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DIVERSITY

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ABSTRACT

Wireless communications is one of the big engineering success stories of the last 20 years, where the progress has been phenomenal. Companies that were completely unknown 20 years ago are now house hold names all over the world.

Wireless communications has been associated with cellular telephony and has had the highest impact on everyday lives. Nowadays, a large number of applications and requirements of wireless communications have been discovered and developed.

Wireless communications has faced a lot of physical and technical challenge like the multipath, spectrum limitations, etc... Wireless companies has discovered solutions for the challenges using (coding, diversity, etc…).

This project talks about how diversity ensures that same information reaches the receiver and fixes the fading problem through channels. A simple simulation which we will use to show how diversity works.

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INTRODUCTION

When looking at the history of communications, we find that wireless communications is actually the oldest form shouts and jungle drums did not require any wires or cables to function. At the same time, the need for bi-directional mobile communications emerged. Police departments and the military had obvious applications for such two-way communications, and were the first to use wireless systems with closed user groups.

A high-level description of the physical challenges to wireless communications systems. This will set the stage for the rest of the project, where these challenges will be discussed and investigated.

Even though advances in wireless communications seem to happen everyday, there are challenges that we have to overcome and it is these same challenges that lead to limitations within telecommunications. These include multipath propagation, spectrum limitation, energy limitations and user mobility, all of which we are going to discuss in further detail within chapter two.

Diversity is most efficient when the different transmission channels (also called diversity branches) carry independently fading copies of the same signal. The basic principle of diversity is that the receiver has multiple copies of the transmit signal, where each of the copies goes through a statistically independent channel with different methods and techniques. Diversity can be realized in several ways. Depending on the environment and the expected interference, designers can employ one or more of these methods to improve signal quality. In fact multiple methods are frequently used to further increase reliability.

Using simulation techniques in this project, we can obtain the Additive White Gaussian Noise, the effect of fading through the communication channel and how it can effect the signal. Finally by applying diversity we can eliminate the fading and by increasing the number of antennas, we can obtain better results closer to the results without fading.

In chapter one, we will discuss about how the transition from analog to digital communications took place. We will also discuss about the different types of communication services, as well as the requirements for different services.

In chapter two we will further discuss the problems that can face the wireless communications, starting with multipath, fading, intersymbol interference to the energy and user mobility.

In chapter three, we will go more in details in the diversity, diversity methods and how to make a combination of signals using selection diversity or switched diversity.

Chapter four shows the results of using the diversity for eliminating the fading and decreasing the number of errors in the signal.

Conclusion shows that the diversity can fix the fading through the communication channels by using its methods and techniques and making sure that the receiver gets the signal that has been transmitted.

CHAPTER ONE

WIRELESS SERVICES

1.1 Overview

Wireless communications is one of the big engineering success stories of the last 20 years not only from a scientific point of view, where the progress has been phenomenal, but also in terms of market size and impact on society.

Quite generally, there are two paths to developing new technical solutions: engineering driven, and market-driven. In the first case, the engineers come up with a brilliant scientific idea without having an immediate application in mind. As time progresses, the market finds applications enabled by this idea. In the other approach, the market demands a specific product, and the engineers try to develop a technical solution that fulfills this demand developed in the past 100 years. Then it follows a description of the types of services that constitute the majority of the wireless market today. Each of these services makes specific demands in terms of data rate, range, number of users, energy consumption, mobility, and so on.

1.2 History

When looking at the history of communications, we find that wireless communications is actually the oldest form shouts and jungle drums did not require any wires or cables to function. Even the oldest electromagnetic (optical) communications are wireless: smoke signals are based on propagation of optical signals along a line-of-sight connection. However, wireless communications as we know it started only with the work of Maxwell and Hertz, who laid the basis for our understanding of the transmission of electromagnetic waves. In 1898, Marconi made his well-publicized demonstration of wireless communications from a boat to the Isle of Wight in the English Channel. It is noteworthy that while Tesla was the first to succeed in this important endeavor, Marconi had the better public relations, and is widely cited as the inventor of wireless communications, receiving a Nobel Prize in 1909. In the subsequent years, radio (and later television) became widespread throughout the world.

1.2.1 The First Systems

At the same time, the need for bi-directional mobile communications emerged. Police departments and the military had obvious applications for such two-way communications, and were the first to use wireless systems with closed user groups. Military applications drove a lot of the research during, and shortly after, the Second World War. This was also the time when much of the theoretical foundations for communications in general were laid. Groundbreaking work: A mathematical theory of communications, appeared during that time, and established the possibility of error-free transmission under restrictions for the data rate and the signal-to-noise ratio. Some of the suggestions in that work, like the use of optimum power assignment in frequency-selective channels, are only now being introduced into wireless systems.[1]

The 1940s and 1950s saw several important developments: CB (Citizens' Band) radios became widespread, establishing a new way of communicating between cars on the road. Communicating with these systems was useful for transferring vital traffic information and related aspects within the closed community of the drivers owning such devices, but it lacked an interface to the public telephone system, and the range was limited to some 100 kilometers, depending on the power of the (mobile) transmitters. In 1946, the first mobile telephone system was installed in the U.S.A. (St. Louis). This system did have an interface to the PSTN (Public Switched Telephone Network), the landline phone system, though this interface was not automated, but rather consisted of human telephone operators. Despite the theoretical breakthrough, cellular telephony did not experience significant growth during the 1960s.

1.2.2 GSM and the Worldwide Cellular Revolution

Even though the public did not see a need for changing from analog to digital, the network operators knew better. Analog phones have a bad spectral efficiency, and due to the rapid growth of the cellular market, operators had a high interest in making room for more customers. Also, research in communications had started its inexorable turn to digital communications, and that included digital wireless communications as well. In the late 1970s and the 1980s, research into spectrally efficient modulation formats, the impact of channel distortions and temporal variations on digital signals, as well as multiple access schemes and much more was explored in research labs throughout the world. It thus became clear to the cognoscenti that the real-world systems would soon follow the research.[2]

Digital phones turned cellular communications, which was already on the road to success, into a blockbuster. In the year 2004, market penetration in Western Europe exceeded 80%, with some Scandinavian countries approaching the 100% mark (many people have two or three cell phones). Also the U.S.A. is exceeding the 50% mark, and Japan has about 70%. In absolute numbers, China has become the single biggest market, with some 300 million subscribers in 2004.

1.3 Types of services

1.3.1 Broadcast

The first wireless service was broadcast radio. In this application, information is transmitted to different, possibly mobile, users, see Fig 1.1.

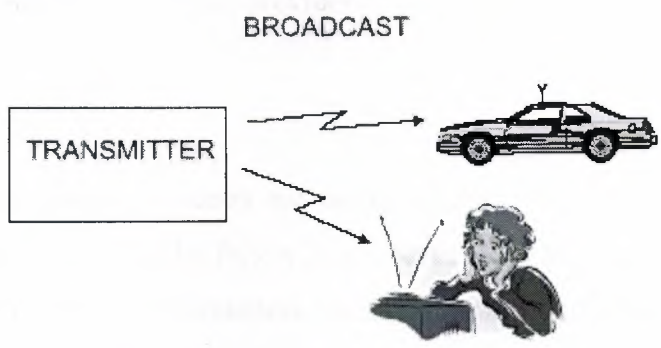

Figure 1.1 Principle of broadcast transmission.

For example, cellular telephony:

1. The information is only sent in one direction. It is only the broadcast station that sends information to the radio or TV receivers; the listeners (or viewers) do not transmit any information back to the broadcast station.
2. The transmitted information is the same for all users.
3. The information is transmitted continuously.
4. In many cases, multiple transmitters send the same information. This is especially true in Europe, where national broadcast networks cover a whole country, and broadcast the same program in every part of that country.

The above properties lead to a great many simplifications in the design of broadcast radio networks. The transmitter does not need to have any knowledge or consideration about the receivers. There is no requirement to provide for duplex channels (i.e., for bringing information from the receiver to the transmitter). The number of possible users of the service does not influence the transmitter structure either irrespective of whether there are millions of users, or just a single one, the transmitter sends out the same information.[3]

The above description has been mainly true for traditional analog broadcast TV and radio. Satellite TV and radio differ by the fact that often the transmissions are intended only for a subset of all possible users (pay-TV or pay-per-view customers), and therefore, encryption of the content is required in order to prevent unauthorized viewing. Note, however, that this problem is different from regular cell phones: for pay-TV, the content should be accessible to all members of the authorized user group, while for cell phones, each call should be accessible only for the single person it is intended for, and not to all customers of a network provider.

1.3.2 Paging

Similar to broadcast, paging systems are unidirectional wireless communications systems. They are characterized by the following properties (see also Fig 1.2):

1. The user can only receive information, but cannot transmit. Consequently, a call (message) can only be initiated by the call center, not by the user.
2. The information is intended for, and received by, only a single user.
3. The amount of transmitted information is very small. Originally, the received information consisted of a single bit of information, which indicated to the user that somebody has sent you a message. The user then had to make a phone call (usually from a payphone) to the call center, where a human operator repeated the content of the waiting message. Later paging systems became more sophisticated, allowing the transmission of short messages (e.g., a different phone number that should be called, or the nature of an emergency). Still, the amount of information was rather limited.

Due to the unidirectional nature of the communications, and the small amount of information, the bandwidth required for this service is small.

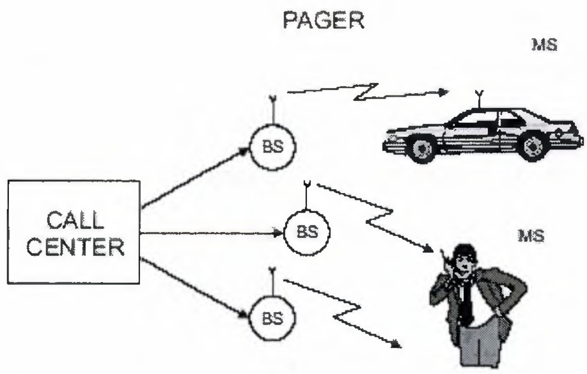

Figure 1.2 Principle of a pager.

This in turn allows the service to operate at lower carrier frequencies, e.g., 150 MHz, where only small amounts of spectrum are available. As we will see later on, such lower carrier frequencies make it much easier to achieve good coverage of a large area with just a few transmitters.

Pagers were very popular during the 1980s and early 1990s. For some professional groups, like doctors, they were essential tools of the trade, allowing them to react to emergencies in shorter time.

1.3.3 Cellular Telephony

Cellular telephony is the economically most important form of wireless communications. It is characterized by the following properties:

1. The information flow is bi-directional. A user can transmit and receive information at the same time.
2. The user can be anywhere within a (nationwide or international) network. Neither (s) he nor the calling party needs to know the user's location; it is the network that has to take the mobility of the user into account.
3. A call can originate from either the network, or the user. In other words, a cellular customer can be called, or initiate a call.
4. A call is intended only for a single user; other users of the network should not be able to listen in.
5. High mobility of the users. The location of a user can change significantly during a call.

Fig 1.3 shows a block diagram of a cellular system. A mobile user is communicating with a Base Station (BS) that has a good radio connection with that user. The BSs are connected to a mobile switching center, which is connected to the public telephone system. Since each user wants to transmit or receive different information, the number of active users in a network is limited. The available bandwidth must be shared between the different users.

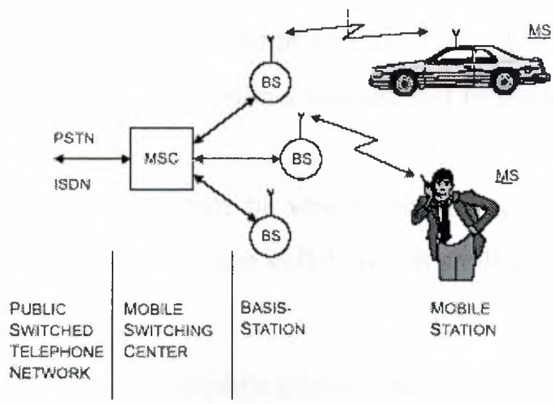

Figure 1.3 Principle of a cellular system

Important difference from broadcast systems, where the number of users (receivers) is unlimited, since they all receive the same information.

In order to increase the number of possible users, the cellular principle is used: the area served by a network provider is divided into a number of sub areas, called cells. Within each cell, different users have to share the available bandwidth: let us consider in the following the case that each user occupies a different carrier frequency. Even users in neighboring cells have to use different frequencies, in order to keep co-channel interference low. However, for cells that are sufficiently far apart, the same frequencies can be used, because the signals get weaker with increasing distance from their transmitter. Thus, within one country, there can be hundreds or thousands of cells that are using the same frequencies.

Another important aspect of cellular telephony is the unlimited mobility. The user can be anywhere within the coverage area of the network (i.e., is not limited to a specific cell), in order to be able to communicate. Also, (s) he can move from one cell to the other during one call. The cellular network interfaces with the PSTN, as well as with other wireless systems. As mentioned in section 1.2, cell phones started to become popular in the 1980s, and are now a dominant form of communications, with more than a billion users worldwide.

1.3.4 Trunking Radio

Trunking radio systems are an important variant of cellular phones, where there is no connection between the wireless system and the PSTN; therefore, it allows the communications of closed user groups. Obvious applications include police departments, fire departments, taxis, and similar services. The closed user group allows implementation of several technical innovations that are not possible (or more difficult) in normal cellular systems:

- Group calls: a communication can be sent to several users simultaneously, or several users can set up a conference call between multiple users of the system (Fig 1.4).

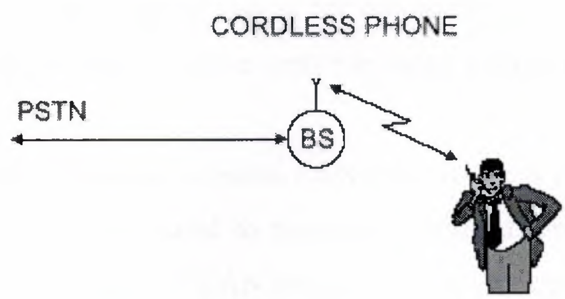

Figure 1.4 Principle of a simple cordless phone.

- Call priorities: a normal cellular system operates on a first-come, first-serve basis. Once a call is established, it cannot be interrupted. This is reasonable for cell phone systems, where the network operator cannot ascertain the importance or urgency of a call. However, for the trunk radio system of, e.g., a fire department, this is not an acceptable procedure. Notifications of emergencies have to go through to the affected parties, even if that means interrupting an existing, lower priority call. A trunking radio system thus has to enable a prioritization of calls, and has to allow dropping a low-priority call in favor of a high-priority one.
- Relay networks: the range of the network can be extended by using each Mobile Station (MS) as a relay station for other MSs. Thus, an MS that is out of the coverage region of the BS might send its information to another MS that is

within the coverage region, and that MS will forward the message to the BS; the system can even use multiple relays to finally reach the BS. Such an approach increases the effective coverage area and the reliability of the network. However, it can only be used in a trunking radio system and not in a cellular system normal cellular users would not want to have to spend their battery power on relaying messages for other users.

1.3.5 Wireless Local Area Networks and Personal Area Networks

The functionality of WLANs is very similar to that of cordless phones connecting a single mobile user device to a public landline system. The mobile user device in this case is usually a laptop computer, and the public landline system is the Internet. As in the cordless phone case, the main advantage is convenience for the user, allowing mobility. Wireless LANs can even be useful for connecting fixed location computers (desktops) to the Internet, as they save the costs for laying cables to the desired location of the computer.

A major difference between wireless LANs and cordless phones is the required data rate. While cordless phones need to transmit (digitized) speech, which requires branch exchange at most 64 kbit/s, WLAN devices can, in principle, connect to any BS (access point) that uses the same standard. However, the owner of the access point can restrict the access, e.g., by appropriate security settings.

An alternative form of WLANs is ad hoc networks (see Fig 1.5). In these networks, several computers set up a network in which all devices have the same functionality: communicating with each other. These networks therefore function without a BS and without any Internet connection at all. While the actual transmission of the data (i.e., physical-layer communication) is almost identical to that of normal WLANs, the medium access and the networking functionalities are very different. Ad hoc networks are usually restricted to a few devices and to a range of 10 m or less.

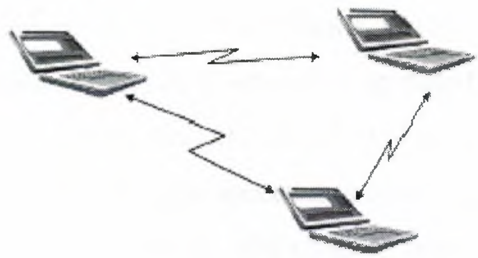

Figure 1.5 Principle of an ad hoc network.

1.3.6 Personal Area Networks

When the coverage area becomes even smaller than that of WLANs, we speak of Personal Area Networks (PANs). Such networks are mostly intended for simple cable replacement duties. For example, devices following the Bluetooth standard allow connecting a hands-free headset to a cellular phone without requiring a cable; in that case, the distance between the two devices is less than a meter. Similarly, wireless links between components in an entertainment system (DVD player to TV), between computer and peripheral devices (printer, mouse), and similar applications can be covered by PANs.

1.3.7 Satellite Cellular Communications

Besides TV, which creates the biggest revenues in the satellite market, cellular communications are a second important application of satellites. Satellite cellular communications have the same operating principles as land-based cellular communications. However, there are some key differences.

The distance between the BS (i.e., the satellite), and the MS is much larger: for geostationary satellites, that distance is 36,000 km; for Low Earth Orbit (LEO) satellites, it is several hundred kilometers. Consequently, the transmit powers need to be larger, high-gain antennas need to be used on the satellite (and in many cases also on the MS), and communications from within buildings is almost impossible.

Another important difference from the land-based cellular system lies in the cell size: due to the large distance between the satellite and the Earth, it is impossible to have cells with diameters less than 100 km even with LEO satellites; for geostationary satellites, the cell areas are even larger. This large cell size is the biggest advantage, as well as the biggest drawback, of the satellite systems. On the positive side, it makes it easy to have good coverage even of large, sparsely populated areas a single cell might cover most of the Sahara region. On the other hand, the area spectral efficiency is very low, which means that (given the limited spectrum assigned to this service) only a few people can communicate at the same time. The costs of setting up a BS, i.e., a satellite are much higher than for a land-based system. Not only is the launching of a communications satellite very expensive, but it is also necessary to build up an appropriate infrastructure of ground stations for linking the satellites to the PSTN.

As a consequence of all these issues, the business case for satellite communications systems is quite different: it is based on supplying a small number of users with vital communications at a much higher price. Emergency workers and journalists in disaster and war areas, ship-based communications, and workers on offshore oil drilling platforms are typical users for such systems. The INMARSAT system is the leading provider for such communications. In the late 1990s, the IRIDIUM project attempted to provide lower priced satellite communications services by means of some 60 LEO satellites, but ended in bankruptcy.

1.4 Requirements for the Services

A key to understanding wireless design is to realize that different applications have different requirements in terms of data rate, range, mobility, energy consumption, and so on. It is not necessary to design a system that can sustain Gigabit/s data rates over a 100-km range when the user is moving at 500 km/h. We stress this fact because there is a tendency among engineers to design a system that does everything but wash the dishes; while appealing from a scientific point of view, such systems tend to have a high price, and low spectral efficiency. In the following, we list the range of requirements encountered in system design, and we enumerate which requirements occur in which applications.

1.4.1 Range and Number of Users

Another distinction among the different networks is the range and the number of users that they serve. By range, we mean here the distance between one transmitter and receiver. The coverage area of a system can be made almost independent of the range, by just combining a larger number of BSs into one big network:

- Body Area Networks (BANs) cover the communication between different devices attached to one body, e.g., from a cell phone in a hip holster to a headset attached to the ear. The range is thus on the order of 1 m. BANs are often subsumed into PANs.
- Personal Area Networks include networks that achieve distances up to about 10 m, covering the personal space of one user. Examples are networks linking components of computers and home entertainment systems.
- Wireless Local Area Networks, as well as cordless telephones, cover still larger ranges, up to 100 m. The number of users is usually limited to about 10. When much larger numbers occur (e.g., at conferences or meetings), the data rates for each user decrease.
- Cellular systems have a range that is larger than, e.g., the range of WLANs. Micro cells typically cover cells with 500 m radius, while macro cells can have a radius of 10 or even 30 km. Depending on the available bandwidth and the multiple access scheme, the number of active users in a cell is usually between 5 and 50. If the system is providing high-speed data services to one user, the number of active users usually shrink
- Fixed wireless access services cover a range that is similar to that of cell phones namely, between 100 m and several tens of kilometers. Also, the number of users is of a similar order as for cellular systems.
- Satellite systems provide even larger cell sizes, often covering whole countries and even continents. Cell size depends critically on the orbit of the satellite: geostationary satellites provide larger cell sizes (1,000 km radius) than LEOs.

1.4.2 Mobility

Wireless systems also differ in the amount of mobility that they have to allow for the users. The ability to move around while communicating is one of the main charms of wireless communication for the user. Still, within that requirement of mobility, different grades exist:

- Fixed devices are placed only once, and after that time communicate with their BS, or each other, always from the same location
- Nomadic devices: nomadic devices are placed at a certain location for a limited duration of time (minutes to hours) and then moved to a different location. This means that during one drop (placing of the device), the device is similar to a fixed device.
- Low mobility: many communications devices are operated at pedestrian speeds. Cordless phones, as well as cell phones operated by walking human users are typical examples.
- High mobility usually describes speed ranges from about 30 km/h to 150 km/h. Cell phones operated by people in moving cars are one typical example.
- Extremely high mobility is represented by high-speed trains and planes, which covers speeds between 300 km/h and 1,000 km/h. These speeds pose unique challenges both for the design of the physical, and for the handover between cells.

1.4.3 Energy Consumption

Energy consumption is a critical aspect for wireless devices. Most wireless devices use (one-way or rechargeable) batteries, as they should be free of any wires, both the ones used for communication, and the ones providing the power supply.

- Rechargeable batteries: nomadic and mobile devices, like laptops, cell phones, and cordless phones, are usually operated with rechargeable batteries
- One-way batteries: sensor network nodes often use one-way batteries, which offer higher energy density at lower prices. Furthermore, changing the battery is often not an option; rather the sensor including the battery and the wireless transceiver is often discarded after the battery has run out. It is obvious that in

this case energy-efficient operation is even more important than for devices with rechargeable batteries.

- Power mains: BSs and other fixed devices can be connected to the power mains. Therefore, energy efficiency is not a major concern for them.
- The weight of an MS is determined mostly (70–80%) by the battery. Weight and size of a handset are critical sales issues.
- Also the costs of a cell phone (raw materials) are determined to a considerable degree by the battery.
- Users require standby times of several days, as well as talk times of at least 2 hours before recharging.

1.4.4 Use of Spectrum

Spectrum can be assigned on an exclusive basis, or on a shared basis. That determines to a large degree the multiple access scheme and the interference resistance that the system has to provide:

- Spectrum dedicated to service and operator: in this case, a certain part of the electromagnetic
- Spectrum is assigned, on an exclusive basis, to a service provider.
- Spectrum allowing multiple operators: Spectrum dedicated to a service: in this case, the spectrum can be used only for a certain service (e.g., cordless telephones in Europe and Japan), but is not assigned to a specific operator. Rather, users can set up qualified equipment without a license.
- Ultra wideband systems spread their information over a very large bandwidth, while at the same time keeping a very low power spectral density.
- Adaptive spectral usage: another approach relies on first determining the current spectrum usage at a certain location, and then employing unused parts of the spectrum.

CHAPTER TWO

TECHNICAL CHALLANGES OF WIRELESS COMMUNICATIONS

2.1 Overview

In the previous chapter, we have described the requirements for wireless communications systems, stemming from the applications and user demands. In this chapter, we will give a high-level description of the physical challenges to wireless communications systems. Most notably, they are:

- Multipath propagation: i.e., the fact that a transmit signal can reach the receiver via different paths (e.g., reflections from different houses or mountains);
- Spectrum limitations;
- Energy limitations;
- User mobility.

This will set the stage for the rest of the project, where these challenges, as well as remedies, will be discussed in more detail. As a first step, it is useful to investigate the differences between wired and wireless communications. Let us first repeat some important properties of wired and wireless systems, as summarized in Table 2.1.

2.2 Multipath Propagation

For wireless communications, the transmission medium is the radio channel between transmitter (TX) and receiver (RX). The signal can get from the TX to the RX via a number of different propagation paths. In some cases, a Line Of Sight (LOS) connection might exist between TX and RX. Furthermore, the signal can get from the TX to the RX by being reflected at or diffracted by different Interacting Objects (IOs) in the environment: houses, mountains (for outdoor environments), windows, walls, etc. The number of these possible propagation paths is very large. As shown in Fig. 2.1, each of the paths has a distinct amplitude, delay (runtime of the signal), direction of departure from the TX, and direction of arrival; most importantly, the components have different phase shifts with respect to each other. In the following, we will discuss some implications of the multipath propagation for system design.

Table 2.1 Wired and wireless communications

Wired communications	Wireless communications
The communication takes place over a more or less stable medium like copper wires or optical fibers. The properties of the medium are well-defined, and time-invariant.	Due to user mobility as well as multipath propagation, the transmission medium varies strongly with time.
Increasing the transmission capacity can be achieved by using a different frequency on an existing cable, and/or by stringing new cables.	Increasing the transmit capacity must be achieved by more sophisticate transceiver concepts and smaller cell sizes (in cellular systems), as the amount of available spectrum is limited.
The range over which communications can be performed without repeater stations is mostly limited by attenuation by the medium (and thus noise); for optical fibers, the distortion of transmitted pulses can also limit the speed of data transmission.	The range that can be covered is limited both by the transmission medium (attenuation, fading, and signal distortion) and by the requirements of spectral efficiency (cell size).
Interference and crosstalk from other users either do not happen, or the properties of the interference are stationary.	Interference and crosstalk from other users is inherent in the principle of cellular communications. Due to the mobility of the users, they also are time variant.
The delay in the transmission process is also constant, determined by the length of the cable, and the group delay of possible repeater amplifiers.	The delay of the transmission depends mostly on the distance between base station and mobile station, and is thus time-variant.

The Bit Error Rate (BER) decreases strongly (approximately exponentially) with increasing Signal-to-Noise Ratio (SNR). This means that a relatively small increase in transmit power can greatly decrease the error rate	For simple systems, the average BER decreases only slowly (linearly) with increasing average SNR. Increasing the transmit power usually does not lead to a significant reduction in BER. However, More sophisticated signal processing helps.
Due to the well-behaved transmission medium, the quality of wired transmission is generally high.	Due to the difficult medium, transmission quality is generally low unless special measures are used.
Jamming and interception of wired transmission is almost impossible without consent by the network operator.	Jamming a wireless link is straightforward, unless special measures are taken. Interception of the on air signal is possible. Encryption is therefore necessary to prevent unauthorized use of the information.
Establishing a link is location-based. In other words, a link is established from one outlet to another, independent of which person is connected to the outlet.	Establishing a connection is based on the (mobile) equipment usually associated with a specific person. The connection is not associated with a fixed location.
Power is either provided through the communications network itself (e.g., for traditional landline telephones), or from traditional power mains (e.g., fax). In neither case is energy consumption a major concern for the designer of the device.	Mobile stations use rechargeable or one-way batteries. Energy efficiency is thus a major concern.

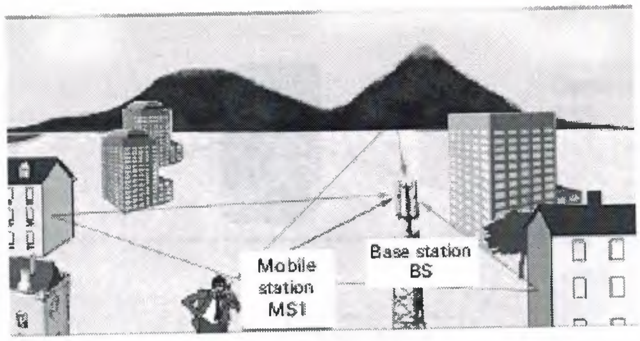

Figure 2.1 Multipath Propagation.

2.2.1 Fading

A simple RX cannot distinguish between the different Multi Path Components (MPCs); it just adds them up, so that they interfere with each other. The interference between them can be constructive or destructive, depending on the phases of the MPCs, see Fig 2.2. The phases, in turn, depend mostly on the run length of the MPC, and thus on the position of the mobile station and the IOs. For this reason, the interference, and thus the amplitude of the total signal, changes with time if TX, RX, or IOs are moving.

This effect namely, the changing of the total signal amplitude due to interference of the different MPCs is called small-scale fading. At 2 GHz carrier frequency, a movement by less than 10 cm can already effect a change from constructive to destructive interference and vice versa. In other words, even a small movement can result in a large change in signal amplitude. A similar effect is known to all owners of car radios moving the car by less than 1 meter (e.g., in stop-and-go traffic) can greatly affect the quality of the received signal. For cell phones, it can often be sufficient to move one step in order to improve signal quality.

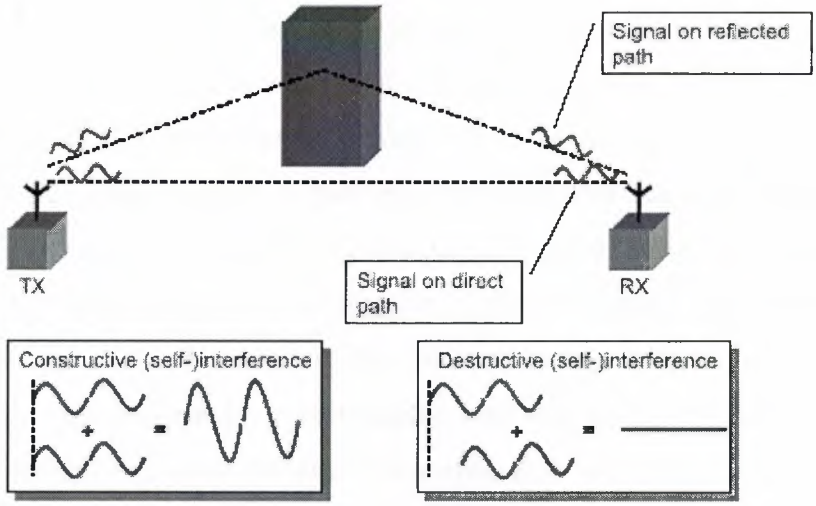

Figure 2.2 Principle of small-scale fading.

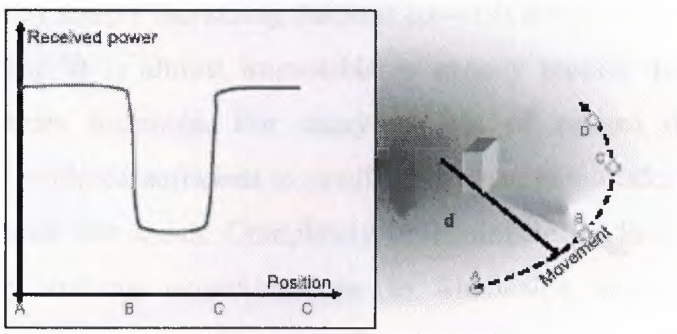

Figure 2.3 The principle of shadowing.

As an additional effect, the amplitudes of each separate MPC change with time (or with location). Obstacles can lead to a shadowing of one or several MPCs. Imagine, for example, the MS (Mobile Station) in Fig 2.3 that at first (at position A) has LOS to the Base Station (BS). As the MS moves behind the high-rise building (at position B), the amplitude of the component that propagates along the direct connection (LOS) between BS and MS greatly decreases. This is due to the fact that the MS is now in the radio shadow of the high-rise building, and any wave going through or around that building is greatly attenuated an effect called shadowing. Of course, shadowing can occur not only for a LOS component, but for any MPC. Note also that obstacles do not throw sharp shadows: the transition from the light (i.e., LOS) zone to the dark (shadowed) zone is gradual. The MS has to move over large distances (from a few meters, up to several hundreds of meters) to move from the light to the dark zone. For this reason, shadowing gives rise to large-scale fading. Large-scale and small-scale fading overlap, so that the received signal amplitude can look like the one depicted in Fig 2.4. Obviously, the transmission quality is low at the times (or places) with low signal amplitude. This can lead to bad speech quality (for voice telephony), high Bit Error Rate (BER) and low data rate (for data transmission), and if the quality is too low for an extended period of time to termination of the connection. It is well known from conventional digital communications that for non-fading communications links, the BER decreases approximately exponentially with increasing Signal-to-Noise Ratio (SNR) if no special measures are taken. However, in a fading channel, the SNR is not constant; rather, the probability that the link is in a fading dip (i.e., location with low SNR) dominates the behavior of the BER. For this reason, the average BER decreases only linearly with increasing average SNR. Consequently, improving the BER often cannot be achieved by simply increasing transmit power is devoted to such techniques.

Due to fading, it is almost impossible to exactly predict the received signal amplitude at arbitrary locations. For many aspects of system development and deployment, it is considered sufficient to predict the mean amplitude, and the statistics of fluctuations around that mean. Completely deterministic predictions of the signal amplitude e.g., by solving approximations to Maxwell's equations in a given environment usually show errors of between 3 and 10 dB (for the total amplitude), and are even less reliable for the properties of individual MPCs.

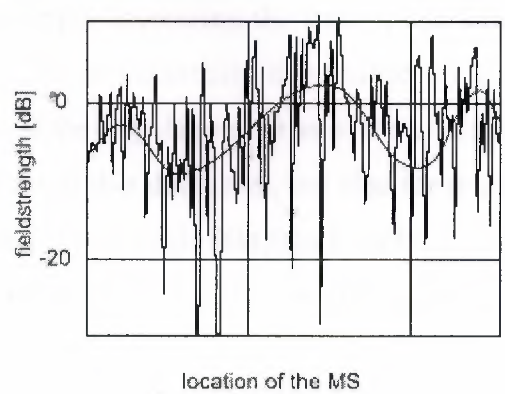

Figure 2.4 Typical example of fading: The thin line is the (normalized) instantaneous field strength; the thick Line is the average over a 1-m distance.

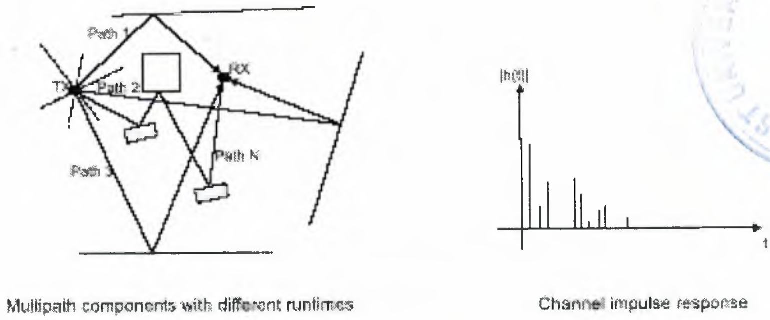

Figure 2.5 Multipath propagation and resulting impulse response.

2.2.2 Intersymbol Interference

The runtimes for different MPCs are different. We have already mentioned above that this can lead to different phases of MPCs, which leads to interference in narrowband systems. In a system with large bandwidth, and thus good resolution in the time domain, the major consequence is signal dispersion: in other words, the impulse response of the channel is not a single delta pulse, but rather a sequence of pulses (corresponding to different MPCs), each of which has a distinct arrival time in addition to having a different amplitude and phase (see Fig 2.5). This signal dispersion leads to intersymbol interference at the RX. MPCs with long runtimes, carrying information from bit k, and MPCs with short runtimes, carrying contributions from (bit k) arrive at the RX at the same time, and interfere with each other (see Fig 2.6). Assuming that no special measures are taken, this Inter Symbol Interference (ISI) leads to errors that cannot be eliminated by simply increasing the transmit power, and are therefore often called irreducible errors. ISI is essentially determined by the ratio between symbol duration and the duration of the impulse response of the channel. This implies that ISI is not only more important for higher data rates, but also for multiple access methods that lead to an increase in transmitted peak data rate Finally, it is also noteworthy that ISI can even play a role when the duration of the impulse response is shorter (but not much shorter) than bit duration.

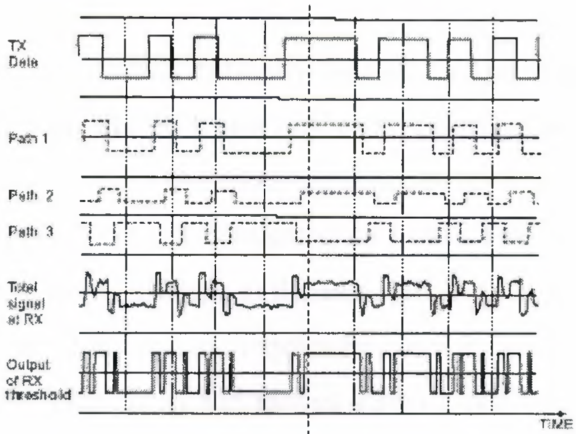

Figure 2.6 Intersymbol interference.

2.3 Spectrum limitations

The spectrum available for wireless communications services is limited, and regulated by international agreements. For this reason, the spectrum has to be used in a highly efficient manner. Two approaches are used: regulated spectrum usage, where a single network operator has control over the usage of the spectrum, and unregulated spectrum, where each user can transmit without additional control, as long as (s)he complies with certain restrictions on the emission power and bandwidth. In the following, we first review the frequency ranges assigned to different communications services. We then discuss the basic principle of frequency reuse for both regulated and unregulated access.

2.4 User Mobility

Mobility is an inherent feature of most wireless systems, and has important consequences for system design. A second important effect is particular to mobile users in cellular systems: the system has to know at any time which cell a user is in. If there is an incoming call for a certain MS (user), the network has to know in which cell the user is located. The first requirement is that an MS emits a signal at regular intervals, informing nearby BSs that it is in the neighborhood. Two databanks then employ this information: the Home Location Register (HLR) and the Visitor Location Register (VLR). The HLR is a central database that keeps track of the location a user is currently at; the VLR is a database associated with a certain BS that notes all the users that are currently within the coverage area of this specific BS. Consider user A, who is registered in San Francisco, but is currently located in Los Angeles. It informs the nearest BS (in Los Angeles) that it is now within its coverage area; the BS enters that information into its VLR. At the same time, the information is forwarded to the central HLR (located, e.g., in New York). If now somebody calls user A, an enquiry is sent to the HLR to find out the current location of the user. After receiving the answer, the call is rerouted to Los Angeles. For the Los Angeles BS, user A is just a regular user, whose data are all stored in the VLR. If an MS moves across a cell boundary, a different BS becomes the serving BS; in other words, the MS is handed over from one BS to another. Such a handover has to be performed without interrupting the call; as a matter of fact, it should not be noticeable at all to the user. This requires complicated signaling.[4]

CHAPTER THREE

DIVERSITY

3.1 Overview

Conventional transceivers that transmit an un-coded bit stream over stream channels can be treated. For Additive White Gaussian Noise (AWGN) channels, such an approach can be quite reasonable: the Bit Error Rate (BER) decreases exponentially as the Signal-to-Noise Ratio (SNR) increases, and a 10 dB SNR leads to BERs on the order of (10^{-4}) BER. However, in Rayleigh-fading the BER decreases only linearly with the SNR. We thus would need an SNR on the order of 40 dB in order to achieve a (10^{-4}) BER, which is clearly unpractical. The reason for this different performance is the fading of the channel: the BER is mostly determined by the probability of channel attenuation being large, and thus of the instantaneous SNR being low.

A way to improve the BER is thus channel the effective channel statistics, i.e., to make sure that the SNR has smaller probability of being low. Diversity is the way to achieve this.

The principle of diversity is to ensure that the same information reaches the receiver (RX) on statistically independent channels. Consider a small case of a receiver with two antennas. The antennas are assumed to be far enough from each other that small-scale fading is independent at the two antennas. The receiver always chooses the antenna that has instantaneously larger receiver power. As the signals are statistically independent, the probability that both antennas are in a fading dip simultaneously is low certainly lower than the probability that one antenna is in fading dip. The diversity thus changes the SNR statistics at the detector input.

3.2 Definition of the Correlation Coefficient

Diversity is most efficient when the different transmission channels (also called diversity branches) carry independently fading copies of the same signal. This means that the joint probability density function of full-strength (or power) $pdf_{r1,r2....(r1,r2,..)}$ is equal to the product of the marginal *pdf*s for the channels, $pdf_{r1(r1)}, pdf_{r2(r2)}, \ldots$ any correlation between the fading of the channels decreases the effectiveness of diversity.

The correlation coefficient characterizes the correlation between signals on different diversity branches. A number of different definitions are being used for this important quantity: complex correlation coefficients, correlation coefficient of the phase, etc. The most important one is the correlation coefficient of signal envelopes x and y:

$$\rho_{xy} = \frac{E\{x.y\} - E\{x\}.E\{y\}}{\sqrt{(E\{x^2\} - E\{x\}^2).(E\{y^2\} - E\{y\}^2)}} \tag{3.1}$$

For two statistically independent signals, the relationship E{xy}=E{x}E{y} holds: therefore, the correlation coefficient becomes zero. Signals are often said to be effectively de-correlated if ρ is below a certain threshold (typically 0.5 or 0.7).

3.3 Microdiversity

As mentioned in the introduction, the basic principle of diversity is that the RX has multiple copies of the transmit signal, where each of the copies goes through a statistically independent channel. This section describes different ways of obtaining these statistically independent copies.

We concentrate on methods that can be used to combat small-scale fading, which are therefore called microdiversity. The five most common methods are:

1. Spatial diversity: several antenna elements separated in space.
2. Temporal diversity: repetition of the transmit signal at different times.
3. Frequency diversity: transmission of the signal at different times.
4. Angular diversity: multiple antennas (with or without spatial separation) with different antenna patterns.
5. Polarization diversity: multiple antennas receiving different polarizations (e.g., vertical and horizontal).

When we speak of antenna diversity, we imply that there are multiple antennas at the receiver. The following important equation will come in handy: Consider he correlation coefficient of two signals that have a temporal separation r and a frequency separation f_1-f_2.

$$\rho_{xy} = \frac{J_0^2(k_0 v \tau)}{1+(2\pi)^2 S_\tau^2 (f_2 - f_1)} \tag{3.2}$$

Note that for moving Mobile Stations (MSs), temporal separation can be easily converted into spatial separation, so that temporal and spatial diversity become mathematically equivalent. Equation above is thus quite general in the sense that it can be applied to spatial, temporal, and frequency diversity. However, numbers of assumptions were made in the derivation of this equation: (i) validity of the Wide Sense Stationary Uncorrelated Scatterer (WSSUS) model, (ii) no existence of Line Of Sight (LOS), (iii) exponential shape of the power delay profile, (iv) isotropic distribution of incident power, and (v) use of omni directional antennas.

3.3.1 Spatial Diversity

Spatial diversity is the oldest and simplest form of diversity. Despite (or because) of this, it is also the most widely used. The transmit signal is received at several antenna elements, and the signals from these antennas are then further processed according to the principles that will be described. But, irrespective of the processing method, performance is influenced by correlation of the signals between the antenna elements. A large correlation between signals at antenna elements is undesirable, as it decreases the effectiveness of diversity. A first important step in designing diversity antennas is thus to establish a relationship between antenna spacing and the correlation coefficient. This relationship is different for BS antennas and MS antennas, and thus will be treated separately.

Mobile station in cellular and cordless systems: it is a standard assumption that waves are incident from all directions at the MS. Thus, points of positive and negative interference of Multi Path Component (MPCs), i.e., points where we have high and low received power respectively are spaced approximately $\lambda/4$ apart.

The above considerations imply the minimum distance for antenna elements in GSM system. For Wireless Local Area Network (WLANs), the distances are even smaller. It is thus clearly possible to place two antennas on an MS of a cellular system. This has also been demonstrated by the Japanese Pacific Digital Cellular (PDC) system, where antenna diversity at the MS is required in order to achieve acceptable quality.

Base station in cordless systems and WLANs: in a first approximation, the angular distribution of incident radiation at indoor BSs is also uniform, i.e., radiation is incident with equal strength from all directions. Therefore, the same rules apply as for MSs.

Base station in cellular systems: for a cellular BS, the assumptions of uniform directions of incidence are no longer valid. Interacting Object (IOs) are typically concentrated around the MS. Since all waves are incident essentially from one direction, the correlation coefficient is much higher. Expressed differently, the antenna spacing required to obtain sufficient de-correlation increases.

To get an intuitive insight, we start with the simple case when there are only two MPCs whose wave vectors are at an angle ά with respect to each other.

It is obvious that the distance between the maxima and the minima of the interference pattern is larger the smaller ά is. For very small ά, the correlation line between antenna elements lies on a ridge of the interference pattern and antenna elements are completely correlated.

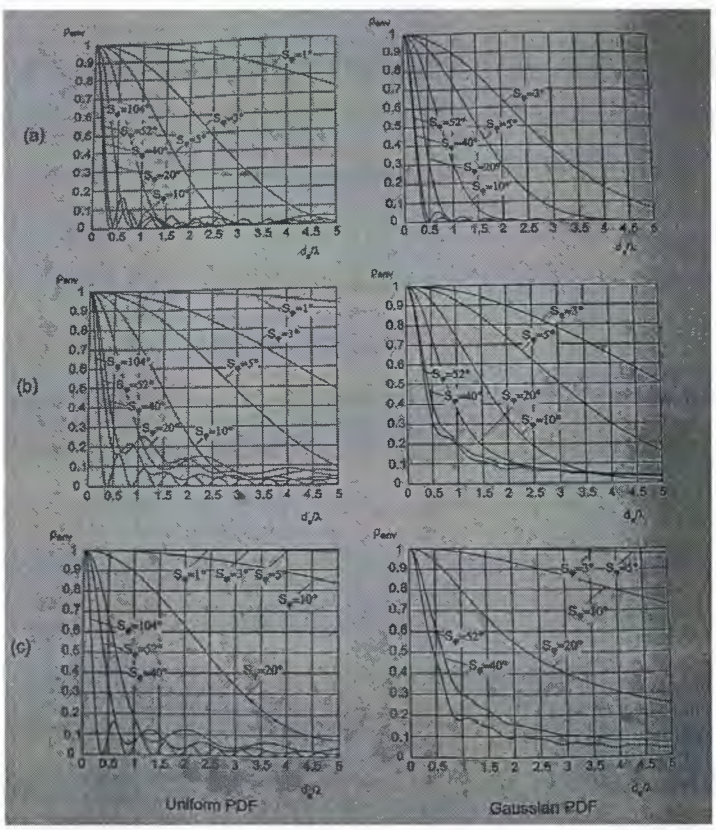

Figure 3.1 Envelope correlation coefficient as the BS for uniform (left) and Gaussian (right) probability density function (pdf) of directions of arrival.

Numerical evaluations of the correlation coefficient as a function of antenna spacing are shown in above. The first column shows the results for rectangular angular power spectra; the results for Gaussian distributions are shown in the second column. We can see that antenna spacing as to be on the order of 2-20 wavelengths for angular spreads between 1° and 5° in order to achieve de-correlation. We also find that it is mostly rms angular spread that determines the required antenna spacing, while the shape of the angular power spectrum has only a minor influence (Fig 3.1).

3.3.2 Temporal Diversity

As the wireless propagation channel is time-variant, signals that are received at different times are uncorrelated. For sufficient de-correlation, the temporal distance must be at least $1/(2\nu\max)$, where $\nu\max$ is the maximum Doppler frequency. Temporal diversity can be realized in different ways:

1. Repetition coding: this is the simplest form. The signal is repeated several times, where the repetition intervals are long enough to achieve de-correlation. This obviously achieves diversity, but is also highly bandwidth-inefficient. Spectral efficiency decreases by a factor that is equal to the number of repetitions.
2. Automatic repeat request (ARQ): here, the RX sends a message to the transmitter (TX) to indicate whether it received the data with sufficient quality. If this is not the case, then the transmission is repeated (after a wait period that achieves de-correlation). The spectral efficiency of ARQ is better than that of repetition coding, since it requires multiple transmissions only when the first transmission occurs in bad fading state, while for repetition coding, retransmissions occur always. On the downside, ARQ requires a feedback channel.
3. Combination of interleaving and coding: a more advanced version of repetition coding is forward error correction coding with interleaving. The different symbols of a codeword are transmitted at different a time, which increases the probability that at least some of them arrive with a good SNR. The transmitted codeword can then be reconstructed.

For the case when only the MS is moving. While the IOs and the BS are fixed, temporal correlation can be converted into spatial correlation. From this it is clear that temporal diversity is useless in a static scenario where BSs, MSs and IOs are immobile; such a situation can occur, e.g., for WLANs. In such a case, the correlation coefficient is ρ=1 for all time intervals and temporal diversity is useless.

3.3.3 Frequency Diversity

In frequency diversity, the same signal is transmitted at different frequencies. If these frequencies are spaced apart by more than the coherence bandwidth of the channel, then their fading is approximately independent, and the probability is low that the signal is in a deep fade at both frequencies simultaneously. For an exponential PDP the correlation between two frequencies can be obtained as:

$$\rho = \frac{1}{1+(2\pi)^2 S_\tau^2 (f_2 - f_1)} \tag{3.3}$$

This again confirms that two signals have to be at least one coherence bandwidth apart from each other.

It is not common to actually repeat the same information at two different frequencies, as this would greatly decrease spectral efficiency. Rather, information is spread over a large bandwidth, so that small parts of the information are conveyed by different frequency components. The RX can then average over the different frequencies to recover the original information.

This spreading can be done by different methods:

- Compressing the information in time, i.e., sending short bursts that each occupy a large bandwidth – TDMA.
- Code Division Multiple Access – CDMA.
- Multi-carrier CDMA and coded orthogonal frequency division multiplexing.
- Frequency hopping is conjunction with coding: different parts of a codeword are transmitted on different carrier frequencies.

These methods allow the transmission of information without wasting bandwidth. For the moment, we just stress that the use of frequency diversity requires the channel to be frequency-selective. In other words, frequency diversity (delay dispersion) can be exploited by the system to make it more robust, and decrease the effect of fading.

3.3.4 Angle Diversity

A fading dip is created when MPCs, which usually come from different directions, interfere destructively. If some of these waves are attenuated or eliminated, then the locations of fading dip changes. In other words, two co-located antennas with different patterns differently weighted MPCs, so that the MPCs interfere differently for the two antennas. This is the principle of angle diversity (also known as pattern diversity).

Angular diversity is usually used in conjunction with spatial diversity; it enhances the de-correlation of signals at closely spaced antennas. Different antenna patters can be achieved very easily. Of course, different types of antennas have different patterns. But even identical antennas can have different patterns when mounted close to each other (in Fig 3.2). This effect is due to mutual coupling; antenna B acts as a reflector for antenna A, whose pattern is therefore skewed to the left. Analogously, the pattern of antenna B is skewed to the right due to reflections from antenna A, thus, the two patterns are different.

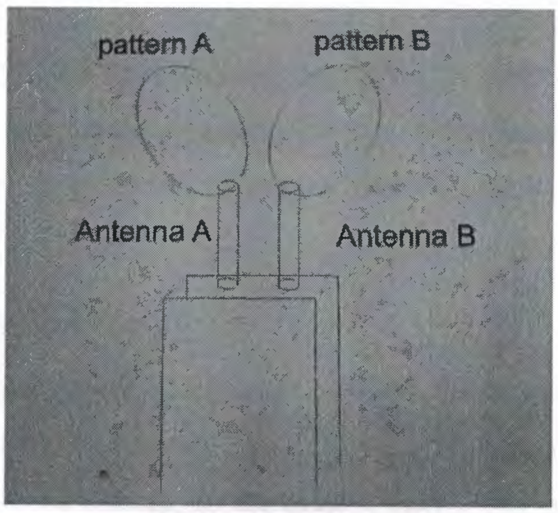

Figure 3.2 Angle diversity for closely spaced antennas

3.3.5 Polarization Diversity

Horizontally and vertically polarized MPCs propagate differently in a wireless channel, as the reflection and diffraction processes depend on polarization. Even if the transmit antenna only sends signals with a single polarization, the propagation effects in the transmit antenna only sends signals with a single polarization arrive at the RX. The fading of signals with different polarizations is statistically independent. Thus, receiving polarizations using a dual-polarized antenna, and processing the signals separately, offers diversity. This diversity can be obtained without any requirement for a minimum distance between antenna elements.

Lets us now consider more closely the situation where the transmit signal is vertically polarized, while the signal is received in both vertical and horizontal polarization. In that case, fading of the two received signals is independent, but the average received signal strength in the two diversity branches is not identical. Depending on the environment, the horizontal (i.e., cross-polarized) component is some 3-20 dB weaker than the vertical (co-polarized) component. As we will see later on, this has an important impact on the effectiveness of the diversity scheme. Various antenna arrangements have been proposed in order to mitigate this problem.

It has also been claimed that the diversity order that can be achieved with polarization diversity is up to 6: three possible components of the E-field and three components of the H-field can all be exploited. However, propagation characteristics as well as practical considerations prevent a full exploitation of that diversity order especially for outdoor situations. This is usually not a serious restriction of diversity systems, as we will see later on that going from diversity order 1 to diversity order 2 gives larger benefits than increasing the diversity order from 2 to higher values. However, it is important issue for Multiple Input Multiple Output (MIMO) systems.

3.4 Macrodiversity and Simulcast

The previous section described diversity methods that combat small-scale fading, i.e., the fading created by interference effects. As we have seen, spatial diversity for such cases requires antenna spacing on the order o only a few wavelengths. However, these diversity methods are not suitable for combating large-scale fading, which is created by shadowing effects. Shadowing affects different MPCs almost equally, so that frequency diversity or polarization diversity are not effective. Furthermore, the correlation distances for large-scale fading are on the order often or hundreds of meters, so that spatial diversity or temporal diversity (with reasonable antenna spacing and latency times, respectively), cannot be used either. In other words, if there is a hill between the TX and RX adding antennas on either the BS or the MS does not help to eliminate the shadowing caused by the hill. The only way to circumvent the problem is to use a separate base station (BS2) that is placed in such a way that the hill is not in the connection line between the MS and BS2. This in turn implies a large distance between BS1 and BS2, which gives rise to the word macrodiversity.

The simplest method for macrodiversity is the use of on-frequency repeaters that receive the signal and retransmit an amplified version of it. Simulcast is very similar to this approach; the same signal is transmitted simultaneously from different BSs. In cellular applications the two BSs should be synchronized, and transmit the signals intended for a specific user in such a way that the two waves arrive at the RX almost simultaneously (timing advance). Note that synchronization can only be obtained if the runtimes from the two BSs to the MS are known. Generally speaking, it is desirable that the synchronization error is no larger than the delay dispersion that the RX can handle. Especially critical are RXs in regions where the strengths of the signals from the two BSs are approximately equal.

Simulcast is also widely used for broadcast applications, especially digital TV. In this case, the exact synchronization of all possible RXs is not possible; each RX would require a different timing advance from TXs.

A disadvantage of simulcast is the large amount o signaling information that has to be carried on landlines. Synchronization information as well as transmit data has to be transported on landlines (or microwave links) to the BSs. This used to be a serious problem in the early days of digital mobile telephony, but the current wide availability of fiber-optic links has made this less of an issue.[5]

The use of on-frequency repeaters is simpler than that of simulcast, as no synchronization is required. On the other hand, delay dispersion is larger, because (i) the runtime from BS to repeater, and repeater to MS is larger (compared with the runtime from a second BS), and (ii) the repeater itself introduces delays due to the group delays of electronic components, filters, etc.

3.5 Combination of Signals

Now we turn our attention to the question of how to use diversity signals in a way that improves the total quality of the signal that is also to be detected. To simplify the notation, we speak here only about the combination of signals from different antenna signals at the RX. However, the mathematical methods remain valid for other types of diversity signals as well.

In general, we can distinguish two ways of exploiting signals from the multiple diversity branches:

1. Selection diversity, where the best signal copy is selected and processed (demodulated and decoded), while all other copies are discarded. There are different criteria for what constitutes the best signal.
2. Combining diversity, where all copies of the signal are combined (before or after the demodulator), and the combined signal is decoded. Again, there are different algorithms for combination of the signals.

Combining diversity leads to better performance, as all available information is exploited. On the downside, it requires a more complex RX than selection diversity. In most RXs, all processing is done in the base band. Thus, an RX with combining diversity needs to down convert all available signals, and combine them appropriately in the base band. Thus, it requires Nr antenna elements as well as Nr complete Radio Frequency (RF) (down conversion) chains. An RX with selection diversity requires only one RF chain, as it processes only a single received signal at a time.

In the following, we give a more detailed description of selection (combination) criteria and algorithms. We assume that different signal copies undergo statistically independent fading this greatly simplifies the discussion of both the intuitive explanations and the mathematics of the signal combination.

In these considerations, we also have to keep in mind that the gain of multiple antennas is due to two effects: diversity gain and beam forming gain. Diversity gain reflects the fact that it is very low signal level is thus decreased by the use of multiple antenna elements. Beam forming gain reflects the fact that (for combining diversity) the combiner performs an averaging over the noise at different antennas. Thus, even if the signal levels at all antenna elements are identical; the combiner output SNR is larger than the SNR at a single antenna element.[6]

3.5.1 Selection Diversity

Received-signal-strength-indication-driven diversity

In this method, the RX selects the signal with the largest instantaneous power (or Received Signal Strength Indication, RSSI), and processes it further. This method requires Nr antenna elements, Nr RSSI sensors, and an Nr -to-1 multiplexer, but only one RF chain.

The method allows simple tracking of the selection criterion even in fast-fading channels. Thus, we can switch to a better antenna as soon as the RSSI becomes higher there.

1. If the BER is determined by noise, then RSSI-driven diversity is the best of all the selection diversity methods, as maximization of the RSSI also maximizes the SNR.
2. If the BER is determined by co-channel interference, then RSSI is no longer a good selection criterion. High receive power can be caused mainly a high level f interference, such that the RSSI criterion makes the system select branches with a low signal-to-interference ration. This is especially critical when interference is caused mainly by one dominant interferer – a situation that is typical for Frequency Division Multiple Access (FDMA) or TDMA systems.
3. Similarly, RSSI-driven diversity is suboptimum if the errors are caused by the frequency selectivity of the channel. RSSI-driven diversity can still be reasonable approximation, because that errors caused by signal distortion occur mainly in the fading dips of the channel. However, this is only an approximation, and it can be shown that (un-coded, un-equalized) systems with RSSI-driven selection diversity have a BER that is higher by a constant factor compared with optimum (BER-driven) diversity.

Bit-Error-Rate-Driven Diversity

For BER-driven diversity, we first transmit a training sequence, i.e., a bit sequence that is known at the RX. The RX then demodulates the signal from each receive antenna element and compares it with the transmit signal. The antenna whose associated signal results in the smallest BER is judged to be the best, and used for the subsequent reception of data signals.

A similar approach is the use of the mean square error of the soft-decision demodulated signal, or the correlation between transmit and receive signal.

If the channel is time-variant, the training sequence has to be repeated at regular intervals and selection of the best antenna has to be done anew. The necessary repetition rate depends on the coherence time of the channel. BER-driven has several networks:

1. The RX needs both Nr RF chains and demodulators (which makes the RX more complex), or the training sequence had to be repeated Nr times (which decreases spectral efficiency), so that the signal at all antenna elements can be evaluated.
2. If the RX has only one demodulator, then it is not possible to continuously monitor the selection criterion (i.e., the BER) of all diversity branches. This is especially critical if the channel changes quickly.
3. Since the duration of the training sequence is infinite, the selection criterion, i.e., bit error probability cannot be determined exactly. The variance of the BER around its true mean decreases as the duration of the training sequence increases. There is thus a tradeoff between performance loss due to erroneous determination of the selection criterion, and spectral efficiency loss due to longer training sequences.

3.5.2 Switched Diversity

The main drawback of selection diversity is that the selection criteria (power, BER, etc.) of all diversity branches have to be monitored in order to know when to select a different antenna. As we have shown above, this leads to either increased hardware effort or reduced spectral efficiency. An alternative solution, which avoids these drawbacks, is switched diversity, in this method. The selection criterion of just the active diversity branch is monitored. If it falls below a certain threshold, then the RC switches to a different antenna. Switching only depends on the quality of the active diversity branch; it does not matter whether the other branch actually provides a better signal quality or not.

Switched diversity works well for those cases where there is sufficient signal quality on at least one diversity branch. If both branches have signal quality below the threshold, then the RX just switches back and forth between the branches. This situation can be avoided by introducing a hysteresis or hold time, so that the new diversity branch is used for a certain amount of time, independent of the actual signal quality. We thus have two free parameters: switching threshold, and hysteresis time. These parameters have to be selected very carefully: if the threshold is chosen too low, then a diversity branch is used even when the other antenna might offer better quality; if it is chosen too high, then it becomes probable that the branch the RX switches to actually offers lower signal quality than the currently active one. If hysteresis time is chosen too long, then a bad diversity branch can be used for a long time; if it is chosen too short, then the RX spends all the time switching between two antennas.

Summarizing, the performance of switched diversity is worse than that of selection diversity.

CHAPTER FOUR

RESULTS

4.1 Communication Channel with Additive White Gaussian Noise (AWGN)

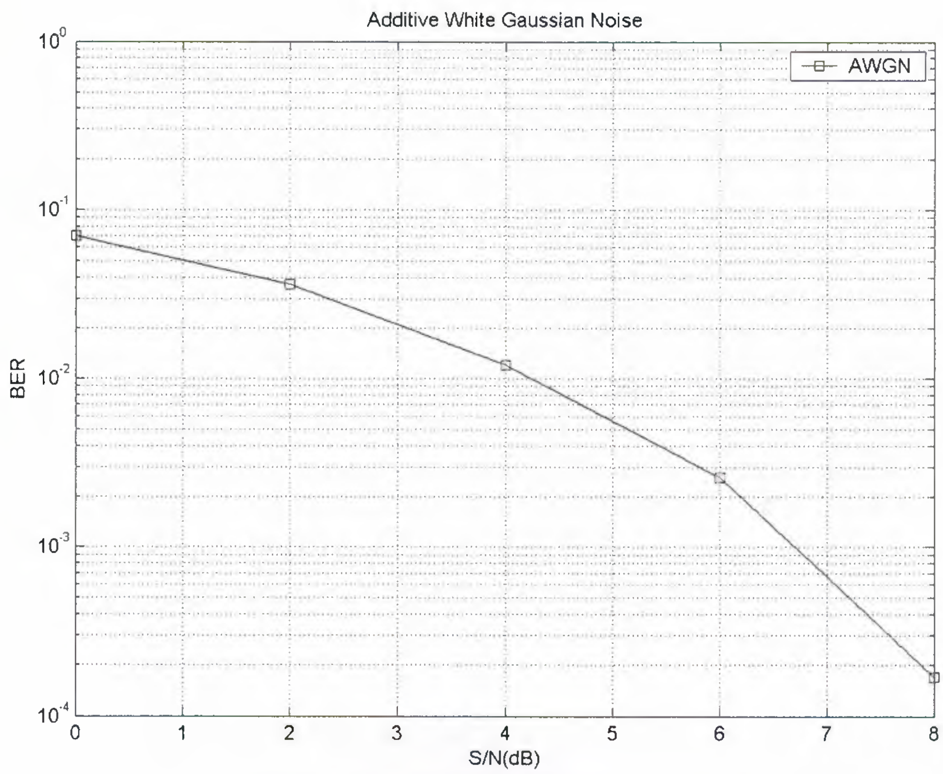

Figure 4.1 Additive White Gaussian Noise

Fig 4.1 shows the AWGN, shows a downlink slope as the BER increases, the power of the signal increases indicated by SNR. At the "0" value, as we transmit a code with 10 bits, one error occurs during transmitting 10 bits. As we increase the SNR, the number of detected errors that happened during transmission through the channel by the decoder will decrease since the power of the signal increases.

4.2 Communication through Fading Channel

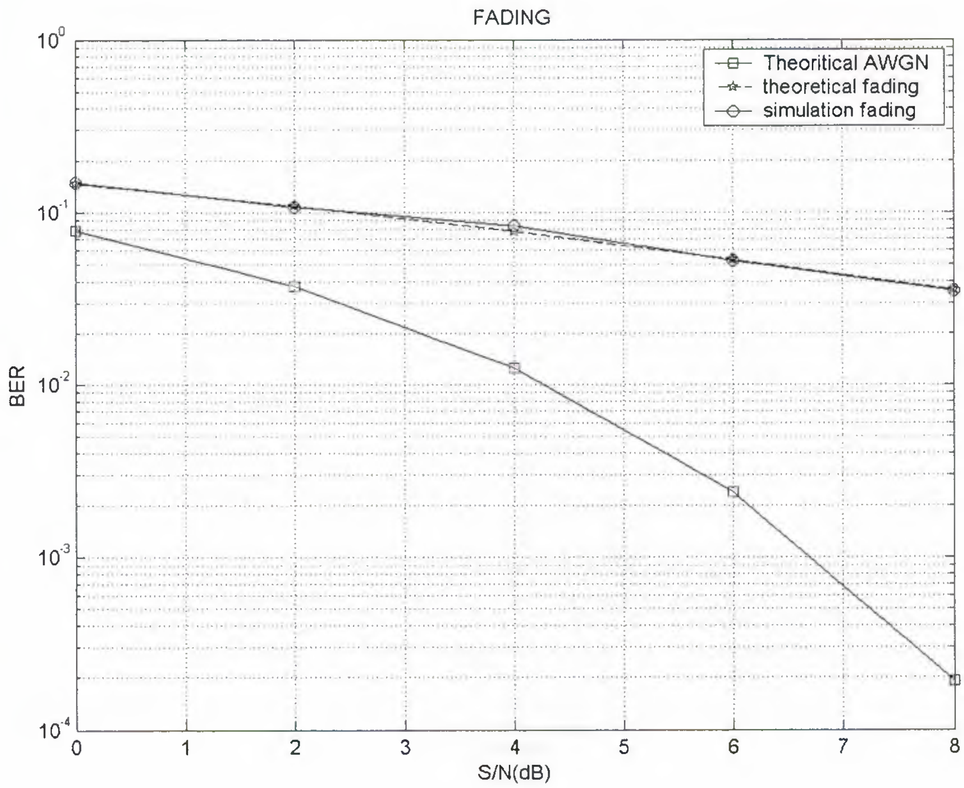

Figure 4.2 Fading

Fig 4.2 shows how different the behavior of both curves, the theoretical and the simulated fading. As the signal transmitted through the channel, it will face fading that effect the behavior of the downlink curve (AWGN) and it will increase the chance of having errors. Fading curve will include fading plus AWGN, therefore it will effect the signal and make it worse. Since we know the sequence of the theoretical fading, the fading curve will remain the same. During the transmission through the channel, the signal will face fading so the curve will vary.

4.3 Diversity

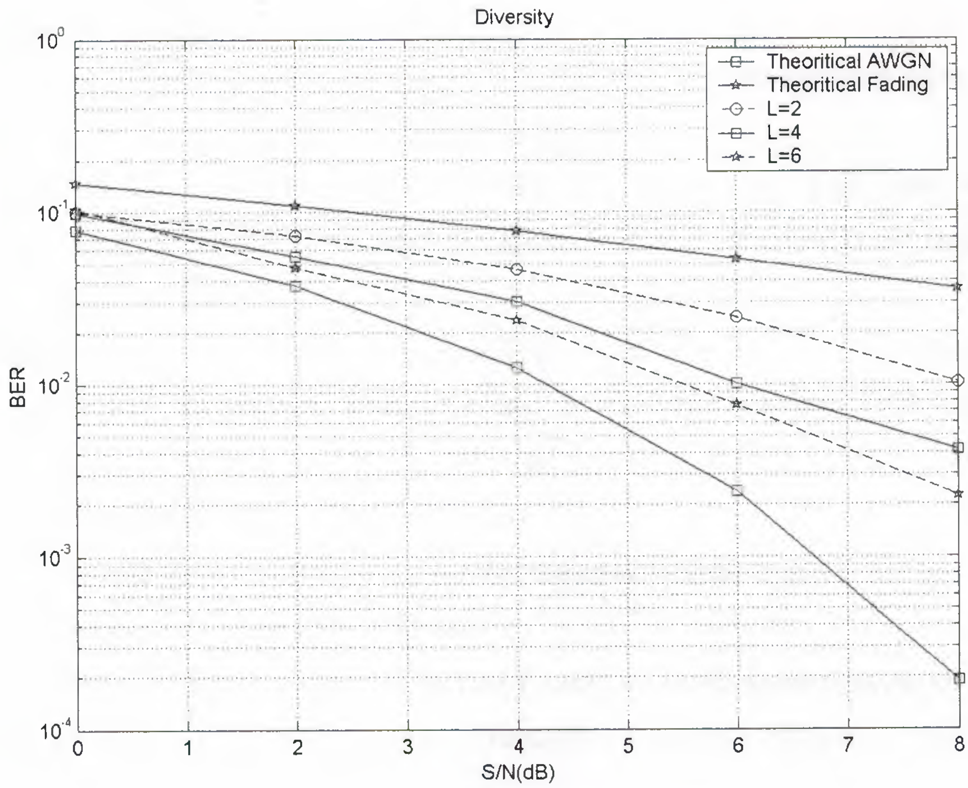

Figure 4.3 Diversity

Fig 4.3 shows that the objective of the diversity is to fix the corrupted signal due to fading and gives almost back the original signal that has been sent. As we increase the number of antennas (L), but still we will have fading but the signal get to a close results to the case without fading which is the original signal has been sent.

CONCLUSION

Wireless communications is one of the big engineering success stories of the last 20 years not only from a scientific point of view, where the progress has been phenomenal, but also in terms of market size and impact on society.

When looking at the history of communications, we find that wireless communications is actually the oldest form shouts and jungle drums did not require any wires or cables to function.

Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading is usually modeled as a time-varying random change in the amplitude and phase of the transmitted signal.

The principle of diversity is to ensure that the same information reaches the receiver (RX) on statistically independent channels.

Microdiversity which is a part of diversity uses five most common methods are like (Spatial diversity, temporal diversity, Frequency diversity, Angular diversity and Polarization diversity).

Combining diversity leads to better performance, as all available information is exploited. On the downside, it requires a more complex RX than selection diversity. In most RXs, all processing is done in the base band. Thus, an RX with combining diversity needs to down convert all available signals, and combine them appropriately in the base band.

As the signal transmitted through the channel, it will face fading that effect the behavior of the AWGN and it will increase the chance of having errors. Fading curve will include fading plus AWGN, therefore it will effect the signal and make it worse.

Transmitter will send the signal in different ways using diversity methods. All of the antennas will send the same copy but they will be independent from each other.

We are trying to receive the signal that has been transmitted with less power and less errors. The wireless channel will make it hard for us to correct the errors and there fore we are combining methods to fix the fading which is a main problem in the channel. We can have better results by either keeping the power of the signal constant or keeping the nose low or increase the power of the signal and keep the noise constant.

By increasing the number of antennas that send the same copy of the signal different ways (times, frequencies, etc…), the chance that when they are all transmitting the chance that all of them will go bad or be corrupted is very low. For example using 4 antennas, the chance that they will go bad is lower than two antennas will go bad. The chance that 6 antennas will go bad while transmitting is lower than 4 antennas will go bad.

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APPENDICES

Appendix I Simulation of Additive White Gaussian Noise

```
%AWGN
clear %clear the variables
clc %clear command window
SNR1=0:2:8;
%BER=[];
for T=1:length(SNR1)
    SNR1(T)
    SNR=10^(SNR1(T)/10);
    VARIANCE=1/(2*SNR);
    error=0;
    data=0;
    while (error<100)
        for i=1:10
            original_data(i)=rand;
            if (original_data(i)>0.5)
                original_data(i)=1;
                out(i)=1;
            else
                original_data(i)=0;
                out(i)=-1;
            end
            data=data+1;
            noise=sqrt(VARIANCE)*randn;
            R(i)=noise+out(i);
            if R(i)>=0
                Tq(i)=1;
                if Tq(i)~=original_data(i)
                    error=error+1;
                end
            else
```

```
                Tq=0;
                if Tq~=original_data(i)
                    error=error+1;
                end
            end
        end
    end
BER(T)=error/data
end
%error
semilogy(SNR1,BER,'sk-')
title('AWGN')
xlabel('S/N(dB)'),ylabel('BER')
legend('Additive White Gaussian Noise')
grid
axis([0 8 10e-5 1]).
```

Appendix II Communication Through Fading channel

```
%FADING
clear %clear the variables
clc %clear command window
SNR1=0:2:8;
%BER=[];
for T=1:length(SNR1)
    SNR1(T)
    SNR=10^(SNR1(T)/10);
    VARIANCE=1/(2*SNR);
    error=0;
    data=0;
    while (error<100)
        for i=1:10
            original_data(i)=rand;
            if (original_data(i)>0.5)
                original_data(i)=1;
                out(i)=1;
            else
                original_data(i)=0;
                out(i)=-1;
            end
            data=data+1;
            noise=(sqrt(VARIANCE))*randn;
            x1=sqrt(0.5)*randn;
            x2=sqrt(0.5)*randn;
            Fade=sqrt((x1^2)+(x2^2));
            R(i)=(Fade*out(i))+noise;
            if R(i)>=0
                Tq(i)=1;
                if Tq(i)~=original_data(i)
                    error=error+1;
                end
```

```
                else
                    Tq=0;
                    if Tq~=original_data(i)
                        error=error+1;
                    end
                end
            end
        end
        BER(T)=error/data; %simulation fading
        Flat_pe(T)=0.5*(1-sqrt(SNR/(1+SNR))); %theoretical
fading
        q(T)=0.5*erfc(sqrt(SNR)); %theoretical awgn
    end
    %error
    semilogy(SNR1,q,'ks-',SNR1,Flat_pe,'kp--
',SNR1,BER,'ko-')
    title('FADING')
    xlabel('S/N(dB)'),ylabel('BER')
    legend('Theoritical                 AWGN','theoretical
fading','simulation fading')
    grid
    axis([0 8 10e-5 1]).
```

Appendix III Simulation of Diversity

```
clear %clear the variables
clc %clear command window
SNR1=0:2:8;
%BER=[];
L=[2 4 6];
for T=1:length(SNR1)
    SNR1(T)
    SNR=10^(SNR1(T)/10);
    VARIANCE=1/(2*SNR);
    for i=1:length(L)
          error(i)=0;
          data(i)=0;
    while (error(i)<100)
            original_data(i)=rand;
            if (original_data(i)>0.5)
                original_data(i)=1;
                out(i)=1;
            else
                original_data(i)=0;
                out(i)=-1;
            end
            data(i)=data(i)+1;

               Z(i)=0;
               for j=1:L(i)
            x1=sqrt(0.5/L(i))*randn;
            x2=sqrt(0.5/L(i))*randn;
            Fade=sqrt((x1^2)+(x2^2));
            noise=(sqrt(VARIANCE))*randn;
            R=(Fade*out(i))+noise;
            Z(i)=Z(i)+(Fade*R);
         end
```

```
            if Z(i)>=0
                Tq(i)=1;
                if Tq(i)~=original_data(i)
                    error(i)=error(i)+1;

                end
            else
                Tq=0;

                if Tq~=original_data(i)
                    error(i)=error(i)+1;
                    BER(T,i)=error(i)/data(i);
                end
            end
        end

    end
    Flat_pe(T)=0.5*(1-sqrt(SNR/(1+SNR)));       %theoretical
fading
    q(T)=0.5*erfc(sqrt(SNR)); %theoretical awgn
end
semilogy(SNR1,q,'ks-',SNR1,Flat_pe,'kp-',SNR1,BER(:,1),'ko-
-',SNR1,BER(:,2),'ks-',SNR1,BER(:,3),'kp--')
title('Diversity')
xlabel('S/N(dB)'),ylabel('BER')
legend('Theoritical                          AWGN','Theoritical
Fading','L=2','L=4','L=6')
grid
axis([0 8 10e-5 1])
```