



Performance Analysis of Diversity Techniques for Wireless Communication System

Md. Jaherul Islam

mzissv@gmail.com

This Thesis is a part (30 ECTS) of Master of Science degree (120 ECTS) in Electrical Engineering emphasis on Telecommunication

Blekinge Institute of Technology

February 12

Blekinge Institute of Technology
School of Engineering
Department of Telecommunication
Supervisor: Magnus G Nilsson
Examiner: Magnus G Nilsson
Contact: magnus.g.nilsson@bth.se

Abstract

Different diversity techniques such as Maximal-Ratio Combining (MRC), Equal-Gain Combining (EGC) and Selection Combining (SC) are described and analyzed. Two branches ($N=2$) diversity systems that are used for pre-detection combining have been investigated and computed. The statistics of carrier to noise ratio (CNR) and carrier to interference ratio (CIR) without diversity assuming Rayleigh fading model have been examined and then measured for diversity systems. The probability of error (p_e) vs CNR and (p_e) versus CIR have also been obtained. The fading dynamic range of the instantaneous CNR and CIR is reduced remarkably when diversity systems are used [1]. For a certain average probability of error, a higher valued average CNR and CIR is in need for non-diversity systems [1]. But a smaller valued of CNR and CIR are compared to diversity systems. The overall conclusion is that maximal-ratio combining (MRC) achieves the best performance improvement compared to other combining methods. Diversity techniques are very useful to improve the performance of high speed wireless channel to transmit data and information. The problems which considered in this thesis are not new but I have tried to organize, prove and analyze in new ways.

ACKNOWLEDGEMENT

I am grateful to my thesis supervisor, Dr. Magnus Nilsson for his sincere help. The way he encouraged me to finish this thesis, was really great. It was impossible to finish this thesis without his support.

Md. Jaherul Islam

Contents

<u>Abstract</u>	2
<u>Acknowledgement</u>	3
<u>Chapter 1 Introduction</u>	
1.1 Background	9
1.2 Outline of Thesis	9
<u>Chapter 2 Overview of Wireless Communications</u>	
2.1 Some Latest Contributions of Wireless Communication	10
2.1.1 First Generation Technology	11
2.1.2 Second Generation Technology	12
2.1.3 Second-plus Generation Technology	14
2.1.4 Third Generation Technology	14
2.1.5 Fourth Generation Technology	16
2.2 Comparison of Data Services for Different Generation Networks	16
2.3 Multiple Access Formats for Wireless Communications	
2.3.1 Frequency Division Multiple Accesses (FDMA)	19
2.3.2 Time Division Multiple Access (TDMA)	19
2.3.3 Code Division Multiple Access (CDMA)	20
<u>Chapter 3 Performance Degradation Factors in Wireless Communication Channels</u>	
3.1 Characteristics of Wireless Communication Channels	22
3.2 Factors Affecting the Wireless Channels	24

3.2.1 Path Loss	25
3.2.2 Shadowing Loss	26
3.2.3 Interference	
3.2.3.1 Inter-symbol Interference (ISI)	27
3.2.3.2 Co-channel Interference (CCI)	28
3.2.4 Noise	29
3.2.5 Channel Spreading	30
3.2.6 Channel Fading	31
3.3 Parameters of Fading Channels	32
3.3.1 Multipath Spread T_m	32
3.3.2 Coherence Bandwidth $(\Delta f)_c$	33
3.3.3 Coherence Time $(\Delta t)_c$	33
3.3.4 Doppler Spread B_d	33
3.3.5 Mean Path Loss (MPL)	34
3.4 Classification of Fading Channels	
3.4.1 Frequency Non-selective vs Frequency Selective Fading	35
3.4.2 Slow Fading versus Fast Fading	35
3.4.3 Large Scale Fading vs Small Scale Fading	36
3.4.4 Ricean Fading vs Rayleigh Fading	37

Chapter 4 Diversity Techniques for Wireless Channel

4.1 Diversity Concept	38
4.2 Diversity Branches	39
4.3 Diversity Techniques	39
4.3.1 Frequency/Multipath Diversity	40
4.3.2 Space/Spatial Diversity	41

4.3.2.1 Receive Diversity	42
4.3.2.2 Transmit Diversity	42
4.3.3 Time/Temporal Diversity	42
4.3.4 Polarization Diversity	44
4.3.5 Angle/Direction/Pattern Diversity	44
4.3.6 Antenna Diversity	45
4.4 Why Transmit Diversity	45
4.5 Types of Transmit Diversity	46
4.6 Capacity of Receive and Transmit Diversity	47

Chapter 5 Diversity Combining Techniques

5.1 Concepts of Diversity Combining Techniques	49
5.2 Maximal-ratio Combining (MRC)	50
5.3 Equal Gain Combining (EGC)	51
5.4 Selection Combining (SC)	52
5.5 Switched Combining	53
5.6 Periodic Switching Method	54
5.7 Phase-sweeping Method	55

Chapter 6 Performance Analysis of Different Diversity Combining Techniques

6.1 Performance of Maximal Ratio Combining	56
6.2 Carrier-to-noise Ratio (CNR) and Carrier-to-interference Ratio (CIR) Performance Improvement	57
6.3 Average Probability of Error (P_e) Performance Improvement	59
6.3.1 (P_e) versus CNR Performance Improvement	59
6.3.2 (P_e) versus CIR Performance Improvement	61

Chapter 7 Methodology and Result

7.1 Computational Method	62
7.2 Performance Analysis	68

Chapter 8 Discussion and Conclusion

8.1 Discussion	69
8.2 Conclusion	70
8.3 Future Feasible Work	70

<u>References</u>	71
--------------------------------	----

Chapter 1

Introduction

1.1 Background:

Communications between creatures is very important in our world. Wired communication and wireless communication are the major types of communications effective in the present world. Some examples of wireless communications are 'Hand held CB (Citizens' Band) radio' and 'cellular phone'. There are two main categories of Wireless communications such as mobile communications and fixed wireless communications. Customer needs and technology requirements, these two play vital role to make their own market in the wireless communications [2]. Mobility or non-tethered communications are required for the mobile communications. Mobility of the mobile communications ensures to communicate anytime and anywhere. Mobile communications technology must be able to allow roaming. Roaming is the ability to provide usability to the mobile phone users while outside their own network. However, fixed wireless is just an alternative to wired communications. The fixed wireless users do not get the mobility facility but they need cost effective communications from their fixed locations. The alternative of wireless in the means of providing service is the only means. When the customers attempt to communicate from the remote locations, Satellite is the only alternative. Wireless communication is a revolution of human communications. The technology to send idea and information to remote location could not even be imagined before wireless communication technology was invented. The wireless communication technology makes that dream true of the human being. Wireless hand held devices such as mini-computers and phones deliver the world to our fingertips whatever our locations are, with enough speed and flexibility. Wireless cellular networks are growing rapidly around the world day by day un-imaginably and it seems this trend will to continue for several years. Over the last few years, the subscribers of wireless communications have an exponential growth. The ongoing progress in radio technology provides more and more new and improved services. Current wireless services include transmission of fax, voice and low-speed data flexibly [1]. Usability of more band width in communications with consuming interactive multimedia services like video-on-demand like TV viewing and internet access for transferring essential data is supported in wireless communications.

1.2 Outline of Thesis:

Diversity techniques are the useful methods to reduce fading problem in wireless communications. The best diversity techniques can be selected by analyzing and comparing the different types of diversity techniques. Moreover, different diversity techniques can be combined and used in wireless communication systems to get the best result to mitigate fading problems.

Description of wireless communications has given in chapter 2. Several performance degradation factors of wireless communication were described in chapter 3. Useful Diversity techniques were described in chapter 4. It's important to combine two or more diversity techniques to get full advantage of diversity techniques. Some diversity combining techniques were described in chapter 5. The mathematical equations needed for simulation in diversity combining techniques were collected and defined in chapter 6. Simulation results in graph and in words and described the performance analysis in chapter 7. Chapter 8 concludes the entire thesis work.

Chapter 2

Overview of Wireless Communications

The basics of wireless communication systems are described in chapter2, based on their services such as speech communication, data transmission, etc. The generations of communication technologies such as 1st generation, 2nd generation, 2nd -plus generation, 3rd generation and 4th generation are described in this chapter. Multiple access formats for wireless communication and their operations are also described briefly at the last section of this chapter.

2.1 Some Latest Contributions of Wireless Communication:

Cellular has standards such as first generation cellular system which is an analogue system, second and third generation digital cellular systems. There is one intermediate technology which is called second generation-plus communications system. It supports high speed data transfer over today's digital cellular systems. Table1 shows the main future of the above technologies. A short discussion and comparison of data services of these technologies are following:

Table1: Main futures of cellular technologies [1][2][3]

First Generation	Second Generation	Second + Generation	Third Generation
Analog transmission	Digital data transmission	Digital data transmission	Digital data transmission
Mainly for talking	Mainly talking	Mainly talking	talking and video
Voice bands data	Digital data	Increasing digital data	Mainly digital data
Circuit switched	Circuit switched	Increasingly packet switched over IP network	Mainly packet switched over IP network
Local systems	Global roaming facility	Global roaming facility	Global roaming facility with full flexibility

2.1.1 First Generation Technologies:

First-generation (1G) mobile communication systems is a basic analog radio communication systems that established the first cellular radio infrastructure. The main problem of 1G mobile communication systems for cellular service providers is that it has less capacity to handle the sheer number of users which demand voice services [3]. Circuit switched connections are used in the analog cellular networks for data transfer. However, the performance of the radio link for data transport is considered marginally because of the limitations creates by the nature of the analog technology. The dynamics of the radio channels like dropouts, fade of signals, and multi-path (multipath can be tolerated during a voice connection), can be disastrous to the subscribers for mobile data transport [11]. Using standard modems with some adaptation can sustain Subscriber data rates of 2400 bits/s or less to the cellular network [3]. Generally, Due to limited available capacities, limitations of data recovery, low security, and the high cost of use for many applications, the analog cellular infrastructure systems are not so efficient of sending data. Some of the widely used standards are discussed as following.

Advanced Mobile Phone System (AMPS):

The AMPS was the first standardize cellular service in the world. It was released in 1983 in the USA for commercial use in the North America. The system uses 824 MHz to 894 MHz frequency band, multiple accesses FDMA, FM modulation and the 30 KHz channel bandwidth [2]. This is the analog cellular standard which most widely used.

Narrow-band Advanced Mobile Phone System (N-AMPS):

This system operates in the same range like AMPS and provides three times greater capacity than AMPS by using 10 KHz channel bandwidth instead while 30 KHz channel bandwidth is used in the AMPS system [2]. Other features are as the same as in AMPS.

Nordic Mobile Telephone (NMT):

This was the system which was widely used throughout the Nordic countries. The system has two types based on the frequency allocation such as NMT-450 and NMT-900. Amongst them NMT-450 operates on 450 to 470 MHz frequency band and 25 KHz channel bandwidth which was introduced in 1981, while NMT-900 operates on 890 to 960 MHz frequency band and 12.5 KHz channel bandwidth which was introduced in 1986 [2].

2.1.2 Second Generation Technologies:

Second-Generation (2G) mobile communication systems are the most common in the wireless communication industries currently. Digital technologies are used in 2G to provide many advantages for both the voice-based and the data-based mobile communication systems. Available facilities in this technology are the increased system capacity, increased security against eavesdropping, superior cell hand-off, and better radio signal recovery under different conditions. In addition, rather than quality speech these technologies support services such as fax, short messaging service (SMS), and roaming for mobile subscribers.

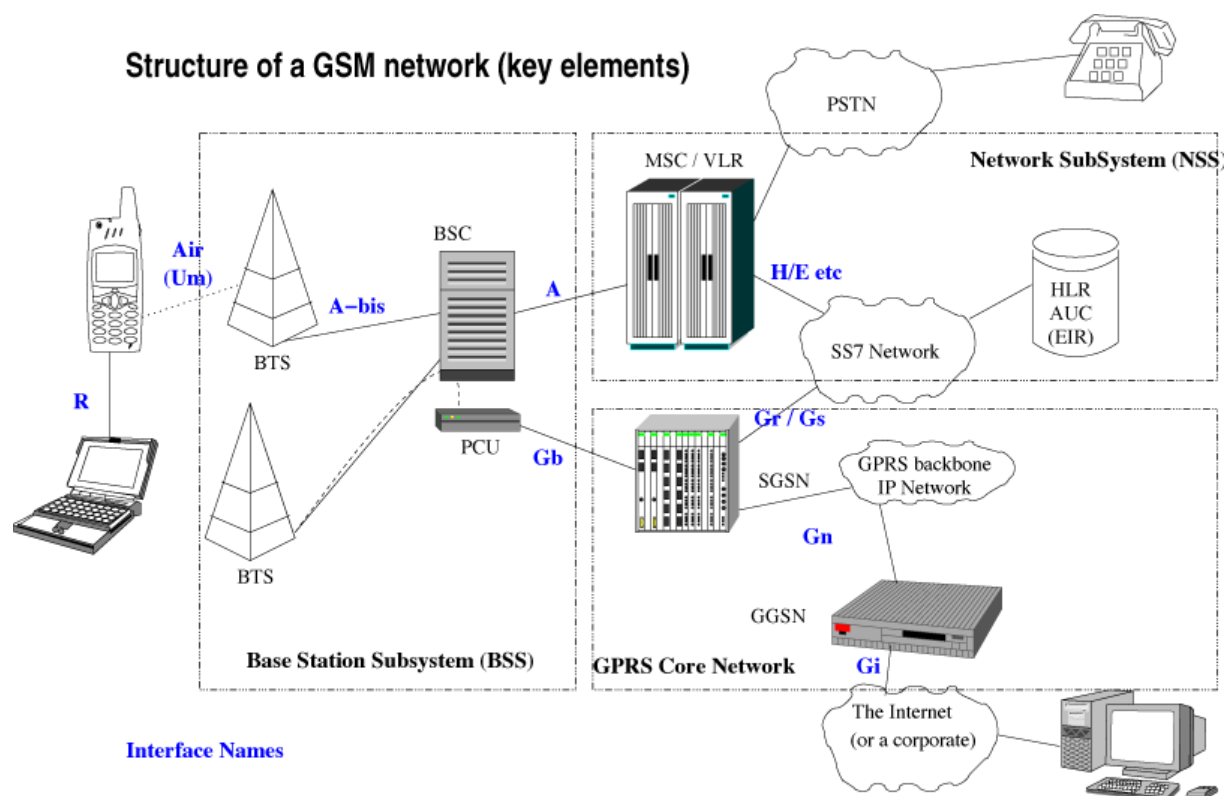
Table2: Technical Summary of Second Generation Technologies [1] [2] [3]

	Europe	USA	
Characteristics	GSM	TDMA	CDMA
Frequency band	890-960 MHz	824-894 MHz	824-894 MHz
Allocated bandwidth	50	50	50
Access scheme	TDMA	TDMA	CDMA
Duplex method	FDD	FDD	TDD
Channel bandwidth	200 KHz	30 KHz	1250 KHz
No. of voice / Frequency Channel	8/16	3/6	
Total traffic channels	1000/2000	2496/4992	
Channel bit rate	270.833 kbps	48.6 kbps	Vendor dependent
Voice coding	22.8 kbps	8/4.5 kbps	8
Data rate	9.6 kbps	9.6 kbps	14.4 kbps

Circuit switched connections are used in the second generation technologies for transporting data and providing data transmission rate in between 9.6 to 14.4 Kbps [11]. These technologies implement a high level flow control and error connection to provide reliable data transfer. With second generation systems, a single cellular channel can be shared by multiple users. This system function reduces congestion and provides access for more users. The multiple access methods to the users provide extensive coverage with a proved and reliable communications infrastructure in 2G. The standards within 2G in use worldwide are the following:

GSM (Global System for Mobile Communications):

This was the first European digital open standard and was commercialized for use in 1992. It was developed intending to establish cellular consistent throughout the Europe. But it was so successful that it was spread to all parts of the world. There were over 250 million subscribers worldwide by the year 2000 [3]. The GSM technology was established based on a combination of TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) techniques. It operates at 900 MHz and 1800 MHz frequency bands in the most parts of Europe and Asia. And the frequency band for this technology is 1900 MHz in North America. It provides an almost error-free internet access at 9600 bps to the subscribers now a day. According to GSM association's 2009 press release around 80% mobile subscribers use GSM technology worldwide [3].



Picture 1: Structure of GSM network [12]

2.1.3 Second-plus Generation Technologies:

The second generation technologies capable to transfer data at the rate of only up to 14.4 Kbps [2]. The high data speeds are needed for video and graphical image transmissions. But this speed is not available on the most mobile phone systems today. Providing such capabilities the technologies are required a highly complex and robust platform that will not be available in most of the countries next few years, according to researchers. An intermediate step to the next generation technologies is second-plus generation or 2.5G technologies. Supporting data transfer rates is 57.6 Kbps or higher in these technologies and offer subscribers access to the internet at speeds that are comparable to a wire-line Integrated Services Digital Network (ISDN) connection or even faster than ISDN sometimes. These technologies include HSCSD (High speed Circuit Switched Data), GPRS (General Packet Radio Services) and EDGE (Enhanced Data Rates for Global Evolution).

2.1.4 Third Generation Technologies:

Two common but effective limitations of the second generation communication networks are low bandwidth and limited network capacity [3]. These two limitations impact negatively to the users' experience and the reliability of the service. To overcome these limitations, it was very important to initiate a new technology. Third generation or 3G technology took foot step to initiate at such a time and it is a new technological revolution that will offer far more bandwidth and greater data and voice call capacity than today's digital mobile networks capable. It is a next big step in wireless communication technology for mobile network development with its goal being full inter-operability and inter-working of mobile communication systems. The 3G will unite the disparate standards those are used in today's second generation wireless networks.

Wired broadband connections and portable bandwidth are the same level with 3G technology and the data transfer rates is up to 2Mbps in fixed applications. But data transfer rate is 128 Kbps in a car and 384 Kbps when a device remains stationary. When the targeted speed is achieved fully, wireless technology will be more attractive to users those are interested in internet browsing, gaming with wireless connection, and listening to music with broadband mobile connection [3]. Voice and text messaging are available with the present mobile networks. On the other hand, 3G networks are allowed us more faster and complex data transmission such as streaming video and audio, satellite navigation, video conferencing and sharing with interactive application. Packet switched data access provided with this kind of networks to the internet end-to-end IP connection. A mobile phone has been connected automatically to the internet when the cell activated. Then subscribers get the similar facilities to today's fixed-line internet connection with significant add-ons such as location-based and highly personalized services. Some of these features already achieved and some are on the road to come to public hands.

3G technologies allow handsets to connect to network permanently and use only available capacity when they receive or transmit packets. Subscribers are expected to pay for the volume of data transfer ignoring the length of talk time.

Although 3G technology seems complicated still this technology makes our life very easy and flexible. Much of those we have already been getting. Much of these facilities we have already been getting with limited conditioning usability. The quality media information and entertainment will be at our fingertips irrespectively location and time. The end user device will not be just a mobile phone but a terminal after achieving all those functionalities with 3G wireless communications.

Standards:

The 3G technology began to standardize in 1990s under the supervision of the International Telecommunication Union (ITU). The goal of 3G was full interoperability and inter-activity of mobile systems providing capability of value-added services. The ITU called for Radio Transmission Technology (RTT) in the year 1998 with proposals for IMT-2000 (International Mobile Communication for the year 2000) [13]. The ITU IMT-2000 standards are currently separated into two major organizations reflecting the two 3G camps: 3GPP (3G partnership project for wideband CDMA standards based on backward compatibility with GSM and IS-136/PDC) and 3GPP2 (3G partnership Project for cdma2000 standards based on backward compatibility with IS-95). The eventual 3G evolution for 2G CDMA systems leads to cdma2000. CDMA 2000 are developed in several research based on IS-95 and IS-95B technologies. The eventual 3G evolution for GSM, IS-136, and PDC system leads to wideband CDMA (W-CDMA) (Wideband Code Division Multiple Access) also called Universal Mobile Communication Service (UMTS). W-CDMA was invented based on the network fundamental of GSM as well as improved version of GSM and IS-136 through EDGE. It is fair to say that these two major 3G technology camps, cdma2000 and W-CDMA, is remain popular throughout the early part of the 21st century. In January 1998, The ETSI incorporated W-CDMA standard in 1998 was also incorporated with terrestrial Radio Access specifications, and W-CDAM and UMTS are used synonymously sometimes [13]. IMT-2000 ensures that these technologies can work in different networks even in the GSM as well as American ANSI networks. Most of the major network operators in Europe and Asia are committed to the W-CDMA standard for 3G mobile communications while other parts of the world implements other standards. In Asia Pacific and North America, the next generation wireless network is going to be mainly based on CDMA2000, and China, the largest market for mobile communication in the world, will be using TD-SCDMA standard for 3G networks.

Availability:

Upgrading 2G to 3G technology requires a big amount of capital investment. Some European Government auctioned off radio spectrum bands to accommodate the 3G networks. In the UK, for example, five 3G mobile licenses were auctioned off at a total of \$35 billion USD with the expecting cost for each license between \$4 billion and \$9 billion USD to form out their 3G network [3]. For this reason carriers have opposed to upgrade networks because they wanted to be ensured and see a real demand for high speed wireless data, and many of them viewed that 2.5G is more than just an interim solution following the reason that it delivers significant bandwidth improvements at a lower cost.

However, major wireless service providers estimated the high costs of deploying 3G services and warned about technical difficulties such as 3G handset and network infrastructure foundation, a few are already working on W-CDMA in Europe and Japan, And some other country also applying the technology step by step from lower income to high income countries. A market structure and status of deployment of mobile internet technologies in some of these countries are shown in table 3. NTT DoCoMo in Japan released a third generation phone service FOMA (Freedom of Mobile multimedia Access) in major urban location of the country. The receiving data of FOMA data at 384 Kbps and transmitting data rate is 64 Kbps. Subscribers get access for almost everything in a limit such as movie trailers, sports highlights, music, video clips and news feeds.

The strategies group predicted that there would be 9.5 million 3G mobile high-speed data subscribers by 2005 but it crossed the limit of the predictors. Within 6 years of 3G introduction, it gains 402 million subscribers by 2008, and 30 million subscribers are added in every quarter. According to the UMTS Forum prediction by 2010 data services will represent \$300 billion or 66% of all worldwide 3G revenues. Japan, South Korea and the USA already the number of 3G subscribers have already surpassed that of 2G subscribers [14].

2.1.5 Fourth Generation Technologies:

Growth of science is so fast and wireless communication is not exceptional from it. After a lot of research and implementation works the network providers started to provide 3G services. But some researchers could not be satisfied with this limit of wireless communication. As a result they started to work on more upgraded wireless services which are called 4G. This 4G technology will take mobile communication step forward in integrate radio and television transmissions for all users with flexibility and it will unite world's phone standards into one technology with very speed.

There are two key elements which are required to deliver a legitimate 4G network. First is the ability to roam across different wireless network standards with the one device; and the second, and most obvious, is a higher level of bandwidth [3].

Though function of 4G is not defined fully yet, still it can predict that 4G technology will replace 3G, and it will use a combination of Wi-MAX and Wi-Fi. Standard bodies or carriers have not defined definitely what exactly 4G will be but it is expected that IP end to end and streaming quality with high quality will be featured in 4G technologies.

There are two competing 4G standards working mainly. One of them is a joint effort by Hewlett Packard and another is Japan's NTT DoCoMo to create Moto-Media. Moreover, the wireless World Research Forum specifications with the backing of some of the Europe's largest phone markets.

Most of the wireless observer bodies made a question that is how the 4G market going to be, and when can the industries reasonably expected to invest in a new network. Some of the analysts have estimated that the 4G mobile systems would have more 50 million subscribers by the end of year 2007, and it would account for 14 percent of total mobile data revenues. But it is estimated that the subscriber for 3G/4G who use WCDMA/HSDPA, TD-SCDMA, mobile Wi-MAX, EV-DO and LTE networks was 230 million in 2007 and rose to 375 million in 2008 [15]. But most of the analyst estimate the technology to be ready around 2008-2010. Nokia and Samsung have teamed up to create 4G wireless equipment; a move demonstrates the support for the 4G mobile systems.

2.2 Comparison of Data Services for Different Generation Networks:

The demand for mobile data services is growing day by day. Increased mobility has attracted an expanding market for both vast consumers and the enterprise bodies. Various data services comparison for cellular networks is known in table 3. For consumers, second-plus and third generation networks have already brought access to the internet with an amazing performance nearly wire-line speed and quality. 2.5G services are used mostly text-based with still images and short audio clips. Service included web browsing, financial transactions, image downloads, e-mail and instant messaging. As networks migrated to 3G, these same services enriched with multimedia content including full audio and video clips. For enterprises, second-plus generation networks allowed access to corporate intranet and e-mail, business applications and data bases, and increasing mobile sales. 3G technologies enable even greater benefits from wireless business applications through VOIP (Voice over IP), rapid file transfer and video-conferencing.

Table 3: Comparison of Data Services for 2G, 2.5G and 3G Networks [1] [2] [3]

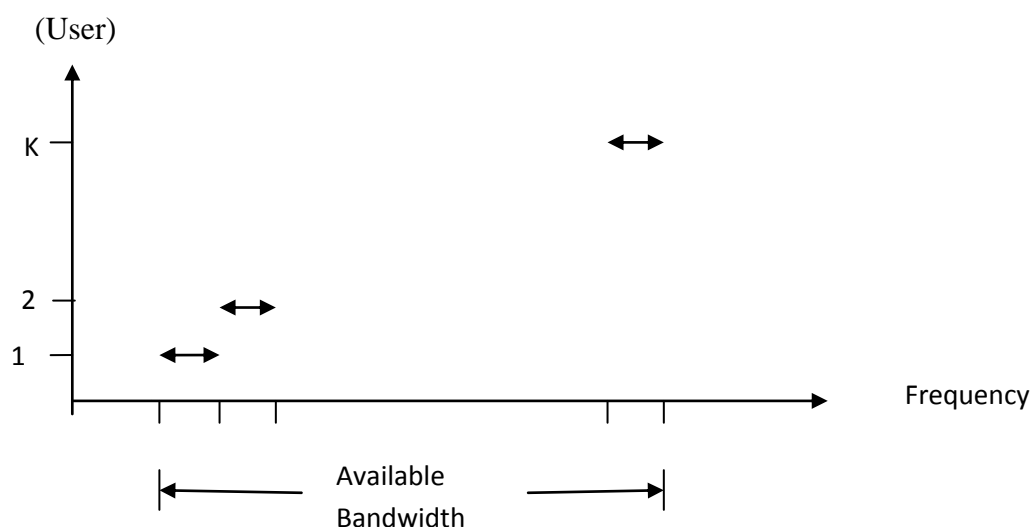
Services	2 nd Generation	2 nd + Generation	3 rd Generation
Web browsing	Short text screens	100KB web page takes approx. 30 sec to download	100KB web page takes Approx.2 sec to download
File Transfers	No	500KB document takes approx. 2mn to download	500KB document takes approx.10sec to download
E-mail	Short Message Service (SMS)	Text-based with small attachments	Full attachments
Instant messaging	SMS	Text-based	With audio/video clips
VOIP(Voice Over IP)	No	Limited	Yes
Streaming audio/video	No	Short clips	Yes
Access to corporate intranet	Very limited	Text-based	Yes
Access to corporate apps	Very limited	Text-based	Yes

2.3 Multiple Access Formats for Wireless Communications:

Multiple access schemes are used to allow many mobile users to share simultaneously a common bandwidth. Different types of multiple access formats are in use and we can discuss them under the following standards:

2.3.1 Frequency Division Multiple Access (FDMA):

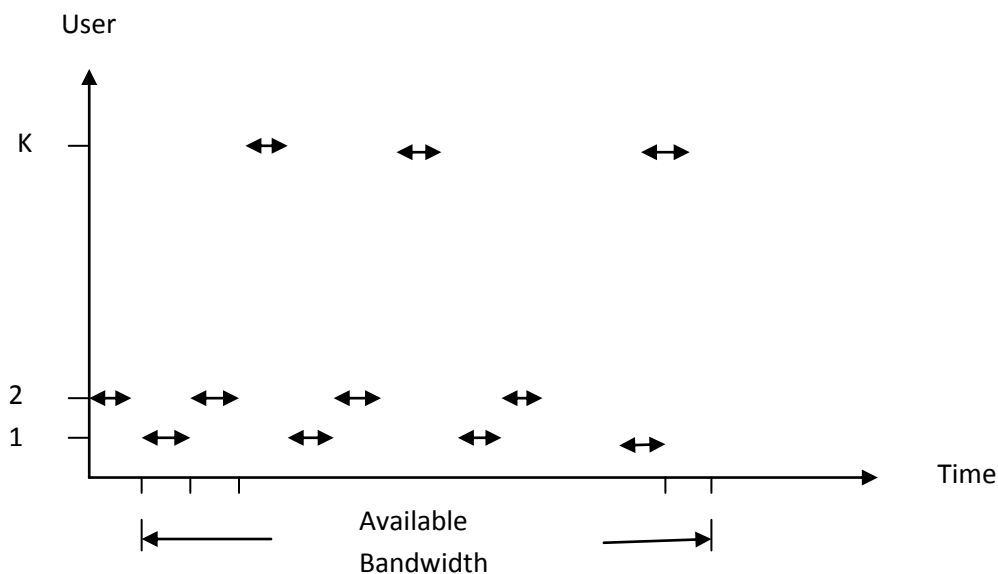
It assigns single channels (frequency band) to single users. According to the figure below each user is allocated a unique frequency band. These bands are assigned on demand to users who request for service. No other users can share the same frequency band during a call made. The bandwidths of FDMA channels are relatively narrow (25-30 KHz) as each channel supports only one call per carrier [13]. FDMA is usually implemented in narrowband systems. If an FDMA channel is not in use it sits idle and can't be used by other users to increase the system capacity. It can't be used by other users even if a user stays in pause during a phone call.



Picture 2: FDMA schemes in which different users are assigned different frequency bands

2.3.2 Time Division Multiple Access (TDMA):

Transmission time is divided into time slots here, and only one user is allowed to either transmit or receive in each time slots. According to following figure 1.2, it is seen that each user occupies cyclically repeating wording, so a channel might think of as a particular time slot that reoccurs at slot locations in every frame. The FDMA system can accommodate analog frequency modulation (FM) but TDMA uses digital data digital modulation.



Picture 3: TDMA schemes in which each user occupies a cyclically repeating time slot

TDMA shares a single carrier frequency amongst many users, where each user uses non-overlapping time slot. In the case of FDMA, if a channel is not in use then the corresponding time slot sits idle and can't be used by other users. In TDMA system data transmission for users is not continuous but occurs in bursts transmission [3]. Synchronization overhead is required in TDMA systems Because of this burst transmission. Moreover, it is important to use guard slots for separating users. In general, TDMA mobile systems are more complex than the FDMA systems.

Each user of a multiple access system like FDMA or TDMA is limited by bandwidth and time allocated to it, the degradation caused by background noise, multipath fading and shadowing effects. Another weakness is that its relatively low frequency reuse factor of FDMA and TDMA.

A common performance degradation source to all multiple access system is fading in its terrestrial environments. Fading is occurs by interference between different versions of the transmitted signals which arrive at the receiver at very minor different time. This phenomenon is very severe when each channel is allocated narrow bandwidth with the FDMA systems.

2.3.3 Code Division Multiple Access (CDMA):

A completely different approach is realized in CDMA systems. It does not try to allocate separated frequencies or time resources to each user. Instead of this the system allocates all resources to all users. Potentially, radio channel capacity in CDMA is larger than FDMA and TDMA systems.

Spread spectrum communication system is applied with Code Division Multiple Access in which multiple users have access to the same frequency band. Spread spectrum refers to power spreading over a given transmission bandwidth in DS-SS (Direct-Sequence-SS). This is accomplished by spreading the base-band binary data by means of high speed pseudo noise (PN) code (called the chip rate). The composite high speed data are then modulated and demodulated over the air.

In direct sequence CDMA (DS-SS) systems, the narrowband message signal is multiplied by a very large-bandwidth signal which is called the spreading signal. The same carrier frequencies are being used by all users in DS-SS systems and may transmit simultaneously. Each user has its own spreading signal which is almost orthogonal to all other users' spreading signals. A correlation operation is performed by the receiver for detecting the message addressed to a given user. The signals from other users appear as noise because of de-correlation operation. The receiver requires the spreading signal for detecting the message signal used by the transmitter. Each user operates independently to the other users with no message which is called uncoordinated transmission.

CDMA Frequency Bands:

There are 12.5 MHz existing cellular bands which are divided to derive 10 different CDMA bands. Therefore per band is 1.25 MHz. Each of these bands supports 64 Walsh codes limited like W0, W1, W2, W3.....W63, where each code is functioned like a channel [3] [1]. Although these codes are not permitted to be used in the same band, but they can be used in another band simply. However, several frequency bands are being permitted to be used in the same cell or sector to enhance its capacity, as long as the frequencies are different.

CHAPTER 3

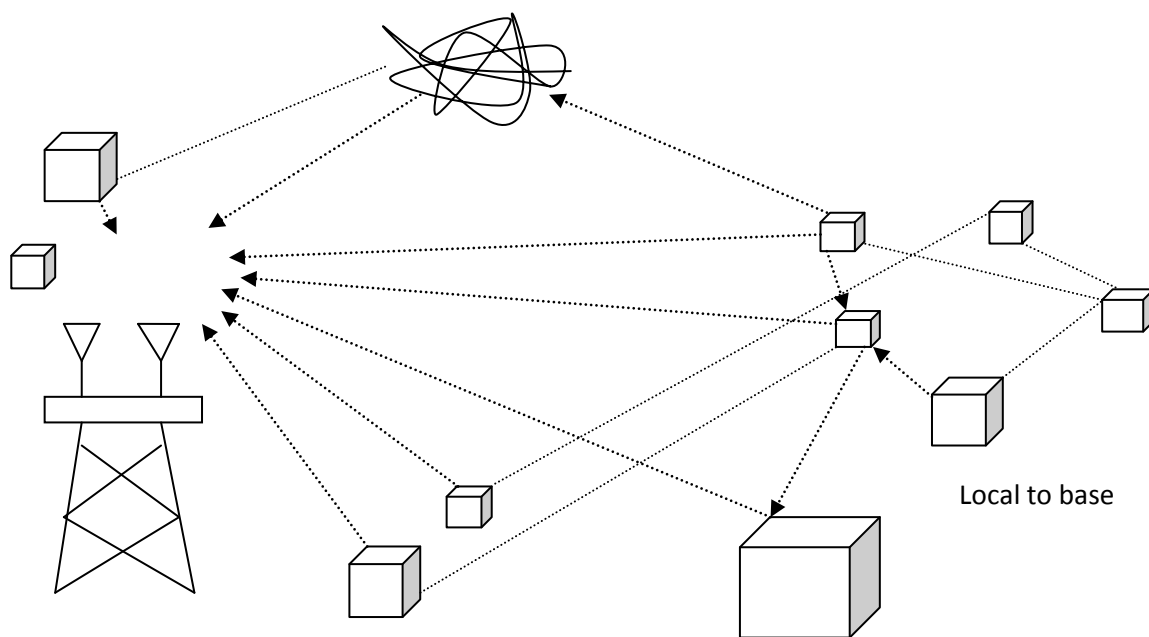
Performance Degradation Factors of Wireless Communications

There are several factors responsible for performance degradation in wireless communication channels. Those factors are described in this chapter. The main performance degradation factors are Path-loss, Shadowing-loss, Interference, Noise, Channel Spreading and Fading of channels. Fading is specially described here because our main focus of this thesis is fading based.

3.1 Characteristics of Wireless Communication Channel:

In radio communications, wireless communication channel works as transmission medium. Characteristics of wireless communication depend on transmitting signal or information riding on radio. Radio means electromagnetic wave here. Hence, the information suffers attenuation effects by several reasons which are called fading of radio waves. These attenuation effects can vary with time. This variation depends on user mobility, which makes wireless a challenging medium of communication. Uncertainty or randomness is the main characteristic of wireless communication. Types of randomness are two: randomness in users' transmission channels and randomness in users' geographical locations. These factors of user in the wireless network systems lead a signal to random signal attenuation independently through users.

Modulation of electromagnetic (radio) waves is utilized by wireless communication with a carrier frequency. The frequencies vary from a few hundred MHz to several GHz but it depends on the system. As a result, the behavior of the wireless communication channel is a function of the radio (electromagnetic waves) propagation effects in an environment.



Picture 4: Local to base [16]

A typical wireless propagation environment at outdoor is seen in figure 2.1, where the mobile wireless node is communicating with base station or a wireless access point. The transmitted signal from the mobile may travel two ways. The signal may reach the access point directly which is called line of sight (LOS) [16] or it may reach the access point through multiple reflections on local scatters (buildings, mountains, bridges, trees etc.). As a result the received signal has multiple random attenuation and of course with some delays. Moreover, the mobility or movement of either the nodes or the scattering objects may cause these random fluctuations to vary with time. Time variation results in random increasing or decreasing of the transmitted signal strength over time period. In conclusion, an undesired interference may be occurred by a shared wireless propagation because of simultaneous transmissions to the transmitted signal. The combined effects of these discussed factors put wireless in a challenging communication environment.

The difference from wired communication such as twisted pair, coaxial cable, optical fiber, is that the transmission channel can't be predicted or random and it can vary over as very short time scales as microseconds [16]. The consequence gives the limited power resources which leads the communication systems to new challenges in signal transmission. Moreover, the equitable sharing of limited resources is an important challenge while the medium is frequently shared by several users. In addition, freedom of mobility is an important factor to the users and for that, the end users need to be located in order to information to them. This situation makes the network topology very complex and a challenging dealing is needed for

the challenging and complex wireless network. Finally, wireless devices are needed to connect with an internet network infrastructure which is wired connected. As result a newly challenge creates which is interoperability of these disparate communication media.

In wireless communication, it is impossible to get proper Line Of Sight (LOS) or properly communicate between the communicating nodes because of some obstacles, made naturally or constructively, between the nodes [16]. To overcome from this problem, a transmission path is modeled randomly which has varying propagation path in such an environment. In this kind of environment, signal propagation over multipath made us need to model wireless channels as wireless multi-path channels.

Services are increasing dramatically because of users demand. Excess services lead air time usage. Moreover, easy usability and cheaper services creates more and more users in wireless communication industries. But the radio spectrum resources are limited, so system capacity is a challenge to the wireless device and infrastructure designers. Some more challenges include like-

1. Unfriendly medium due to presence of noise, interference, multipath and time variations.
2. Users' hand-held terminals have limited life time.
3. Offering efficient quality of services by efficient radio resource management.

3.2 Factors Affecting the Wireless Channels:

Wireless communication systems are performed by sending signals through radio propagation environment. But radio propagation environment has some limitations of its performance because of natural and constructive obstacles. Following impairments are responsible to the sufferings of radio propagation.

- Path loss
- Shadowing loss
- Channel spreading
- Channel fading
- Interference
- Noise

Different copies of signal undergo different attenuation, distortion, phase shift and delays during transmission. The overall performance of system degraded severely due to the above problem.

3.2.1 Path Loss:

When radio signal propagates in a space it loses power on the way of its propagation that is called path loss. This is the signal attenuation and it happens because of the distance between the communicating nodes of the system. This is a function of the distance between the mobile and the base station and it defines the mean attenuation of the radio signal. The fact is that, when radio wave propagates through an environment from a transmitter (Omni directional), the fraction of the transmitter power gained by the receiver at a distance r away from the receiver decreases with r . Experiments show that attenuation $D \approx r^{-\alpha}$ [16]. The scale of variation of D varies depending on the variation of distance r with time which is achieved by mobility of communicating nodes. Additionally, radio frequencies, used antenna height and propagation environment also play important roles on path loss. If huge obstructions obstructed the propagation way of radio frequencies then it causes a very high attenuation comparing to free space loss. The obstructions can be very high hills, buildings, bridges, deep forests etc. As a result, the path loss is very less in flat and rural areas comparing to urban and hilly areas. The character of path is that path loss is very slow with variation amongst the attenuation effects.

The path loss in power varies gradually because of the signal attenuation which is determined by the geometry of the path creates from received power in its whole area. Simply, a signal attenuates according to propagation in a real channel. If a radio wave transmitted from a point source in free space the path loss is power is,

$$L = (4\pi d/\lambda)^2 \quad \text{-----} \quad (3.1)$$

Where λ is wavelength of the signal; and d is distance between source and receiver.

The power of the signal decays is the square of the distance. The same thing happens in landline wireless communication also.

The mean power of a signal decays as the n^{th} power of the distance:

$$L = cd^n \quad \text{-----} \quad (3.2)$$

Here, c is a constant and n is path loss exponent. The values of c and n depend on the type of environment. The n value is in between 2 and 5 but 4 is a common value in urban environment in mobile communication. The value of n is 2 in free space propagation. The signal variation in power follows the well known Friis Formula [2]. If the value is more than 2, it means there is an influence of structure on the way of propagation on the surface. The value of n in sub-urban area is 2 to 4 and in a dense urban area n is 4 to 5. The power loss causes the limit of coverage area of a wireless communication system.

3.2.2 Shadowing:

Second factor is shadowing loss which effects on wireless channel. It is very difficult to model Shadowing Loss. Shadowing is happen due to absorption of radio wave in the propagation by scattering structures. In a normal sense, shadowing causes by the land surface and obstructions between the transmitter and receiver in communication system. It remains independent in concern of distance between receiver and transmitter. It is a random variable which varies according to types of environment where radio wave propagates. Experiment shows that it is modeled as well by a log normal distribution, for example, the attenuation behavior is like, $\delta \sim A_{SL}$ [16]. Where $\log(A)$ always follows the well known Gaussian distribution. It can be said in other way like that, the measured attenuation is Gaussian distribution in decibels. Moreover, Variation of time occurs when scattering environment is changed. It can be said by an example like that that when a mobile moves to a corner of a street, the time variation of shadowing loss is very difficult t model, and there are very few experiment to study this situation. If we think about the quality and compare with path loss and fading, we can describe that, shadowing loss varies faster than the path loss, but it is slower than the fading (loss) [16] [3].

If a mobile unit is on moving, it does not affect the short term characteristics of the shadowing. It's because of the relatively large obstacles. However, shadowing behavior is determined from the nature of the terrain surrounding of the base station, the mobile unit and the height of the antenna. Shadowing adds some additional fluctuations around the system. As a result, the received power as mean varies around the system area. Normally, shadowing is modeled as a random process which is slowly time-varying and also multiplicative. If we avoid all the other impairments, the received signal is [16]:

$$r(t) = g(t)s(t) \dots\dots\dots (3.3)$$

Here $s(t)$ = transmitted signal

And $g(t)$ = the random process which models the shadowing effect.

If we use an observation interval, we might let $g(t)$ is a constant g . Normally, this s modeled as a log normal random variable which has a density function as:

$$\ln(g) = \frac{1}{\sqrt{2\pi\sigma g}} \exp \left[-\frac{(\ln g - \mu)^2}{2\sigma^2} \right] \quad \text{if } g \geq 0 \quad \dots\dots\dots (3.4)$$

$$\text{Or, } \ln(g) = 0, \quad \text{if } g < 0 \quad \dots\dots\dots (2.5)$$

Here $\ln(g)$ is a Gaussian random variable and μ is mean value. Here σ^2 is the variance. The variance σ^2 and the mean μ of the shadowing loss are measured in decibels. σ , the function of the terrain and the antenna height, can be ranged between 4 dB to 12 dB in cellular and micro-cellular environment.

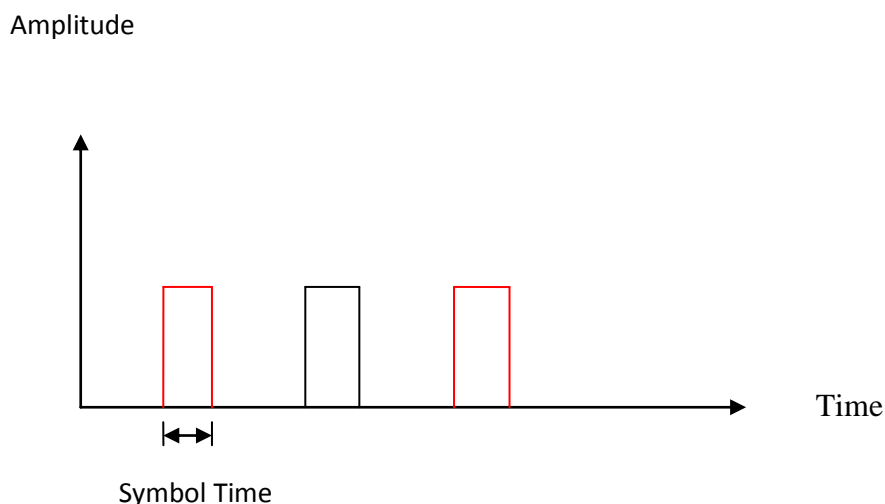
3.2.3 Interference:

The source of interference in a radio system can be originated at the system itself or it can be located at external source. The self-centered interference can be divided into two types: inter-cell and intra-cell interface. The inter-cell comes from other mobile stations and it normally approximately 60% of total interference in a system. In the uplink case, the intra-cell interface comes from other mobile station cells. If a communicating system uses multi-option access technique, the users of the same cell or the neighboring cells of the system can be interfaced with each other. Moreover, multiple propagation paths in a multi-paths channels interface with each other. There are two types of interference, such as:

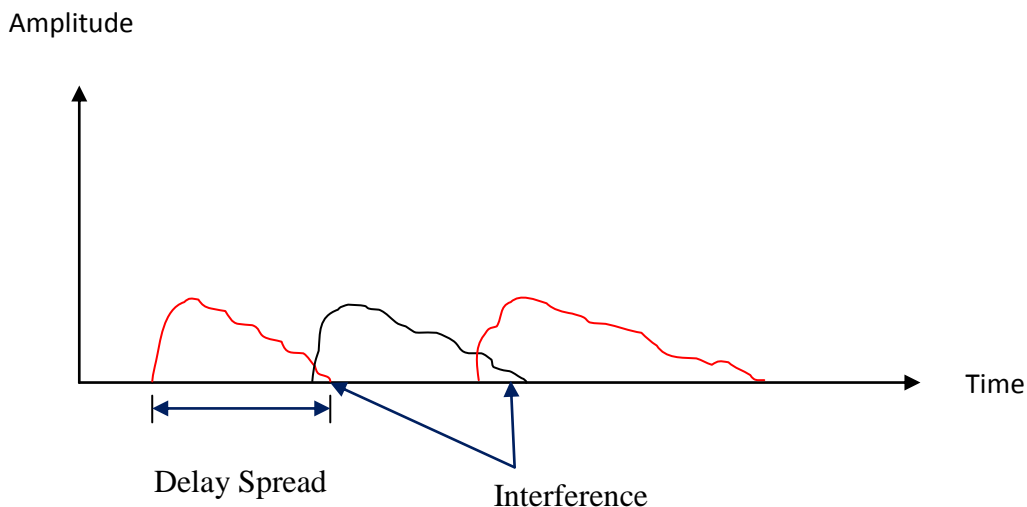
- Inter-symbol-interference (ISI)
- Co-channel-interference (CCI)

3.2.3.1 Inter-Symbol-Interference (ISI):

Inter symbol interference (ISI), an unavoidable consequence, is introduced by the delay spread in a propagating channel in the both wired and wireless communication systems. When symbol attempt to transmit, it spreads more than normal extension and smeared into the next symbol and make interference. In short, a small part of symbol overlap on the next symbol while transmit. It can be shown in figure:



Picture 5: (a) The transmitter symbols

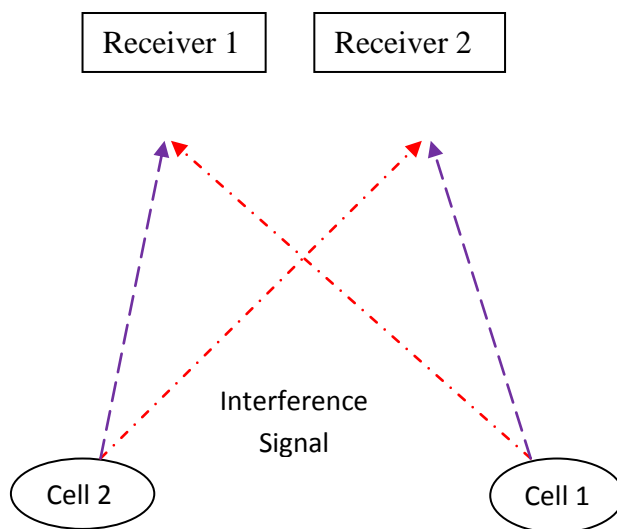


Picture 6: (a) The received symbols

ISI can be controlled by slowing down the transmit data. When the received signal damps down, then the next pulse of information should send [1]. The time it takes to damp is called delay spread, and the original time of pulse is called symbol time. To suppressed ISI, we can select a space-time filter that equalizes the channel. Moreover it can be controlled by using a maximum likelihood sequence detector.

3.2.3.2 Co-Channel Interference (CCI):

The reason of creation of CCI is, when the neighboring cells operate at the same frequencies. Some other factors of creation of CCI are insufficient cross-polarization isolation, non-linearity of power amplifier, poor radiation from antenna side lobes, faulty filtering etc. The CCI can be suppressed by using an orthogonal space time filter to the interference channels. Another method to solve this problem is the estimation of Time of Arrival (TOA). This method uses the synchronized time difference between original signal and the CCI signal. An un-synchronized base station is used to suppressed the CCI signal and the signal without CCI is received which has good data quality and good speech quality [17].



Picture 7: Co-channel interference scenario for neighboring base station

3.2.4 Noise:

There are two types of noise which have a role play in radio wave propagation, natural noise and man-made noise. The main source of 1st type of noise is the ignition systems of vehicles. However, natural noise source such as galactic noise, solar, atmospheric noise, has less effect in land-mobile communication systems but lots in radio channel. The noise generated in the components in the communication systems also corrupt the received signals besides the natural and man-made noise. The characteristics of different noise sources are simply different but the noise process most commonly and frequently modeled with Additive White Gaussian Noise (AWGN). If the receiver components introduced thermal noise and dominates the noise process then AWGN assumption the component is valid [3]. The AWN should be taken into account when considering a system with very few users as it will impose a lower bound on the bit error rate. However, if we want to think about the system capacity then we consider the state in which the system has large number of users. In this case the noise is not important factor like interference introduced by the other users in the system.

3.2.5 Channel Spreading:

When information carrying signal energy spreads in space or concerning time or frequency axis then the spreading of the signal is called ‘Channel Spreading’. Propagation of a radio wave from a user or to a user in multipath channel is the reason why the signal energy to spread in the space dimension, time or in the frequency axis. The design of receiver is affected by the characteristics of channel spreading.

There are two types of channel spreading such as:

- Doppler spread
- Delay spread

3.2.5.1 Doppler Spread:

Due to movement of the communicating device or other components in a multipath propagation environment the information carrying radio signal experience a shift in frequency domain. The shift in frequency domain is also called Doppler shift. The amplitude of the Doppler shift is depends on the path direction of the signal arrival. Doppler shift is much smaller than the carrier frequency and it is bounded to positive and negative amplitude. For example, it can be seen that component waves arriving from ahead of the vehicle experience a positive Doppler shift, while those arriving from behind the vehicle have a negative Doppler shift [18].

If surrounding scatters are present with multi-directions and a pure tone is spread over a finite bandwidth, then Doppler power spectrum is the Fourier transform of the received signal in time domain and the support of the Doppler power spectrum is the Doppler spread. If the scatters equally distributed in angle, then the Doppler power spectrum is given by classical spectrum.

$$S(f) = \frac{3}{2} \frac{\sigma^2}{\pi f_m} \left[1 - \left\{ \frac{f - f_c}{f_m} \right\}^2 \right]^{1/2}, \quad f_c - f_m < f < f_c + f_m \quad \text{----- (3.6)}$$

where $f_m = v/\lambda$, is the maximum Doppler shift, v is the mobile velocity, f_c is carrier frequency, σ^2 is the variance.

If there is a source of energy coming from a particular direction such as in Line-of-sight situation, the expression for the spectrum needs to be corrected as following. In that case the Doppler shift of dominant path f_D :

$$S(f)+B\delta(f-f_D) \dots\dots\dots(3.7)$$

Here B is the ratio of direct to scattered path energy.

The result of Doppler spread in the channel characteristics is that it change the channel characteristics sharply in time, it gives rise to the so called time selectivity. The fading channel can be considered as constant during the coherent time and the coherent time is inversely proportional to the Doppler spread. Typical values of Doppler spread are 10 to 250 Hz (Suburban areas), 10 to 20 Hz (Urban areas), 10 to 100 Hz (Office areas). A person walking at 10km/h induce a maximum Doppler spread of ± 22 Hz at 2.4 GHz. (Reference: Broadband wireless access by Benny Bing, page- 5). A Doppler spread makes good channel tracking which is an important feature of receiver design.

3.2.5.2 Delay Spread:

Sometimes, multipath propagation is characterized by different version of transmitted signal arriving at the receiver attenuation factors and delays. When spreading in time domain then it called delay spread and this is responsible for the selectivity of the channel in frequency domain. The coherence bandwidth is inversely proportional to the delay spread. The significant delay spread causes strong inter-symbol interference.

3.2.6 Channel Fading:

Fading in a channel is the propagation losses by radio signal on both forward and reverse links. This impairment is a major problem of wireless communication channel. Fading introduce for the combined effect of multiple propagation paths, high speed of mobile units and reflectors. Multiple path fading has a small scale effect. In a multi-path propagation, received signal by a mobile terminal comes from a large number of propagation paths. Reflection, diffraction, scattering in radio wave in natural structure and human made structure like building, bridge are responsible for the creation of multi-path propagation [4]. Received signal suffers variation in magnitude and phase due to the multiple propagation paths and it interfere each other in both constructively and destructively which depends on the spatial position of the receiver. This variation in the received signal is called multipath fading and this fading is depends on the rate of speed of the receiver motion and the objects around the receiver. The performance of a wireless communication system in term of probability error can be severely degraded by fading.

In mobile communication, there is not only multipath propagation exists but also its time varying. The phenomena results a time-varying fading channel. It's very difficult to communicate through this kind of fading channel in communication systems. But there is some special technique may be taken to achieve satisfactory performance. In wireless communication, the received signal comes from both direct part and the path of scattering,

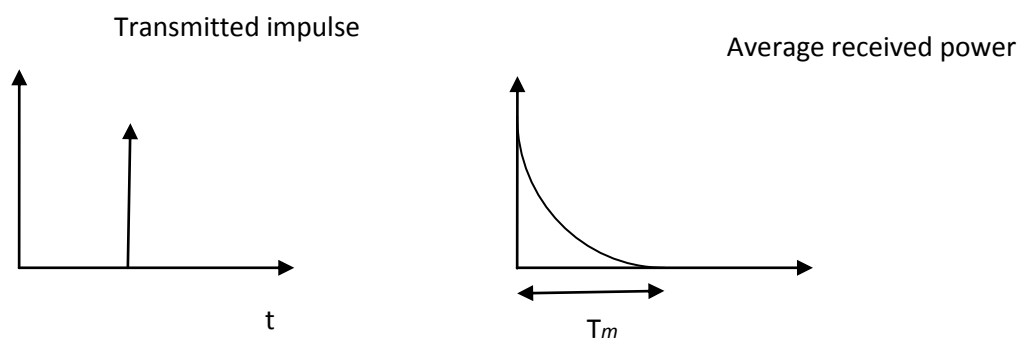
reflections and diffractions. Because of the propagation loss, the effect of the terrain configuration implement small-scale long term fading which is also called shadowing fading and it changes with the atmosphere and electrical constants. Natural and man-made structures such as buildings, traffic, motion, trees, hills and the other nearby environment would cause the multi-path fading on the received signal called short-term fading.

3.3 Parameters of a Fading Channel:

The general time-varying channel model is not so easy but very complex for understanding as well as performance analysis for wireless communication channels. One of many approximate channel models is the WIDE-SENSE STATIONARY UNCORRELATED SCATTERING (WSSUS). In WSSUS model, the time varying fading is seems to be wide-sense stationary random process and the signal copies from the scattering by different objects are assumed to be independent. The followings are some parameters used sometimes to characterize a WSSUS channel.

3.3.1 Multi-path Spread, T_m

When we send a very narrow pulse in a fading channel, the received power can be measured as a function of time delay as shown in figure 2.2. The average received power $P(r)$ is called multi-path intensity profile or delay power spectrum when τ is a function of excess time delay. Sometimes, $P(r)$ is essentially non-zero over a range of values of a function of excess time delay τ . Then it's called multipath spread of the channel, symbol is T_m . We can find the maximum delay between paths of significant power in the channel. In an urban environments, and the range of T_m is between $0.5 \mu\text{s}$ and $5 \mu\text{s}$ [3].



Picture 8: Multi-path delay profile

3.3.2 Coherent Bandwidth, $(\Delta f)_c$

In a fading channel, signals with different frequencies can undergo different degrees of fading. Coherent bandwidth in channel gives us an idea how far signals should be separated in frequency. If two frequency signals are separated by more than coherent bandwidth then the signals may undergo different degrees of fading. The relationship between $(\Delta f)_c$ and T_m is [18]:

$$(\Delta f)_c \approx \frac{1}{T_m} \dots\dots\dots (3.8)$$

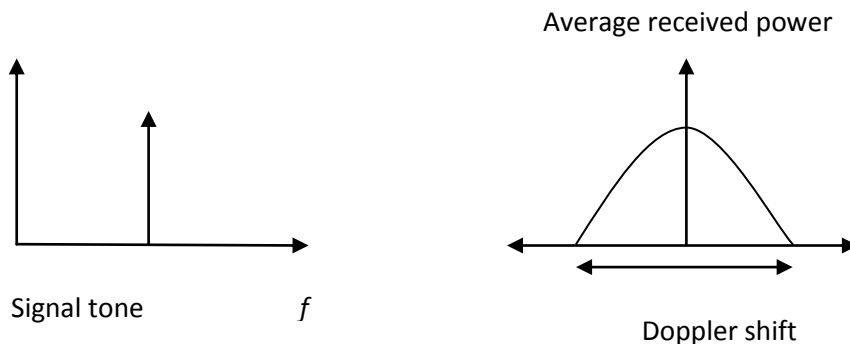
3.3.3 Coherent Time, $(\Delta T)_c$

The channel impulse responses vary with time in a time varying channel. The coherent time identify the time duration over which the channel impulse is invariant or highly correlated. As a result, if the time duration is smaller than the coherent time then the channel considerably invariant during the reception of symbol [11]. Different time –invariant model is still need in different symbol intervals due to the time varying nature of a channel.

3.3.4 Doppler Spread, B_d

A signal propagating in a channel may undergo frequency shift or Doppler shift due to its time varying nature. If a bunch of frequency is transmitted through a channel, the received power spectrum can be plotted against the Doppler shift according to following figure. The consequence is called Doppler power spectrum. The Doppler spread is the range of the values where the Doppler power spectrum is non-zero. It gives the maximum range of Doppler shifts. Coherent bandwidth and Doppler spread is related by the following equation:

$$(\Delta f)_c \approx \frac{1}{B_d} \dots\dots\dots (3.9)$$



Picture 9: Doppler power spectrum

3.3.5 Mean Path Loss:

The mean path loss describes the attenuation of a radio wave in a free space propagation environment due to isotropic power spreading which is given by the inverse square law [2],

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r \dots\dots\dots (3.10)$$

Here P_r and P_t are received and transmitted powers, λ is wavelength of the radio wave, d is the range G_t, G_r are gains of transmitter and receiver respectively. The main path is accompanied sometimes by a surface reflected path which may destructively interfere with the primary path. There is a model called path loss model is developed to handle this effect. The model is [2]:

$$P_r = P_t \left(\frac{h_t h_r}{d^2}\right)^2 G_t G_r \dots\dots\dots (3.11)$$

Here h_t, h_r are the effective heights of transmitter and receiver respectively. This path loss model built in according to an inverse fourth power law and the path loss exponent may vary from 2.5 to 5 depending on the environment.

3.4 Classification of Fading Channels:

Time varying fading channels may be classified as following depending on the parameters of the channels and characteristics of the signal to be transmitted:

- Frequency non-selective vs. frequency selective fading.
- Fast fading vs. slow fading
- Large scale fading vs. small scale fading
- Ricean fading vs. Rayleigh fading

3.4.1 Frequency Non-selective vs. Selective Fading:

Considering the comparison between bandwidth of transmitted signal and coherent bandwidth, if the bandwidth of transmitted signal is small, then all the frequency components of signal may approximately undergo the same degree of fading. This kind of channel is called frequency non-selective or flat fading [8]. In a frequency non-selective channel, the symbol duration is large enough comparing with coherent bandwidth because of the reciprocal relationship between coherent bandwidth $(\Delta f)_c$ and coherent time $(\Delta t)_c$, and bandwidth and symbol duration. In this situation, delays are relatively small between different paths compare to the symbol duration. It is expected to receive only one copy of signal with the gain and phase determined by the superposition of all those copies come within the coherent time.

However, considering the same parameters if the bandwidth of the transmitted signal is large then different frequency component may undergo of different fading. This kind of channel is called frequency selective fading. The symbol duration is small comparing to coherent bandwidth due to their reciprocal relationship. Delays between different paths can be large respect to the symbol duration. It is then expected to receive multiple copies of signal.

3.4.2 Fast Fading vs. Slow Fading:

If there is a long term shadowing effect of buildings or natural objects in terrain then slow fading occur in a channel. The local mean is influenced by the environment types. Therefore, it is really difficult to make a prediction. However, if it is plotted the signal fluctuation in a logarithmic scale, the fluctuation approaches a normal distribution. This kind of distribution is called log-normal. The typical value of the standard deviation of shadowing distribution is 8 in Decibel.

When the symbol duration is small comparing to coherent time $(\Delta t)_c$, then the channel is called slow fading channel. This type of channel often modeled as time invariant channels

over a number of symbol intervals. Moreover, slow varying channel parameters can be estimated by different types of estimation techniques.

Multipath propagation characteristics of a radio signal results path signals to add up to random phases in both ways constructively or destructively at the receiver end. These phases can vary extremely rapid way along with the receiver end and can be determined by the path length, and the carrier frequencies. If we consider a large number of scattered wave fronts which has random amplitude and angles and if we consider that it arrives at the receiver end with uniformly distributed phases $[0, 2\pi]$, then in-phase and quadrature-phases components of the vertical electrical field E_z can described Gaussian process. The presence of a direct path in space, it will no longer be a Rayleigh distribution. Then it becomes a Ricean distribution.

When there is a close or smaller coherent time to/than symbol duration, the channels is fast fading or time-selective fading. It is still a difficult phenomenon to estimate the parameters of the channel in a fast fading channel.

3.4.3 Large Scale Fading vs. Small Scale Fading:

Large scale fading is considered the mean path loss variation over distances that are proportional to the size of obstructive features between base station and the mobile. In this case, the receiver is differently shadowed by the obstructive features at a sufficient distance. The signal variation in level due to large-scale fading follows a log-normal distribution. The standard deviation of the signal in this kind of fading channels depends on the propagation environment and the distance between the mobile and the base station.

However, small-scale fading is a phenomenon creates by the multipath propagation in a channel. Multi-path channels include one or more than one reflected propagation paths between a transmitter and a receiver to a feasible line-of-sight (LOS) propagation path. In addition with propagation via dominating reflectors such as high mountains, large buildings, the transmitted signal can be scattered by structures present in around of transmitter or receiver. The destructive interference between multi-paths may be a reason to fade the channel greater than 20 dB [3].

3.4.4 Rician Fading vs. Rayleigh Fading:

There is a variation of fading loss during sampling a radio wave in various spatial locations. If there are enough scatters in a dense multipath environment, the complex amplitude is well modeled by a Gaussian distribution. If there is a line-of-sight (LOS) propagation path in between transmitter and receiver, then the mean Gaussian distribution is non-zero [2]. It leads to attenuation with absolute value of complex amplitude which is Ricean distribution and it terms as Rician fading. The signal variation follows Rice probability density function (PDF) in channel here.

If there is a line-of-sight (LOS) propagation path in a dense urban environment, then there is a zero mean Gaussian distribution which is leading to a Rayleigh distributed attenuation and the channels is called Rayleigh fading channel. The envelope fluctuations of the signal follow the Rayleigh PDF in Rayleigh fading channel and the signal comes from almost the directions with the same average power. The Rayleigh fading is predominant and worst case in typical land mobile communication systems. Multipath fading phenomena occurs in three situations. If the mobile unit and the nearby scattering objects all moving, If the mobile unit is standing but the nearby scattering objects are moving and if the mobile unit and the nearby scattering objects all standing.

CHAPTER 4

Diversity Technique for Wireless Channel

Several types of diversity techniques are described in this chapter. In section 4.3, several types of diversity techniques such as Multipath Diversity, Spatial Diversity, Time Diversity, Polarization Diversity, Angle diversity, Antenna Diversity are described. Every diversity technique has some branches. Those are also introduced with the respective diversity technique description. For example, Transmit diversity has two branches such as close-loop transmit diversity and open-loop transmit diversity.

4.1 Diversity Concept:

The reception of a signal in a channel transmitted through any type of fading channel degrades in quality if the signal level attenuation is below the expected operation region of the receiver. In this situation, the received signal power is not expectedly enough comparing with signal noise and interference power for reliable reception. The solution to overcome the channel attenuation because of fading problem in channel is to increase the transmitted power adjusted to the attenuation which is called power control (PC) [4]. On the other hand, there are two primary problems with this power control (PC) system.

One of these problems is that the dynamic range of the transmitter and the required transmitting power is extremely high if it's intended to fully compensate the fading. This is impossible because of the radiation power limitations, the cost and the size of the amplifiers, and the limited battery power in the portable unit. Moreover, excess transmitted power increases the interference level at the other channels and users in the system unit. Another problem in power control (PC) approach that a feedback link is needed for the channel unless the operation of the radio channel is in time division duplex (TDD) mode. In a TDD system, the same frequency band is used for the downlink transmission from the base station to mobile unit and for the uplink transmission from the mobile unit to the base station. As a result, the transmitted signal undergoes the fading channel as the received signal due to its reciprocal characteristic of the channel, the transmitted power of transmitter is adjusted according to the received signal power. The feedback information usage decreases throughout the channel and increases the complexity in the system [4]. Even an appropriate feedback link may not available in some application.

Using PC the fading can't be overcome completely but the attenuation may compensate considerably. It can mention that large-scale fading can be compensated as well in the uplink of a system, for example CDMA. But stringent power control is required in prevention near-far problem in the system. The rate of large-scale fading is simply slow, as a result it can be tracked well and the delay in the feedback of the power control commands can be neglected

comparing with the rapid fading. On the other hand, small-scale fading can result in such rapid variations in the signal power that even the power control can't follow them.

Another approach to minimize fading effect in a system is to supply multiple replicas of the transmitted signal to the receiver which already have passed through different fading channels. The result of this approach is that the probability that all replicas of the signal will fade simultaneously is reduced [1]. This is called diversity and it is effectively and commonly used to overcome degradation in performance due to interference and fading. If there is D number of fading channels and the probability of any one channel may fade under some threshold is P , then the probability of all D signals which fade below the threshold is P^D . The number of diversity channel D is called diversity order in the system.

4.2 Diversity Branches:

Diversity in wireless radio communication is originated at various sources and this diversity can be achieved by several techniques. Moreover, several methods can be combined to obtain higher diversity and its advantage. A diversity technique needs a number of transmitted signal paths which are called diversity branches. These diversity branches carry the same information with uncorrelated multi-path fading. A circuit also needed to combine the received signals or need to select one of them. There are a number of methods to construct a diversity branches depending on the land mobile radio propagation characteristics.

4.3 Diversity Techniques:

Diversity technique is used to decreased the fading effect and improve system performance in fading channels. In this method, we obtain L copies of desired signal through M different channels instead of transmitting and receiving the desired signal through one channel. The main idea here is that some the signal may undergo fading channel but some other signal may not. While some signal might undergo deep fade, we may still be able to obtain enough energy to make right decision on the transmitted symbol from other signals. There is a number of different diversity which is commonly employed in wireless communication systems. Some of them are following:

- Multipath/frequency diversity
- Spatial/space diversity
- Temporal/time diversity
- Polarization diversity
- Angle diversity
- Antenna diversity

4.3.1 Multipath or Frequency Diversity:

In a channel, Transmitted signals with different frequencies are affected different way in frequency domain. The fact is an advantage in frequency diversity technique. Multiple replicas of information signal are sent over several affected frequency band in this diversity [5]. There should be a distance more than coherent bandwidth between the frequency bands and achieve small-scale fading according to following equation.

$$(\Delta f)_c \approx \frac{1}{f_d}$$

Moreover, frequency hopping (FH) might be use to achieve such kind of diversity instead of sending multiple frequency replicas over different affecting frequencies. Frequency band can be changed many times per symbol in fast frequency hopping (FFH) and this results frequency diversity on each transmitted symbol. This process is very beneficial in an environment where there is a partial band jamming in channel [5]. However, a different frequency band is used for a burst of symbol in slow frequency hopping (SFH). If SFH is combined with time domain coding and interleaving, it is seen as like an additional block interleaving in the frequency domain. This kind of spreading of information in a frequency domain introduces frequency diversity benefit.

Frequency diversity can also be implied as in the case of multipath diversity. Transmission of a wideband signal is given by the following equation where the bandwidth is more than the coherence bandwidth $(\Delta f)_c$ of the previously used channel and this results a frequency selective fading [3].

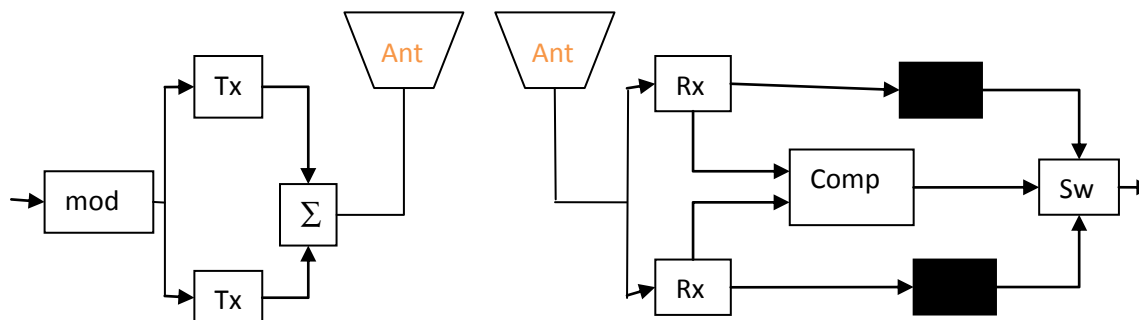
$$(\Delta f)_c \approx \frac{1}{T_m}$$

In a sufficient wide signal bandwidth, multipath components can resolve. In the result, it is possible to obtain different independently fading signal. The number of resolvable multipath given by the following equation is used to approximate the maximum achievable diversity order for multipath diversity:

$$L = [T_m W] + 1$$

Channel equalization is another approach to achieve multipath diversity. A filter is used at receiver to make channel equalization to compensate the channel impairments. This process combines the multipath of signals and reduces inter-symbol-interference (ISI) and produce diversity.

In general, the information signals are modulated through different carriers M in frequency diversity scheme. It is important that different signals undergo independent fading. The carriers should be separated by at least coherent bandwidth from each other. L copies of signals are optimally combined at the receiver to make a statistic decision. The maximum ratio combiner is the optimal combiner.



Picture 10: Frequency Diversity

4.3.2 Spatial/Space Diversity:

Multiple antennas are used to transmit signals with carrying information at the transmitter and/or receiver to provide multiple independent fading paths in space diversity. This technique is used to provide significant performance gain with not sacrificing any valuable bandwidth on the transmitted power resources. Spatial diversity is widely used because it is easy to implement and it's cost effective and very simple. This technique has a single transmitting but multiple receiving antennas. The receiving antennas should be at enough distance for that the multiple fading in the diversity will be uncorrelated. There should be a balanced average power between channels and the correlation coefficient should be very low to achieve a good diversity gain [9]. While wide distance is required between antennas for obtaining low correlation between channels but close distance is also required to synthesize to make a narrow beam not generating grating lobes which prevent introducing interference. Only one or two co-channel interfering signals are used in time division multiple access (TDMA) systems. However, the number of signals is more in code division multiple access (CDMA) the maximal ratio combining (MRC) is better than the performance of optimum adapting processing. It is suggested that if we increase antenna element separation as much as feasible the then high space diversity gain can be achieved with maximal ratio combining in a CDMA system. Most of the cellular communication system has only one transmitting antenna at the base station and two receiving antennas those are widely separated per sector in a space diversity system.

In general, if we want to receive M copies of transmitted signals then we need M number of antennas in a space diversity system [7]. It is very important to keep enough space between the antennas so that the received signals undergo independent fading. Space diversity is different than frequency and temporal diversity. Unlike those spaces diversity needs no additional work at the transmission end and no additional bandwidth is required on the transmission time.

On the other hand, physical complexity restricts its application widely. Like several receiving antennas use in space diversity, several transmission antennas also can be used to send several copies of transmitted signals. This kind of diversity can be employed combating frequency and time selective fading both.

There are two types of spatial diversity techniques such as receive diversity and transmit diversity.

4.3.2.1 Receive Diversity:

Multiple antennas are use at the receiver to obtain diversity and employ switching and combining or selection intending to improve the quality of received signal. Since it is easier and cost effective to use multiple antennas at the base station than the terminal which is a positive manner of receive diversity. This technique may utilize channel state information (CSI) at receiver and it's fully fit for uplink which is remote to base. But the main problems of receive diversity are cost, size and necessary power at the remote units. This technique is larger in size and expensive in cost because of multiple antennas, radio frequency chains or selections and its switching circuits.

4.3.2.2 Transmit Diversity:

Unlike receive diversity, transmit diversity needs multiple transmitting antennas. Moreover, unlike receive diversity, transmit diversity does not utilize CSI in its single information signal. Effective signal processing technique should be used to extract the noisy and distorted received signal in transmit diversity.

4.3.3 Time / Temporal Diversity:

Interleaving and coding, over symbols across different coherent time periods, is used to obtain time or temporal diversity. This technique utilizes coding of channel and interleaving to mitigate channel fading at a cost of added delay and loss of bandwidth efficiency. It is uses on slow fading channels and on the channels which is delay sensitive.

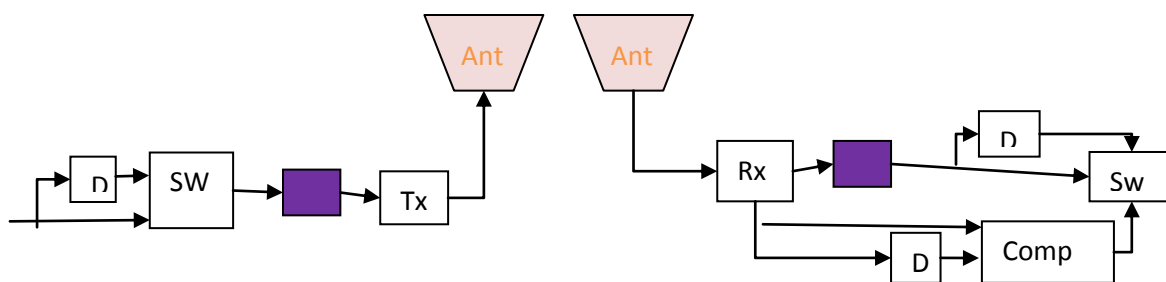
Intentional redundancy is introduced into the transmitted signal to achieve time diversity in the temporal domain. Redundancy can be done by repetition of channel coding. To make repetition coding, information bearing signals are transmitted in several time slots. But the separation between time slots should be more or equal than the coherent time of the channel to obtain independent faded signals which helps to gain full diversity advantages. Moreover, it

is possible to obtain repetition coding by spreading in direct-sequence code division multiple access (DS-CDMA).

Channel coding, when there is an error control capability, may be performed separately or with modulation. If we want to perform coding and modulation separately, then we can use conventional error control coding to achieve redundancy in the form of extra symbols. The advantage to this case is that the transmission of extra symbols leads to lower efficiency in system bandwidth. On the other hand, if we want to perform coding and modulation together (the process also called as coded modulation) then the redundancy comes from the channel-set expansion. But the most beneficial process is coded modulation because it is bandwidth efficient since it allows error control coding without increasing the bandwidth.

If the successive channel symbols are independent and the channel is Rayleigh fading then the effective minimum time diversity of the channel code is equal to its lowest hamming distance in signal symbols. But the problem is that if the fading is not very fast then there are no successive and independent channel symbols. As a result we can't achieve full diversity in the system. Longer fade duration with slower fading results burst errors if there is no use of interleaving or effective burst error corresponding codes. The purpose of the interleaving is to impose further spread out in time coded signal symbols to achieve independent errors at the place of burst error. Therefore, a code is used which is capable to correct errors.

In general, a desired signal is transmitted in M different periods of time in time diversity. For example, every symbol is transmitted M times. As it is mentioned earlier that intervals between the transmitted symbols should be at least coherence time to make ensure that different copies of the same symbol undergo independent fading. Maximum ratio combiner can be used to obtain optimal combiner [10]. If we send the same symbol M times then it applies the $(M, 1)$ repetition code. We can also use non-trivial coding. Error control coding and interleaving is an effective way to combat time selective or fast fading.



Picture 11: Time diversity

4.3.4 Polarization Diversity:

In polarization diversity, transmitted signals have uncorrelated fading statistics in VHF and VHF land mobile radio system when signals should be transmitted through two orthogonally propagations path [6].

Spatial diversity may achieve by using multiple antennas with independent polarizations in the same location instead of multiple antennas in use in different locations. This is the method of polarization diversity. If an implementation of spatial diversity with small dimensions is desired, this is very attractive process. Normally two orthogonally polarized antennas are used on horizontal and vertical planes or with a slope of $\pm 15^\circ$ to employ polarization diversity [6]. Experiments show that polarization diversity may obtain in dense scattering environments when there is line of sight (LOS) and non-line of sight (non-LOS) situations.

4.3.5 Angle Diversity/ Pattern Diversity / Direction Diversity:

Equal data traffic is used on the both uplink (reverse link) and downlink (forward link) in digital cellular communication but the system requires better reverse link performance because of the limitation of mobile terminal transmit power. There is uplink capacity deployed in CDMA system due to synchronize operation on forward link and asynchronous operation on reverse link [7] [6]. If we need to achieve better uplink reliability then we can use space diversity or polarization diversity. On the other hand, there is a huge demand of data applications on downlink capacity comparing to the uplink capacity. Improvement of reliability or downlink capacity is a major issue in three generation mobile system and the other generation mobile communication systems in future. One promising solution to improve downlink capacity is forming beam on downlink. It can also be implemented by forming multiple fixed narrow beams or by steering a beam toward a user in the system. Additional protection which the angle diversity provides is protection from deep multipath fading in multiple beam systems. It is experimentally proved that the angle diversity is equally effective as conventional space diversity in dense urban area and it provides approximately 8 dB diversity gain at reliability level with selection combining.

A multiple fixed narrow-beam antenna or an array antenna, which is fully adaptive, transmits and receives much more energy between the mobile terminal and base station comparing to a wide beam antenna system [9]. On the other hand, a beam forming system using multiple antennas may experiences multipath fading sometimes when the multipath components are applied from very close angles. The base station antenna system in a dense urban environment experiences antenna gain reduction and the multipath components will spread in wider angles. In this case, it is wise to use angle diversity to avoid deep multipath fading by choosing the best beam to collect energy. The size of the angle diversity is very smaller comparing to the space diversity system where we need the wide separation between the receiving antennas.

This diversity system needs a number of directional antennas those responds independently to wave propagation. An antenna response to a wave propagates at a specific angle and receives a faded signal which is uncorrelated with other signals.

Multipath components in a cluster those have individual arrival angles travel through different paths and employ different fading. Very basic procedure to obtain angle diversity is to fix antennas with narrow beam widths different sector in the system. Then the arriving multipaths from the different beam directions are resolved and combined advantageously. This procedure not only creates diversity but also increases the antenna gain and reduces interference by providing angular discrimination. It is mentioned earlier that one more method of achieving diversity is to use antenna array with adaptive beam forming which termed as path diversity sometimes.

4.3.6 Antenna Diversity:

Antenna diversity is a popular and extensively used technique to improve performance in wireless communication systems. The technique reduces fast fading and inter-channel interference effects in the wireless network system. In an antenna diversity system, two or more antennas are used and fixed in positions which will provide uncorrelated signals with the same power level. Then the signals are combined and created an improved signal. The basic method of antenna diversity is that the antennas experiences different kind of signals because of individual channel conditions and the signals are correlated partially. Then we can expect that if one signal from one antenna is highly faded, other signals from other antennas are not faded such way and these signals are our expected quality signals. In a multipath propagation environment, each receiving signal experiences individual fading characteristic.

4.4 Why we use Transmit Diversity:

Sometimes, a base station has to serve for hundreds of thousands remote units. Therefore, it is cost saving to add the necessary equipments to the base stations instead of the remote units. This is the main reason that transmit diversity is very attractive to the wireless service operators. For example, for covering service area of a base station, one antenna and one transmit chain can be added to that base station to improve the reception quality of all the remote units under the base station. Transmit diversity is more effective than receive diversity for increasing the forwarding link that is the bottleneck in broadband asymmetric applications such as browsing internet and downloading files.

4.5 Types of Transmit Diversity Techniques:

There are three types of transmit diversity techniques:

- Schemes using feedback
- Schemes using forwarding feed without feedback
- Blind schemes

In the feedback schemes, the scheme uses either direct or indirect feedback from the receiver to the transmitter to adjust the channel conditions. Indirect feedback can be used in time division duplex (TDD) systems due to reciprocal channel in uplink and downlink. The same diversity combining system, used for received signals from multiple antennas, can be converted to distribute and weight for the transmission signals from multiple antennas. Indirect feedback accuracy depends on the channel change during the dwell time between the uplink and downlink transmission. In the direct feedback the receiver provides the transmission information about the preferred weighting of the transmission antennas based on the measurement of the receiver. The feedback information amount is a tradeoff between antenna weighting accuracy and data throughput reduction of the uplink.

The next category schemes use feed forward information to compensate the receiver response in the channel. The pilot symbol insertion is the commonly used method to obtain channel estimation for coherent detection. For spreading the information across antennas, this diversity schemes use feed forward information and linear processing at the transmitter. In the reception section, the schemes estimate the state of the channel based on pilot symbols using maximum-likelihood decoding sequence.

The last schemes category does not need feedback or feed forward information. Non-coherent or differential detection is used generally in these schemes because coherent detection without feed forward may be impossible due to fast fading. The phase sweeping transmit diversity is one example of blind schemes. We may need to combat burst error due to slow fading by using two transmit antennas, which are uncorrelated spatially, to generate force fading. After that the interleaving depths and short block codes are used for making correction of forward error. Quaternary differential phase shift keying (QDPSK) with differential detection is used in these schemes category.

Again there are two main classes of transmit diversity, they are:

- Close-loop transmit diversity and
- Open-loop transmit diversity

The close-loop (CL) uses a feedback channel to send Channel state information (CSI) required at the receiver. The receiver sends back to transmitter which uses for signal design while the Open-loop does not need CSI. On the condition of availability of CSI, which is ideal meant error free and instantaneous, at the transmitters, close-loop techniques have an SNR advantage of $10 \log_{10} (M_t)$ over open-loop techniques due to the factor of ‘array gain’ [5]. But there are some other factors which are responsible to degrade the performance of close-loop techniques such as channel estimation errors at the receiver, errors in feedback link (for noise, interference, quantization effects), and feedback delay. Amongst them, feedback delay causes a mismatch between the available CSI and the actual CSI. All of these factors combined with extra bandwidth and system complexity resources. The process make open-loop technique more attractive as a robust means for improving downlink performance for high mobility applications while close-loop techniques become attractive under low-mobility applications.

Delay diversity is one simple example for open-loop diversity. In a delay diversity scheme employed for a single base station, where the symbols are transmitted different times through multiple antennas, creates an artificial multipath distortion. It is essential to resolve the multipath distortion. For that, a Maximum Likelihood Sequence Estimator (MLSE) or a Minimum Mean Square Error (MMSE) equalizer is used then obtain the targeted diversity gain. So the main theme of delay diversity is that to transmit of the same information for M antennas simultaneously with individual delay and the operating flat fading channel intentionally into a frequency selective channel.

4.6 Capacity of Receive and Transmit Diversity:

Theoretically, receive diversity along with optimum combining improves capacity significantly in fading channels. The capacity of receive diversity, transmit diversity and combined receive-transmit diversity can be derived in the case of complex AWGN based on the Shannon’s classical formula. But the capacity should be derived with independent components at each of the receiver branches, and Rayleigh fading with independent fading on each of the diversity branches.

The capacity of receiver diversity with possible combining can be presented by following equation:

$$C = \log_2 (1 + \gamma \chi_{2M}^2)$$

Where γ = average signal to noise ratio (SNR) at each of the receiver branches.

M= Number of receiver diversity branches

χ_{2M}^2 = Random variable formed by summing M random variables of χ_2^2 .

The power gain of the Rayleigh fading channel is Random variable χ_2^2 with unit variance. The probability density function (PDF) of χ_{2M}^2 is a central chi-square with variance $1/2$ and zero mean. Representation of random variable χ_{2M}^2 means the variation of received power from the branches of fading diversity. In the result, the fading channel capacity is a random variable.

However, in the transmit diversity, the total transmitted power distributed amongst the transmitted antennas. As a result the average signal-to-noise-ratio (SNR) of transmitted signal components from the branches of diversity is a fraction of total SNR at the receiver. Therefore, if the number of transmitting antenna is J then the capacity of the transmit diversity is:

$$C = \log_2 \left(1 + \frac{\gamma}{J} \chi_{2J}^2 \right)$$

Here $\frac{1}{J} \chi_{2J}^2 \rightarrow 1$, using the large number rule. So, the capacity becomes as Gaussian capacity $C = \log_2 (1 + \gamma)$. The fact is applicable when the number of transmitting antennas increases. The practical gain in term of capacity is very little if more than four transmit antenna and only one receive antenna is used.

If we use combined transmit-receive diversity then the capacity is absolutely greater than if we use only receive diversity. The minimum level of capacity gain for a combined transmit-receive diversity when $J \geq M$ is:

$$C > \sum_{i=J-(M-1)}^J \log_2 \left(1 + \frac{\gamma}{J} \chi_{2M}^2 \right)$$

The upper level of capacity for transmit-receive diversity is:

$$C < \sum_{i=1}^J \log_2 \left\{ 1 + \left(\frac{\gamma}{J} \right) \chi_{2M}^2 \right\}$$

Here the transmitted signal components are un-coupled and there is no interference in the received signal. It is observable that the capacity of combined transmit-receive diversity increases linearly as a function of J when $J \geq M$. It is feasible to obtain almost all the diversity capacity by using six transmit antennas and two receive antennas.

Chapter 5

Combining Techniques of Diversity

If we want to get benefit from diversity technique then we must need to combine some diversity technique to get advantage. Therefore, diversity combining concepts are described in this chapter, in section 5.2, we described Maximal-ratio Combining (MRC), in section 5.3, we described Equal-gain Combining (EGC) and in section 4.4, we described Selection Combining (SC). Above three combining systems are our main focuses and applied in experiments to improve performance in wireless communication systems. Block diagram of combining methods are drawn in this chapter. Switched combining method, Periodic combining method, Phase-sweeping methods are described shortly and their diagrams also drawn in this chapter.

5.1 Concepts of Diversity Combining Techniques:

It is important to combine the uncorrelated faded signals which were obtained from the diversity branches to get proper diversity benefit. The combining system should be in such a manner that improves the performance of the communication system. Diversity combining also increases the signal-to-noise ratio (SNR) or the power of received signal. Mainly, the combining should be applied in reception; however it is also possible to apply in transmission. There are many diversity combining methods available but only three of them are going to be discussed here.

- Maximal ratio combining (MRC)
- Equal gain combining (EGC)
- Selection combining (SC)

The combining processes which use to combine multiple diversity branches in the reception, has two classes such as post-detection combining and pre-detection combining. The signals from diversity branches are combined coherently before detection in pre-detection combining. However, signals are detected individually before combining in post-detection. The performance of communication system is the same for both combining techniques for coherent detection. However, the performance of communication system is better by using pre-detection combining for non-coherent detection. It does mean that there is no effect in performance by the type of combining procedure for the coherent modulation case. The post-detection combining is not complex in non-coherent detection, results very common in use. There is a difference in system performance when used pre-detection combining and post-detection combining for non-coherent detection such as frequency modulation (FM) discriminator or differential detection schemes. Moreover, the terms pre-detection and post-

detection are also indicates the time of combining means when the combining is performed, before or after the hard decision.

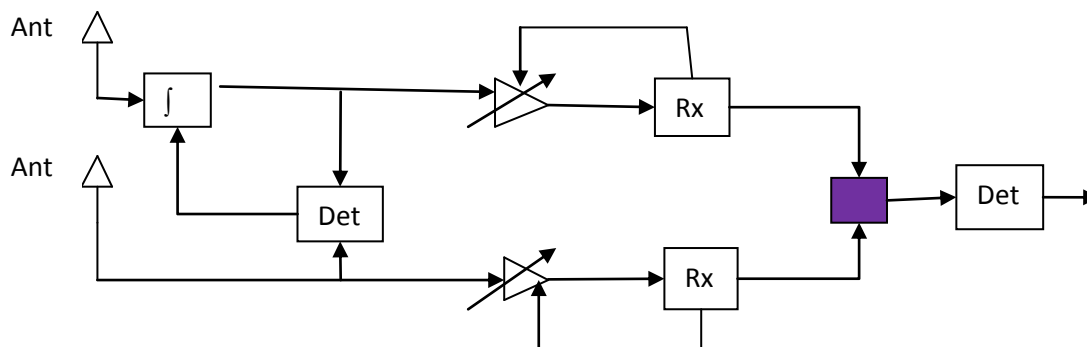
Squire-law non-coherent combining is employed frequently in diversity reception when non-coherent modulation methods are used. The demodulator outputs of all diversity branches are squired and summed to form a decision variable when used squire-law pre-detection combining. The system performance is decreased in non-coherent combining comparing to coherent combining and the degradation is called combining loss.

5.2 Maximal Ratio Combining (MRC):

This is a very useful combining process to combat channel fading. This is the best combining process which achieves the best performance improvement comparing to other methods. The MRC is a commonly used combining method to improve performance in a noise limited communication systems where the AWGN and the fading are independent amongst the diversity branches. But the MRC employment needs summing circuits, weighting and co-phasing. In the MRC combining technique, the signals from different diversity branches are co-phased and weighted before summing or combining. The weights have to be chosen as proportional to the respective signals level for maximizing the combined carrier-to-noise ratio (CNR). The applied weighting to the diversity branches has to be adjusted according to the SNR. For maximizing the SNR and minimizing the probability of error at the output combiner, signals of d^{th} diversity branch is weighted before making sum with others by a factor, $c_d^* / \sigma_{n,d}^2$. Here $\sigma_{n,d}^2$ is noise variance of diversity branch d^{th} and c_d^* is the complex

conjugate of channel gain [1]. As a result the phase-shifts are compensated in the diversity channels and the signals coming from strong diversity branches which has low level noise, are weighted more comparing to the signals from the weak branches with high level of noise. The term $\sigma_{n,d}^2$ in weighting can be neglected conditioning that $\sigma_{n,d}^2$ has equal value for all d. Then the realization of the combiner needs the estimation of gains in complex channel and it does not need any estimation of the power of noise.

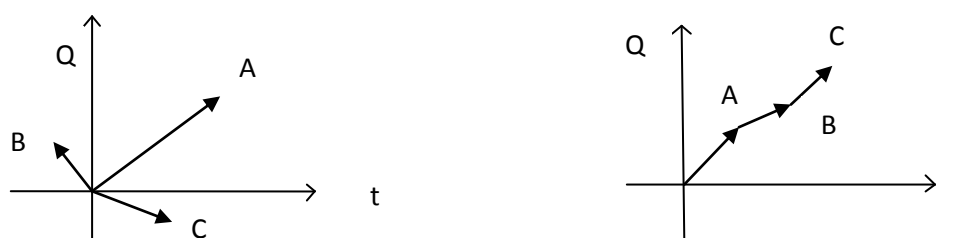
It is feasible to employ MRC in transmission process of transmit diversity. But in this case the transmitter should get proper feedback information about the sub-channels state between single receive antenna and multiple transmit antennas. However, it is not feasible to weight transmissions from multiple antennas optimally for every receiving antenna, in a combined transmit-receive diversity channel. Moreover, if interference is limited in a communication system, then there is a scheme which combines the diversity branches in order to maximize the signal-to-interference-plus-noise ratio may allow much better performance than MRC provides. The assumption is valid for spatially white Gaussian noise if we can observe noise power at the receiver where just thermal noise is accounted. If we use the same type antenna elements then the thermal noise power is uncorrelated and equal for each branch.



Picture 12: Maximal-ratio combining (MRC)

5.3: Equal-gain Combining (EGC):

MRC is the most ideal diversity combining but the scheme requires very expensive design at receiver circuit to adjust the gain in every branch. It needs an appropriate tracking for the complex fading, which very difficult to achieve practically. However, by using a simple phase lock summing circuit, it is very easy to implement an equal gain combining. The EGC is similar to MRC with an exception to omit the weighting circuits. The performance improvement is little bit lower in EGC than MRC because there is a chance to combine the signals with interference and noise, with the signals in high quality which are interference and noise free. EGC's normal procedure is coherently combined the individual signal branch but it non-coherently combine some noise components according to following figure:



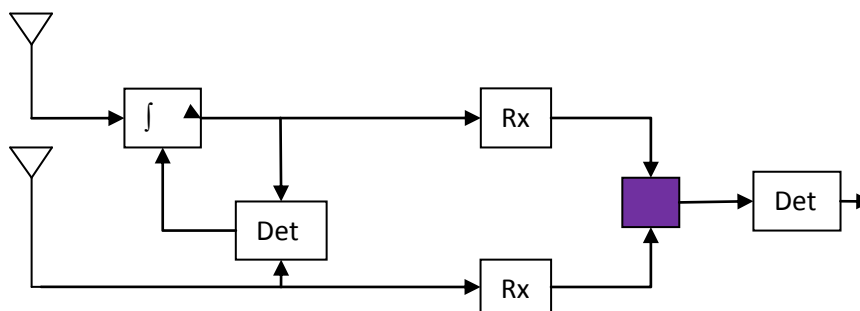
(1) Non-coherent branch signal.

(2) Coherent combining

Picture 13: Concept of coherent combining, complex signal diagram illustration.

The EGC can employ in the reception of diversity with coherent modulation. The envelope gains of diversity channels are neglected in EGC and the diversity branches are combined

here with equal weights but conjugate phase. The structure of equal-gain combining (EGC) is as following since there is no envelope gain estimation of the channel.



Picture 14: Equal gain combining (EGC)

5.4 Selection Combining (SC):

MRC and EGC are not suitable for very high frequency (VHF), ultra high frequency (UHF) or mobile radio applications. Realization of a co-phasing circuit with precise and stable tracking performance is not easy in a frequently changing, multipath fading and random-phase environment. SC is more suitable comparing to MRC and EGC in mobile radio application because of simple implementation procedure. In SC, the diversity branch which has the highest signal level has to be selected. Therefore, the main algorithm of this method is on the base of principle to select the signal amongst the all signals at the receiver end. If there is even a fast multipath fading environment, the stable operation easily can be achieved. It is experimentally proved that the performance improvement achieved by the selection combining is just little lower than performance improved achieved by an ideal MRC. As a result the SC is the most used diversity technique in wireless communication.

The general form of selection combining is to monitor all the diversity branches and select the best one (the one which has the highest SNR) for detection. Therefore we can say that SC is not a combining method but a selection procedure at the available diversity. However, measuring SNR is quite difficult because the system has to select it in a very short time. But selecting the branch with the highest SNR is similar to select the branch with highest received power when average power of noise is the same on each branch. Therefore, it is practical to select the branch which has the largest signal composition, noise and interference. If there is an availability of feedback information about the channel state of the diversity branch the selection combining also can be used in transmission.

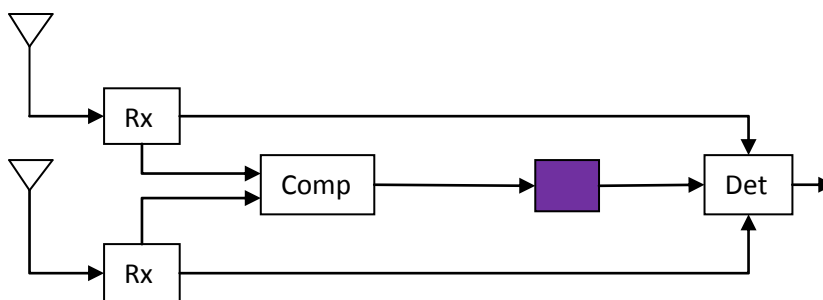
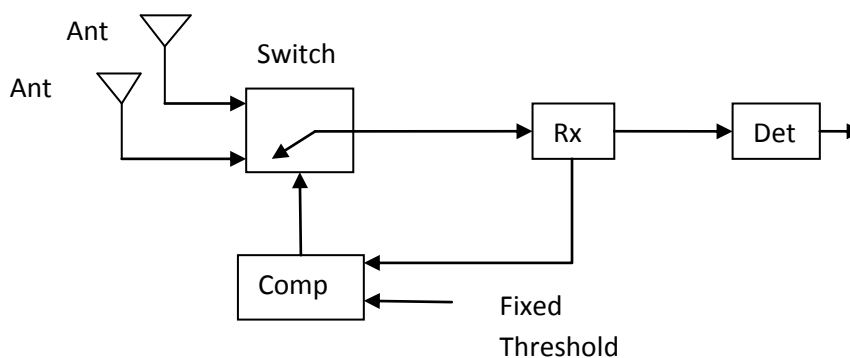


Figure: Selection combining (SC)

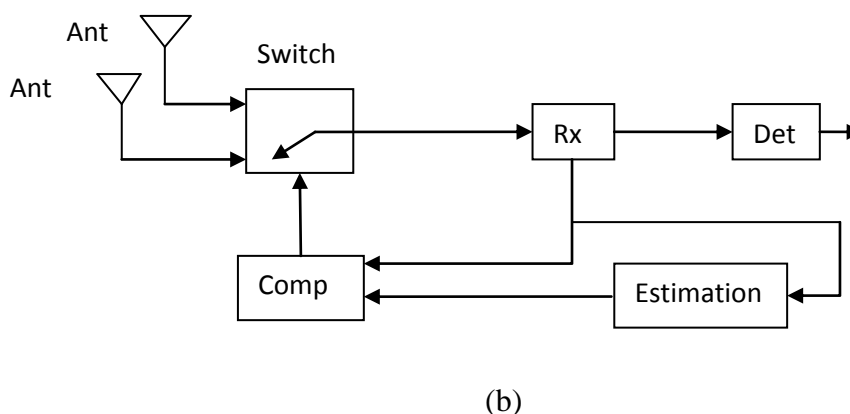
5.5 Switched Combining (SWC):

It is impractical to monitor the all diversity branches in selection combining. In addition, if we want to monitor the signals continuously then we need the same number of receivers and branches. Therefore, the form of switched combining is used to implement selection combining. According to the figure (a), switching from branch to branch occurs when the signal level falls under threshold. The value of threshold is fixed under a small area but the value is not the best necessarily over the total service area. As a result the threshold needs to be set frequently according to the movement of vehicle fig (b). It is very important to determine the optimal switching threshold in SWC. If the value of threshold is very high, then the rate of undesirable switching transient increases. However, if the threshold is very low then the diversity gain is also very low. The switching of switch combining can be performed periodically in the case of frequency hopping systems.

Performance improvement obtained by the switching method leys on the value of threshold selection, the delay of time that creates from the loop of feedback of monitoring estimation, switching and decision. Moreover, phase transients and envelope of a carrier can reduce the improvement of performance. In the system of angle modulation, for example, GSM, the phase transient is responsible to create errors in detection stream of data. In this case, a pre-detection band pass filter may be used to remove envelope transients.



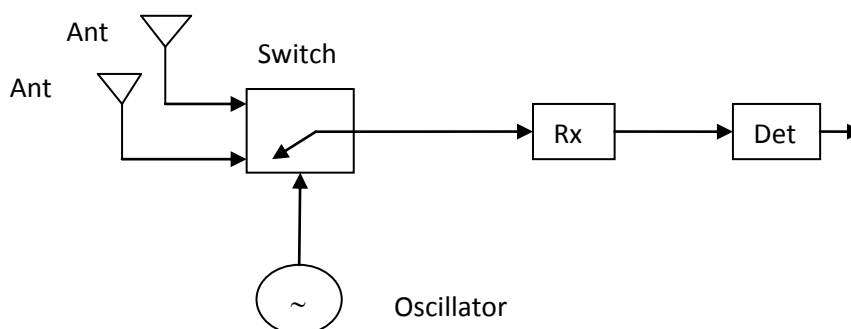
(a)



Picture 15: Switching combining methods with fixed threshold (a) and variable threshold (b).

5.6 Periodic Switching Method:

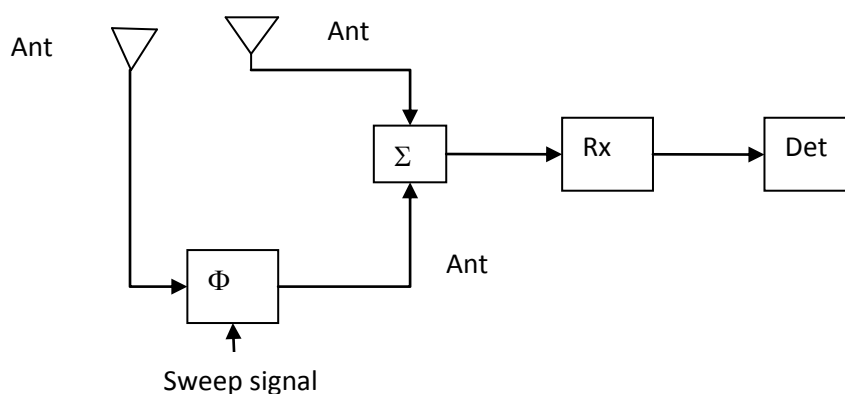
In a simple switching method, the diversity branches are selected periodically by a conventional, free-running oscillator. This procedure is useful in comparably large deviational and low-speed frequency modulation systems which includes phase transients creates by switching can be diminished. The only selectable parameter switching rate can be chosen as twice the height of the bit rate of signal. As a result the signal of the better branch can select per signaling period. The performance can be improved as the same amount as it does at conventional switching method by using FM discriminator which follows a suitable low-pass filter (LPF). However, performance improvement may reduce in adjust-channel area because this channel spectrum may be folded into desired channel band by periodic switching in the pre-detection radio frequency stage. So we can see an overlap here which can be solved by rising selectivity of the adjust-channel at the receiver.



Picture 16: Periodic switching method

5.7 Phase Sweeping Method:

Phase sweeping method is another version of switching method which uses a single receiver. In phase sweeping method sweeping rate is more than twice the highest frequency of modulation signal. But we can gain the same diversity improvement which we achieve by the periodic switching method. The phase sweeping method is as like mode-averaging method where spaced antennas are used with electrically scanned directional patterns. On the other hand, Phase sweeping method may be applicable to Digital Phase Shift Keying (DPSK) and FM systems.



Picture 17: Phase sweeping combining.

CHAPTER 6

Performance Analysis of Different Combining Techniques

To analyze the performance the performance of several combining techniques, necessary mathematical equations are written and obtained. Section 6.1 describes the performance of maximal ratio combining. In section 6.2 Carrier to Noise Ratio (CNR) and Carrier to Interference Ratio (CIR) are examined in the cases of with and without diversity. The equations for CNR and CIR are obtained in the case of Maximal-ratio Combining (MRC), Equal-gain Combining (EGC) and Selection Combining (SC). The calculations used in this chapter were taken from [1] and some of them were calculated.

6.1 Performance of Maximal Ratio Combining:

If we consider that the fading is constant over one symbol period, the bit error probability of maximal-ratio combined the Quadrature Phase Shift Keying (QPSK) with gray coding over Rayleigh fading of D diversity branches. Which are corrupted by AWGN and having equal Signal to noise ratio. Then the equation of the bit error probability is:

$$Pb = \frac{1}{2} \left[1 - \frac{\mu}{\sqrt{2-\mu^2}} \sum_{d=0}^{D-1} \binom{2d}{d} \left(\frac{1-\mu^2}{4-2\mu^2} \right)^d \right] \text{----- (6.1)}$$

Where μ is depends on the type of channel estimation and can be interpreted as cross correlation coefficient. μ cab be expressed using following equation in the case of coherent detection in conditioning perfect channel estimation.

$$\mu = \sqrt{\frac{\gamma_c}{1+\gamma_c}} \text{----- (6.2)}$$

γ_c is received SNR for every diversity channel in average. The equation of M-array Phase Shift Keying (PSK) in the corresponding SNR per bit is:

$$\gamma_b = \frac{D\gamma_c}{\log_2 M} \text{----- (6.3)}$$

A QPSK signal can be expressed as two Binary Phase Shift Keying (BPSK) signals in phase quadrature [3]. As a result, if there is no cross talk or interference between signals on two quadratures then the bit error probability for QPSK and BPSK is similar. If there is no additional interference in an AWGN channel then the noise in the in-phase and quadrature components is independent. Therefore, the equation of bit error probability of coherent BPSK is used to find the bit error probability of coherent QPSK or the reverse way. On the other

hand, if the bit error probability is a function of γ_c , the received SNR per channel in average must be normalized by the number of bits per symbol in QPSK.

The bit error probability in AWGN channel is expressed by the following equation:

$$P_b = Q(\sqrt{2\gamma_b}) \text{-----} (6.4)$$

The equation (5.1) can't apply if the SNR in all branches are identical. If the mean SNR of all diversity branches are distinct then the bit error probability for coherent QPSK is defined by:

$$P_b = \frac{1}{2} \sum_{d=1}^D \pi_d \left(1 - \sqrt{\frac{\gamma_d}{2+\gamma_d}} \right) \text{-----} (6.5)$$

Here

$$\pi_d = \prod_{i=1}^D \frac{\gamma_d}{\gamma_d - \gamma_i} \text{-----} (6.6)$$

The estimated correlation between two diversity branches is equal. In such dual diversity, the bit error probability of QPSK and BPSK with MRC for correlated fading is:

$$P_b = \frac{1}{4\rho} \left\{ (1 + \rho) \left[1 - \sqrt{\frac{(1+\rho)\gamma_b}{2+(1+\rho)\gamma_b}} \right] - (1 - \rho) \left[1 - \sqrt{\frac{(1-\rho)\gamma_b}{2+(1-\rho)\gamma_b}} \right] \right\} \text{-----} (6.7)$$

6.2 Performance Improvement in the case of Carrier-to-Noise Ratio (CNR) and Carrier-to-Interference Ratio (CIR):

Here we need to investigate a diversity system with two branches using pre-detection combining. Practically, mobile radio systems use these systems very effectively. We need to define the statistics of CNR and CIR without diversity summing a Rayleigh fading model. In CNR, γ is proportional to the square of a Rayleigh distributed signal envelope (Reference). The probability density function (pdf) of γ is expressed by the exponential distribution equation, ($\gamma \geq 0$)

$$p(\gamma) = \frac{1}{\Gamma} e^{-\frac{\gamma}{\Gamma}} \text{-----} (6.8)$$

Here the average of γ is Γ .

In the case of CIR, λ is the ratio of squared signal envelope to squared interference envelope. Both of the envelopes are independent and Rayleigh distributed random variables. The pdf of λ ($\lambda \geq 0$) is F-distribution and measured by the equation,

$$p(\lambda) = \frac{\Lambda}{(\lambda + \Lambda)^2} \text{-----} (6.9)$$

The average value of λ is Λ .

Let the CNR of each diversity branch γ_i , where $i=1, 2$ and let the CNR of combined branch λ .

The three combining method is expressed by the following equations,

$$\gamma = \gamma_1 + \gamma_2 \text{ for the case of maximal-ratio-combining -----(6.10a)}$$

$$\sqrt{\gamma} = \sqrt{\frac{\gamma_1}{2}} + \sqrt{\frac{\gamma_2}{2}} \text{ for the case of equal gain combining ----- (6.10b)}$$

$$\gamma = \begin{cases} \gamma_1 & \dots \dots \dots \gamma_1 > \gamma_2 \\ \gamma_2 & \dots \dots \dots \gamma_1 < \gamma_2 \end{cases} \text{ for the case of selection or switching -----(6.10c)}$$

Rayleigh fades are independent on the diversity branches and faded signals have equal average power such as $\Gamma = \Gamma_1 = \Gamma_2$.

Here Γ_i ($i=1,2$) means the average value of γ_i ($i=1,2$). The equations of pdf for the three combining methods of γ are:

$$p(\gamma) = \frac{\gamma}{\Gamma^2} e^{-\frac{\gamma}{\Gamma}} = \frac{\gamma}{\Gamma^2} \text{ Maximal-ratio-combining ----- (6.11a)}$$

$$p(\gamma) = \frac{4}{3} \frac{\gamma}{\Gamma^2} \text{ Equal gain combining ----- (6.11b)}$$

$$p(\gamma) = \frac{d}{d\gamma} \left\{ \left(1 - e^{-\frac{\gamma}{\Gamma}} \right)^2 \right\} = 2 \frac{\gamma}{\Gamma^2} \text{ Selection or switching combining----- (6.11c)}$$

It is approximated that $\gamma \ll \Gamma$. The probability that γ does not exceed the specified value of γ_s , can be calculated by the integral,

$$\text{prob}[\gamma \leq \gamma_s] = \int_0^{\gamma_s} p(\gamma) d\gamma \text{ ----- (6.12)}$$

In the same way, the pdf of λ can be expressed by following equations,

$$p(\lambda) = \frac{d}{d\lambda} \left[\left(\frac{\lambda}{\lambda + \Lambda} \right)^2 \right] \text{ Maximal-ratio combining ----- (6.13a)}$$

$$p(\lambda) = \frac{d}{d\lambda} \left[\left(\frac{\lambda}{\lambda + \frac{\sqrt{3}\Lambda}{2}} \right)^2 \right] \text{ Equal gain combining ----- (6.13b)}$$

$$p(\lambda) = \left[\frac{2\Lambda}{(\lambda + \Lambda)^2} - \frac{2\Lambda}{(2\lambda + \Lambda)^2} \right] \text{ Selection or switching combining ----- (6.13c)}$$

This has been assumed a perfect-pilot co-phasing scheme for maximal ratio and equal gain combining methods. However, comparably larger desired signal power algorithm assumed for

selection combining method. The mutual correlation within four Rayleigh fades which is visible on desired signals and the interference which is undesired found at respective branches are negligible. As like as average CNRs, average CIRs are equal to each. Therefore, $A = A_1 = A_2$. The value of out-age is,

$$prob[\lambda \leq \lambda_s] = \int_0^{\lambda_s} p(\lambda) d\lambda \quad \text{----- (6.14)}$$

6.3 Average Probability of Error (p_e) Performance Improvement:

The reduction of permissible value (p_e) of CNR and CIR is considered for the performance improvement of diversity techniques. Extensive study taken place about diversity improvement which effects on the average (p_e) performing at multipath radio fading transmission channels. The effects of nonselective envelope fades have been taken into account to analyze diversity improvements for digital land mobile radio transmission systems. We are going to discuss a two branch prediction diversity improvement effects on the average (p_e) performance of minimum shift keying (MSK) wireless communication systems in a nonselective Rayleigh fading environment.

The resultant study of the simplest MSK diversity systems can be useful in advance modulated wireless diversity structures.

6.3.1 Carrier-to-Noise Ratio (CNR) vs p_e Performance Improvement:

Taking a case study where the effect of co-channel interference (CCI) is ignored. Using an ideal selection method, we consider the average (p_e) vs CNR performance in two condition such as with diversity [$p_e^{(2)}(I)$] and without diversity [$p_e^{(1)}(I)$]. Both are expressed from the equations (5.8) and (5.11c) mentioned before.

$$[p_e^{(2)}(I)] = \int_0^\infty p_e(\gamma) \frac{d}{d\gamma} \left\{ (1 - e^{-\frac{\gamma}{I}})^2 \right\} d\gamma \quad \text{----- (6.15)}$$

$$[p_e^{(1)}(I)] = \int_0^\infty (\gamma) \frac{1}{I} e^{-\frac{\gamma}{I}} d\gamma \quad \text{----- (6.16)}$$

Here $p_e(\gamma)$ is static p_e vs CNR performance in the non-fading channel. As a result the relationship between [$p_e^{(1)}(I)$] and [$p_e^{(2)}(I)$] is as following,

$$[p_e^{(2)}(I)] = 2[p_e^{(1)}(I)] - p_e^{(1)}\left(\frac{I}{2}\right) \quad \text{----- (6.17)}$$

In the similar way following equation is obtained for maximal-ratio combining using the equation (5.10a),

$$\left[p_e^{(2)}(I) \right] = \left[p_e^{(1)}(I) \right] - \frac{1}{\Gamma} \frac{\partial}{\partial \left(\frac{1}{\Gamma} \right)} \left[p_e^{(1)}(I) \right] \quad \text{----- (6.18)}$$

These relationships can also be used for the case of M-branches diversity reception instead of 2-branch.

Using relationship obtained in Feher and [p_e⁽¹⁾(I)] in the case of non-diversity MSK modulation, we get

$$\left[p_e^{(1)}(I) \right] = \frac{1}{2} \left[1 - \frac{\Gamma}{[(\Gamma+1)(\Gamma+\frac{4}{3})]^{\frac{1}{2}}} \right] \quad \text{----- (6.19a)}$$

$$= \frac{7}{12\Gamma} \quad \text{in the case of discriminator detection}$$

$$\left[p_e^{(1)}(I) \right] = \frac{1}{2} \left[1 - \frac{A}{(A+1)} \right] \quad \text{----- (6.19b)}$$

$$= \frac{1}{2\Gamma} \quad \text{In the case of differential detection.}$$

$$\left[p_e^{(1)}(I) \right] = \frac{1}{2} \left[1 - \sqrt{\frac{\Gamma}{(\Gamma+1)}} \right] \quad \text{----- (6.19c)}$$

$$= \frac{1}{4\Gamma} \quad \text{In the case of coherent detection}$$

Now we substitute equations from (6.19) into equation (6.17) to find the equations for [p_e⁽²⁾(I)] in selection method,

$$\left[p_e^{(2)}(I) \right] = \frac{1}{2} \left[1 - \frac{2\Gamma}{[(\Gamma+1)(\Gamma+\frac{4}{3})]^{\frac{1}{2}}} \right] + \frac{1}{2} \left[\frac{\Gamma}{[(\Gamma+2)(\Gamma+\frac{8}{3})]^{\frac{1}{2}}} \right] \quad \text{----- (6.20a)}$$

$$= \frac{11}{8\Gamma^2} \quad \text{In the case of discriminator detection}$$

$$\left[p_e^{(2)}(I) \right] = \frac{1}{(\Gamma+1)(\Gamma+2)} \quad \text{----- (6.20b)}$$

$$= \frac{1}{\Gamma^2} \quad \text{In the case of differential detection}$$

$$\left[p_e^{(2)}(I) \right] = \frac{1}{2} \left[1 - 2\sqrt{\frac{\Gamma}{(\Gamma+1)}} \right] + \frac{1}{2} \sqrt{\frac{\Gamma}{(\Gamma+2)}} \quad \text{----- (6.20c)}$$

$$= \frac{3}{4\Gamma^2} \quad \text{In the case of coherent detection}$$

Again, we substitute equations from (6.19) into equation (6.18) to find $[p_e^{(2)}(\Gamma)]$ in the case maximal ratio combining method,

$$[p_e^{(2)}(\Gamma)] = \frac{1}{2} \left[1 - \frac{\Gamma}{[(\Gamma+1)(\Gamma+\frac{4}{3})]^{\frac{1}{2}}} - \frac{\Gamma(\frac{2}{6}\Gamma+\frac{4}{3})}{[(\Gamma+1)(\Gamma+\frac{4}{3})]^{\frac{3}{2}}} \right] \text{----- (6.21a)}$$

$$= \frac{11}{8\Gamma^2} \quad \text{In the case of discriminator detection}$$

$$[p_e^{(2)}(\Gamma)] = \frac{1}{2(\Gamma+1)^2} \text{----- (6.21b)}$$

$$= \frac{1}{2\Gamma^2} \quad \text{In the case of differential detection}$$

$$[p_e^{(2)}(\Gamma)] = \frac{1}{2} \left[1 - \sqrt{\left(\frac{\Gamma}{\Gamma+1}\right)} + \frac{1}{2} \sqrt{\left(\frac{\Gamma}{(\Gamma+1)^3}\right)} \right] \text{----- (6.21c)}$$

$$= \frac{3}{16\Gamma^2} \quad \text{In the case of coherent detection}$$

5.3.2 P_e Vs carrier-to-interference (CIR) performance improvement:

The case we consider here is ‘the effect of co-channel interference is the major cause of error’. The deviation of the P_e -Vs-CNR performance and the P_e -Vs-CIR performance is equal.

The final equations in maximal ratio combining method are [1],

$$[p_e^{(2)}(\Lambda)] = \frac{1}{2(\Lambda+1)^2} \text{----- (6.22a)}$$

$$= \frac{1}{2\Lambda^2} \quad \text{In the case of discriminator detection}$$

$$[p_e^{(2)}(\Lambda)] = \frac{1}{2} \left[1 - \frac{2\Lambda}{[(\Lambda+1)^2 - (1/\pi)^2]^{\frac{1}{2}}} + \frac{\Lambda^2(\Lambda+1)}{[(\Lambda+1)^2 - (\frac{1}{\pi})^2]^{\frac{3}{2}}} \right] \text{----- (6.22b)}$$

$$= \frac{1}{2\Lambda^2} \left(1 + \frac{2}{\pi^2} \right)$$

$$= \frac{1}{2\Lambda^2} \quad \text{In the case of different detection}$$

$$[p_e^{(2)}(\Lambda)] = \frac{1}{2} \left[1 - \frac{3}{2} \sqrt{\frac{\Lambda}{(\Lambda+1)}} + \frac{1}{2} \sqrt{\frac{\Lambda^3}{(\Lambda+1)^3}} \right] \text{----- (5.22c)}$$

$$= \frac{3}{16\Lambda^2} \quad \text{In the case of coherent detection}$$

Chapter 7

Computational Method and Computational Result

7.1 Computational Method:

The parameters used in the equations and computations are:

γ = The instantaneous carrier-to-noise ratio (CNR)

λ = The instantaneous carrier-to-interference ratio (CIR)

$p(\gamma)$ = The probability density function (pdf) of γ

$p(\lambda)$ = The probability density function (pdf) of λ

Γ = The average value of γ

Λ = The average value of λ

γ_s = A specified value of γ

λ_s = A specified value of λ

p_e = Probability of error

$$\frac{E_b}{N_o} = \lambda_s, \gamma_s \text{ and average } \frac{E_b}{N_o} = \Gamma, \Lambda$$

Program 1:

Equation (6.12) for equations (6.8), (6.11a) and (6.11c) gives graphs in terms of probability distribution of γ versus the ratio (γ/Γ) in dB.

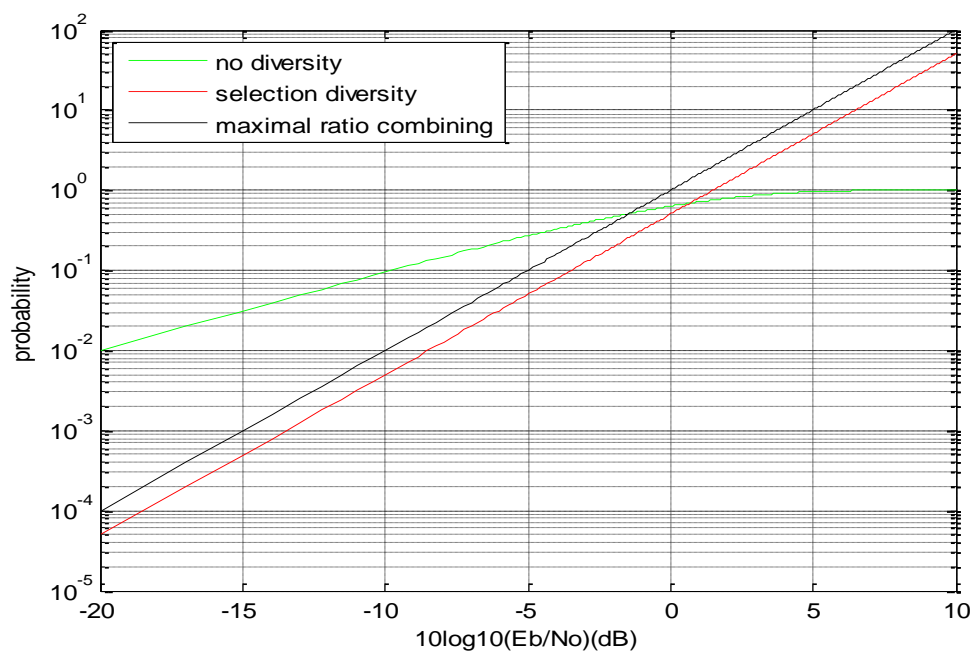


Figure 7.1: Cumulative probability distribution as function of CNR γ (Average CNR at 0 in X-axis).

Program2:

Equation (6.14) for equations (6.9), (6.13a) and (6.13c) gives graphs in term of probability distribution of λ versus the ratio (λ/Λ) in dB.

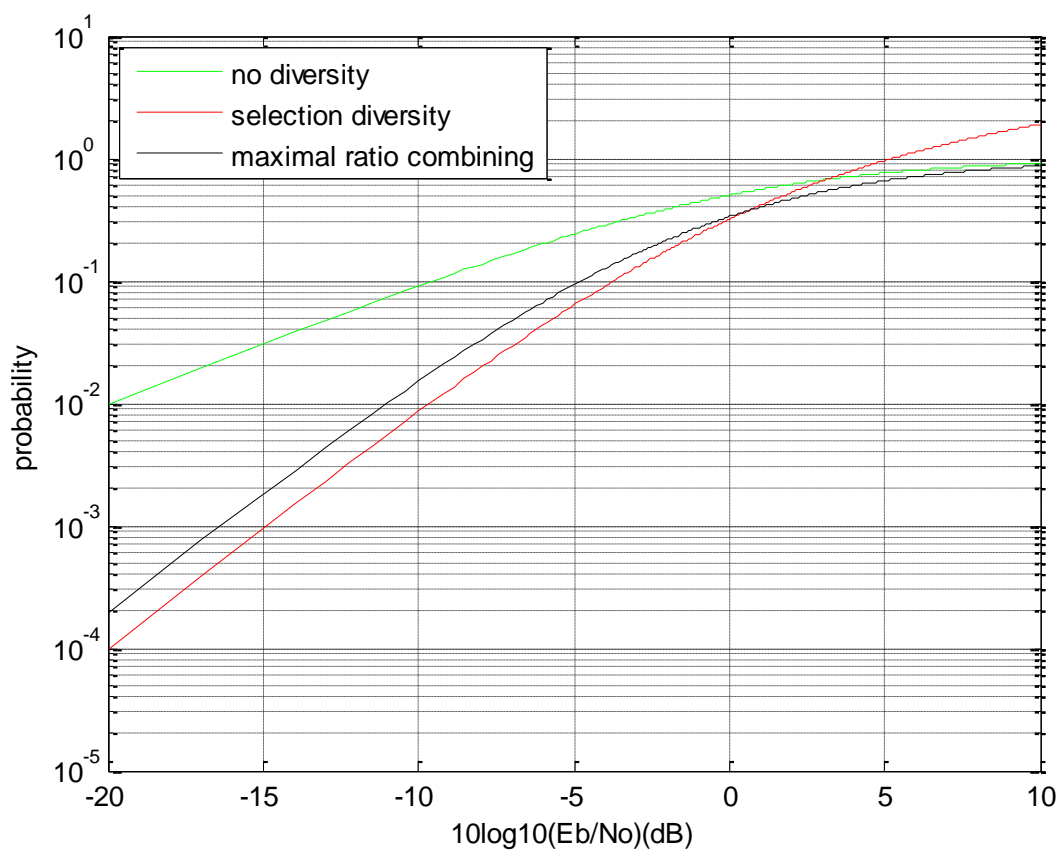


Figure 7.2: Cumulative probability distribution of CIR λ (Average CIR at 0 in X-axis)

Program3:

Equation (6.19) and (6.20) gives graphs for average p_e -versus-CNR performance for the selection method.

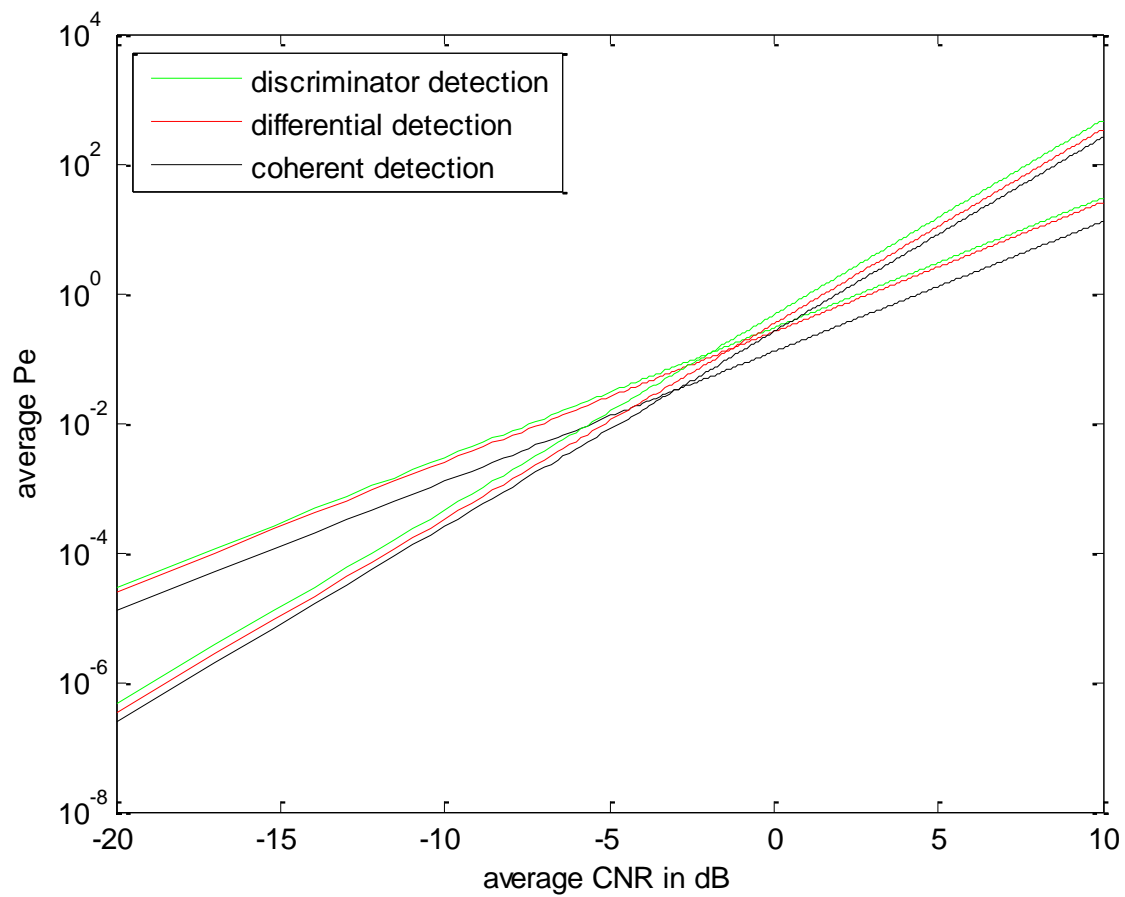


Figure7.3: Average P_e -versus-CNR performance for selection method.

Program4:

Equation (6.19) and (6.20) gives graphs for average p_e -versus-CNR performance for maximal-ratio-combining method.

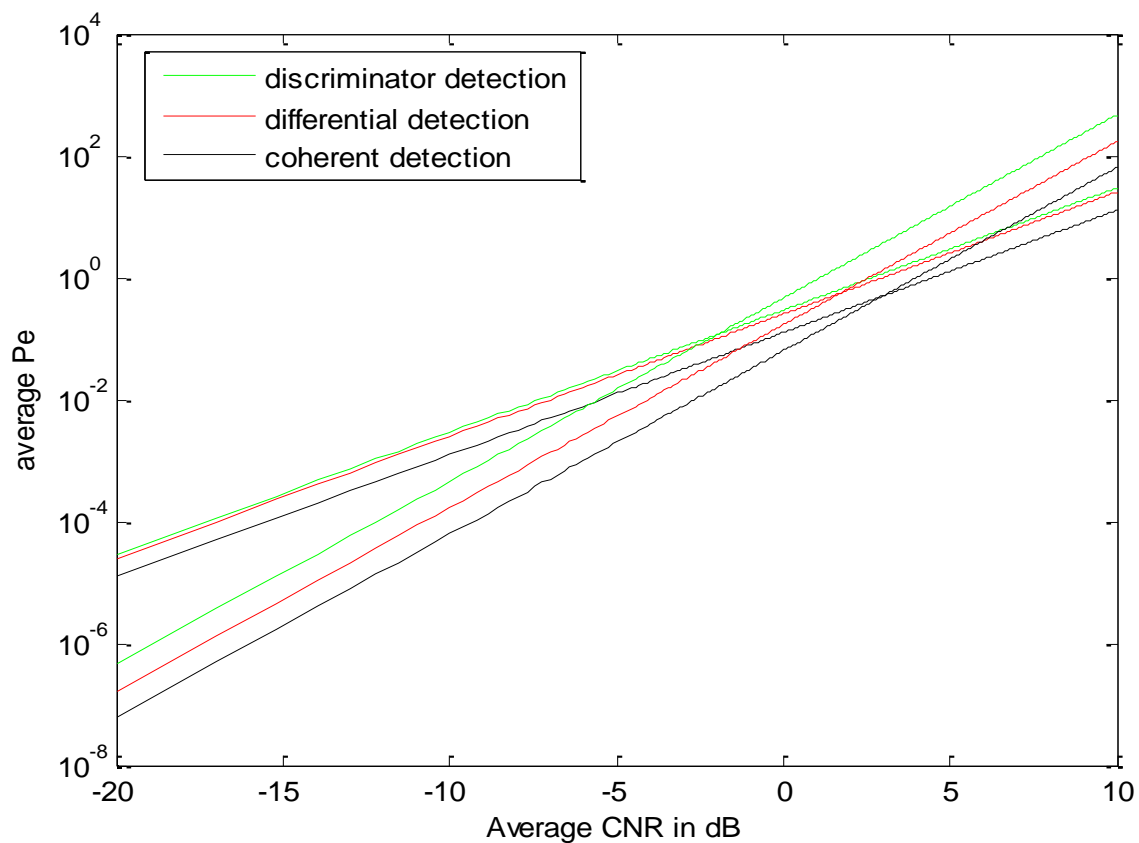


Figure 7.4: Average P_e -versus-CNR performance for the maximal ratio combining method.

Program5:

Equations (6.19a), (6.19c) and (6.22a), (6.22c) gives graphs for average p_e -versus-CIR performance for maximal ratio combining method.

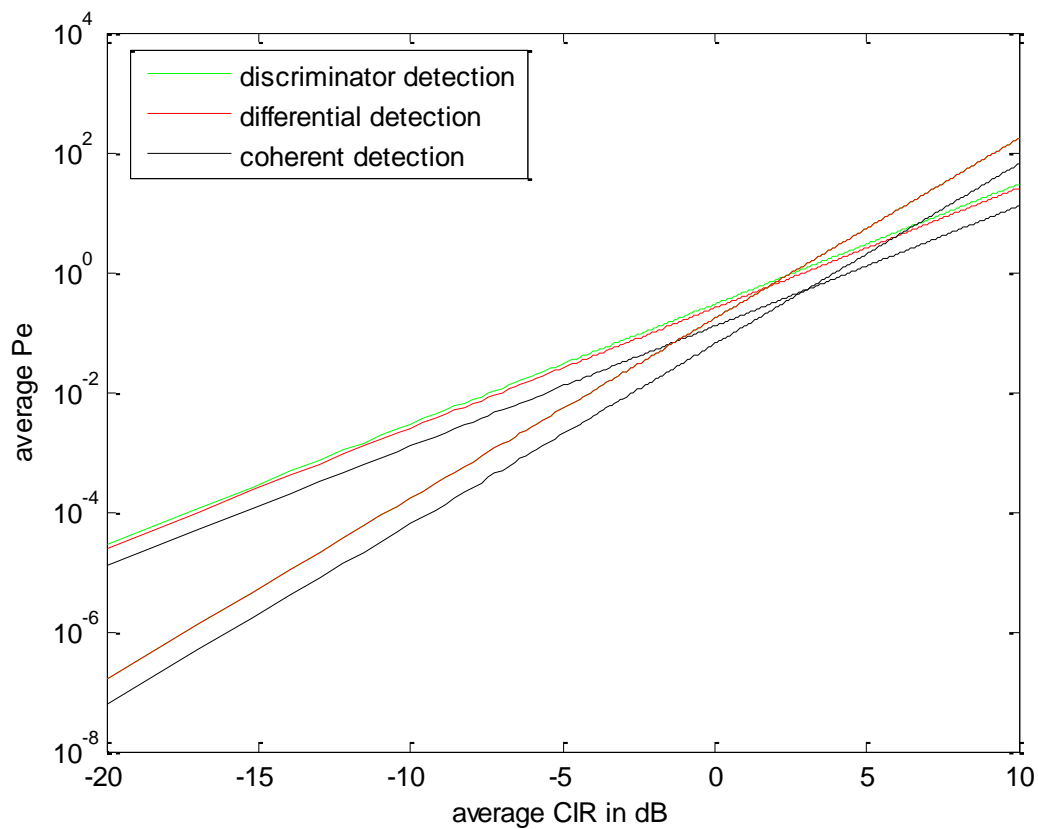


Figure 7.5: Average P_e -versus-CIR performance for the maximal ratio combining method.

7.2 Performance Analysis:

The performance improvement of diversity systems is expressed in terms of the permissible reduction of the minimum carrier-to-noise ratio (CNR) and carrier-to-Interference ratio (CIR) that are required to obtain a specified probability of error (P_e). The performance improvement is also evaluated in terms of the statistical reduction of the fading dynamic range of the average CNR and CIR.

The intention of this study is to investigate two branches ($N=2$) of diversity systems using pre-detection combining which is very useful and effective in radio mobile communications. The first examination is done to study the statistics of CNR and CIR without diversity concerning a Rayleigh fading model. The same experiment is done with diversity. The study for p_e -versus-CNR and p_e -versus-CIR performance improvements also has been done.

It can be concluded from figure 7.1 that the fading dynamic range of the instantaneous CNR γ is reduced remarkably by the use of the diversity techniques and there is only a slight difference among the performance improvements of the combining methods. Γ is the average value of γ . We considered average CNR at point 0 in X-axis.

In figure 7.2, it is shown that the fading dynamic range of the instantaneous CIR λ is reduced remarkably by diversity techniques. There is only a slight difference in performance improvements of the various combining methods. The Λ is the average value of λ . The probability is the probability that CIR λ is less than a determined value of λ . We considered average CIR at point 0 in Y-axis.

Figure 7.3 and 7.4 indicate that for a certain average P_e , a higher amount of average CNR is required for non-diversity system, while a smaller amount of CNR is required for a two branch diversity technique. Diversity improvement effect is shown in case of an MSK modulation system in nonselective Rayleigh-fading environment.

Figure 7.5 indicates that as in figure 7.3 and 7.4, in order to improve the average P_e at a particular time, it is only necessary to increase the CIR by a smaller factor when two-branch diversity improvement is available, whereas an increase of higher CIR is required in the case of no diversity reception. In this case MSK and FQPSK, modulated and coherently demodulated GMSK systems are considered in the Rayleigh-fading environment.

We can see that the maximal-ratio combining (MRC) achieves the best performance improvement comparing to other methods.

Chapter 8

Discussion and Conclusion

8.1 Discussion:

Communication is very important in this world. We have two types of communication such as wired communication and wireless communication. Wireless communication is divided into mobile communications and fixed wireless communications. Each type of communication has huge demand according to customers need in the market. Wireless communication have passing a revolutionary era to transmit data and information to remote area which we would not even imagine. Wireless data transmission gives us every opportunity to get all feasible necessary access to the world wherever we are and wherever we need from. It has gained exponential growth of subscribers during last 10 to 12 years and continues to expand everyday with new technology invention.

The uncertainty or randomness is the main characteristic of wireless communication. This randomness appears in users' transmission channel and users' location. Transmission of data and information is carried out in radio propagation environment. Again radio propagation environment has some basic limitations in performing in wireless communication systems. For such reasons, wireless communication suffers channels from much impairment which leads the overall system performance severally degradation.

Though there are many performance degradation factors in wireless communication channels but fading problem is the major impairment problem. Fading means the loss of propagation experienced by the radio signal on forward and reverse links. The signals which is received by mobile terminals come from several propagation paths those are called multi-path propagation. Reflection, diffraction and scattering of radio waves in natural and human made structures are the main causes to introduce multipath in propagation. The received signal at the receiver suffers magnitude and phase variation due to multiple paths of propagation. Those interfere themselves constructively and destructively. This variation of received signal is called multipath fading.

To improve the performance of those fading channels, diversity techniques are used. In diversity technique, the receiver is supplied multiple replicas of transmitting signals instead of one signal that have passed over different fading channels. As a result, the probability that all replicas of signals will fade simultaneously is reduced considerably.

For getting full benefit, uncorrelated faded signals are collected from diversity branches and combine in such manner that can improve the performance of communication systems. This is called diversity combining method and also used to optimize received signal power or signal-to-noise ratio (SNR). The main idea of diversity combining is to combine several copies of transmitted signals which were gone through independent fading in order to increase overall received SNR. This combining method can be used in receiver mainly.

The performance improvement of a diversity system means its ability to reduce the permissible values of carrier to noise ratio (CNR) and carrier to interference ratio (CIR) those are required to obtain specified probability of error (p_e). The performance improvement also can be evaluated in terms of statistical reduction of fading dynamic range of the average CNR and CIR.

8.2 Conclusion:

This paper describes the characteristics of the signal propagation and performance degradation issues in wireless communication channels. There are many impairment factors and fading is the major factor amongst them which degrades the performance of wireless communication system severally. Several types of diversity techniques are described which can be use to mitigate fading problem in the channels. Diversity is used to supply the receiver with several replicas of the same signal. Diversity combining techniques are used to improve the channels' performance without transmitting any additional power. If high received signal are de-correlated, the gain of diversity is also high. The performance of diversity system is expressed by its ability to reduce the value of carrier to noise ratio (CNR) and carrier to interference ratio (CIR) at a specified probability of error (p_e). The performance evaluated in terms of statistical reduction of the fading dynamic range of the average CNR and CIR. We have concluded that the fading dynamic range of the instantaneous CNR γ and instantaneous CIR λ is reduced remarkably by the use of diversity techniques. We have also seen there is only a slight difference between the combining methods. For a certain average of P_e , a higher amount of CNR and CIR is required for non-diversity systems, while a smaller amount of CNR and CIR is required for a diversity technique. We see that maximal-ratio combining (MRC) achieves the best performance improvement comparing to the other methods.

8.3 Future Work:

This work is limited within theoretical aspects for the lack of required practical instruments and time. If instruments are supplied various statistical data may be collected. There are two branch of diversity data considered but branches can be many. The study of MSK modulation system can be extended to more modern and advanced modulation techniques. Maximal ratio combing technique and selection combining technique are considered but another combining technique may be considered for more experiment. Performance analysis was limited within CNR and CIR but can be extend to other aspects. There is also possible space to analyze and compare several diversity performance improvements with each other. The users' geographical location is always uncertain. As a result the degradation factors are also uncertain. More study can be done to find more degradation factors and find the possible ways to mitigate them.

References:

- [1] Dr. Kamilo Feher, Wireless Digital Communication-Modulation and Spread spectrum Application. Prentice Hall of India, New Delhi, 2001.
- [2] Rappaport, Theodore S., Wireless Communications, Principles and practice, prentice hall PTR, 1996.
- [3] Saleh Faruque, Cellular Mobile Systems Engineering, Artech House, Boston, London, 1996.
- [4] Hafeth Hourani, 'An Overview of Diversity Techniques in Wireless Communication Systems', Post Graduate Course in Radio Communications. Helsinki University of Technology, Communications Lab, 2004/2005.
- [5] Siavash Alamouti, 'A simple Transmit Diversity Technique for Wireless Communications', IEEE Journal on selected areas in Communications, Vol. 16, No 8, October 1998.
- [6] Carl B. Dietrich, Kai Dietze, J. Raandall Nealy, Warren L. Stutzman, 'Spatial, Polarization and Pattern Diversity for Wireless Handheld Terminals', IEEE Transaction on Antennas and Propagation, Vol 49, No 9, September 2001.
- [7] P.L. Perini and C.L. Holloway, 'Angle and Space Diversity Comparisons in different Mobile Radio environments', IEEE transaction on Antenna and Propagation, Vol 46, June 1998.
- [8] R.G. Vaughan, J. B Andersen, ' Antenna Diversity in Mobile Communications', IEEE Transaction on Vehicular Technology, Vol 36, No 4, Nov 1987.
- [9] Xexian Li and Matti Latva-aho, ' Spatial Transmit diversity Techniques for MC-CDMA systems', Centre for Wireless Communication, University of Oulu, Finland, Sept. 2002.
- [10] J.H Winters, 'The impact of Antenna Diversity on the Capacity of Wireless Communication System,' IEEE Transaction of Communications, Vol 42, No. 2/3/4, April 1994.
- [11] William C.Y Lee, 'Mobile Cellular Telecommunications', McGraw-Hill Book Company, 1982.
- [12] <http://en.wikipedia.org/wiki/GSM>
- [13] Stefan Person, "Compendium in the course 'Wireless Communication', University of Kalmar, Sweden, 2007".
- [14] <http://www.itfacts.biz/402-mln-3g-subscribers-worldwide/7775>).
- [15] http://findarticles.com/p/articles/mi_m0EIN/is_2008_Feb_28/ai_n24354710/)

[16] Suhas N. Diggavi, Naofal Al-Dhahir, A. Stamoulis and A.R. Calderbank. " Great Expectations: The value of Spatial Diversity in Wireless Networks".

[17] <http://www.freepatentsonline.com/7206583.html>

[18] Asha Malhotra. 'Cellular Radio Performance Engineering', Prentice Hall of India, 2004.

The End

