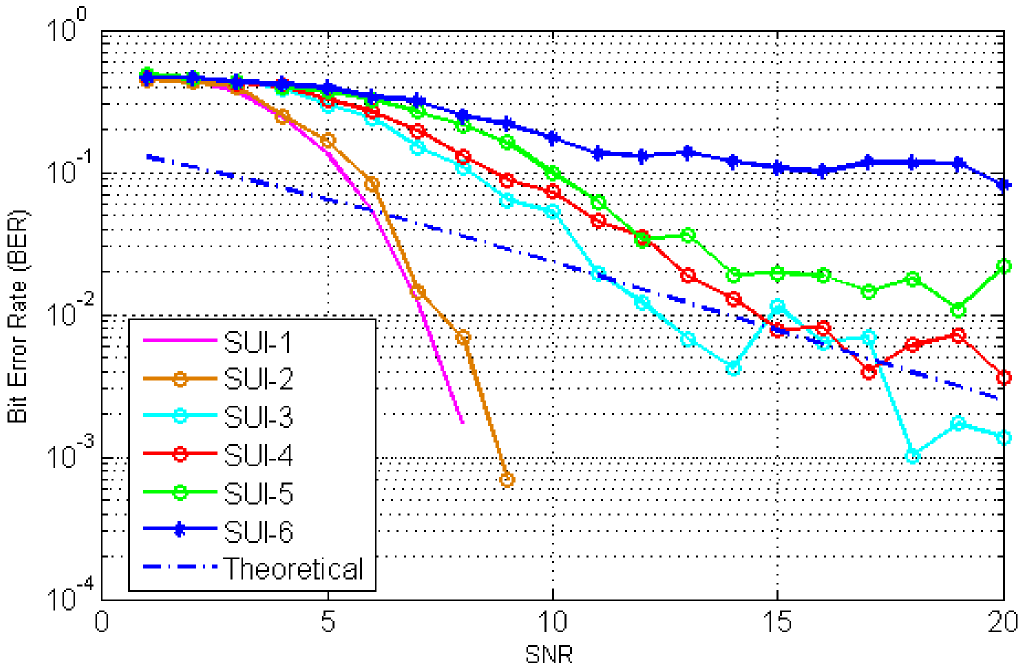


Figure 5.10 Illustrate implementations of different SUI channel plus AWGN with BPSK modulation over a maximum channel bandwidth 28MHz

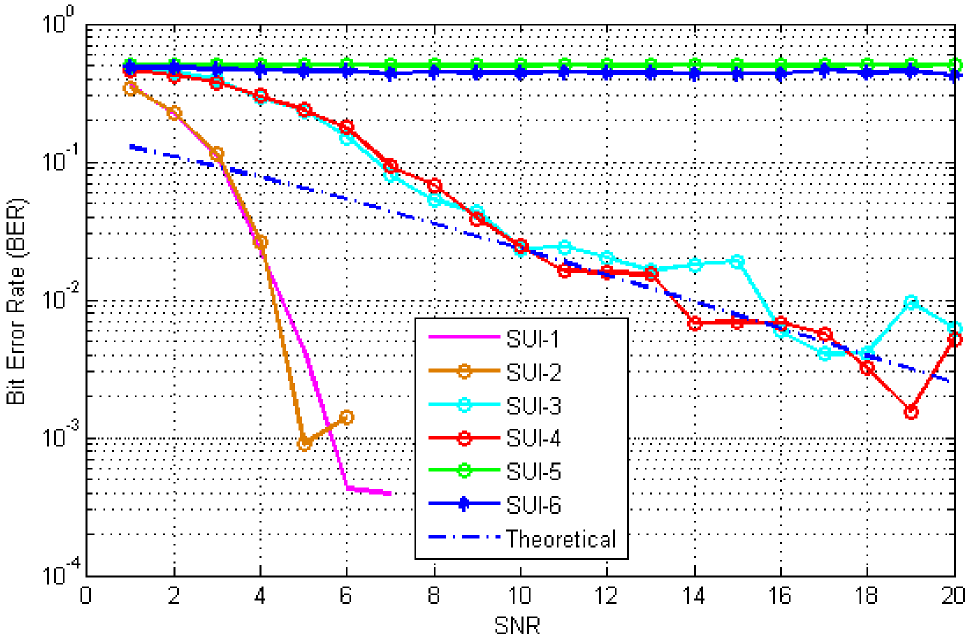


Figure 5.11 Illustrate implementations of different SUI channel with QPSK modulation over a maximum channel bandwidth 28MHz

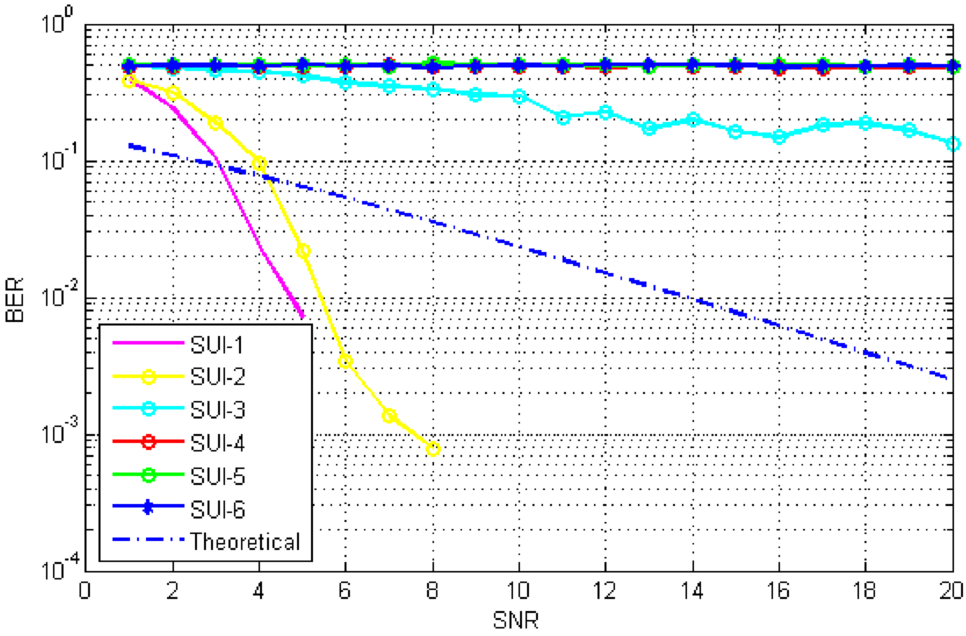


Figure 5.12 Illustrate implementations of different SUI channel with 16QAM modulation over a high channel bandwidth 24MHz

5.3.4 BER Plots Analysis

This case presents various BER vs. SNR plots for all SUI channels profiles as they recommended to fixed wireless applications, Figure 5.10 Illustrated different channels simulation with BPSK modulation type and smallest value of cyclic prefix , with high channel bandwidth, this chart shows channels in category A (SUI5 & SUI6) contain more noise with high attenuations and needs higher signal to noise ratio and that’s means it needs more power for date to transmitted over a highly fading channel from base station toward subscriber station. In figure 5.11 the simulation result which is done for SUI channels set, with QPSK and maximum bandwidth 28MHz, it shows that the channels for Urban area with highly foliage density contain more degradations and reflect high attenuation, that’s due to the characteristic of urban arias and the effect of multipath is very clear on the behaviour of the system, channels in Category C (SUI1 & SUI2) seems to behave perfectly with this simulation parameters and they show minimum path loss, that’s due to the flat terrain with light tree densities.

In Figure 5.12 implementation of SUI sets have been done, with 16QAM and with high bandwidth 24MHz, the results come up explaining the variation in signal performance between different cases, SUI4 and 5 underlie on SUI6 and draw a straight ling which is means that channels undergo high fading affect with huge corruption and large amount of scatter in signal quality at the receiver side, it needs more SNR to transmit the signal to customer end. In all three figures theoretical AWGN has been calculated. It obvious the figures that the severity of corruption is highest on SUI6, SUI5 and lowest in SUI1 channel model. The order of the severity of corruption can be easily understood by analyzing the tap power and delays of the channel models, since the Doppler Effect is reasonably small for fixed deployment. But, in this case tap power dominates in determining the order of severity of corruption. SUI6 has highest tap power value and SUI1 has lowest value.

5.4 Case 3: WiMax system simulation in which all the modulations are used (BPSK, QPSK, 16QAM and 64QAM)

As we discuss earlier the modulation is the process of changing the amplitude, frequency, or the phase of a radio frequency carrier signal to change with the information signal such as voice or data. WiMax system uses different kinds of modulations depending on variety of transmission factors, these modulations as the defined in IEE 802.16 standard are BPSK, QPSK, QAM.

In this case, various BER vs. SNR plots have been presented for all essential modulation profiles in the standard with different ratio of cyclic prefix and low channel bandwidth. Simulation scenario and parameters for this case are explained in this table 5.6.

Parameter	Values
Number of Subcarriers	256
Gard band	55
Number of pilot subcarriers	8
Number of Used Subcarrier, Nused	192
Length of CP for CP-OFDM	1/4 , 1/32
Channel Estimation Scheme	Optimal
Channel models	Theoretical AWGN, SUI3
Doppler frequency shift	Maximum
Modulation	BPSK, QPSK 16QAM, 64QAM
Signal Bandwidth	1.25, 2.5 MHz
Overall coding rate	½ BPSK, ½ QPSK, ¾ 16QAM, ¾ 64QAM

Table 5.6: Parameters to Simulate Different Modulation Techniques In IEEE 802.16-2004 OFDM PHY

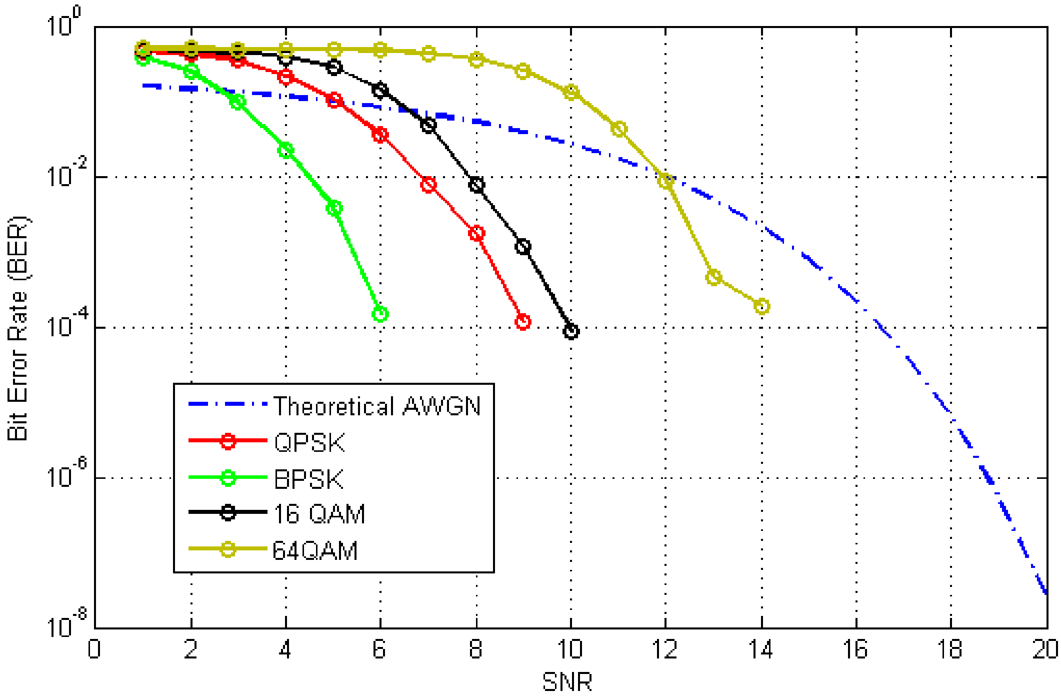


Figure 5.13: Simulation of variant modulation technique as the defined in the IEEE 802.16 standard Under AWGN channel conditions

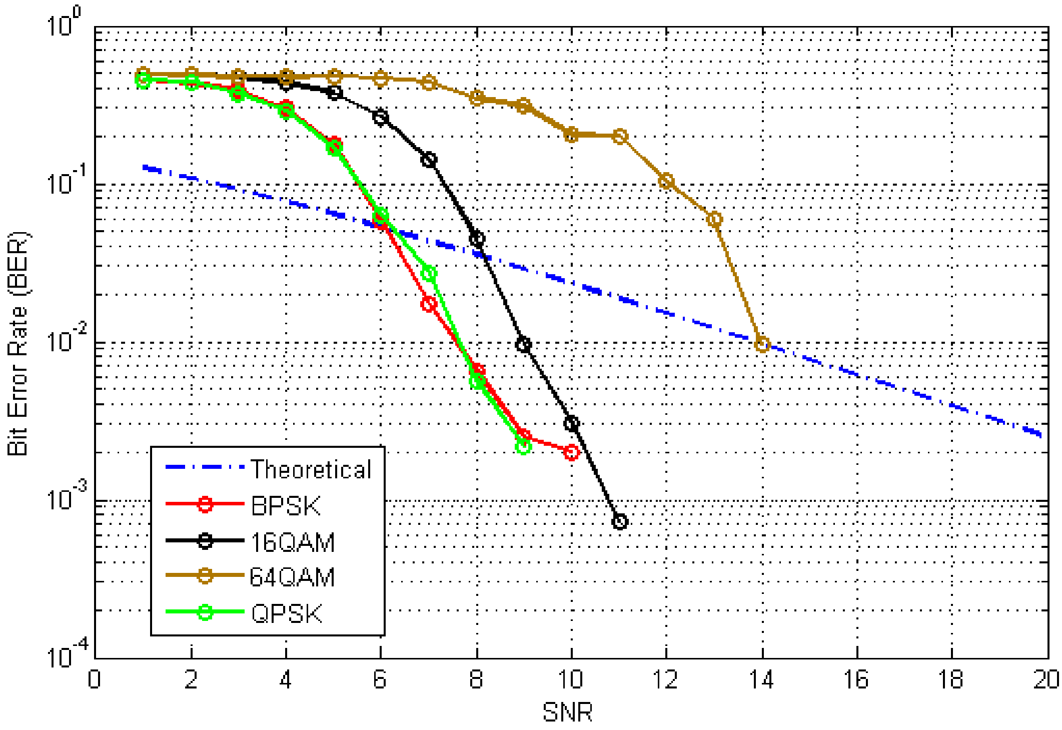


Figure 5.14: Simulation of variant modulation technique as the defined in the IEEE 802.16 standard under moderate urban area SUI3 channel conditions

Modulation	**BPSK**	**QPSK**	**16QAM**	**64QAM**
Code rate	1/2	1/2	3/4	3/4
Channel	SNR(dB) at BER level 10^{-2}			
AWGN	4.5	6.9	7.9	12
SUI-3	7.7	7.8	9	15

Table 5.7: SNR required at BER level 10^{-2} for different modulation and coding profiles

5.3.1 BER Plots Analysis

In this case, various BER vs. SNR plots have been presented for all the mandatory modulation and coding profiles as specified in the standard on variant channel models. Figure 5.13 and 5.14 shows the performance on AWGN and SUI3 channel models respectively. It can be seen from this figures that the lower modulation and coding scheme provides better performance with less SNR. This can be easily visualized by look at their constellation mapping; larger distance between adjacent points can tolerate larger noise (which makes the point shift from the original place) at the cost of coding rate. By setting threshold SNR, adaptive modulation schemes can be used to attain highest transmission speed with a target BER. SNR required to attain BER level at 10^{-2} are tabulated in Table 5.6.

Having observed performance of different profiles under different outdoor environments channel models, let us monitor the variations with the change in channel conditions. It can be seen from the figures 5.13 & 5.14 that the severity of corruption is highest on SUI3 and lowest in AWGN channel model. The performance under AWGN channel is very clear and that’s because the lack of multipath propagation leads to no more attenuation in received signal. In case of semi-Urban area in SUI3 contains more attenuation and high noise with signal degradation at receiver side. The order of the severity of corruption can be easily understood by analyzing the tap power and delays of the channel models, since the Doppler Effect is reasonably small for fixed deployment. But, in this case tap power dominates in determining the order of severity of corruption in received signal.

5.5 Case 4: WiMax system Simulation with variant size of the cyclic prefix (1/4, 1/8, 1/16, 1/32)

The robustness of any OFDM transmission against multipath delay spread is achieved by having a long symbol period with the purpose of minimizing the inter-symbol interference.

A cyclic prefix is added to the time domain samples to fight the effect of multipath, for different duration of cyclic prefix is available in the standard. Guard interval (G) the ratio of CP time to OFDM symbol time, this ratio can be equal to 1/32, 1/6, 1/8 and 1/4. This guard interval, that is actually a copy of the last portion of the data symbol, is known as the cyclic prefix (CP).

In this case the simulation parameters would be according to table 5.8 below:

Parameter	Values
Number of Subcarriers	256
Gard band	55
Number of pilot subcarriers	8
Number of Used Subcarrier, Nused	192
Length of CP for CP-OFDM	1/4 , 1/8, 1/16, 1/32
Channel Estimation Scheme	Optimal
Channel models	SUI2, SUI6
Doppler frequency shift	Maximum
Modulation	16QAM, QPSK
Signal Bandwidth	28, 1.25,7 MHz

Table 5.8: Shows Parameters To Simulate Different OFDM cyclic prefix In IEEE 802.16-2004 PHY

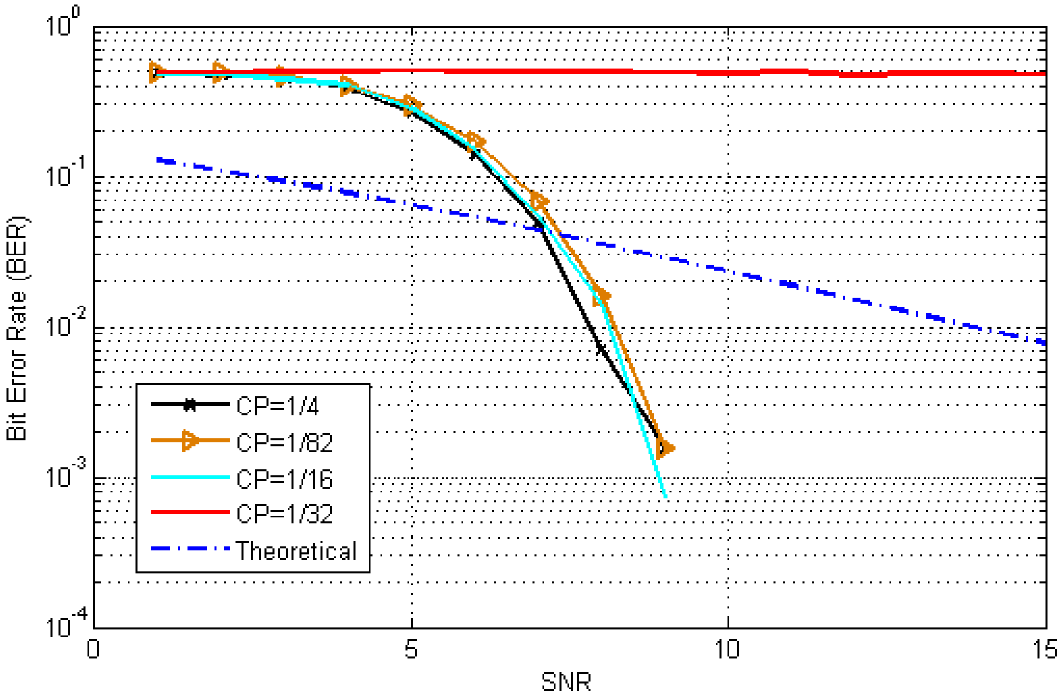


Figure 5.15: Simulation of different cyclic prefix with theoretical curve under rural area

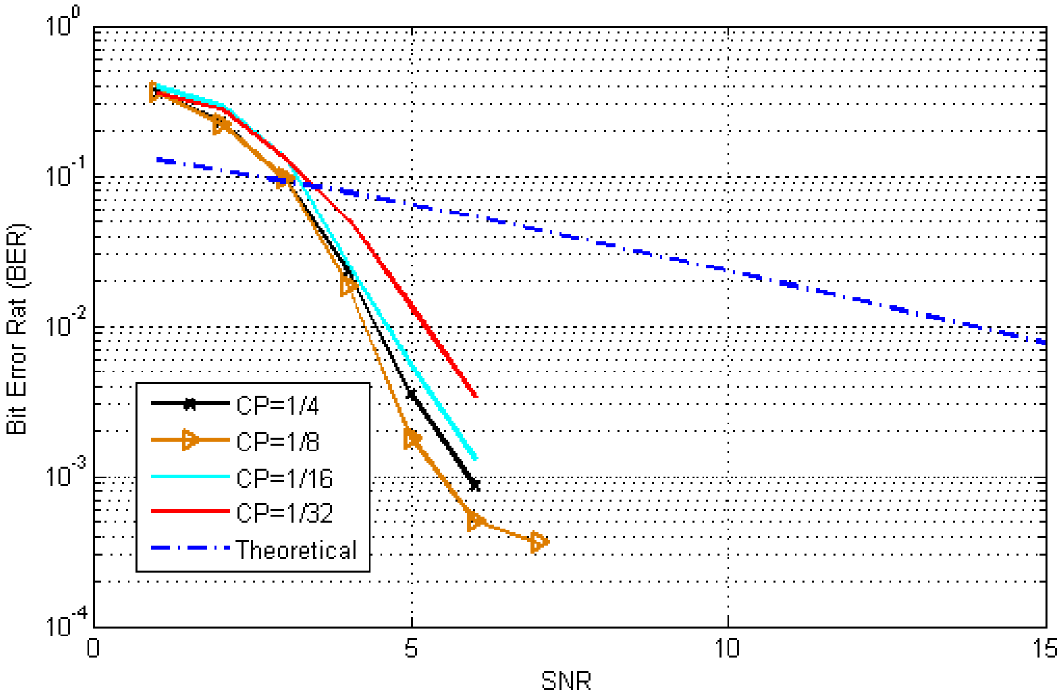


Figure 5.16: Simulation of different cyclic prefix with theoretical curve under rural area with QPSK

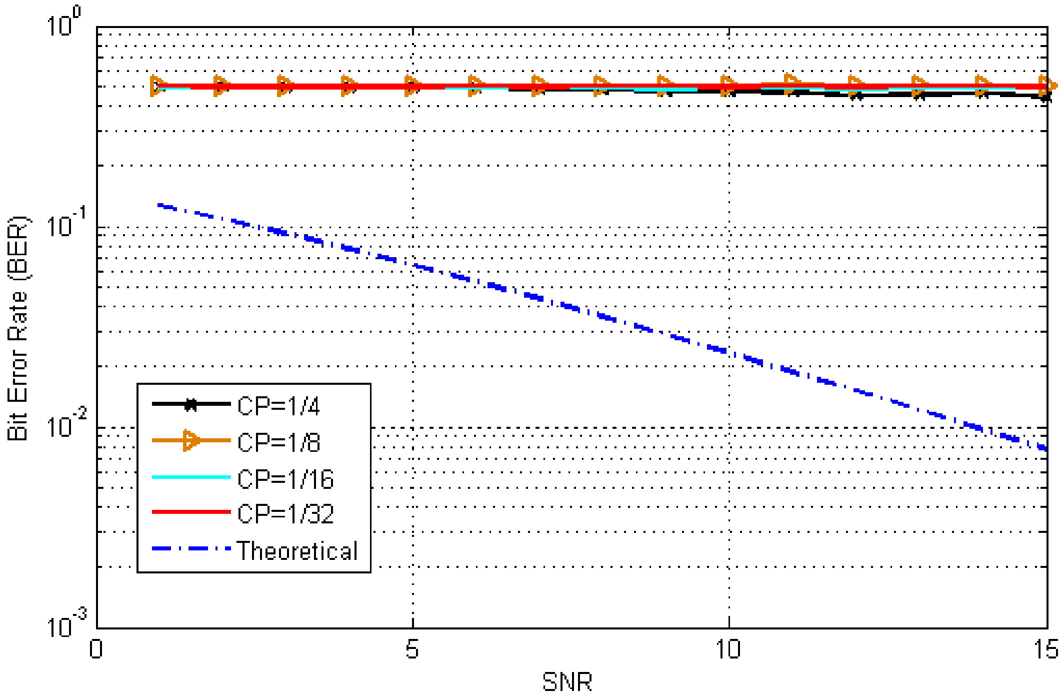


Figure 5.17: Simulation of different cyclic prefix with theoretical curve under urban area

5.5.1 BER Plots Analysis

WiMAX allows a wide range of guard times that allow system designers to make appropriate trade-offs between spectral efficiency and delay spread robustness. For maximum delay spread robustness, a 25 percent guard can be used; people usually plot the BER curves to describe the functionality of a digital communication system. The subcarrier orthogonality of an OFDM system can be jeopardized when passes through a multipath channel, as it mentioned before the CP is used to combat ISI and ICI introduced by the multipath channel. Figure 5.15 illustrate the affect of cyclic prefix over the rural are with low fading characteristic and low tree density as well with 16QAM with high channel bandwidth, it’s obvious that the channel with greater value of guard interval is stronger against the fading affect and multipath interference, the curve with guard equal to 1/32 is contain more attenuation and more venerable ageist channels noise, that’s because length of the CP less than the maximum delay spread of the target multipath environment.

Figure 5.16 shows the simulated cyclic prefix values with QPSK modulation type and with low channel bandwidth under urban area too, it obvious that the lowest cyclic prefix value is less venerable agents fading effect in wireless channel, by looking closely to the figure, it can be noticed at BER equal to 10^{-2} one dB gain in SNR performance with guard equal to 1/32 with respect to 1/4, and that’s prove the higher cyclic prefix gives constant capacity loss. In figure 5.17 simulation of different size of cyclic prefix with theoretical curve has been implemented under urban area, and when it says urban area that means its highly fading channel with high tree density and more path loss , it’s clear in this figure that the channel delay is more than the values of cyclic prefix, and that’s why the curves unstable and straight which make the signals less robust against ISI, The wisdom is to choose cyclic prefix to be roughly as the same length of channel delay spread, The length of the cyclic prefix must be at least equal to the length of the multipath channel.

5.6 Case 5: WiMax simulation with different values of the nominal BW of the system

In electronic communication, bandwidth is the width of the range (or band) of frequencies that an electronic signal uses on a given transmission medium. In this usage, bandwidth is expressed in terms of the difference between the highest-frequency signal component and the lowest-frequency signal component. Since the frequency of a signal is measured in hertz (the number of cycles of change per second), a given bandwidth is the difference in hertz between the highest frequency the signal uses and the lowest frequency it uses. Simulation parameters for this case illustrated in the table 5.8.

Parameter	Values
Number of Subcarriers	256
Gard band	55
Number of pilot subcarriers	8
Number of Used Subcarrier, Nused	192
Length of CP for CP-OFDM	1/16
Channel Estimation Scheme	Optimal
Channel models	AWGN, SUI2, SUI5, SUI6
Doppler frequency shift	Maximum
Modulation	BPSK, QPSK
Signal Bandwidth	1.25, 2.5, 10, 15, 20, 28MHz

Table 5.9: Parameters to simulate Different Channel Bandwidth In IEEE 802.16-2004 OFDM PHY

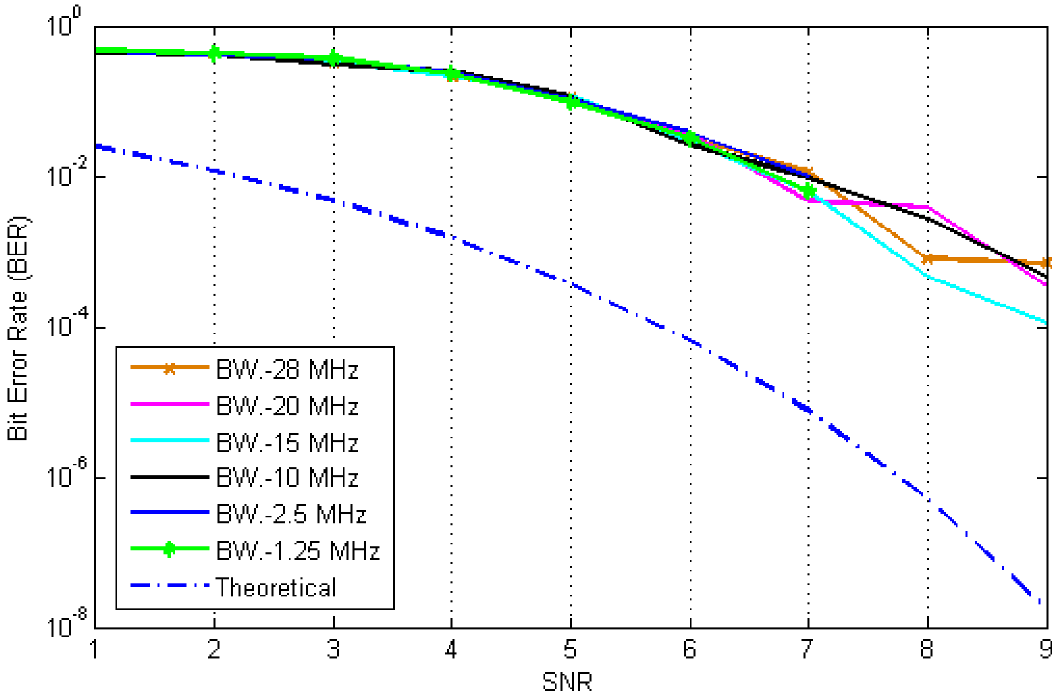


Figure 5.18: BER of received symbols under AWGN channel Condition

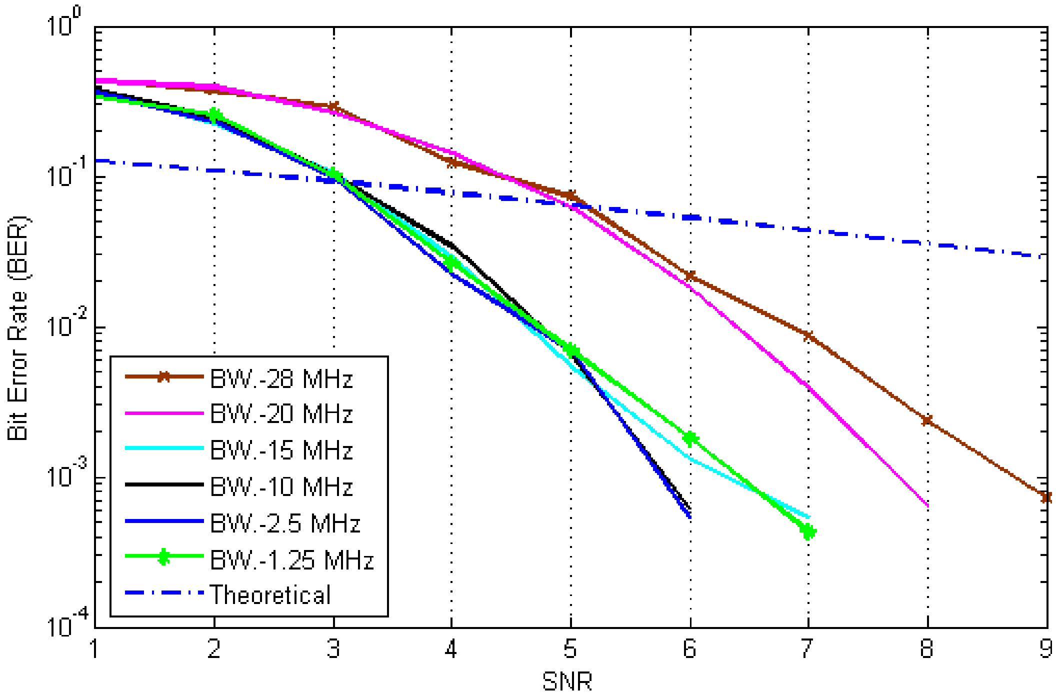


Figure 5.19: BER of received symbols under rural channel Condition

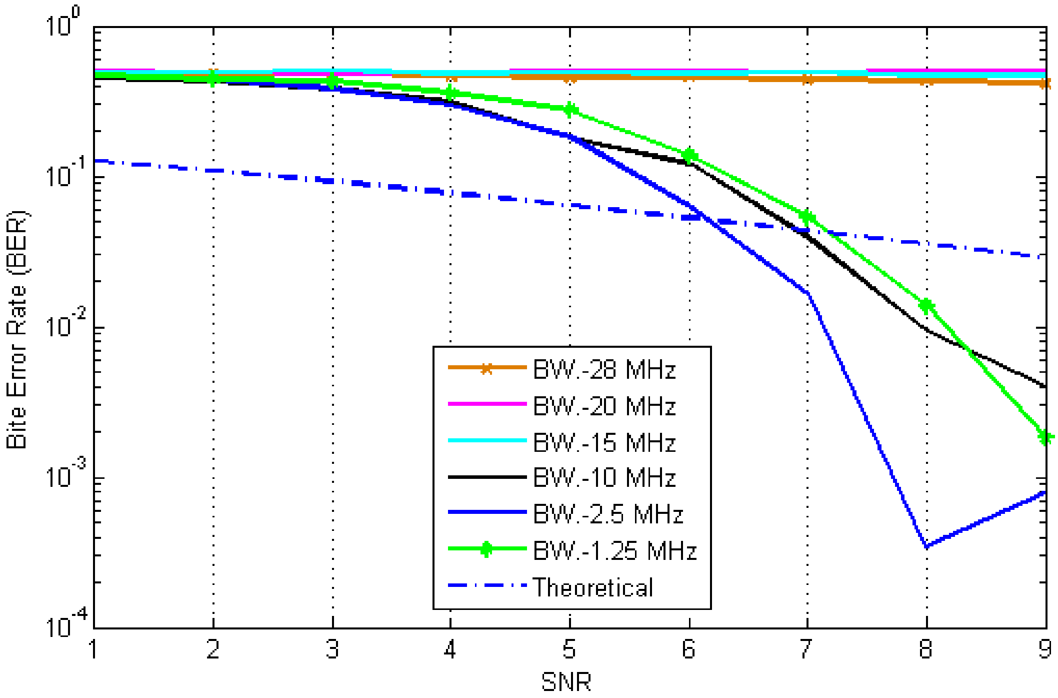


Figure 5.20: BER of received symbols under urban channel Condition

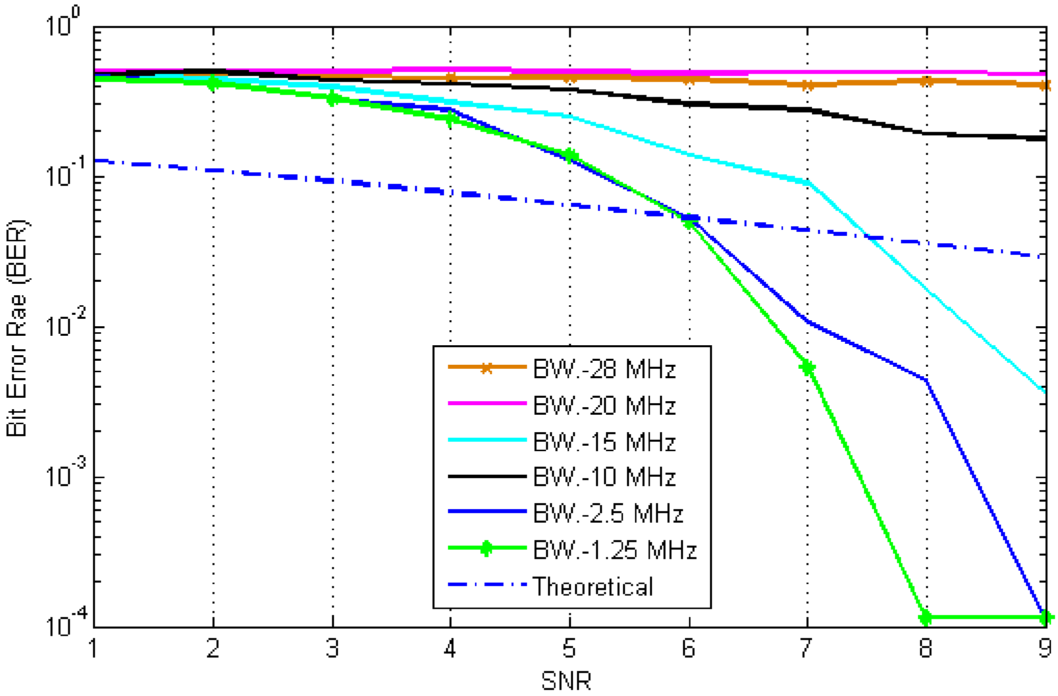


Figure 5.21: BER of received symbols under rural channel Condition with high tree density

5.6.1 BER Figures Analysis

The study of BW aspect of system is found necessary since most of new generation communication and telecommunication systems are exploiting a supple BW in their over air interference. Figure 5.18 illustrates BER result for different bandwidth signals which is varied by using property of AWGN channel in MATLAB coding technique, this figure shows that there is no more different in BER plot and the performance does not change because of the lack of multipath propagation which is the feature of AWGN channel leads to not much variation in signals performance between different signals bandwidth but there is slight degradation exist in performance under Rural area which consider as flat area with light tree density as it illustrated in figure 5.19.

Finally, the effect of bandwidth under highly fading channel condition SUI5 and SUI6 has been illustrated in figure 5.20 and 5.21 illustrate the performance of different channel bandwidth in urban hilly terrain aria with moderate to high tree density, it can be seen that increase in signal bandwidth causes extra degradation of signal quality. This is due to significant increase of fading effects of channel with raising signal bandwidth. Because further the difference between signal bandwidth and channel coherence bandwidth deeper the fading of channel on the signal. When larger bandwidths are used, the subcarrier spacing increases, and the symbol time decreases. Decreasing symbol time implies that a larger fraction needs to be allocated as guard time to overcome delay spread. It is known that the higher the communication bandwidth the more challenging the system design would be. Based on this fact, any broadband wireless system design should have a precise study of channel circumstances related to that system so it can override potential problems facing system in reality.

5.7 Case 6: Realize the simulation WITH and WITHOUT encoding of the bits and study the difference

Channel coding is the application of forward error correction codes to an RF channel to improve performance and throughput; Channel coding protects digital data from errors by selectively introducing redundancies in the transmitted data. Channel codes that are used to detect errors are called error detection codes, while codes that can detect and correct errors are called error correction codes.

The basic purpose of error detection and error correction technologies is to introduce redundancies in the data to improve wireless like performance. The introduction of redundant bits increases the raw data rate used in the link, and this would increase the bandwidth requirements for fixed source data rate. This reduces the bandwidth efficiency of the link in high SNR conditions, but provides excellent BER performance at low SNR values. A channel coder operates on digital message (Source) data by encoding the source information into a code sequence for transmission through the channel.

In this case, explanatory study and implementation test of the performance of IEEE802.16 with and without encoding have been done and plotted BER vs. SNR for each case separately.

5.7.1 Adaptive Modulation and Coding

The specified modulation schemes in the downlink (DL) and uplink (UL) are binary phase shift keying (BPSK), quaternary PSK (QPSK), 16QAM and 64QAM to modulate bits to the complex constellation points. The FEC options are paired with the modulation schemes to form burst profiles. The PHY specifies seven combinations of modulation and coding rate, which can be allocated selectively to each subscriber, in both UL and DL [59]. There are tradeoffs between data rate and robustness, depending on the propagation conditions. Table 5.10 shows the combination of those modulation and coding rate.

Modulation	Uncoded Block Size (bytes)	Coded Block Size (bytes)	Overall coding rate	RS code	CC code rate
BPSK	12	24	1/2	(12,12,0)	1/2
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16QAM	48	96	1/2	(64,48,8)	2/3
16QAM	72	96	3/4	(80,72,4)	5/6
64QAM	96	144	2/3	(108,96,6)	3/4
64QAM	108	144	3/4	(120,108,6)	5/6

Table 5.10: Mandatory channel coding rates

Simulation parameters for this case illustrated in the table 5.11 below:

Parameter	Values
Number of Subcarriers	256
Gard band	55
Number of pilot subcarriers	8
Number of Used Subcarrier, Nused	192
Length of CP for CP-OFDM	1/16, 1/4 , 1/8
Channel Estimation Scheme	Optimal
Channel models	SUI1, SUI3, SUI4, SUI6
Doppler frequency shift	Maximum
Modulation	16QAM, QPSK
Signal Bandwidth	1.25, 24, 1.75, 3.5 MHz
Overall coding rate	3/4with 16QAM and QPSK

Table 5.11: Shows Parameters to Simulate Different Channels with and without encoding In IEEE 802.16-2004 OFDM PHY

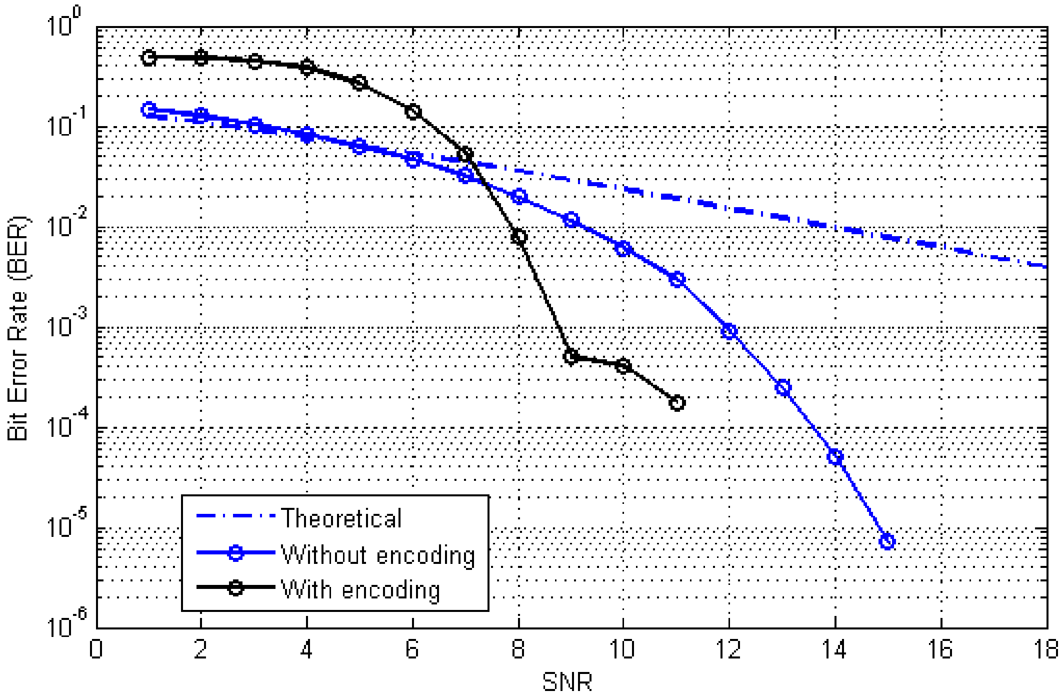


Figure 5.22: Shows the effect of Encoding in Rural area

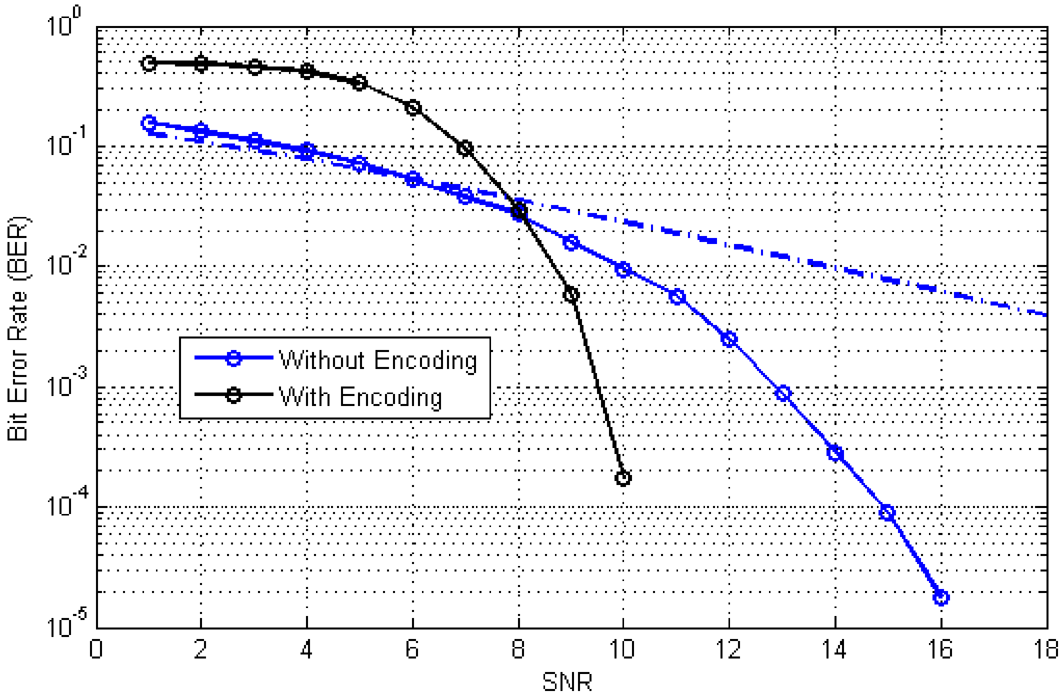


Figure 5.23: shows the effect of Encoding in the intermediate path loss model semi-urban area(SUI3)

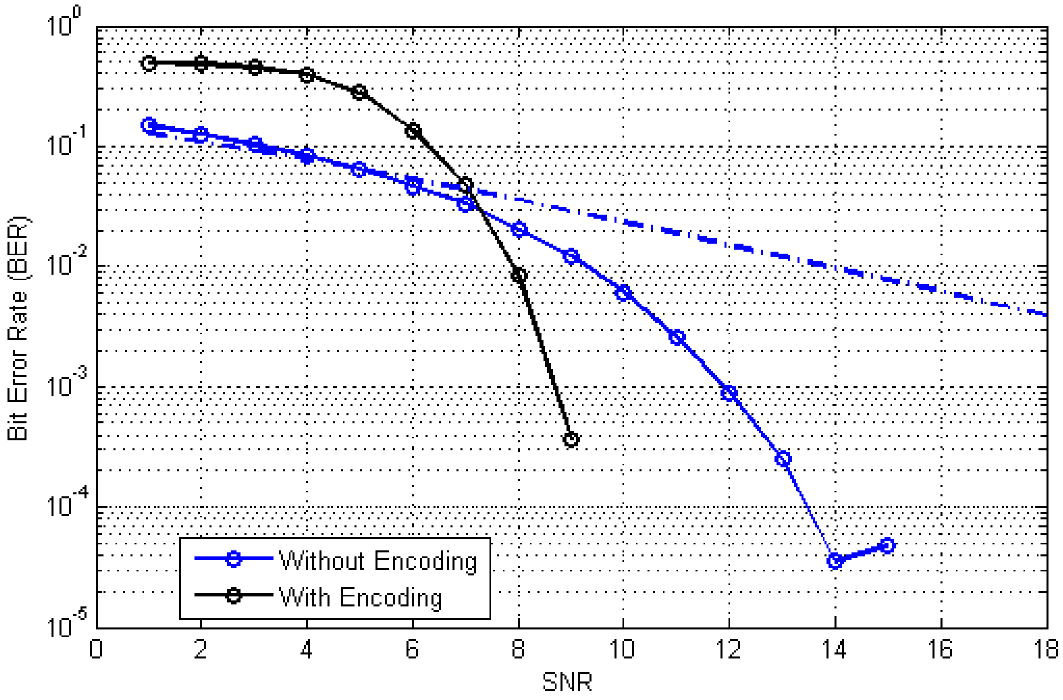


Figure 5.24: Shows the effect of Encoding in the intermediate path loss model with high tree density (SUI4)

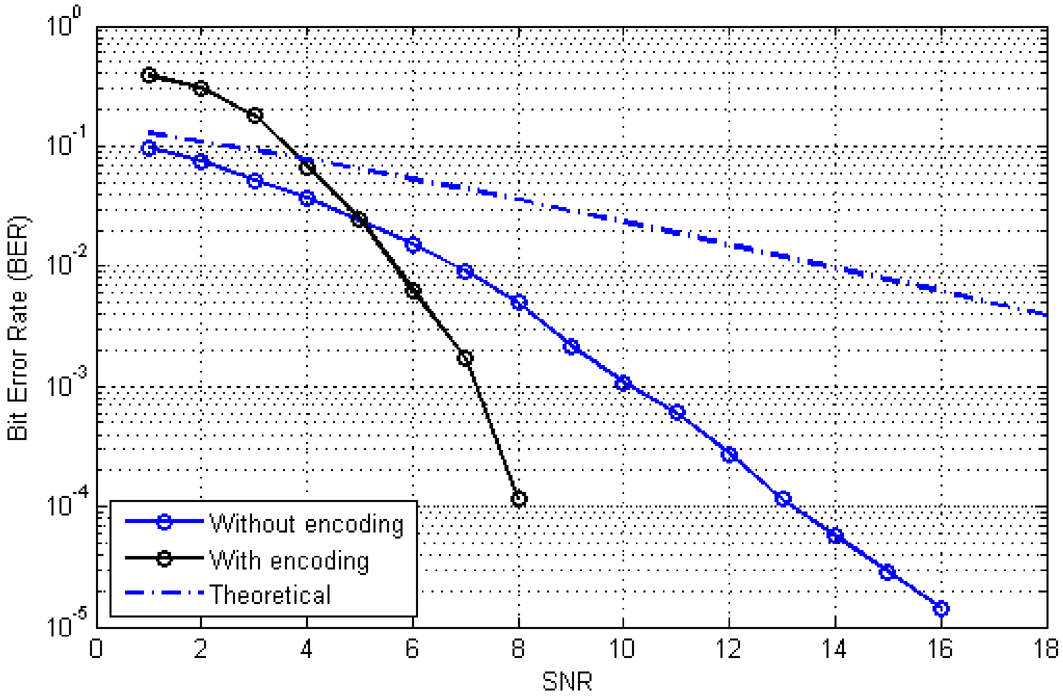


Figure 5.25: Shows the effect of Encoding in Urban areas

5.7.2 BER Figures Analysis

Measuring the bit error ratio helps people choose the appropriate forward error correction codes. In this part various BER vs. SNR plots have been presented for the entire mandatory modulation and coding profiles as specified in the standard on same channel models. This case, Realizes the simulation With and Without encoding of the bits to test the effect of encoding on received signals, simulation has been done with different terrestrials condition for Rural area with low tree density then with semi-Urban area with moderated tree density and finally for Urban area with highly foliage density, different channel bandwidth has been used during this transmission and with two modulation types 16QAM and QPSK , at the end, theoretical result has been plotted to be compare with the simulated one.

In Figure 5.22 shows the effect of Encoding in Rural area, it seem that the using of encoding reduce the BER in the transmitted signal, and it’s more robust against noise in low fading channels. Figure 5.23 obviously illustrates the effect of encoding in the intermediate path loss model (SUI3) makes the signal more reliable and contain less attenuation even with high channel bandwidth 24 MHz which used.

Signal simulation with and without encoding in figure 5.24 for semi-urban area SUI4 with 1.75 MHz communication channel bandwidth and with 16 QAM modulation type with ¾ coding rate has been implemented, it has been concluded that coding make the channel stronger against error but in the same time needs more channel bandwidth and that reduce bandwidth efficiency of link in high SNR conditions but provides excellent BER performance at low SNR values, and it can be easily seen the signal without encoding is unstable against fading and contains more attenuations.

Finally, system response has been plotted in highly fading channel with highly tree density, as it seen in figure 5.25, 1/8 cyclic prefix length has been used, with QPSK for this modulation, the result is quiet satisfactory and it meet the needs for low BER for received data. It can be seen from this figures that the lower modulation and coding scheme provides better performance with less SNR.

Chapter: 6 Conclusion and future work

6.0 Conclusion

SUI Channel Model serial was proposed to simulate the fixed broadband wireless applications where IEEE802.16d is to be deployed. This channel model serial embraces six channel models that are grouped into three categories according to three typical diverse outdoor terrains in order to give a comprehensive effect of fading channels on the overall performance of the system. WiMax supports NLOS environment with high data rate transmission as well. The aims of this thesis are to model and simulate the fixed OFDM IEEE 802.16d physical layer under variant combinations of digital modulation with diverse Combination of channels.

The key contribution was the implementation of the IEEE 802.16 OFDM PHY layer using MATLAB coding in order to evaluate the PHY layer performance under variant fading channel model, and then study the affect of high fading channel in overall performance of the system. The implemented PHY layer supports all mandatory features like modulation and some coding schemes as well have been explained, the length of CP as it defined in the specification. As it known, WiMax system support flexible channel bandwidth, they have been simulated and plotted the BER vs. SNR. One of the optional features of 802.16 is transmitter and receiver diversity, Space Time Block Code (STBC) is employed in DL to provide transmit diversity. MIMO channel also has been implemented and the throughput of the system has been calculated. As it known, wireless channels key problem is fading, in order to combat this fading and improve the capacity and the throughput of the system, multiple antennas at both ends of the communication link are used, The degree of diversity is defined as the performance improvement in BER However, simulating with a 1 x 2 or a 2 x 1 system, which have diversity order of two, better performance is achieved. Equally, the degree of diversity achieved with the 2 x 2 system is of order four. Therefore, it can be concluded that the degree of diversity is equal to $N_T N_R$, being N_T and N_R the number of transmit and receive antennas, respectively.

In addition, it is shown that although both 1 x 2 and 2 x 1 achieve the same degree of diversity, the system that uses multiple antennas at the receiver offers a significant improvement of 3 dB of gain in the channel SNR. That was the conclution in case1of simulation chapter, case two was about modified Stanford University Interim (SUI) Channel Models as they recommended for fixed wireless applications, they have been modified to account for 30^o directional antennas with 90% cell coverage with 99.9% reliability of signal inside its geographical area, The maximum path loss category is hilly terrain with moderate-to-heavy tree densities (Category A). The minimum path loss category is mostly flat terrain with light tree densities (Category C). Intermediate path loss condition is captured in Category B. By using directional antenna 30^o at transmitter side, some of transmitted power have been saved, instead of spreading the signal in all directions as it happens in Omni antenna, Directional antenna focus the beamform on specific geographical area inside the cell, and achieves power utilization.

In case three, it has been concluded that the lower modulation and coding scheme provides better performance with less SNR. This can be easily visualized by looking at their constellation mapping; larger distance between adjacent points can tolerate larger noise (which makes the point shift from the original place) at the cost of coding rate.

Case four, concludes, the wisdom is to choose cyclic prefix to be roughly as the same length of channel delay spread, the length of the cyclic prefix must be at least equal to the length of the multipath channel.

The study of BW aspect of system is found necessary in case five since most of new generation communication and telecommunication systems are exploiting a supple BW in their over air interference, it can be seen that increase in signal bandwidth causes extra degradation of signal quality. This is due to significant increase of fading effects of channel with raising signal bandwidth. Because further the difference between signal bandwidth and channel coherence bandwidth deeper the fading of channel on the signal. It is known that the higher the communication bandwidth the more challenging the system design would be.

Last case (case six) was about realizing the simulation with and without encoding of the bits, it has been found out that coding make the channel stronger against error but in the same time needs more channel bandwidth and that reduce bandwidth efficiency of link in high SNR conditions but provides excellent BER performance at low SNR values.

Measuring the bit error ratio helps people choose the appropriate forward error correction codes, to keep matters simple; perfect channel estimation have assumed to avoid the effect of any particular estimation method on the simulation results.

6.1 Future Work

The developed simulator in this thesis can be easily modified to implement new features in order to enhance the PHY layer performance. This is based on the fact that the implemented PHY layer model still needs some improvement. Also, the channel estimator can be implemented to obtain a depiction of the channel state to combat the effects of the fading channel using an equalizer or by using channel estimation algorithms if channel estimation algorithm has been selected properly, combing preamble and pilot can improve the performance, Since preamble is only sent at the beginning of each frame, it can foresee channel estimation with preamble only must be poor, when the coherent time of channel is small. It

Concluded that channel estimation with pilot only is poor when the coherent bandwidth of channel is narrow. Therefore, to improve the channel estimation performance, Advantage must be taken of preamble and pilots to realize it.

In fact, the IEEE 802.16 standard comes with many optional PHY layer features, which can be implemented to further improve the performance. The optional Block Turbo Coding (BTC) and the Convolutional Turbo Coding (CTC) can be implemented to enhance the performance of FEC.

Finally, the SUI channels are envisaged to be modified in order to carry out the evaluation of the mobile WiMax which is known as IEEE 802.16e. That in return shall gives SUI channels more flexibility to be established on mobile radio channels.

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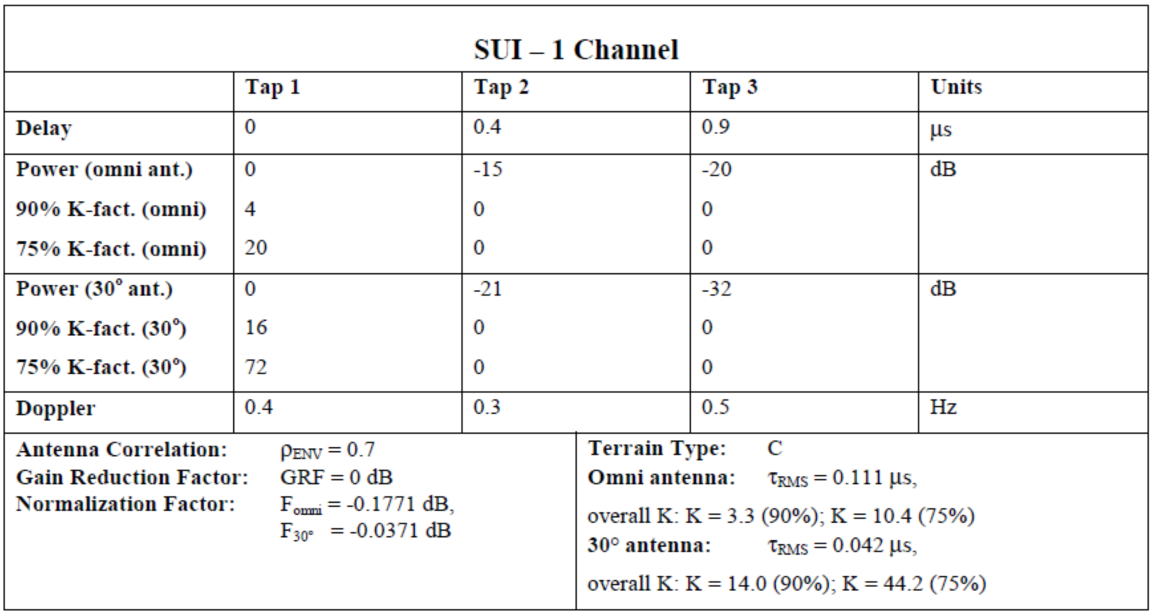
Appendix A:

Modified Stanford University Interim (SUI) Channel Models

It is obvious that there are many possible combinations of parameters to obtain such channel descriptions. A set of 6 typical channels was selected for the three terrain types that are typical of the continental US. In this case SUI channel models have been presented, that modified to account for 30^o directional antennas. These models can be used for simulations, design, development and testing of technologies suitable for fixed broadband wireless applications. The parameters were selected based upon statistical models described [57].

The parametric view of the SUI channels is summarized in the following tables.



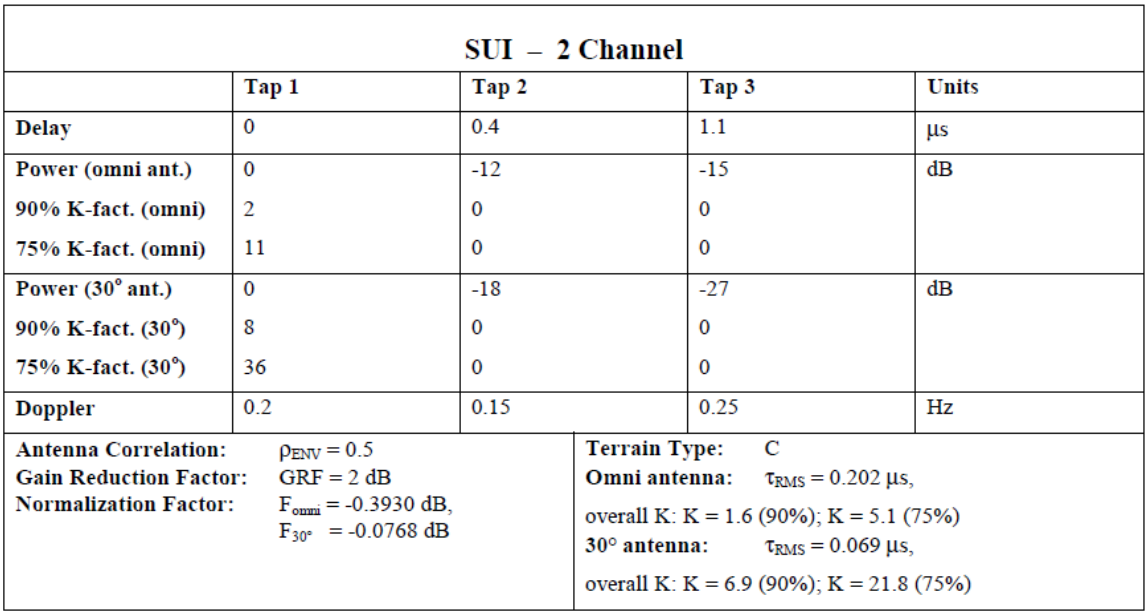
SUI – 1 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	0.4	0.9	µs
Power (omni ant.)	0	-15	-20	dB
90% K-fact. (omni)	4	0	0	
75% K-fact. (omni)	20	0	0	
Power (30° ant.)	0	-21	-32	dB
90% K-fact. (30°)	16	0	0	
75% K-fact. (30°)	72	0	0	
Doppler	0.4	0.3	0.5	Hz

Antenna Correlation: $\rho_{ENV} = 0.7$
Gain Reduction Factor: GRF = 0 dB
Normalization Factor: $F_{omni} = -0.1771$ dB, $F_{30^\circ} = -0.0371$ dB

Terrain Type: C
Omni antenna: $\tau_{RMS} = 0.111$ µs,
overall K: K = 3.3 (90%); K = 10.4 (75%)
30° antenna: $\tau_{RMS} = 0.042$ µs,
overall K: K = 14.0 (90%); K = 44.2 (75%)

Table (A.1): SUI-1 channel model definition



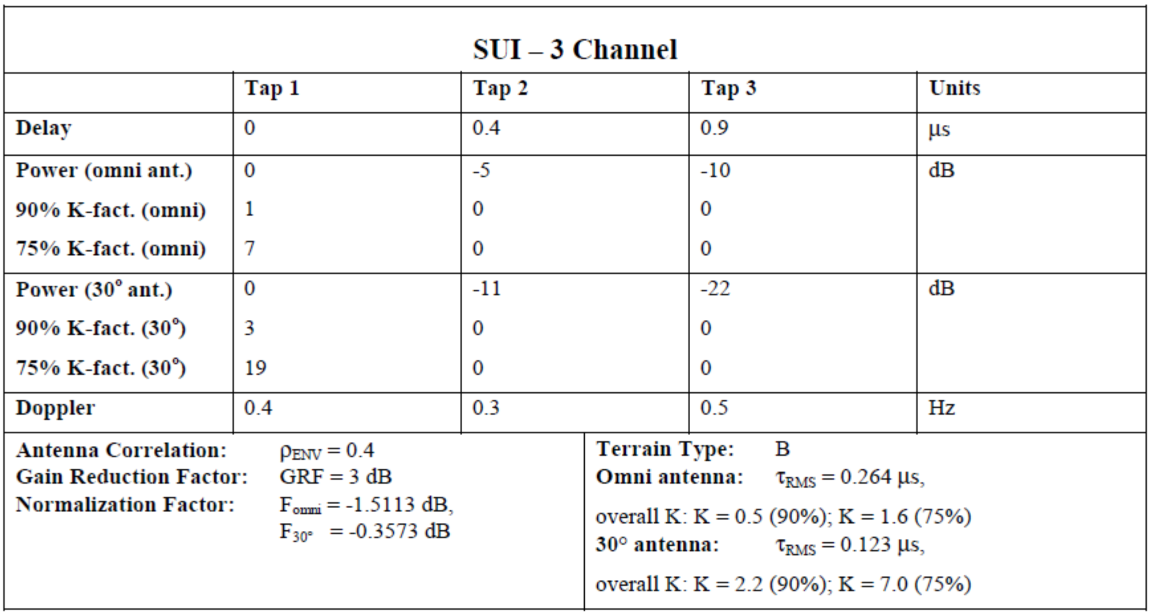
SUI – 2 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	0.4	1.1	µs
Power (omni ant.)	0	-12	-15	dB
90% K-fact. (omni)	2	0	0	
75% K-fact. (omni)	11	0	0	
Power (30° ant.)	0	-18	-27	dB
90% K-fact. (30°)	8	0	0	
75% K-fact. (30°)	36	0	0	
Doppler	0.2	0.15	0.25	Hz

Antenna Correlation: $\rho_{ENV} = 0.5$
Gain Reduction Factor: GRF = 2 dB
Normalization Factor: $F_{omni} = -0.3930$ dB, $F_{30^\circ} = -0.0768$ dB

Terrain Type: C
Omni antenna: $\tau_{RMS} = 0.202$ µs,
overall K: K = 1.6 (90%); K = 5.1 (75%)
30° antenna: $\tau_{RMS} = 0.069$ µs,
overall K: K = 6.9 (90%); K = 21.8 (75%)

Table (A.2): SUI-2 channel model definition



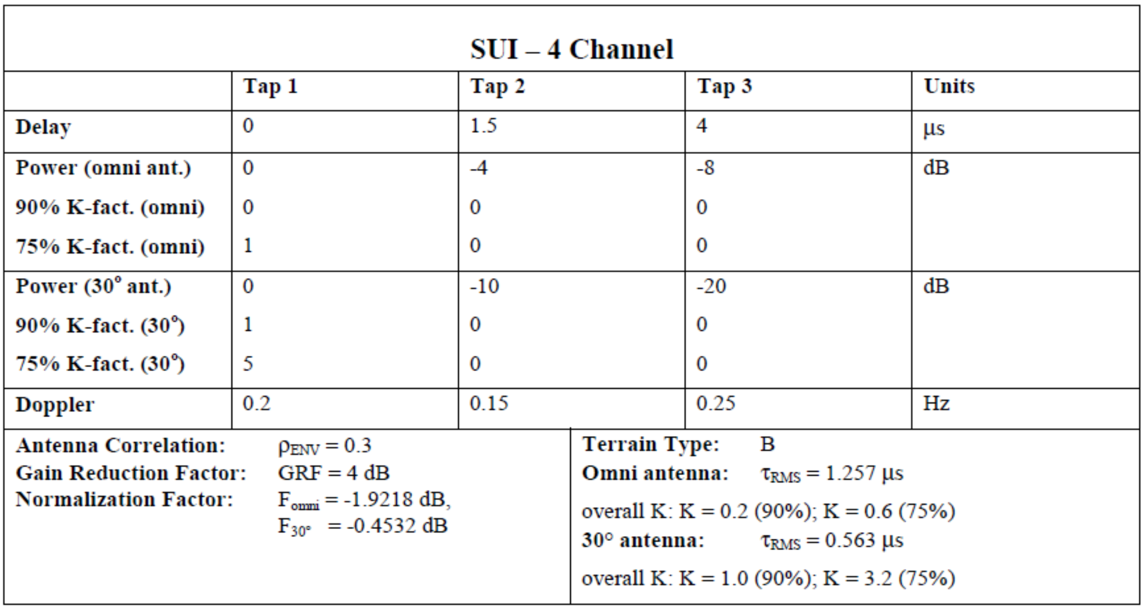
SUI – 3 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	0.4	0.9	µs
Power (omni ant.)	0	-5	-10	dB
90% K-fact. (omni)	1	0	0	
75% K-fact. (omni)	7	0	0	
Power (30° ant.)	0	-11	-22	dB
90% K-fact. (30°)	3	0	0	
75% K-fact. (30°)	19	0	0	
Doppler	0.4	0.3	0.5	Hz

Antenna Correlation: $\rho_{ENV} = 0.4$
Gain Reduction Factor: GRF = 3 dB
Normalization Factor: $F_{omni} = -1.5113$ dB, $F_{30^\circ} = -0.3573$ dB

Terrain Type: B
Omni antenna: $\tau_{RMS} = 0.264$ µs,
overall K: K = 0.5 (90%); K = 1.6 (75%)
30° antenna: $\tau_{RMS} = 0.123$ µs,
overall K: K = 2.2 (90%); K = 7.0 (75%)

Table (A.3): SUI-3 channel model definition



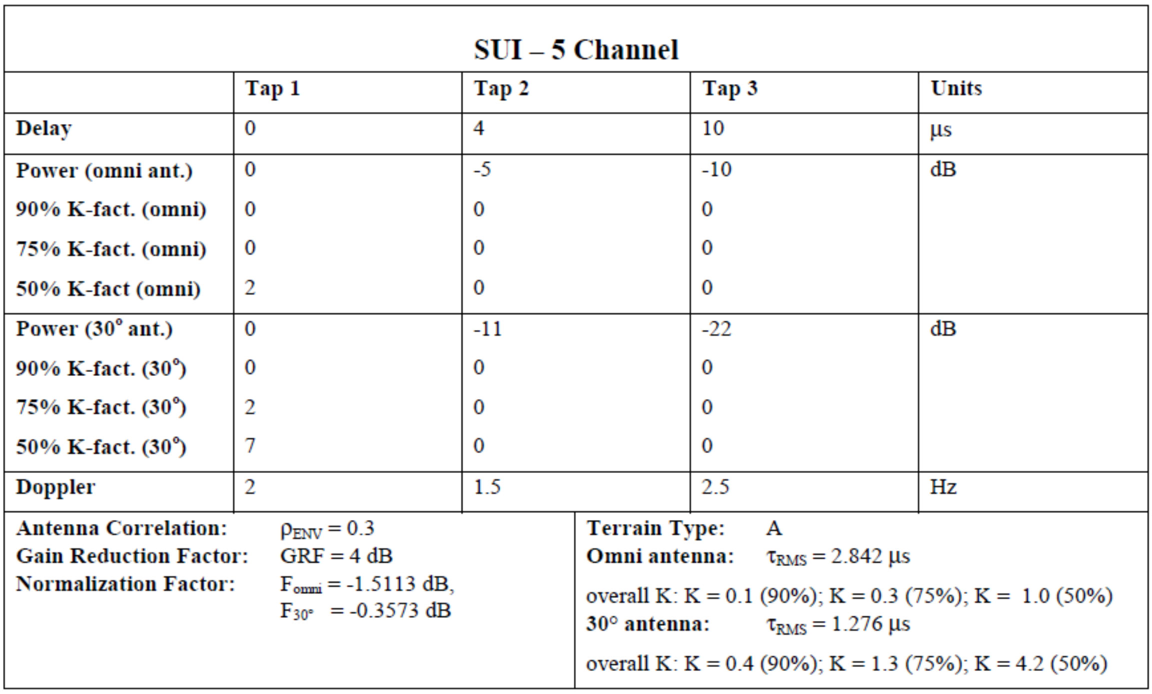
SUI – 4 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	1.5	4	µs
Power (omni ant.)	0	-4	-8	dB
90% K-fact. (omni)	0	0	0	
75% K-fact. (omni)	1	0	0	
Power (30° ant.)	0	-10	-20	dB
90% K-fact. (30°)	1	0	0	
75% K-fact. (30°)	5	0	0	
Doppler	0.2	0.15	0.25	Hz

Antenna Correlation: $\rho_{ENV} = 0.3$
Gain Reduction Factor: GRF = 4 dB
Normalization Factor: $F_{omni} = -1.9218$ dB,
$F_{30°} = -0.4532$ dB

Terrain Type: B
Omni antenna: $\tau_{RMS} = 1.257$ µs
overall K: K = 0.2 (90%); K = 0.6 (75%)
30° antenna: $\tau_{RMS} = 0.563$ µs
overall K: K = 1.0 (90%); K = 3.2 (75%)

Table (A.4): SUI-4 channel model definition



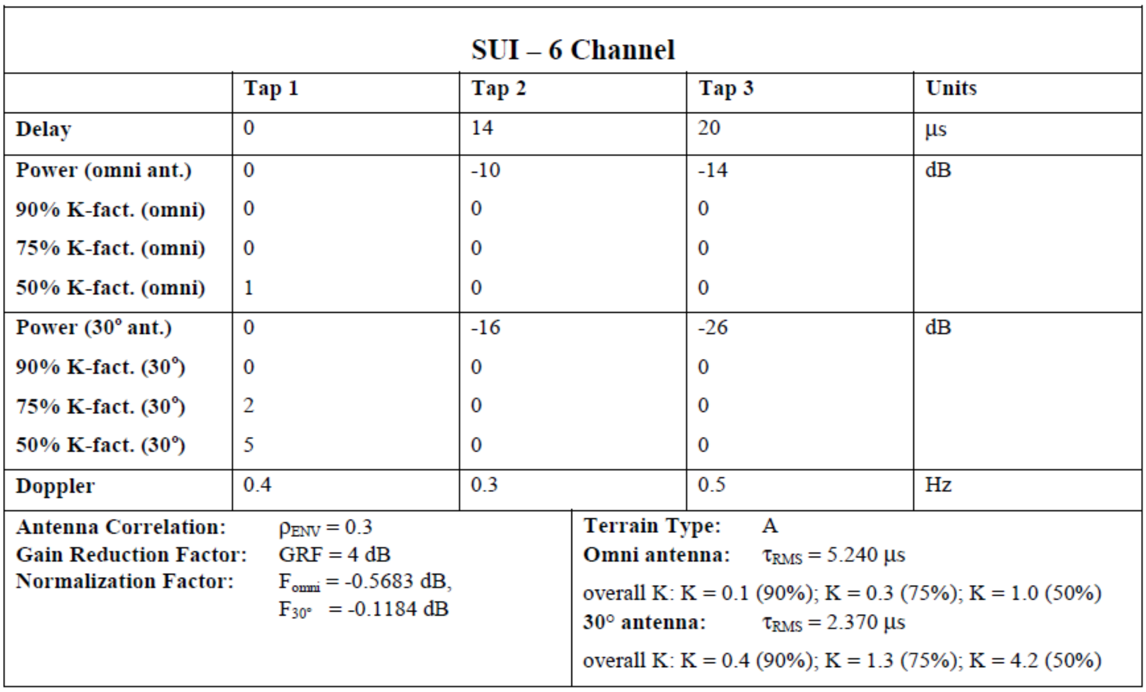
SUI – 5 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	4	10	µs
Power (omni ant.)	0	-5	-10	dB
90% K-fact. (omni)	0	0	0	
75% K-fact. (omni)	0	0	0	
50% K-fact (omni)	2	0	0	
Power (30° ant.)	0	-11	-22	dB
90% K-fact. (30°)	0	0	0	
75% K-fact. (30°)	2	0	0	
50% K-fact. (30°)	7	0	0	
Doppler	2	1.5	2.5	Hz

Antenna Correlation: $\rho_{ENV} = 0.3$
Gain Reduction Factor: GRF = 4 dB
Normalization Factor: $F_{omni} = -1.5113$ dB,
$F_{30°} = -0.3573$ dB

Terrain Type: A
Omni antenna: $\tau_{RMS} = 2.842$ µs
overall K: K = 0.1 (90%); K = 0.3 (75%); K = 1.0 (50%)
30° antenna: $\tau_{RMS} = 1.276$ µs
overall K: K = 0.4 (90%); K = 1.3 (75%); K = 4.2 (50%)

Table (A.5): SUI-5 channel model definition



SUI – 6 Channel

	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	0	14	20	µs
Power (omni ant.)	0	-10	-14	dB
90% K-fact. (omni)	0	0	0	
75% K-fact. (omni)	0	0	0	
50% K-fact. (omni)	1	0	0	
Power (30° ant.)	0	-16	-26	dB
90% K-fact. (30°)	0	0	0	
75% K-fact. (30°)	2	0	0	
50% K-fact. (30°)	5	0	0	
Doppler	0.4	0.3	0.5	Hz

Antenna Correlation: $\rho_{ENV} = 0.3$
Gain Reduction Factor: GRF = 4 dB
Normalization Factor: $F_{omni} = -0.5683$ dB,
$F_{30°} = -0.1184$ dB

Terrain Type: A
Omni antenna: $\tau_{RMS} = 5.240$ µs
overall K: K = 0.1 (90%); K = 0.3 (75%); K = 1.0 (50%)
30° antenna: $\tau_{RMS} = 2.370$ µs
overall K: K = 0.4 (90%); K = 1.3 (75%); K = 4.2 (50%)

Table (A.6): SUI-6 channel model definition

Appendix B:

IEEE® 802.16-2004 OFDM PHY Link, Including Space-Time Block Coding

Appendix B describes how to represents an end-to-end baseband model of the physical layer of a wireless metropolitan area network (WMAN) according to the IEEE® 802.16-2004 standard [60]. More specifically, it models the OFDM-based physical layer called Wireless MAN-OFDM, supporting all of the mandatory coding and modulation options. It also illustrates Space-Time Block Coding (STBC), an optional transmit diversity scheme specified for use on the downlink.

Structure of the system

This structure showcases the main components of the WMAN 802.16-2004 OFDM physical layer using model with STBC, which has all the mandatory coding and modulation options.

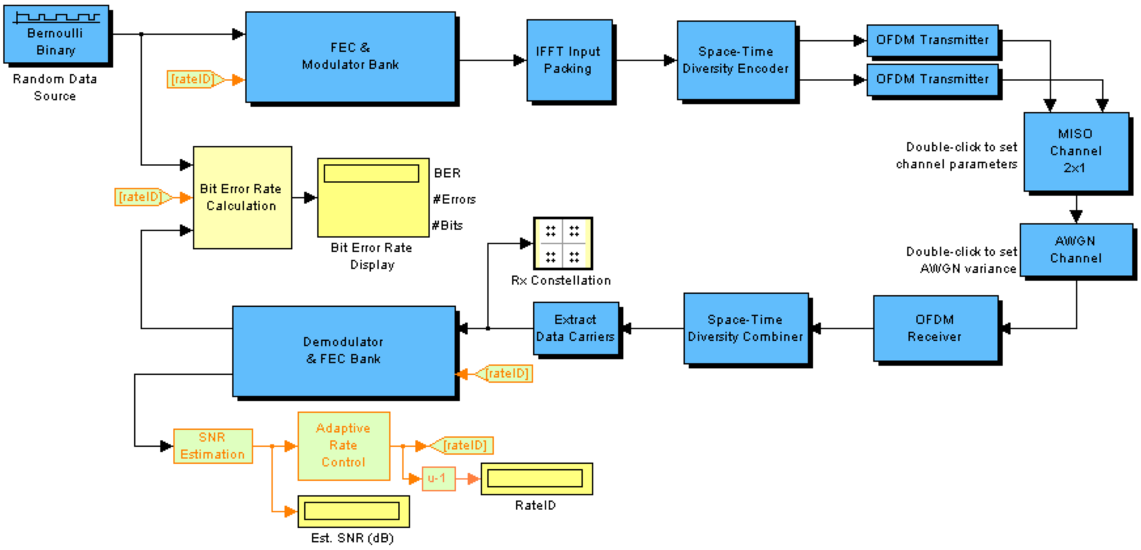


Figure (B.1): IEEE 802.16-2004 OFDM PHY link, Including Space-Time Block Coding [61]

The tasks performed in the communication system models include:

- Generation of random bit data that models a downlink burst consisting of an integer number of OFDM symbols.
- Forward Error Correction (FEC), consisting of a Reed-Solomon (RS) outer code concatenated with a rate-compatible inner convolutional code (CC).
- Data interleaving.
- Modulation, using one of the BPSK, QPSK, 16-QAM or 64-QAM constellations specified.
- Orthogonal Frequency Division Multiplexed (OFDM) transmission using 192 sub-carriers, 8 pilots, 256-point FFTs, and a variable cyclic prefix length.
- Space-Time Block Coding using Alamouti's [53] scheme. This is implemented using the OSTBC Encoder and Combiner blocks in Communications Blockset.
- A single OFDM symbol length preamble that is used as the burst preamble. For the optional STBC model, the single symbol preamble is transmitted from both antennas.
- A Multiple-Input-Single-Output (MISO) fading channel with AWGN for the STBC model. A choice of non-fading, flat-fading or dispersive multipath fading channel for the non-STBC model.
- OFDM receiver that includes channel estimation using the inserted preambles. For the STBC model, this implies diversity combining as per[53].
- Hard-decision demodulation followed by deinterleaving, Viterbi decoding, and Reed-Solomon decoding.

This model also use an adaptive-rate control scheme based on SNR estimates at the receiver to vary the data rate dynamically based on the channel conditions.

The STBC link model uses a MISO fading channel to model a two transmitter, one receiver (2x1) system. The fading parameters specified are assumed to be identical for the two links. The Space-Time Diversity Combiner block uses the channel estimates for each link and combines the received signals as per [53]. The combining involves simple linear processing using the orthogonal signalling employed by the encoder.

Furthermore, the models include blocks for measuring and displaying the bit error rate after FEC, the channel SNR and the rate_ID. A scatter plot scope is used to display the received signal, which helps users visualize channel impairments and modulation adaptation as the simulation runs.

The Model Parameters configuration block allows you to choose and specify system parameters such as channel bandwidth, number of OFDM symbols per burst and the cyclic prefix factor. Varying these parameter values allows you to experiment with the different WiMax profiles as defined by the WiMax Forum [62], and gauge the system performance for each. Another area of variability includes the channel blocks in the model. The model allow you to vary the fading parameters [63] and the AWGN variance (in SNR mode) added to the signal. As a result, you can examine how well the receiver performs with different fade characteristics and generate BER curves for varying SNR values.

List of Research Papers

(1) S. Askar, S. Memon, H. Al-Rewashidy,, “Impact of Implementing Different fading channels on Wireless MAN Fixed IEEE802.16d OFDM system with Diversity Transmission Technique”, Accepted in Bahria University Journal of Information and Communication Technology, (BUJICT), Volume-III, 2010

(2) S. Askar, S. Memon, H. Al-Rewashidy, “Fading Channels for Fixed IEEE802.16 WiMAX System” 3rd SED Research Student Conference (RESCON-10) Brunel University, London