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Multiple Antenna Technique (MIMO)

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Abstract

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In the wireless communication field, multiple antennas are gaining increased interests because of their dramatic increase in capacity and speed of data transmissions. The purpose of this thesis is to give a brief look into multiple antenna techniques with the main focus on MIMO (Multiple-Input Multiple-Output). Basic principles of the entire popular multiple antenna techniques are briefly discussed here.

For better understanding of multiple antennas, basic parameters and antenna mechanisms are also discussed here. Being a hot topic for upcoming mobile generations, different settings of multiple antennas and their differences and their implications are also analyzed.

Throughout this thesis, the benefits of multiple antennas are discussed. Current uses of multiple antennas are also briefly focused on. However, the purpose is also to explain why MIMO will be used in a broader range in the near future. As no experiments or developments were done during this project, this thesis is purely based on theoretical works.

Keywords	MIMO, Multiple Antenna, LTE, 4G, WiMAX

Contents

List of Symbols and Abbreviations

4G	Fourth Generation
AAS	Adaptive Antenna System
BER	Bit Error Rate
BLAST	Bell Laboratories Layered Space-Time
BS	Base Station
CATV	Community Antenna Television
CDD	Cyclic Delay Diversity
CSI	Channel State Information
dB	Decibel
DD	Delay Diversity
DFTS-OFDM	Discrete Fourier Transform Spread OFDM
DoA	Direction of Arrival
EGC	Equal Gain Combining
EMF	Electromotive Force
FDM	Frequecy Division Multiplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FHDC	Frequency Hopping Diversity Coding
GI	Guard Interval
GPS	Global Positioning System

IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
ISI	Intersymbol Interference
LoS	Line of Sight
LTE	Long Term Evolution
MC-CDMA	Multi Career CDMA
MIMO	Multiple Input Multiple Output
MIMO-OFDM	MIMO Orthogonal Frequency Division Multiplexing
MISO	Multiple Input Single Output
MRC	Maximal Ratio Combining
OFDMA	Orthogonal Frequency Division Multiple Access
OFDMA-FSCH	OFDMA Fast Sub-Carrier Hopping
OFDMA-SSCH	OFDMA Slow Sub-Carrier Hopping
OFDM-CDMA-SFH	OFDM-CDMA Slow Frequency Hopping
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RFID	Radio Frequency Identification
SC	Selection Combining
SD	Spatial Diversity
SFBC	Space-Frequency Block Code
SIMO	Single Input Multiple Output
SISO	Single Input Single Output

SM	Spatial Multiplexing
SNR	Signal to Noise Ratio
STBC	Space Time Block Coding
STC	Space-Time Coding
STTS	Space-Time Trellis Code
TSD	Transmit Selection Diversity
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
ϵ_R	Radiation Efficiency
$P_{radiated}$	Radiated Power
P_{input}	Input Power
D	Directivity
E	Electric Field Intensity
G	Gain
λ	Wavelength
C	Channel Capacity
N_0	Noise Power
P_t	Transmit Power

1 Introduction

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.

With an enormous amount of yearly publications, research into multiple antennas has helped it to evolve pretty quickly. Up to now, there have been hundreds of research papers and research works behind it. There have been many different types of proposals towards the implementation of such a technology.

The objective of this final year thesis is to provide a brief overview of this exciting new technology. Especially one branch of it will be focused on more. It is known as MIMO (Multiple-input Multiple-output). In this paper, a gist of the last ten years' work by many engineers will be given. Moreover, some advanced technology for upcoming evolutions in mobile communications will also be discussed.

In this paper, antenna concepts will be discussed from the very basic level for proper understanding the MIMO method. This paper can be helpful for any individual who would like to have a brief look into the world of multiple antennas.

2 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. [1]

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 [1]. 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" [1]. 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. [1]

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. [1]

3 Antenna Basics

An antenna is a metallic object which acts as a medium for receiving and transmitting electromagnetic energy. It acts as a transitional structure between the transceivers and the free space. Officially the Institute of Electrical and Electronics Engineers (IEEE) defines an antenna as "that part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves". [2]

By moving electrons in the antenna, electromagnetic waves are formed. The antenna is connected to a transmitter which is designed to output current as a function of time. This current is an electromotive force (EMF) which forces free charge in the conductive element of the antenna to travel back and forth along the transmitting antenna. In the receiving antenna, there is free charge in the conductive element. They are affected by the movement of charge in the transmitting antenna. As there is usually a long distance between the transmitting antenna and the receiving antenna, that movement of charge in the receiving antenna is much smaller than the quantity of charge and movement in the transmitting antenna. This small and somewhat distorted signal is then amplified by the receivers. [2]

In order to understand the basic antenna principle, there are some parameters which have been taken into account. The basic antenna parameters include radiation pattern, antenna efficiency, bandwidth, directivity and antenna gain. [2]

3.1 Radiation Pattern

An antenna radiation pattern is the angular distribution of the power dissipated by the antenna [3]. It is a graphical explanation of the relative field strength transmitted and received by an antenna. As an antenna radiates through open space, several graphs are sometimes needed to describe the characteristics of an antenna.

The graphs can be drawn using Cartesian (rectangular) coordinates or a polar plot. The radiation pattern of a half-wave dipole antenna is shown in figure 1.

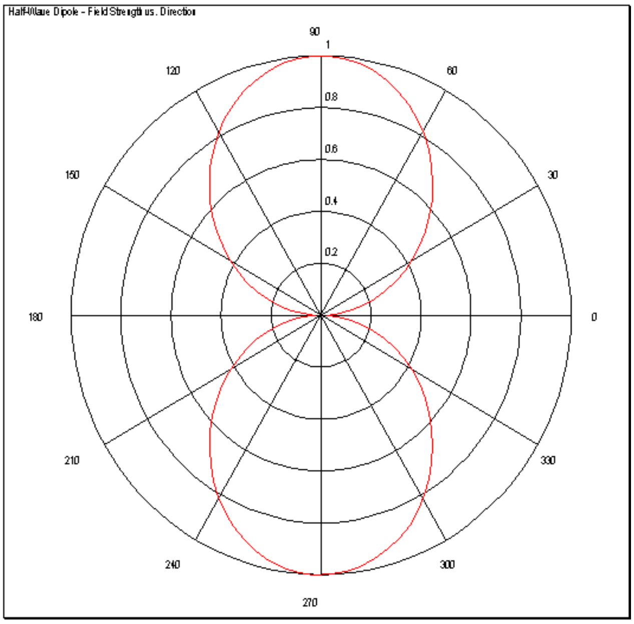


Figure 1: Radiation pattern of half-wave dipole antenna [4]

The radiation pattern can be different between different manufacturers. They can be either three-dimensional drawing or two-dimensional.

3.2 Antenna Efficiency

The ratio of the total radiated power to the total input power is the antenna efficiency. The total radiated power is the measure of how much power is radiated by an antenna while it is connected to a transmitter. Most of the power from a high efficiency antenna is radiated away while a low efficiency antenna has most of the power absorbed as losses within the antenna or reflected away due to impedance mismatch. The antenna efficiency can be described by the following equation:

$$\epsilon_R = \frac{P_{radiated}}{P_{input}}, \qquad (1)$$

Where, ϵ_R is the antennas radiation efficiency, $P_{radiated}$ is the radiated power and, P_{input} is the input power. Efficiency is a ratio which is often described as a percentage. It is quoted in decibels (dB) [3].

3.3 Bandwidth

Bandwidth is the range of frequencies in which the antenna remains effective. According to IEEE, bandwidth is "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." [2]

Bandwidth is a key factor upon choosing the right antenna. For instance, antennas with narrow bandwidths cannot be used for wide band operations. Bandwidth is typically quoted in VSWR (Voltage Standing Wave Ratio). For example, an antenna may be described as operating at 100-400 MHz with a VSWR<1.5. This statement implies that the reflection coefficient is less than 0.2 across the quoted frequency range. Hence, of the power delivered to the antenna, only 4% of the power is reflected back to the transmitter. [3]

3.4 Directivity

A commonly used parameter to measure the overall ability of an antenna to direct radiated power in a given direction is directive gain. [5]

The maximum directive gain of an antenna is called the directivity of the antenna. It is the ratio of the maximum radiation intensity to the average radiation intensity [5]. Then the formula for directivity (D) can be written as

$$D = \frac{4\pi |E_{max}|^2}{\int_0^{2\pi}\int_0^{\pi} |E(\theta,\phi)|^2 sin\theta d\theta d\phi} \quad (2)$$

Where, E is the electric field intensity.

3.5 Antenna Gain

Antenna gain is an important topic to consider while designing an antenna. It combines the efficiency with its directivity into a single figure. In case of transmission, the gain has to deal with how effectively an antenna can convert its input power to radio waves heading to a specific direction [5]. On the other hand, during reception, gain tells about how effective the antenna is in case of converting received waves into electrical power. Gain can be denoted by the following formula.

$$G = \varepsilon_R . D \tag{3}$$

Where, ε_R is the efficiency and D is the directivity.

3.6 Motivation for Advanced Antenna Techniques

As technologies are progressing, a need for enhanced services and higher data rates is created. Previously wireless connections were mostly voice centered, and the needs of high speed data were mainly taken care of by wired connections. However, now that there are mobile phones with cameras and built in GPS (Global Positioning System), in order to meet the constant needs of various wireless systems, antenna structures also have to be changed. One possibility is to merge the signal processing functionality with multiple antenna elements. Then what is called, "intelligent antennas" are created [6]. Their characteristics and functions can vary over the specific system requirements. They can greatly increase the capacity, quality and service given by the antenna itself.

Advanced antennas are also needed to overcome the wideband effects, improved power delivery and also interferences. As the world is moving towards 4G, LTE (Long Term Evolution) and beyond that, advanced antennas are the key parts that have to be modified to support those technologies.

3.7 Different Types of Advanced Antennas

In case of advanced antenna designs, mostly different array antenna solutions are studied. One possibility is to use multi-beam antennas or spatial multiplexing antenna systems. Different types of advanced antenna configurations include [6], sector antennas, omni-direction antennas, one transmit and one receive antenna and one transmit and two receive antennas.

3.7.1 Omnidirectional Systems

With the ever-growing number of subscribers, with limited frequency and number of channels, maintaining capacity is becoming a big problem in radio communication. One way to solve this problem is using the same channel repeatedly. That is, using a specific channel to carry out various calls or data simultaneously. In order to accomplish this, mobile phones using the same frequency had to be placed far from each other to avoid the collision. It is when the concept of cellurization arises.

Cellurization consists of splitting a large geographical area into smaller areas or cells. Every call can use a portion of available frequency, thus providing good services to the subscribers. Depending on the area sizes, cells can be categorized into different types as macrocells (1-20km), microcells (0.1-1.0 km) , picocells (indoor use) and femtocells (operating at low transmit powers and covering a small area) [6]. Capacity of a system largely depends on the distance between each cell using the same frequency. This distance is called channel reuse distance. Every cell is equipped with an omnidirectional antenna in its center. An omnidirectional antenna is an antenna which can radiate power uniformly in every direction.

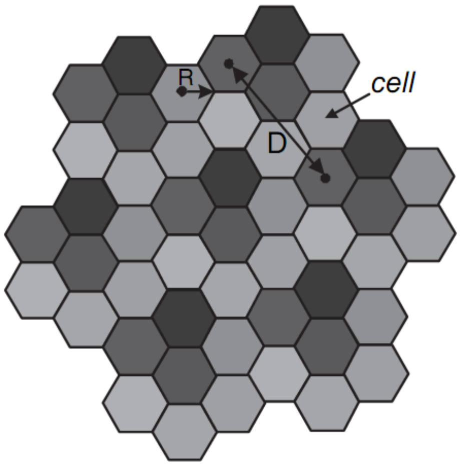


Figure 2: A typical cellular structure [6]

The radiation pattern of an omnidirectional antenna is almost donut shaped. Figure 2 shows the basic concept of a typical cellular structure. In figure 2 each hexagonal area represents a single cell. Each hexagon with the same color uses the same frequency.

Here *D* is the distance between cells using the same frequencies, otherwise known as channel reuse distance. *R* is the maximum radius of each cell.

In the beginning, cells were only equipped with omnidirectional antennas, as the number of users was much smaller. As the number of users grew, so did the interference, and thus the overall capacity was decreasing. This issue had been dealt with the concept known as cell splitting, in which each cells was further divided into smaller areas. However, this concept also proved problematic as the cost was much higher. Thus, a new way of antenna configuration had to be developed. [6]

3.7.2 Sector Antennas

A sector antenna is a type of directional antenna which has a sector shaped radiation pattern. It is typically used in mobile phone base-stations. A sectorized system subdivides a cell area into different sectors with the help of sector antennas. This technique is called cell-sectoring. In cell sectoring, a single omnidirectional antenna is replaced by several sector antennas.

A sectorized system is proved to be better than an omnidirectional system since each sector is treated as a different cell in the system. Thus the power can be focused onto a smaller area. Moreover, sectorized systems can enhance the possiblity of reusing a frequency channel by dropping interferences across the original cell.

Typically, three sector antennas are used to cover a cell (120^0+$120^{0+}$$120^0$ = 360^0), although larger numbers of sectors are also possible [6]. Figure 3 shows a typical sectorized system with three sector antennas.

Figure 3: A sectorized antenna configuration [6]

In a sectorized system, capacity is largely increased by reducing the number of cells, leading to better frequency reuse. The interference is also greatly eliminated as, unlike in an omnidirectional system, only two neighboring cells interfere the signal, whereas this number is six in case of an omnidirectional system [6].

3.7.3 One Transmit and One Receive Antenna

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 4 shows the basic structure of an one transmit and one receive antenna system.

Figure 4: One transmit and one receive antenna

Both the transmitter and receiver have a common radio frequency. This type of antenna configuration is largely used in radio systems, television systems and personal wireless technologies such as Bluetooth and Wi-Fi (Wireless Fidelity). They are commonly referred as T1R1.

3.7.4 One Transmit and Two Receive Antennas

Like the name of this antenna system suggests there is one antenna to transmit and a couple of antennas in the receiver side. Figure 5 shows a basic diagram illustrating a one-transmit and two-receive antennas system.

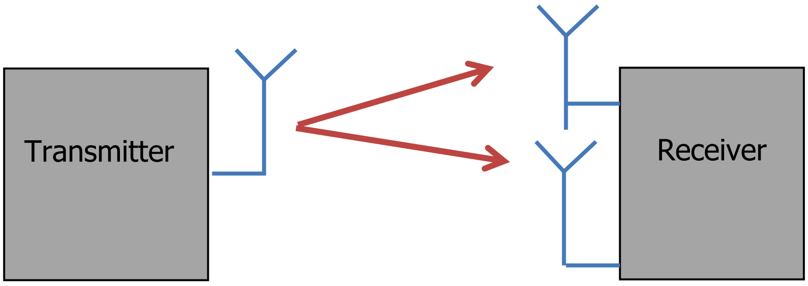


Figure 5: One transmit and two receive antennas

This type of setup is largely used to improve reliability and performance of radio station channels, as the programs are transmitted from one single base station and there are many users tuning into the same frequency. In this case, the receiver has freedom of either choosing the best antenna to receive a stronger signal, or combining the signal of both antennas and taking an aggregated result.

4 Multiple Antenna Techniques

Traditionally, wireless communications mainly focused on voice and smaller data transfers, whereas most high-rate data transfer products were using wired communications. In recent years, however, there has been a dramatic boost in wireless multimedia applications, such as cell phones having an integrated camera, emailing capability and GPS. As a result, the focus has now shifted towards wireless high speed data transfers which traditional antennas are not capable of delivering because of multipath and co-channel interference [6].

Apart from the needs of high speed data transfers, there is also an issue of quality control, which includes low error rate and high capacity. In order to maintain certain Quality of Service (QoS), multipath fading effect has to be dealt with. As the transmitted signal is reflected onto various objects on its way to the receiver, the signal is faded and distorted. This phenomenon is called multipath fading [5]. Co-channel interference refers to the the interference caused by different signals using the same frequency.

Hence as an alternative, multiple antennas can be used to reduce the error rate as well as, improve the quality and capacity of a wireless transmission by directing the radiation only to the intended direction and adjusting the radiation according to the traffic condition and signal environment. All multiple antennas are equipped with several antennas either in the transmitter or the receiver or both of them. A sophisticated signal processor and coding technology is the key factor in multiple antennas. Multiple antenna technique can be broken down into three categories, Spatial Diversity (SD), Spatial Multiplexing (SM) and Adaptive Antenna System (AAS). [5]

4.1 Spatial Diversity (SD)

Spatial diversity is a part of antenna diversity techniques in which multiple antennas are used to improve the quality and reliability of a wireless link. Usually in densely populated areas, there is no clear Line of Sight (LoS) between the transmitter and the receiver. As a result, multipath fading effect occurs on the transmission path [7]. In spatial diversity several receive and transmit antennas are placed at a distance from each other. Thus if one antenna experiences a fade, another one will have an LoS or a clear signal. Figure 6 shows the basic principle of Spatial Diversity.

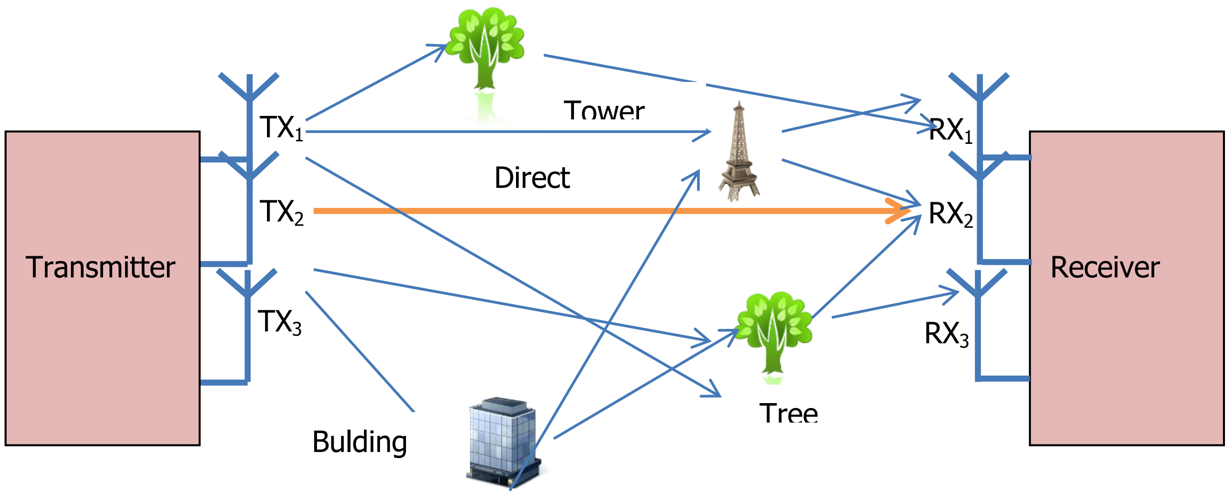


Figure 6: Spatial diversity [7]

The same signal is fed through a single antenna or multiple antennas, and the same signal is captured by a single antenna or multiple antennas.

In figure 6 several antennas are placed in a distance from each other. There are various obstacles on the signal's path. However, it can be noticed in the figure that from transmitter TX_2 there is a clear LoS to receiver RX_2. Despite the multipath fading effect having occurred in other receivers, the receiver can get a fairly good signal.

In the case of base stations in a macro cellular environment, with large cells with high antennas, a distance up to 10 wavelengths is needed to ensure a low mutual fading correlation. However, in case of handheld devices, because of lack of space, half a wavelength is enough for the expected result. The reason behind this space is usually in the macro/cell scenario, the fading of which is caused by multipath correlations that have occurred in the near zone of the terminal. Therefore, from the terminal side, different paths arrive in a much wider angle, thus requiring smaller distances, whereas from the transmitter side, the path angle is relatively slow. That is why a larger distance is required [8].

Recognized spatial diversity techniques involving multiple transmit antennas are, for example, Alamouti's transmit diversity scheme [9] as well as space-time trellis codes [10] invented by Tarokh, Seshadri, and Calderbank. For systems in which multiple antennas are available only at the receiver, there are well-established linear diversity combining techniques dating back to the 1950's [11].

4.2 Spatial Multiplexing

Multiple antenna systems are capable of establishing parallel data streams through different antennas. This is done in order to increase the data transfer rate. This process is called spatial multiplexing [6,7].

The bit stream to be transmitted is divided or demultiplexed into several data segments. These segments are then transmitted through different antennas simultaneously. As several antennas are in use, bit rate increases dramatically without the requirement of extra bandwidth or extra transmission power. The signal captured by the receiving antenna is a mixture of all individual segments. They are separated at the receiver using an interference cancellation algorithm. A well-known multiplexing scheme was developed by Bell Labs, known as BLAST [1].

4.3 Antenna Array

Single element antennas are not always sufficient for required antenna gain and radiation pattern. Combining several single element antennas into an array provides a much better solution. When multiple active antennas are joined together to a common source in order to achieve a directive radiation pattern, this is called an antenna array [8].

Each individual antenna is known as the element of an array antenna. The radiation pattern from the array in a linear medium is determined by vector addition of the components of the electromagnetic fields radiated from the individual antennas or elements.

This process is also known as the principle of superposition. Antenna arrays can be one, two or three dimensional. A typical array antenna is shown is figure 7.

Figure 7: A typical array antenna [12]

There are several different configurations available for array antennas. If the elements are arranged in a straight line, then it is called linear array. If they are arranged parallel to each other, then a plane array in two dimensions is made.

An array is linear when all the elements are placed at a constant distance. The array is called uniform when current of the same magnitude is fed into the array. A broadside array is formed when all the current fed into the arrays are of the same time-phase. There are some key elements otherwise known as array factors that are responsible for the shaping of the radiation pattern of an antenna array. These are:

- Number of elements

  The more elements added to the array, the more the array directivity gains [8]. Figure 8 shows the directivity of three element arrays with 2 (red), 5 (green) and 10 (blue) elements. Spacing between the elements is 0.4 times the wavelength.

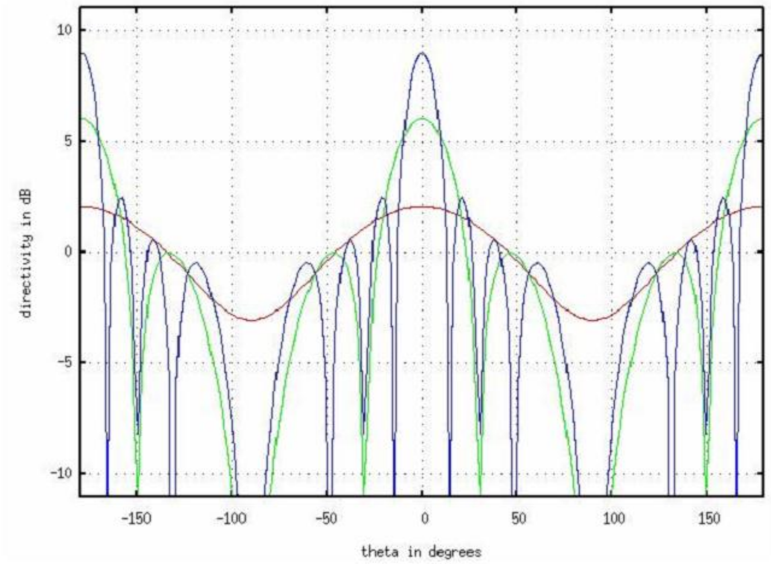


Figure 8 : Directivity of a 2(red), 5(green) and 10 (blue) element array with 0.4 λ element spacing [8]

- Spacing between the elements

  A larger element spacing means a larger directivity. Figure 9 shows the result of different spacing for a 5-element array antenna using wavelength element spacing 0.2 (red), 0.3 (green) and 0.5 (blue) times. However, spacing is always kept below half of the wavelength to avoid unwanted peaks, otherwise known as grating lobes.

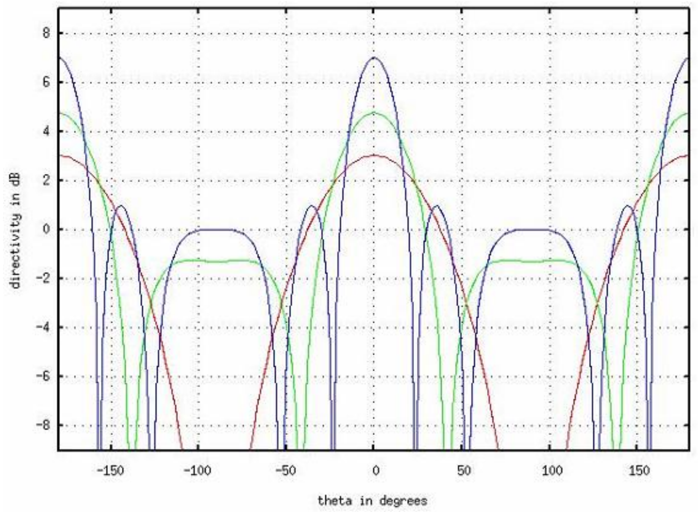


Figure 9: Directivity of a 5-element array with 0.2 (red), 0.3(green) and 0.5 (blue) times λ element spacing [8]

If the spacing is increased, i.e. wavelength element spacing is increased 0.5 (red), 0.75 (green) and 1 (blue) times, directivity also increases. Nevertheless as seen in figure 10, some unwanted peaks also start to appear.

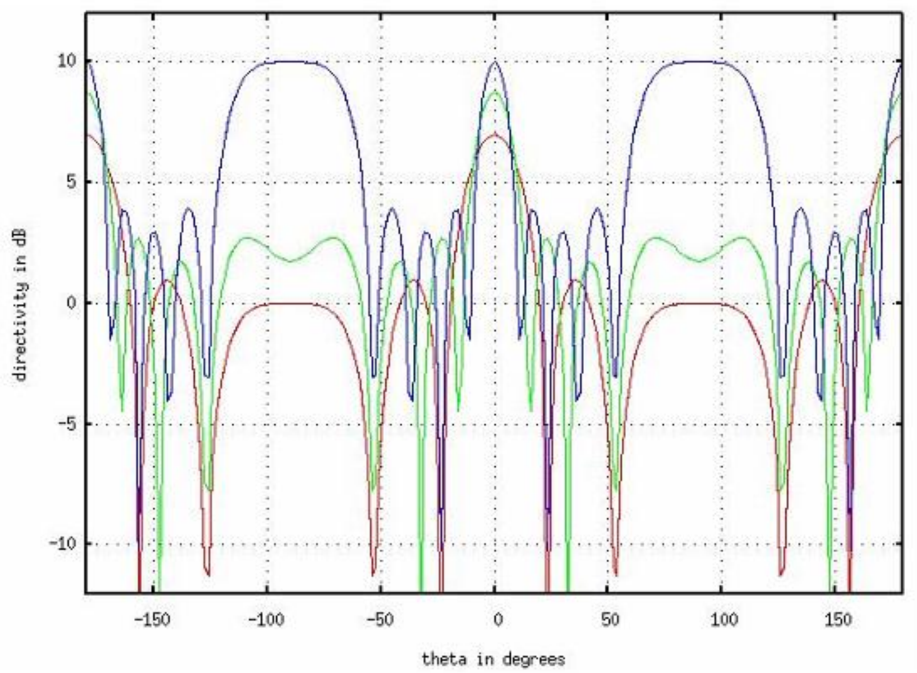


Figure 10: Directivity of a 5-element array with 0.5 (red), 0.75(green) and 1(blue) times λ element spacing [8]

- Radiation pattern of invidual radiating elements

  The overall radiation pattern changes with the individual radiation patterns of the radiating elements.

Figure 11 shows directivity for an isotropic element (red). The radiation pattern is shown in green.

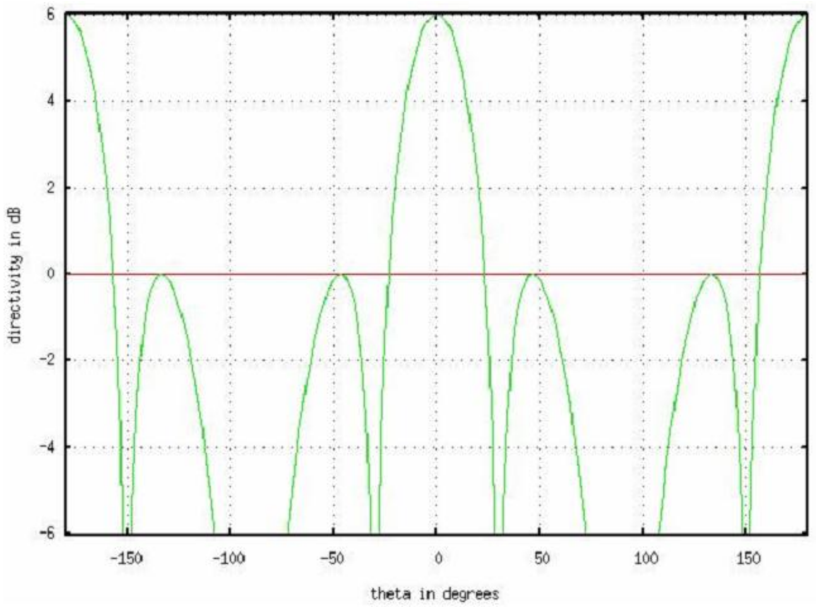


Figure 11: Directivity of an isotropic source (red) in a 5-element array (green) with 0.4 λ element spacing [8]

After that in figure 12, directivity is shown for a dipole element (red). Green is the radiation pattern for an isotropic element and blue is the radiation pattern for dipole.

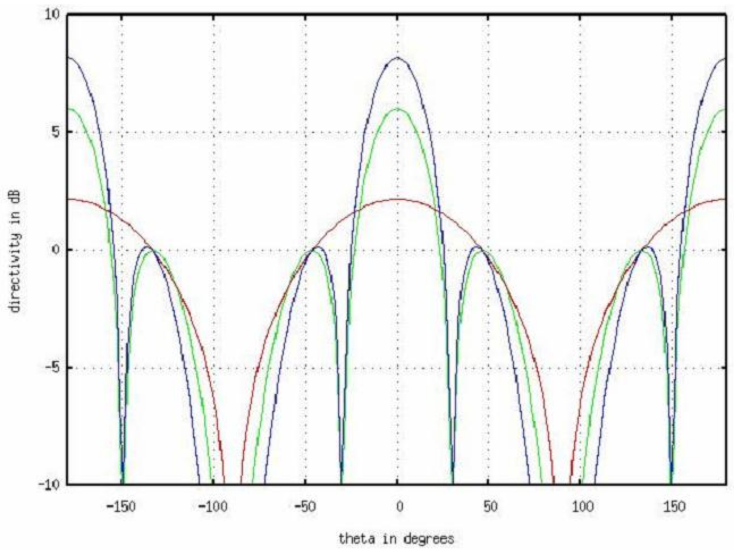


Figure 12: Directivity of a dipole in a 5-element array with 0.4 λ element spacing [8]

The overall radiation pattern is clearly different from figure 11 [8]. Nowadays antenna arrays are used in many wireless communications. They play a vital role in the making of radar systems, radio and TV broadcasting, space probe communications, weather research and RFIDs. By joining algorithms and a signal processing mechanism in an array system, adaptive antenna arrays are produced.

4.4 Smart Antennas

The concept of smart antennas or intelligent antennas dates back to the 1970's and 1980's. In those years IEEE did some research on transactions on antennas and propagation. They both were devoted to adaptive antenna arrays. Initially smart antennas were largely discussed in military applications. In military radar systems, smart antenna techniques were used in World War II. However, today's advancement in building low cost signal processors has gradually made smart antennas available for commercial use [6].

The basic idea of smart antennas was built based on the human auditory system. A person is able to guess the direction of arrival (DoA) of a sound by three simple stages:

- Ears act as the sensor for receiving the sound
- Because of the availability of two ears, a sound created by a source reaches each ear with a slight time difference.
- The human brain, acting as a signal processor, can determine the direction of the source.

With the help of two ears, a human brain can determine the exact location of the sound source, even if the sound source is in motion. Moreover, the brain can also concentrate on the specific sound source if there is more than one source of sound. It can literally enhance the required sound and tune out the unwanted source. Thus it is possible for humans to concentrate on desired conversations even if there are others talking at the same time. In addition, they can respond to a specific sound source by adjusting their mouth towards the source [6].

Smart antennas work in a similar way by using two antennas and a signal processor. Thus by comparing the signal strengths received by both antennas, smart antennas can focus on individual signals. In mobile communication systems, the base station plays the part of the listener and the mobile equipment plays the part of the signal source. A digital signal processor equipped with an antenna array can adjust various system parameters to focus on the required signal while cancelling out other interferences. Smart antennas can be broadly categorized as switched beam systems and adaptive array systems.

4.5 Switched Beam System

Switched beams use some predefined radiation patterns to focus on an individual subscriber. After detecting signal strength, this type of system switches between thousands of predetermined patterns to match the best communication link. As the subscriber moves, the radiation pattern is switched and the best is selected. Figure 13 shows the basic mechanism of a switched beam antenna system [6]

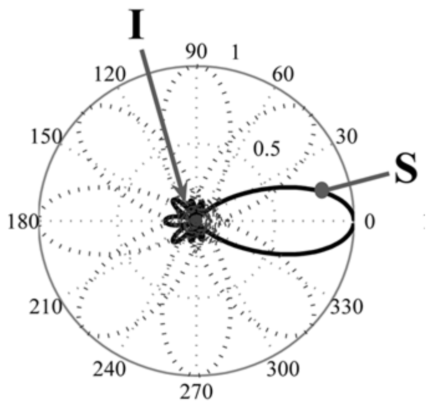


Figure 13: Switched beam system [13]

In a splitting system, macrocells are divided into a few microcells. Every microcell is equipped with different types of preset radiation patterns. When a subscriber enters a macrocell, the microcells with the strongest signals are determined and the corresponding beam is used for the maximum output power. In figure 13, individual subscriber is denoted by S. As it is shown in figure 13, the sector is filled with predetermined patterns. When the subscriber enters into a specific area, only the corresponding pattern is selected. The system constantly monitors the subscriber and switches from beam to beam for the best output [6].

4.6 Adaptive Antenna System

In an adaptive antenna system, multiple antennas are used both in the transmitting and receiving side of a communication link to adaptively optimize the transmission over the channel. An AAS system can focus its transmit energy towards a receiver, and while receiving, it can focus towards the transmitter. The technique used in AAS is known as beam forming [7,14]. Figure 14 shows the basic principle of AAS.

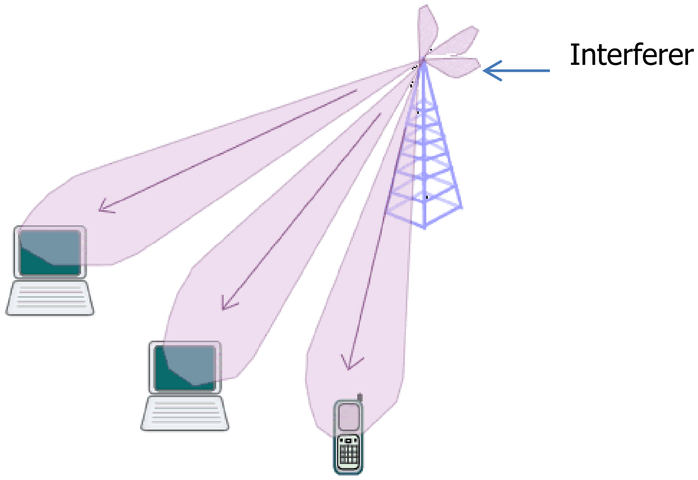


Figure 14: Adaptive antenna system [7]

Beam forming enables directional signal transmission or reception without manually steering the antennas. In the beam forming technique, several transmitters are set apart from each other. They all transmit the same signal with different phase difference and delay. As a result, the interference that occurred in all the transmitters can be used to steer a signal to a specific direction.

Figure 15 shows the signal transmission from a single source in the middle.

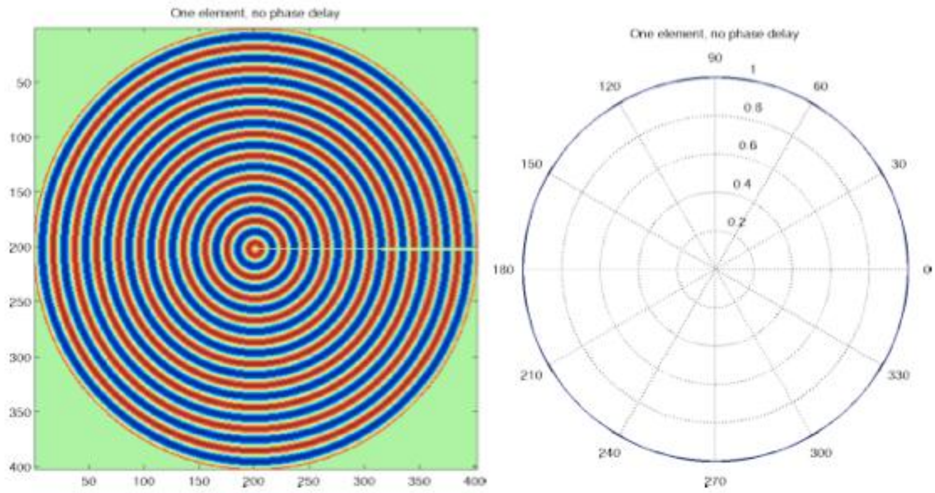


Figure 15: Beamforming from a single source with no phase delay [14]

It is important to notice that the signal is uniform in every direction. When two more sources are added 10 units apart in both sides on the X axis, then the result is shown as figure 16 demonstrates.

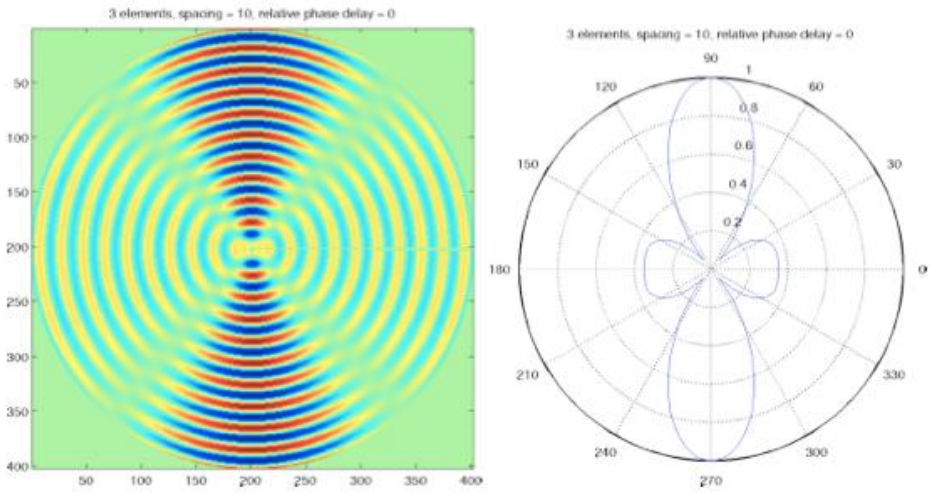


Figure 16: Beamforming from three sources with no phase delay [14]

The phase delay in figure 16 is 0.

However, the signal can be steered by adding two more elements and phase delays. The result is shown in figure 17.

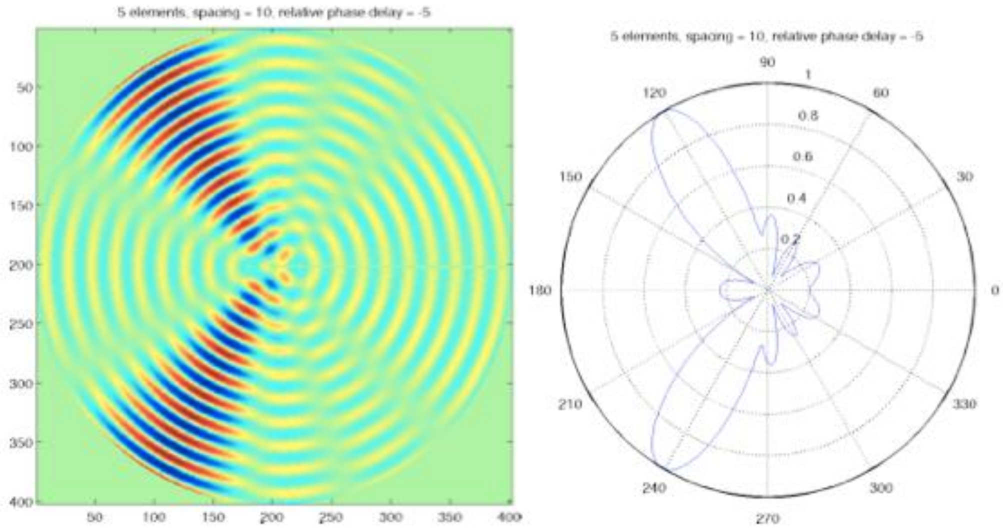


Figure 17: Beamforming from 5 elements with 5 ms phase delay [14]

In figure 17, a 5 millisecond time delay is introduced. By controlling this delay the beam can be steered in every direction. [14]

In an adaptive antenna system, signals can be focused simultaneously on many remote devices. The shape of these beams can be controlled in such a way that the signal between the transmitter and receiver is always maximum [7, 14].

The adaptive antenna system can increase link quality by combining the effects of multipath propagation and exploiting different data streams from different antennas. The key benefits of AAS are the following [6]:

- Increased coverage: The adaptive antenna can improve the coverage of a wireless transmission by increasing the gain. Typically the adaptive antenna gain depends on the number of array elements. For example, a six element array antenna can provide a gain of six.
- Increased capacity: It is one of the main advantages of AAS. Usually in highly populated areas, signals can be interfered by other users. Therefore, the Signal to Noise Ratio (SNR) is usually higher than the Signal to Interference Ratio

(SIR). Experiments showed that the adaptive antenna system can increase SIR up to 10dB (6). Thus increasing the overall capacity.

- Cost reduction: As AAS concentrates on individual users, lower power consumption and lower amplifier cost is easily achievable.
- Improved link quality and reliability: As signals are individually sent to the remote devices, diversity gain is obtained in the receiver by receiving individual parts of the same signal. Diversity gain is the gain in the receiver caused by using two or more antennas. One of the signals can be maximum and thus the link quality is maximized.
- Increased Spectral efficiency: Spectral efficiency is the process of using the available spectrum or bandwidth in such a way that the data transmission rate is maximum with the fewest transmission errors. Spectral efficiency plays an important role in cost assumption for the operator. It also gives a hint about the total required amount of spectrum, the required number of base stations, the required number of sites and the overall consumer affordability. A simplified formula to determine the number of cells needed can be written as follows:

$$\text{Number of cells/km}^2 = \frac{\textit{offerd load}}{\textit{available spectrum X spectral efficiency}} \quad (4)$$

Based on the formula it is obvious that increasing the spectral efficiency would decrease operator costs. The adaptive antenna system can increase spectral efficiency greatly.

- Security: It is more difficult to tap an AAS system, as the intruder must stand in the direction of the signal flow.
- Location based services: As the location of the user is always known to the transmitter, various location based services can be implemented in the adaptive antenna system.

However, there are some disadvantages of the adaptive antenna system, such as complex transceiver mechanism, needing resource management and physical size of the antennas.

4.7 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 18.

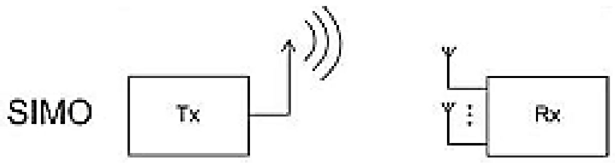


Figure 18: SIMO system [7]

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 [7]:

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

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 [7].

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 [7].

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.

4.8 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 19, a general diagram of MISO is shown.

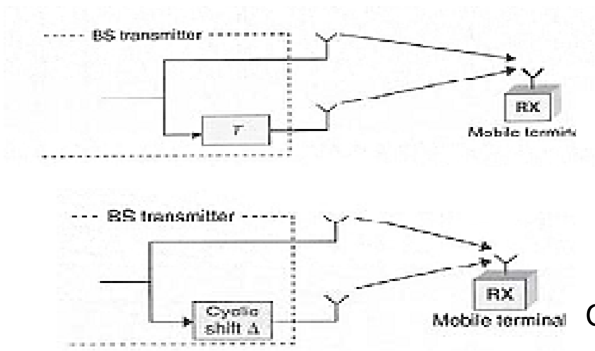
MISO

Figure 19: MISO system [6]

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.

4.8.1 Open Loop MISO

Delay Diversity (DD) is one of the simplest open loop MISO schemes. In this scheme, the signals sent from corresponding antennas are slightly delayed from each other. This means that after sending the signal from the first antenna, there will be a small time gap before sending the signal from the second antenna [7]. Signals received at different times are uncorrelated. However, at the receiver, this delay causes a multipath fading. If the receiver is able to minimize this fading with OFDM or advanced equalization, diversity gain is achieved. Delay diversity is usually implemented by for example forward error correction and repetition coding. If the delay is too large, then uncorrectable inter-symbol interference (ISI) will occur. This type of delay usually occurs through multipath propagation. The transmitted signal is bounced off of different surfaces and reaches the receiver at different times. Thus different versions of the signal are received at different time intervals.



Delay Diversity

Cyclic Delay Diversity

Figure 20: DD and CDD scheme [7]

Cyclic Delay Diversity (CDD) is another type of the open loop MISO scheme. It is, however, quite similar to the Delay Diversity scheme, differing only in the way that, instead of putting time delay while transmitting, a cyclic shift is applied. It can be used with OFDM (Orthogonal frequency-division multiplexing) and DFTS-OFDM (Discrete Fourier transform Spread OFDM). As there is no time delay present in cyclic delay, the possibility of inter-symbol interference (ISI) is minimized. Figure 20 shows the basic diagram of DD and CDD [7].

STBC (Space Time Block Coding) is a type of the open loop MISO scheme. In this scheme the same signal is sent in different coding through different antennas. In the receiver an STBC algorithm is used to achieve diversity gain and coding gain. Coding gain is the effective gain achieved by coding over an uncoded signal. Coding gain is usually measured as the dB difference in SNR (Signal to Noise Ratio) ratios between a coded and uncoded signal producing the same BER. One of the popular STBC schemes is known as the Alamouti scheme. In STBC, data streams are encoded in blocks, and sent through different time and different antennas block wise. The receiver will collect all the blocks and try to extract the information as precisely as possible [6].

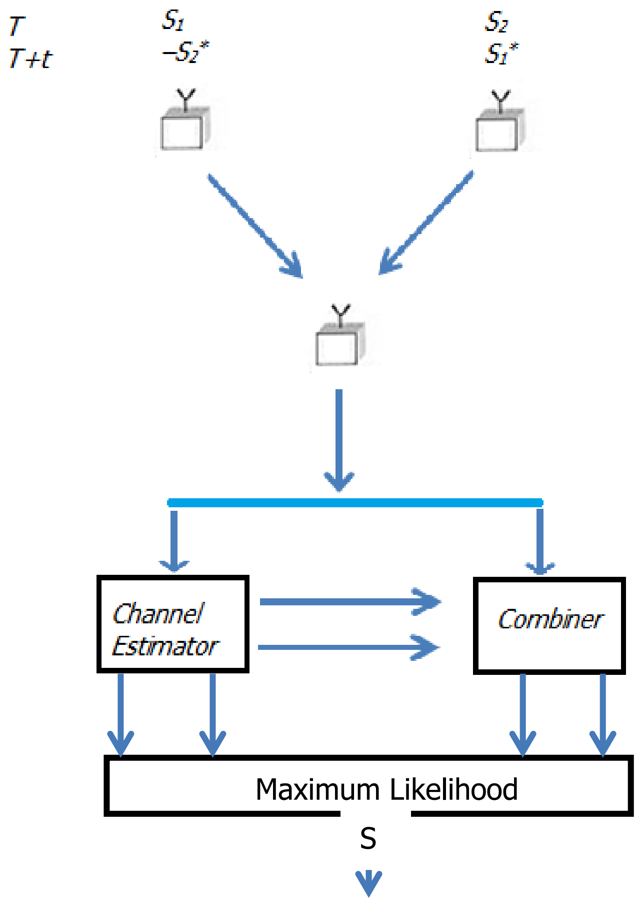


Figure 21: Alamouti scheme [6]

In the Alamouti scheme, the basic idea is to increase the space and time diversity, assuming two antennas are used for transmission. Both antennas transmit two signals S_1 and S_2 in time T. Then in the next time slot $T+t$, they transmit $-S_2^*$ and S_1^* respectively, where S_x^* is the complex conjugate of S_x. The total transmission acts as a single transmission. The process is shown in figure 21. At the receiver, the two consecutive signals in two consecutive time slots are combined and the result is sent to a "Maximum Likelihood Detector" which finally estimates the original signal [6].

Another scheme used is called Frequency Hopping Diversity Coding (FHDC). In this scheme, the same data is transmitted on two different sub-channels and two frequencies. In FHDC the first antenna transmits data as a regular transmission while the Alamouti Scheme is used in the second antenna. [15]

4.8.2 Closed Loop MISO

Closed mode transmission schemes are only useful in fixed or low-mobility scenarios. An encoding algorithm is used for using the channel state information to effectively use its available channels. The basic configuration of closed loop MISO is shown in figure 22.

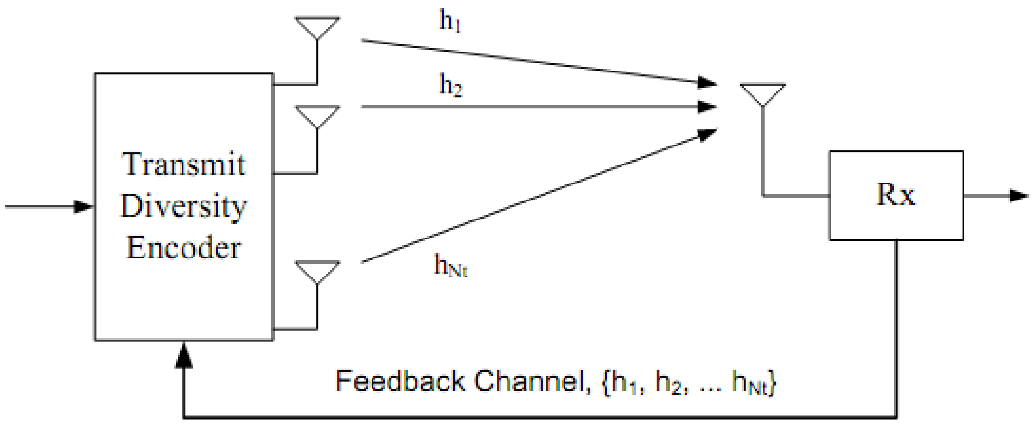


Figure 22: Closed-loop MISO [16]

Transmit selection diversity (TSD) is a type of diversity scheme used in closed-loop MISO. In this scheme, only subsets of antennas are chosen and used of the available antennas. The selected subset resembles the best channel between the transmitter and the receiver [16]. Advantages of this method includes significant simple hardware configuration, elimination of spatial interference and the diversity is in order. In the simplest case, one transmit antenna is selected which results in the highest gain between the transmitter and the receiver.

Linear diversity precoding is a type of diversity scheme in which the Channel State Information (CSI) is used where the data rate is unchanged but used to improve the link diversity. [16]

5 Multiple-Input Multiple-Output

Multiple-Input Multiple-Output (MIMO) uses multiple antennas on both the transmitter and receiver. They have dual capability of combining the SIMO and MISO technologies. They can also increase capacity by using Spatial Multiplexing (SM). The MIMO method has some clear advantages over Single-input Single-output (SISO) methods. The fading is greatly eliminated by spatial diversity, low power is required compared to other techniques in MIMO.

5.1 Basic Building Block

A basic building block of the MIMO system is presented in figure 23.

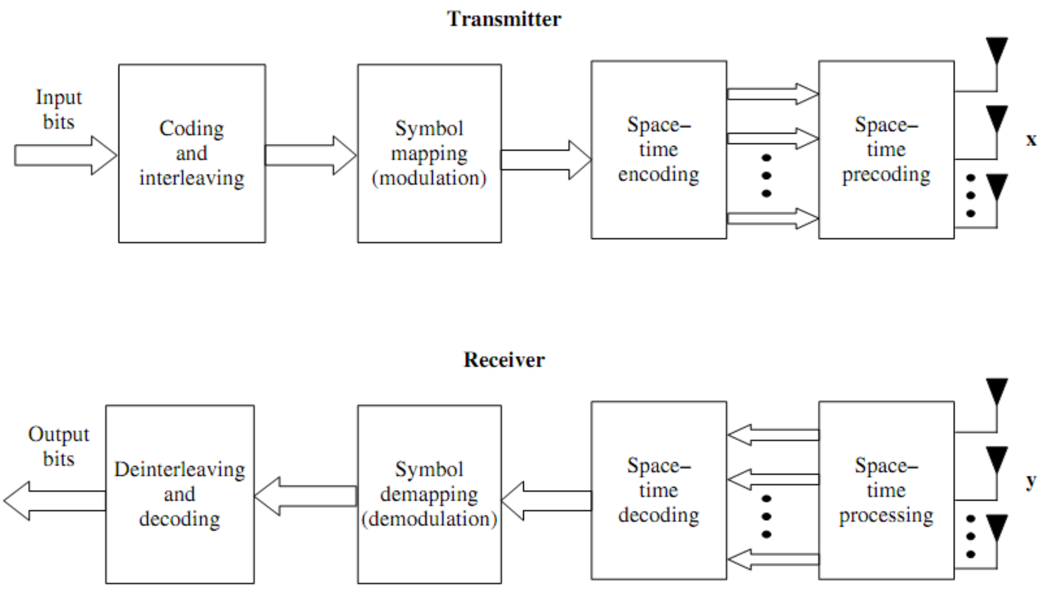


Figure 23: Building blocks of MIMO [17]

In the figure, *x* and *y* represent transmitted and received signal vectors respectively. At first, the information to be transmitted is encoded and interleaved. The symbol mapper maps the encoded information to data symbols. These data symbols are then fed into a space-time encoder which creates some spatial data streams. The data streams are then transmitted by different antennas. The transmitted signals propagate through channels and are received by receiving arrays.

The receiver then collects all the data from the antennas and reverses the operation to decode the data using a space-time processor, space time decoder, symbol demapper and at last the decoder.

5.2 MIMO Channel

The MIMO channel communication takes advantage of multipath propagation. The MIMO channel can be described by the following matric [6]:

$$y = Hx + n \qquad (5)$$

Where y is the received signal vetor, x is the transmitted signal vector, H and n are the channel matrices.

In order to understand MIMO better, it is necessary to look into its channel model. For a system with M_T transmitters and M_R receivers, the MIMO channel at a given time may be represented by M_R X M_T matrix as demonstrated below [6],

$$H = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,M_T} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,M_T} \\ \vdots & \vdots & \ddots & \vdots \\ H_{M_R,1} & H_{M_R,2} & \cdots & H_{M_R,M_T} \end{bmatrix}, \qquad (6)$$

Where $H_{m,n}$ is the channel gain between *m*-th receive and *n*-th transmit antenna. The *n*-th column of *H* is called as the spatial signature of the *n*-th transmit antenna. The geometry of M_T differentiates the signals launched from the transmitter.

5.2.1 MIMO channel capacity

The theoretical capacity of the MIMO channel is expressed by the following formula:

$$C = E_H\left[log_2 \det(I_{Mr} + \frac{\rho}{M_t} HQH^H)\right] \qquad (7)$$

Where $Q = E[xx^H]$ is the input covariance matrix and $\rho\ (SNR)$ is $\frac{E_s}{N_0}$, E_s is the total transmit power and N_0 is the noise power in each antenna.

In equation (7), the capacity depends on the antenna numbers, input covariance matrix and the channel statistics. The matrix Q is diagonal and all the elements are real numbers. There are two cases for this matrix. When the transmitter is an uninformed transmitter, i.e. when it does not have proper knowledge of the channel matrix, then the matrix will be same as the identity matrix, $Q = I_{Mt}$. In other words, the total transmitted power will be devided across all the antennas by the transmitter.

In the case of an informed transmitter, i.e. when the transmitter has knowledge of the channel matrix, the capacity will be optimized by using the so-called waterfilling principle. Here, various levels of transmit power will be distributed among various transmitting antennas depending on their channel strength. The better the channel is, the more power it gets and vice versa. [15; 20]

5.3 Forms of MIMO

The Multiple Input multiple Output (MIMO) method can be divided into various forms depending on uses [17]. MIMO is basically the combination of all the multiple antenna techniques such as SISO, SIMO and MISO. It can use the beam forming or the spatial Multiplexing methods. MIMO can be categorized into two types, multi-antenna types and multi-user types.

Multi-antenna types are listed below:

- SISO (Single-input Single-output)
- SIMO (Single-input Multiple-output)
- MISO (Multiple-input Single-output)

5.4 MIMO Transmitter and Receiver Structure

A basic two chain MIMO transmitter is shown in figure 24.

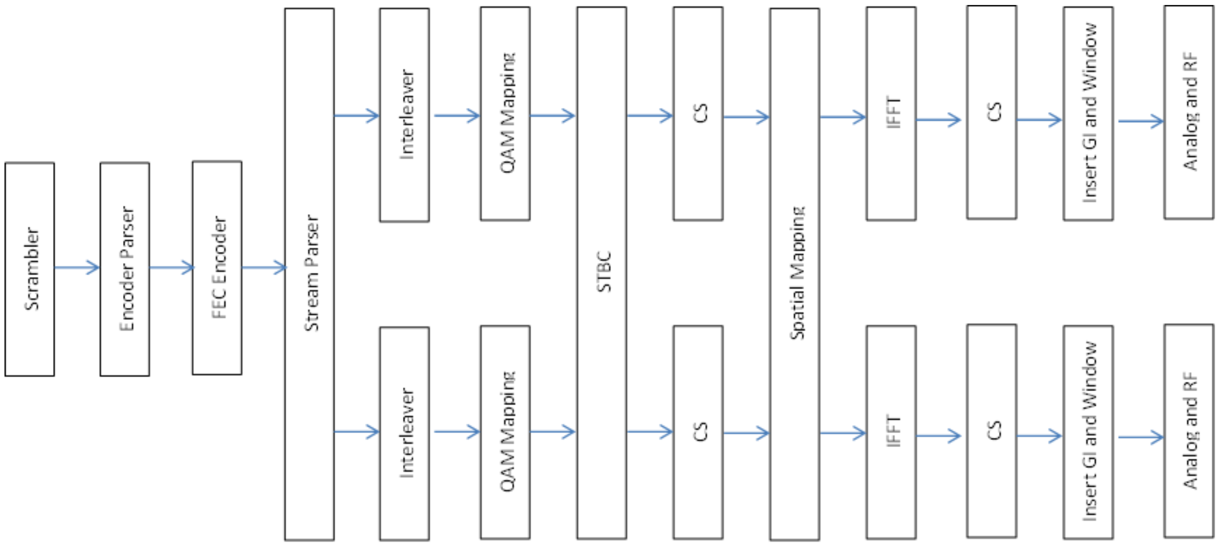


Figure 24: MIMO transmitter diagram [3]

A few explanations of the transmitter diagram are given below:

Scrambler: The scrambler replaces the zeros and ones in the data.
Encoder Parser: De-multiplexes the scrambled bits and encodes them, among the number of FEC (Forward Error Correction) encoders.
FEC Encoder: Encrypts the data to allow error adjustment.
Stream Parser: Splits the output of the encoders into blocks for sending to different interleaver and mapping devices. The blocks of the bits sent to the interleaver are known as spatial streams.
Interleaver: Encloses the bits of each spatial stream to avoid long sequences of noisy bits from entering into the FEC decoder.
QAM (Quadrature Amplitude Modulation) Mapping: Charts the sequence of bits in each spatial stream to different patterns.
STBC (Space time blocking code): The spatial streams are plotted to the space time.
Cyclic Shift Insertion: Throughout the high throughput preamble, cyclic shift is applied to prevent beam forming when similar signals are transmitted in different spatial streams. The same cyclic shift is applied to these streams during the transmission of the data portion of the packet [3].

Spatial mapping: Maps spatial streams to different transmit chains. This may include one of the following:

- Direct mapping – each space time stream is directly mapped to a different transmit chain. When using a direct mapping scheme, the number of space time stream must be equal to the number of chains.
- Spatial expansion – the space time streams are multiplied by a matrix, and then transmitted through different transmit chains. When using a spatial expansion mapping scheme, the space time stream can be shorter than the transmit chain. FFT (Fast Fourier Transform) transformation matrix is selected for a spatial expansion purpose.

IFFT (Inverse Fast Fourier Transform): Converts a block of constellation points to a time domain block.
Insert GI (Guard interval) and Window: Inserts the guard interval, smoothes the edges of each symbol to increase spectral decay.

At the receiver all the processes are inversed to get the original data sent by the transmitter.

5.5 OFDM in Multi-antenna System

Orthogonal Frequency Division Multiplexing (OFDM) is a type of FDM (Frequency Division Multiplexing) modulation technique which is used for larger amount of data transmissions. OFDM works by dividing the data into small sub-signals and transmitting them simultaneously through different frequencies.

Usually at a high data rate, it is not possible to recover the transmitted data by a simple receiver as channel distortion might occur. Hence there is a need of a very complex receiver structure which can estimate the channel correctly. OFDM can, however, simplify this process by turning the frequency selective channel to a flat channel by using FFT. Thus, a simple one-tap equalizer is enough to recover the data. Moreover, a future data transmission system has to be ready to co-operate with a mass amount of users using high data transmissions. (5)

5.5.1 Multi User OFDM Systems

Normally OFDM itself does not inherit any multi user capability to use in the latest technologies. An extra multiple access or channelization technique such as CDMA (Code-Division Multiple Access), FDMA (Frequency Division Multiple Access), or TDMA (Time Division Multiple Access) has to be implemented to OFDM to get the multi user accessibility. A number of multiple access techniques based on OFDM available in today's technology are listed as follows [3]:

- OFDMA (Orthogonal Frequency Division Multiple Access)
- OFDMA-FSCH (OFDMA Fast Sub-carrier Hopping)
- OFDMA-SSCH (OFDMA Slow Sub-Carrier Hopping)
- MC-CDMA (Multi Career CDMA)
- OFDM-CDMA-SFH (OFDM-CDMA Slow Frequency Hopping)
- VSF-OFCDMA (Variable Spreading Factor- Orthogonal Frequency and Code Division Multiple Access)

Although there are a number of techniques available, OFDMA has been taken as the preferred technique for cellular networks by most professionals. [18]

5.5.2 OFDMA

In OFDMA, fractions of OFDM sub-carriers are assigned to different sub-channels. The sub-channels are then distributed among different users. This type of scheme was first proposed for CATV (Community Antenna Television) but was later adopted for wireless communications. [6]

OFDMA can support many identical data streams and also different user data-rates by assigning a different number of sub-carriers to individual users. Different baseband modulation schemes can be used for the individual sub-channels such as QPSK (Quadrature Phase Shift Keying), 16-QAM and 64- QAM. [4]

5.5.3 Combination of OFDM with Receive Diversity (SIMO)

In general, receive diversity is easier, more practical and effective than transmit diversity and other MIMO techniques. It a commonly used for mitigating the multipath fading effect. By employing multiple antennas at the receiver, significant diversity gain is achieved. However, additional antennas also add size, complexity and power consumption, which are the main disadvantages of receive diversity. As a result, in today's system, receive diversity is mostly used in Base Stations (BS).

There are two methods of combining receive diversity with OFDM, Post-DFT and Pre-DFT combining. In the Post-DFT combining scheme, the time-domain OFDM samples from receiver arrays are demodulated using DFT (Discrete Fourier Transform) and then combined to sub-carriers. These sub-carriers enable the combination of only best quality sub-carriers from different diversity branches. However, Post-DFT requires separate DFT processors for each antenna branch, therefore increasing complexity and power consumption.

On the other hand, in Pre-DFT method, the combining process of diversity branches is done before performing OFDM demodulation. This minimizes complexity at the receiver, but also the performance is degraded. If the channel is flat in the whole OFDM spectrum, the performance of the Pre-DFT Maximal Average Ratio Combining (MARC) scheme is similar to that of the Post-DFT whereas in case of frequency selective fading, its performance is degraded and less diversity gain is achieved [18].

5.5.4 Combination of OFDM with Transmit Diversity (MISO)

As it was briefly discussed in chapter 4.8, transmit diversity uses space time coding such as STBC and STTS (Space-Time Trellis Code) or frequency diversity like SFBC (Space-frequency Block Code) [5]. OFDM can take advantage of these diversity techniques. Since no time-domain is used, there is no latency present.

5.5.5 Combination of OFDM with Spatial Multiplexing (MIMO)

The main reason of using OFDM with MIMO is that OFDM is capable of turning a frequency-selective MIMO fading channel into multiple flat fading channels. This makes the multi-channel equalization quite simple since for OFDM only a constant matrix needs to be inverted [6].

In Wideband Scenarios, OFDM can be combined with MIMO systems, for both diversity and multiplexing purposes [6]. The basic idea consists of converting the channel matrix into a circulate matrix via the addition of a cyclic prefix to the transmitted sequence. The most popular coding technique is known as MIMO-OFDM [7,19].

Figure 24 shows a basic diagram of the MIMO-OFDM system. The OFDM-modulator is denoted by OMOD and the OFDM-demodulator is denoted by ODEMOD respectively. The cyclic prefix is the copy of the last part of the OFDM symbol which is long enough to accommodate the delay spread of the channel.

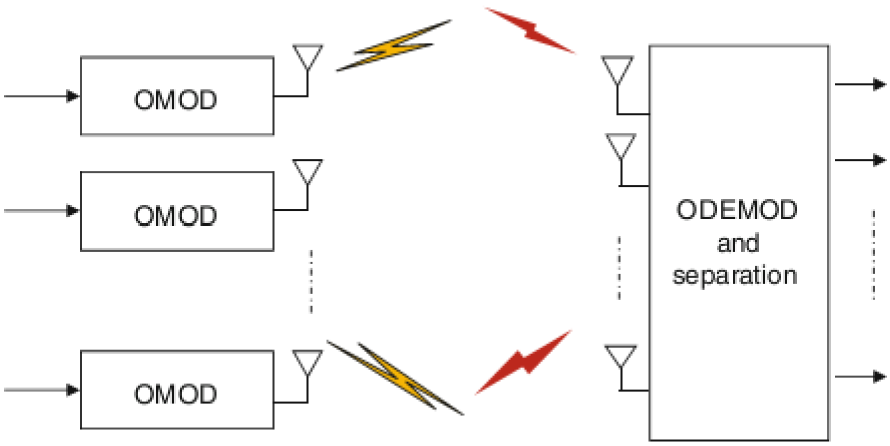


Figure 25: Diagram of MIMO-OFDM [19]

The cyclic prefix transforms the role of the channel in a transmitted signal from linear convolution into a cyclic one. By using IFFT (Inverse Fast Fourier Transform) in the transmitter and FFT (Fast Fourier Transform) in the receiver, the overall transfer function can be diagonalized. This is how the overall frequency-selective channel is converted into parallel flat fading channels.

If an OFDM-MIMO system has N_t transmit antennas, N_r receive antennas and N subcarriers, then the input-output relation for the MIMO system for the k^{th} tone, $k = 1, \dots \dots, N$ may be expressed with the following equation:

$$Y_k = \sqrt{\frac{P_T}{N_T}} H_k s_k + N_k, \tag{7}$$

Where, Y_k and N_k are $N_r \times 1$, H_k is a $N_r \times N_t$ matrix, S_k is a $N_t \times 1$ vector and P_t is the total transmit power. The matrix H_k is the frequency response of the matrix channel corresponding to the k^{th} tone.

MIMO-OFDM is a hot topic of current research. The performance issues particularly in multiuser environment, space time coding and simple receive structure have gained attraction in significant studies.

5.6 MIMO channel measurements in different environments with different antennas

As practical measurements of MIMO performance could not be done, performance test results are not included in this paper.

6 Uses of Multiple Antenna Techniques

Smart antenna technology can be added to any existing antenna technology in order to improve its performance. As an ever growing technology, multiple antenna techniques are proved to be useful in the following areas:

Wi-Fi (Wireless Fidelity): Small devices within an indoor environment generally support adaptive array systems. The main benefits that multiple antennas have to offer in case of Wi-Fi include range increase, modifying interference and uniform coverage. Various VoIP (Voice over Internet Protocol) applications can be benefited from uniform coverage where static Quality of service (QoS) is needed. Multiple antennas can be implemented either in access points or in mobile clients, as the same frequencies are always in use. Higher data rates are a perfect solution given by smart antennas.

WiMax (Worldwide Interoperability for Microwave Access): In WiMax systems, multi-beam antennas are used in base stations, while adaptive arrays are used in clients. The smart antennas in the base station offer greater ranges, and by using spatial re-use, capacity is increased. Adaptive arrays on the clients can be useful in overcoming the fading occurred by buildings which is otherwise known as building penetration losses. Thus, it is possible to use WiMax inside a building rather than outside antenna installations. Moreover, installing on the client alone, using time division duplexing allows achieving equal gain in every direction.

Cellular Networks: Such as WiMax, adaptive arrays and multi-beam antennas are used in cellular networks. Mobile clients also use adaptive arrays. Thus, increased coverage with increased capacity and high rate of data transmission are now possible. In upcoming 4G technology, like in its predecessors WiMax and Long Term Evolution (LTE), OFDMA combined with MIMO will be used.

RFID (Radio Frequency Identification): Smart antennas can be used in the readers to increase the response of RFID receivers.

Ultrawideband (UWB): It is a type of radio technology where a very low energy level for short range high bandwidth communication is used. UWB is commonly used in wireless printing, wireless monitors, short range data transfer between mobile devices and see-through radars. Smart antennas can be used to increase the range of UWB. However the low cost requirementof UWB's and limitations in power transmission is proved to be difficult for implementing smart antennas.

Digital Television System (DTV): in the new digital television systems, the multiple antenna technique such as transmit diversity is implemented. As a result, a large amount of data transmission together with digital audio and video signals are now possible.

Satellite tracking: A multi-beam antenna permits a low-profile antenna to track a vehicle on the move. Therefore when these types of antennas are used on top of some vehicles roof, satellite tracking is made fairly easy.

Satellite radio: Adaptive arrays are used to provide extensive coverage and multipath mitigation in a satellite radio receiver. Furthermore they can improve indoor reception as well as eliminate the need of manually steering the antenna.

Digital Radio: In digital antennas, adaptive arrays are used to get similar effects as a digital television system.

7 Future Outlooks on Multiple Antenna Techniques

The investigation in multiple antenna techniques can be extended in a number of ways, such as:

- There is scope to study the usability of transmit diversity and beam-forming in link adapted system. The available array gain in beam-forming can become greatly important in link adaptation schemes.
- The studies related to transmit diversity and link adaptation can be extended to multi-user environment.
- Diversity and multiplexing can be studied further.
- Possibility of research about joining the spatial diversity and spatial multiplexing together and creating a hybrid diversity method.
- Further studies can be made for constructing less complex transceivers for multiple antenna technique.

8 Conclusion

This thesis focused briefly on various multiple antenna techniques in the present situation. Multiple antenna techniques will be part of all future mobile data transmissions, where multiple users need to transmit information at high transmission speeds. Already there are commercial applications on the market, and advanced multi-antenna techniques are in use, such as in WiMax and LTE.

As devices are getting equipped with high data processing capabilities and reduced power consumption, these types of multiple antenna techniques are becoming much easier to implement. However, on mobile phones, because of the limited form factor and battery life, it is proving difficult to implement advanced antenna techniques.

In addition, all the present devices need to be upgraded and the multi-antenna capability must be added to meet the upcoming 4G standard. Overall, MIMO is a must have technology to adopt the high crisis of data transmission in upcoming times.

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