

## **CHAPTER TWO**

### **Literature review**

## **2.1 Wireless Communication Background**

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. The most common wireless technologies use radio. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications.

### **2.1.1 Benefits of Wireless Communication**

Compared with the wire line communication counterpart, wireless communication offers a number of significant benefits. First, probably the most prominent and important feature of wireless communication is the provision of convenient and reliable tether less connectivity. This offers greater flexibility and mobility. Unlike with a wired connection, people are no longer tied to their dedicated place, instead, they will be able to move freely and access network resource from any location within the wireless coverage area.

Another direct consequence of the tether less connectivity is that wireless communication presents a promising approach to bring network access to the areas which would be difficult to connect to a wired network. For instance, possible applications include remote monitoring of natural environments such as glaciers, volcanoes and bodies of water, monitoring the condition of historic buildings where wiring is difficult, dangerous, or undesirable.

### **2.1.2 Current Wireless Networks**

Depending on the service range, mobility and data transmission rate, wireless networks generally fall into four different categories: Wireless Personal Area Network (PAN), wireless Local Area Network(LAN),

wireless Metropolitan Area Network (MAN), and wireless Wide Area Network (WAN).

**Wireless PAN** is a type of wireless network that interconnects personal devices within a relatively short range (typically up to 10m or so), e.g., from a laptop to a nearby printer or from a cell phone to a wireless headset. It can support both low-rate and high-rate applications with different technologies.

Wireless PAN is standardized under the IEEE 802.15 series [8]. Currently, the market for wireless PAN has been dominated by Bluetooth (IEEE 802.15.1) products, which provide low-rate services with low-power consumption, i.e. wireless control of and communication between a mobile phone and a hands-free headset, wireless mouse, keyboard, and wireless game consoles. Another technology under development for low-rate wireless PAN is defined by the ZigBee specification (IEEE 802.15.4) which is intended to be simpler and less expensive than Bluetooth. For high-rate applications, such as digital imaging and multimedia services, technologies are under development based on the WiMedia specification (IEEE 802.15.3). Overall, the technology for wireless PANs is in its infancy and is undergoing rapid development and research, and it is expected that this technology will find its application in various new environments to provide simple, easy to use connection to other devices and networks.

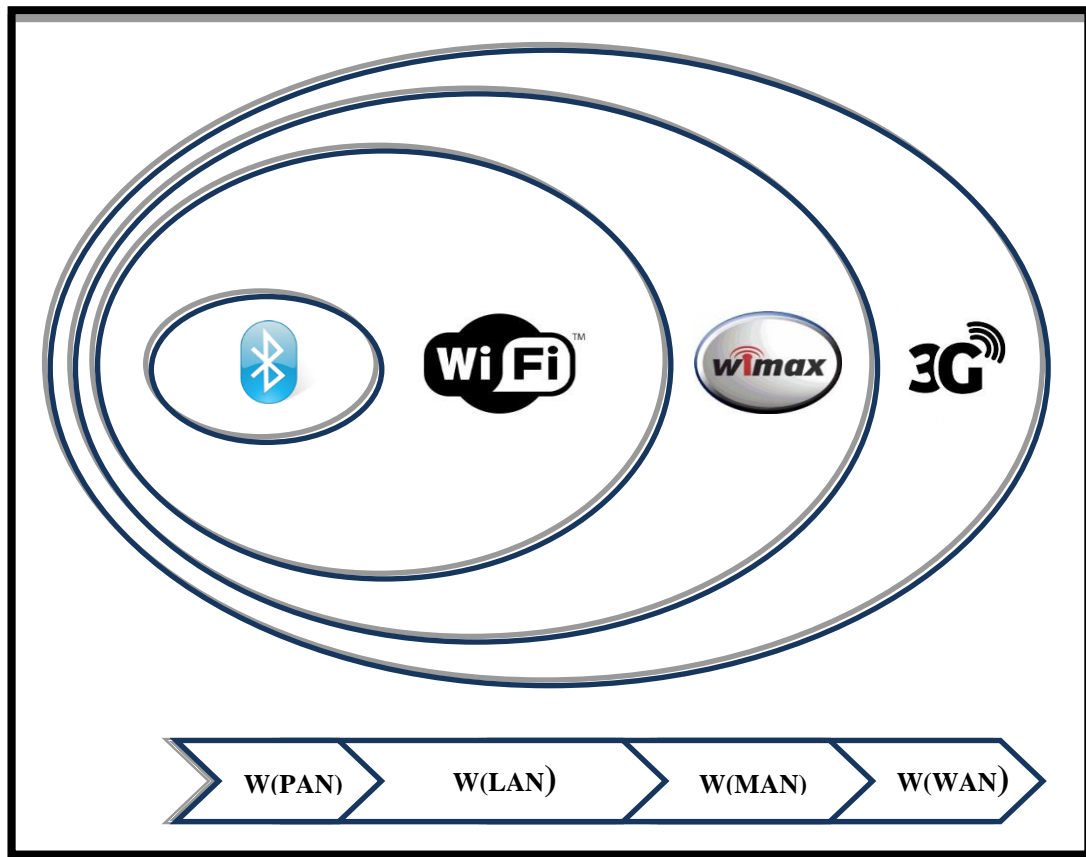
**Wireless LAN** is a type of network that provides high-speed data to wireless devices which are generally stationary or moving at pedestrian speeds within a small region, for instance, residential house, office building, university campus, or airport. With the proliferation of laptops, wireless LAN has become increasingly popular due to its ease of

installation, as well as the location freedom provided. Wireless LAN is standardized under the IEEE 802.11 series [9]. These standard's will be discussed in detailed in next section.

**Wireless MAN** is a type of network which mainly aims at providing broadband wireless access in larger geographical area than a LAN, ranging from several blocks of buildings to an entire city. Its main advantage is fast deployment and relatively low cost, and it has been considered as an attractive alternative solution to the wired last mile access systems such as Digital Subscriber Line (DSL) and cable modem access, especially for very crowded geographic areas like big cities and rural areas where wired infrastructure is difficult to deploy. Wireless MAN is standardized under the IEEE 802.16 series [10], and is also known as Broadband Wireless Access standard. Based on the IEEE 802.16 standard, Worldwide Interoperability for Microwave Access (WiMAX) technology has been put forward by the industry alliance called the WiMAX Forum. The initial standard IEEE 802.16d only supports fixed applications which are often referred to as “fixed WiMAX”. Later, another amendment IEEE 802.16e introduced support for mobility, which is known as “Mobile WiMAX”. WiMAX supports very robust data throughput. The technology could provide approximately 40Mbps per channel. However, services across this channel would be shared by multiple customers which means that the typical rate available to users will be around 3Mbps.

**Wireless WAN** is a form of network which uses mobile telecommunication cellular network technologies such as Universal Mobile Telecommunication System (UMTS), General Packet Radio Service (GPRS) or Global System for Mobile Communication (GSM) to

offer regionally, nationwide, or even globally voice and data services. Wireless WAN has gone through rapid development in the last three decades. In 1980s, the first generation (1G) mobile communication systems were deployed, while the second generation (2G) mobile systems started to operate since 1990s. Both the 1G and 2G systems focus primarily on voice communications, while the 2G system has enhanced voice quality and has better spectrum management over the 1G system. The 2G systems provide data rate in the range of 9.6 – 14.4 Kbps. Currently, the third generation (3G) systems have started to roll out at full pace, and it is expected that 3G systems will provide higher transmission rate: a minimum speed of 2Mbps and maximum of 14.4Mbps for stationary users, and 384Kbps in a moving vehicle. While the improvement on the quality of service by 3G systems is obvious and impressive, more emerging applications are calling for higher data rate wireless service. At the moment, the industry and standardization body have already started to work on the fourth generation (4G) systems, which is intended to be a complete replacement for the current networks and be able to provide voice, data, and streamed multimedia to users on an “anytime, anywhere” basis. It is expected that the 4G systems will be able to deliver data rate of 1Gbps for stationary applications and 100Mbps for mobile applications. Figure 2-1 shows the categories of wireless networks.



**Figure 2-1** Wireless Networks Categories.

### 2.1.3 Wi-Fi Technology

Wi-Fi is a short name for Wireless Fidelity. Generally Wi-Fi refers to the IEEE 802.11 communications standard for Wireless Local Area Networks (WLANs). Wi-Fi works on physical and data link layer. Designed originally for cable replacement in corporate environments, The purpose of Wi-Fi is to hide complexity by enabling wireless access to applications and data, media and streams.

The Wi-Fi Alliance is a nonprofit international association formed in 1999 to certify interoperability of wireless LAN products based on IEEE 802.11 specifications. Currently the Wi-Fi Alliance has over 200 member companies from around the world, and over 1500 products have received Wi-Fi certification since certification began in March of 2000.

The goal of the Wi-Fi Alliance's members is to enhance the user experience through product interoperability. For example, the

deployment of Wi-Fi in populated areas known as hotspots. These include airports, coffee houses, hotels, and other public areas with a high demand for wireless internet access. The trend is widespread with Asia leading the way. Wi-Fi complements cellular technology in many respects. Cellular Wi-Fi convergence gained further significance with the formation of unlicensed mobile access (UMA). Wi-Fi Networks use Radio Technologies to transmit & receive data at high speed.

IEEE 802.11 standard belongs to the family of IEEE 802 standards that include Local Area Network standards and Metropolitan Area Network standards. IEEE 802.11 standard defines over-the-air protocols necessary to support networking in a local area. Table 2-1 shows a comparison of 802.11 and its amendments.

**802.11** the original standard supporting 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS) techniques for radio transmission [11].

There are several specifications in the 802.11 family:

**802.11b** an extension to 802.11 that provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz band. 802.11b uses only DSSS.

**802.11a** an extension to 802.11 that provides up to 54 Mbps in the 5GHz band. 802.11a uses an orthogonal frequency division multiplexing (OFDM) encoding scheme rather than FHSS or DSSS.

**802.11g** an extension to 802.11b that provides up to 54 Mbps in the 2.4 GHz band. 802.11g also uses OFDM.

**802.11n** modifications to physical and MAC layers to provide over 100 Mb/s throughput in the 5 GHz band. 802.11n uses OFDM and MIMO technologies.

**802.11af** (White-Fi) is a term being used to describe the use of a Wi-Fi technology within the TV unused spectrum, or TV white space . In view of the fact that the 802.11af white-fi system operating the TV white spaces would use frequencies below 1 GHz, this would allow for greater distances to be achieved. Current Wi-Fi systems use frequencies in the ISM bands - the lowest band is 2.4 GHz and here signals are easily absorbed, Figure 2.2 Shows the first prototype of IEEE 802.11af.



**Figure 2.2:** 802.11af First Prototype

**Table 2.1:** PHY Comparisons of 802.11Standards and its Amendments

	<b>802.11a</b>	<b>802.11b</b>	<b>802.11g</b>	<b>802.11n</b>	<b>802.11af</b>
<b>PHY technology</b>	OFDM	DSSS /CCK	OFDM & DSSS /CCK	OFDM & DSSS w/CCK	OFDM
<b>Maximum Data rate</b>	25 Mbps	5 Mbps	54 Mbps	600 Mbps	54 Mbps
<b>Frequency Channel</b>	5 GHz	2.4 GHz	2.4 GHz	2.4 or 5 GHz	470-710 MHz
<b>Channel spacing</b>	20	20	20	20 or 40 MHz	6 MHz



### 2.1.4 Wi-Fi Based Long Distance Networks

Wi-Fi based long distance networks have become very popular in providing Internet access to the remote areas in many countries, mostly in developing regions [12],[13]. The unlicensed Wi-Fi spectrum and a variety of commodity IEEE 802.11 hardware make Wi-Fi an attractive communication method because of its wide availability and low cost. These networks typically have long distance point-to-point wireless links enabled by high-gain directional antennas where the links are typically several kilometers long, but often provide low throughput. Their long distance wireless links usually require permanent structures as the antennas are placed on top of a tower or a tall building. Moreover, fine-grain tuning of antenna orientation is needed to achieve the maximum gain (up to 24 dB) having narrow beam widths (down to 8 degrees). Another type of these network is constructed using a polarized directional MIMO antenna with nominal gain (13.5 dB) that is mounted on top of a lightweight movable mast that may be one to three meter tall [1].

## 2.2 Propagation and Fading of The Wireless Channel

The performance of wireless communication systems is mainly governed by the wireless channel environment. As opposed to the typically static and predictable characteristics of a wired channel, the wireless channel is rather dynamic and unpredictable, which makes an exact analysis of the wireless communication system often difficult. In recent years, optimization of the wireless communication system has become critical with the rapid growth of mobile communication services and emerging broadband mobile Internet access services. In fact, the understanding of wireless channels will lay the foundation for the development of high performance and bandwidth-efficient wireless transmission technology.

### 2.2.1 Radio Propagation Phenomenon

In wireless communication, radio propagation refers to the behavior of radio waves when they are propagated from transmitter to receiver. In the course of propagation, radio waves are mainly affected by three different modes of physical phenomena: reflection, diffraction, and scattering [14, 15].

**Reflection** is the physical phenomenon that occurs when a propagating electromagnetic wave impinges upon an object with very large dimensions compared to the wavelength, for example, surface of the earth and building. It forces the transmit signal power to be reflected back to its origin rather than being passed all the way along the path to the receiver.

**Diffraction** refers to various phenomena that occur when the radio path between the transmitter and receiver is obstructed by a surface with sharp irregularities or small openings. It appears as a bending of waves around the small obstacles and spreading out of waves past small openings. The secondary waves generated by diffraction are useful for establishing a path between the transmitter and receiver, even when a line-of-sight path is not present.

**Scattering** is the physical phenomenon that forces the radiation of an electromagnetic wave to deviate from a straight path by one or more local obstacles, with small dimensions compared to the wavelength. Those obstacles that induce scattering, such as foliage, street signs, and lamp posts, are referred to as the scatters.

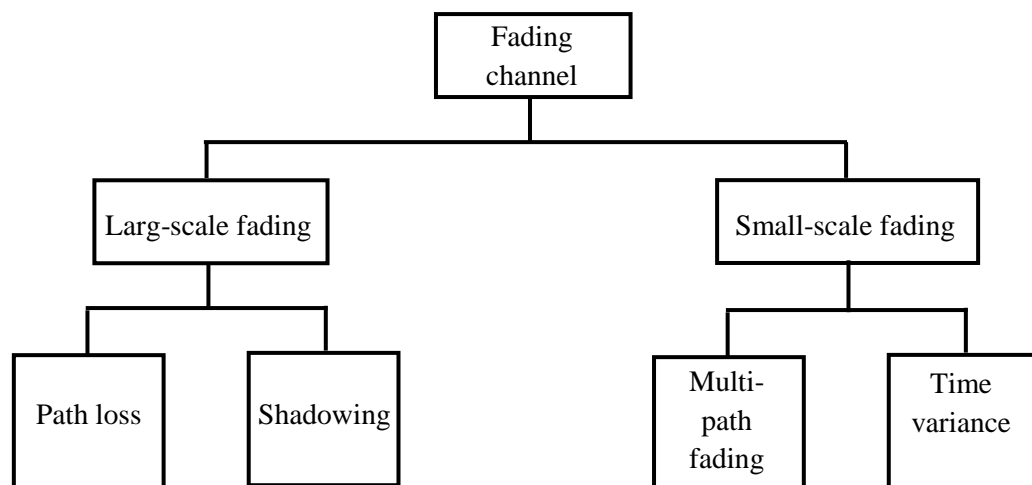
In other words, the propagation of a radio wave is a complicated and less predictable process that is governed by reflection, diffraction, and scattering, whose intensity varies with different environments at different instances.

### 2.2.2 Fading Phenomenon

A unique characteristic in a wireless channel is a phenomenon called ‘fading,’ the variation of the signal amplitude over time and frequency. In contrast with the additive noise as the most common source of signal degradation, fading is another source of signal degradation that is characterized as a non-additive signal disturbance in the wireless channel. Fading may either be due to multipath propagation, referred to as multi-path (induced) fading, or to shadowing from obstacles that affect the propagation of a radio wave, referred to as shadow fading..

The fading phenomenon in the wireless communication channel was initially modeled for HF (High Frequency, 3\_30MHz), UHF (Ultra HF, 300\_3000 GHz), and SHF (Super HF, 3\_30 GHz) bands in the 1950s and 1960s. Currently, the most popular wireless channel models have been established for 800MHz to 2.5 GHz by extensive channel measurements in the field. These include the ITU-R standard channel models specialized for a single-antenna communication system, typically referred to as a SISO (Single Input Single Output) communication, over some frequency bands. Meanwhile, spatial channel models for a multi-antenna communication system, referred to as the MIMO (Multiple Input Multiple Output) system, have been recently developed by the various research and standardization activities such as IEEE 802, METRA Project, 3GPP/3GPP2, and WINNER Projects, aiming at high-speed wireless transmission and diversity gain.

The fading phenomenon can be broadly classified into two different types: **large-scale fading** and **small-scale fading**. Large-scale fading occurs as the mobile moves through a large distance, for example, a distance of the order of cell size [14]. It is caused by path loss of signal as a function of distance and shadowing by large objects such as buildings, intervening terrains, and vegetation. Shadowing is a slow fading process characterized by variation of median path loss between the transmitter and receiver in fixed locations. In other words, large-scale fading is characterized by average path loss and shadowing. On the other hand, small-scale fading refers to rapid variation of signal levels due to the constructive and destructive interference of multiple signal paths (multi-paths) when the mobile station moves short distances. Depending on the relative extent of a multipath, frequency selectivity of a channel is characterized (e.g., by frequency-selective or frequency flat) for small-scale fading. Meanwhile, depending on the time variation in a channel due to mobile speed (characterized by the Doppler spread), short term fading can be classified as either fast fading or slow fading. Figure 2.3 classifies the types of fading channels.



**Figure 2-3:**Classification of Fading Channels

## 2.3 MIMO Antenna System

The use of multiple antenna technique has gained overwhelming interest throughout the last decade. The idea of using multiple antenna configuration instead of a single one has proven to be successful in enhancing data transfer rate, coverage, security and overall the performance of radio networks.

### 2.3.1 Background of MIMO

The history of the MIMO technology dates back to 1984. At that time, Jack Winters of Bell laboratories wrote an article titled “Optimum Combining in Digital Mobile Radio with Co-channel Interference”. After publishing the article a number of efforts have been made by many engineers and academics to better understand the MIMO system. In 1993 Arogyaswami Paulraj and Thomas Kailath proposed the concept of spatial multiplexing (SM) using MIMO [16].

In the year 1996, few major studies had been made in increasing the signal efficiency over MIMO channels. This year Gregory G. Raleigh and V.K. Jones combinedly wrote a paper titled as “Multivariate Modulation and Coding for Wireless Communication”. In that paper they claimed that multi-path channels can have a multiplicative capacity effect if the multi-path-signal propagation is used in an appropriate communications structure. In the same year, Gerard Joseph Foschini sparked the massive international research effort on multiple-input multiple-output wireless systems that continues till today by introducing the BLAST concept in his paper "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas" [16]. BLAST stands for Bell Laboratories Layered Space-Time.

In 1999, Emre Telatar successfully calculated the Shannon capacity of an isotropic fading MIMO channel in his paper, “Capacity of multi-antenna Gaussian channels”. He showed that the channel capacity increases with the number of antennas and is proportional to the minimum number of transmit and receive antennas.

In 1998, Bell laboratories successfully demonstrated the MIMO system under laboratory conditions. In the following year, Gigabit Wireless Inc. and Stanford University jointly held the first prototype demonstration of MIMO. Eventually in 2002, Lospan Wireless Inc. produced the first commercial product based on MIMO. As of today, several companies have developed MIMO-OFDM (Orthogonal frequency-division multiplexing) solution based products. All upcoming 4G systems will be compatible with the MIMO technology [16].

### 2.3.2 SISO Antenna Technique

This type of configuration is the oldest known type of configuration. There is only a single antenna working as a transmitter and a single antenna working as a receiver. Usually, no or less complex configuration is used in the system. Figure 2-4 shows the basic structure of a one transmit and one receive antenna system.

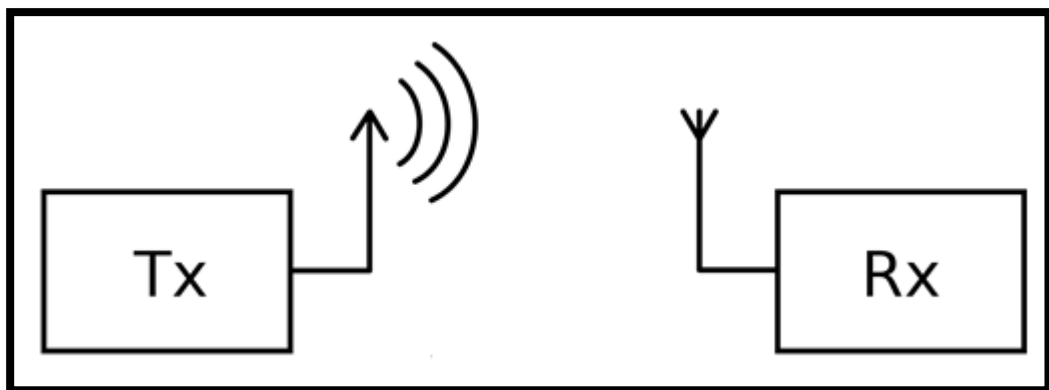


Figure2-4: SISO System

### 2.3.3 SIMO Antenna Technique

When one antenna transmits multiple receive antennas, the system is known as Single input Multiple-output (SIMO). Here one signal is transmitted and two or more are received. Receive diversity is used in the SIMO antenna technique. A typical SIMO structure is shown in Figure 2-5.

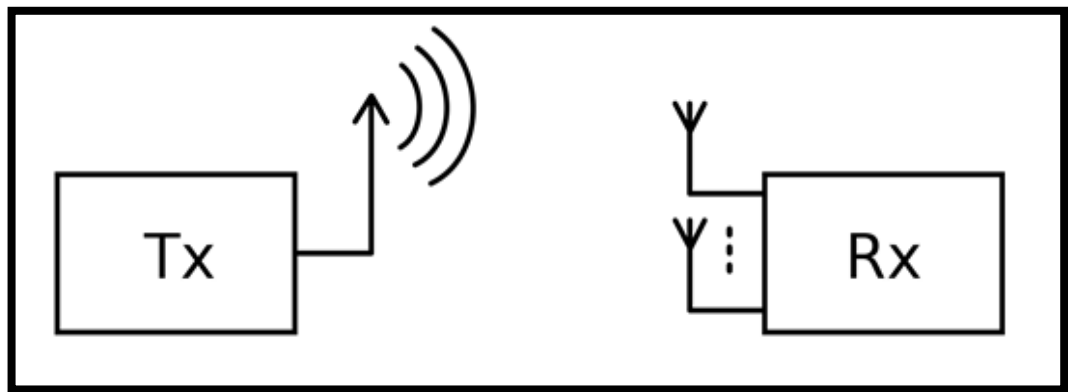


Figure 2-5: SIMO System

Receive diversity means that while receiving a signal, the antenna can either choose the strongest signal or can join all the signals received in different antennas. There are a few techniques that can be used to combine the received signals. The main three of them are the following :

**Maximal ratio combining:** In the MRC method, received signals are combined together to get the most out of the combined signal's Signal to Noise Ratio (SNR). All the signal branches are multiplied by a weight factor which is proportional to the signal amplitude. That is why branches with a higher signal level are further amplified, while weaker ones are dismissed [17].

**Equal gain combining:** In the EGC method, signals from different antennas are co-phased and added together. These types of schemes are

applied at the Radio Frequency level. EGC is simpler to implement than Maximum Ratio Combining (MRC). The adaptive controller amplifiers / attenuators are not needed. Moreover, no channel amplitude estimation is needed [17].

**Selection combining:** This type of diversity combining technique is the simplest of all. SC simply switches between the branches according to their signal strengths. For example, if path one has the maximum received power, then the weighing factor of path one is set to a constant while all other paths are set to zero. Although it is less effective than the other schemes, it is far better than non-diversity schemes.

If the three techniques are compared according to the complexity and improvement of Signal to Noise ratio (SNR), then certainly Maximal Ratio Combiner (MRC) shows the best result, while the worst result is shown by Selection Combining (SC). However, in terms of simplicity, SC is the easiest to implement as there is no need of phase or amplitude calculation.

#### 2.3.4 MISO Antenna Technique

In the MISO (Multiple-input Single-output) antenna technique, multiple antennas are used in the transmitter while a single antenna is used in the receiver. It is a comparatively new technology. This has been a favorite as only multiple antennas need to be installed in the base station (BS). Transmit diversity technique is used in case of MISO. In Figure 2-6, a general diagram of MISO is shown.



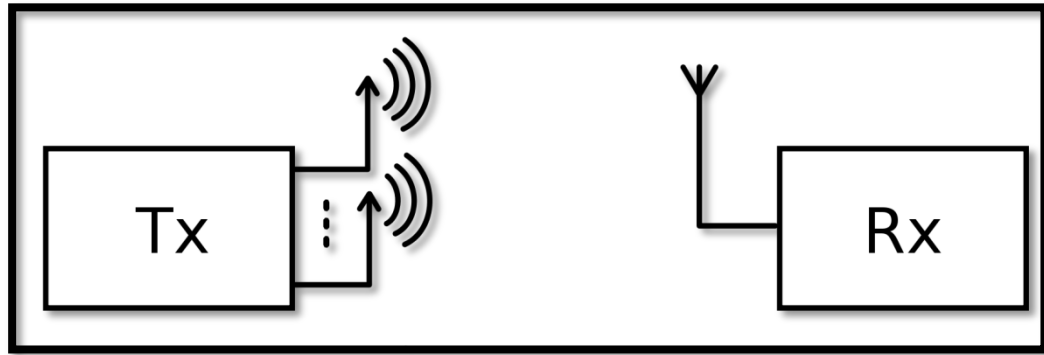


Figure 2-6: MISO System

Transmit antenna diversity is a type of controlled diversity technique which provides spatial repetition of transmitted signals through different antennas. A method recognized as STC (Space Time Coding) is implemented at the transmitter with multiple antennas. STC permits the transmitter to transmit signals simultaneously in time and space, which means the information can be transmitted by multiple antennas at different times consecutively. Transmit diversity can be of two types, open loop and closed loop. In the open loop system, the knowledge of amplitude and phase characteristics of the channel are not needed at the transmitter, whereas in the closed loop system this knowledge is required.

### 2.3.5 MIMO Antenna Technique

When using MIMO technology, multiple receiving and transmitting antennas are used to increase capacity without additional power or bandwidth. The capacity scales linearly with the minimum number antennas used at the transmitter or the receiver. In Figure 2-7, a general diagram of MIMO is shown.

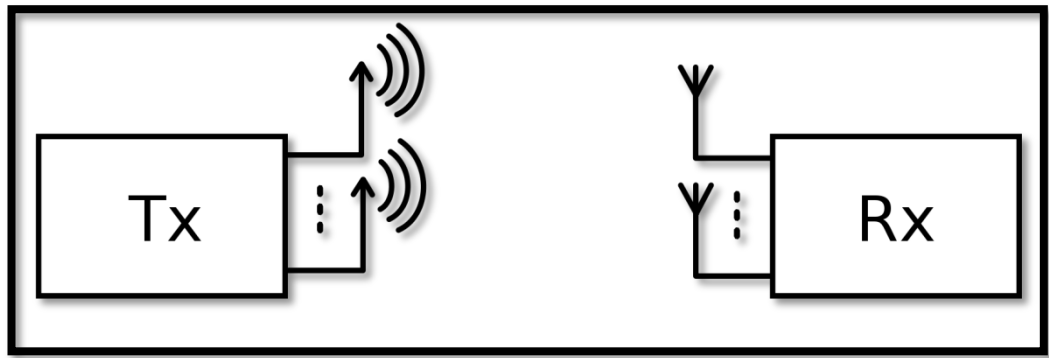


Figure 2-7: MIMO System

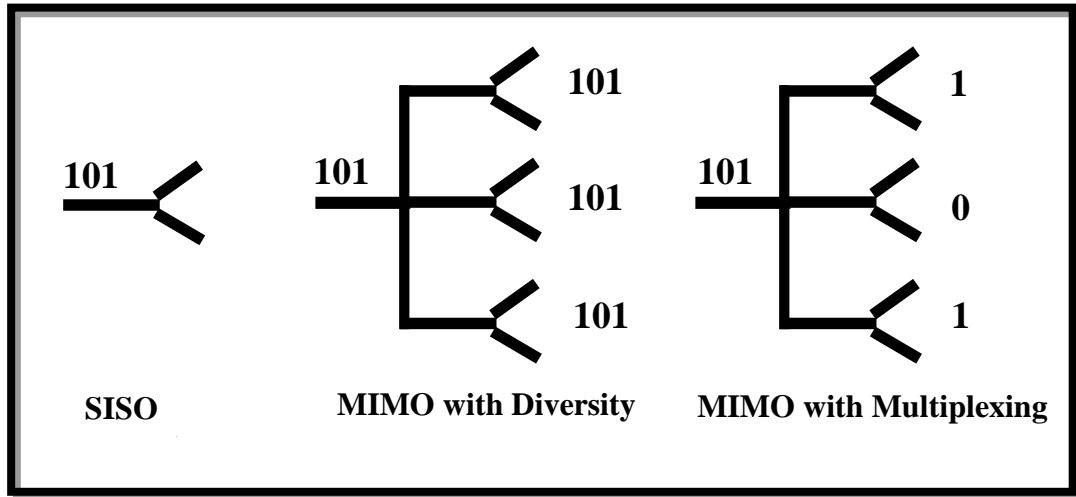
The MIMO design of a communications link can be classified in these two ways. MIMO using diversity techniques and MIMO using spatial-multiplexing techniques. Both of these techniques are used together in MIMO systems [18,19].

**Diversity technique:** In this form same data is transmitted on multiple transmit antennas and hence this increases the diversity of the system. Diversity means that the same data has traveled through diverse paths to get to the receiver. Diversity increases the reliability of communications. If one path is weak, then a copy of the data received on another path maybe just fine.

In Figure 2-4, we see a source with data sequence 101 to be sent over a MIMO system with three transmitters. In the diversity form of MIMO, same data, 101 is sent over three different transmitters. If each path is subject to different fading then the likelihood is high that one of these paths will lead to successful reception.

**Spatial-multiplexing techniques:** The multiple independent data streams are simultaneously transmitted by the multiple transmit antennas, in a diversity technique, we send same data over each path. Here we multiplex the data over all path as shown in figure 2-8. Each

path carries different data, by multiplexing the data we have increased the data throughput or the capacity of the channel, but we have lost the diversity gain. The multiplexing has tripled the data rate. Whereas in a diversity system the gain comes in form of increased reliability, here the gain comes in form of increased data rate.



**Figure 2-8:**Equivalent MIMO Systems (a) SISO System, (b) MIMO Diversity System, (c) MIMO Multiplexing System

## 2.4 Related Work

There are several related works in using Wi-Fi links for long distance in outdoor environment, most of this works mounted the antenna on top of tall towers.

One of the first to deploy a Wi-Fi based outdoor long distances network is Bhaskaran Raman [20], it was consisting of approximately ten links and lengths ranging from 1-16 Km.

In paper [21], a systematic study of long distance 802.11b link performance is performed. They study the behavior of such long links for varying packet sizes, data rates, SNRs and weather conditions.

Paper [22] presented a measurement study of outdoor 802.11g links, their test bed has nine nodes with links varying from 90 m to 1.2 km.

Sheth et al. [23] present a study on most common sources of packet losses in long distance links.

There is a basic difference between this work and our project. All these work have infrastructure APs on top of towers or high buildings to create LOS links. In addition, their main focus is to provide network connection over long distance (up to 16 Km) point-to-point link. In contrast, our link required range is about 1-5 Km, furthermore our antenna is mounted on top of a lightweight movable mast that may be 1-2 m tall.

Shrivastava et al. [24] present the first experimental study of 802.11n and quantify different mechanisms introduced in 802.11n in diverse conditions, analyze the fundamental characteristics of 802.11n links and quantify the gains of each mechanism under diverse scenarios. We show that the throughput of an 802.11n link can be severely degraded (up to \_ 85%) in presence of an 802.11g link.

The authors in [25] present a theoretical model of outdoor MIMO channel in a LOS environment. They show that, in a pure LOS situation, path orthogonality can only be achieved for very short distance links when the conventional linear array antenna model is used with no polarization diversity.

Paper [26] presents an experimental performance evaluation study of Wi-Fi links in an open-space outdoor environment. They considered an outdoor Wi-Fi network for land-based oil and gas exploration wireless sensor networks. The scenario is different from the traditional long distance Wi-Fi network in the sense that nodes are placed closer to ground level compared to other work. They present a measurement experimental study of two types of links of this network. For the first-hop link, they use 802.11a/b/g to find the maximum link range. They use 802.11n for the backhaul link and evaluate different PHY/MAC layer features provided in 802.11n.

In paper [27] the author presented a quantitative analysis of the performance of a network of Wi-Fi-like access points (APs) operating in TVWS in order to obtain a realistic estimate of the achievable range and downlink rate of such a secondary system.

The author in paper [28] presented the world's first prototype system of Wi-Fi in TVWS based on the TGaf draft specification. The prototype system verifies the PHY and MAC design of TGaf and the database query protocols that is needed for TVWS operation but not in the scope of TGaf.

The work in this thesis [29] focus on the capacity and performance analysis of MIMO antenna systems operating over general and practical propagation channels. There are primary two key aspects in this thesis: the first is to give a thorough investigation on the fundamental capacity limits of several important MIMO channels, while the second is to analyze in details for some practical transmission methods over matrix product channels.