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Transreciver Using MIMO Concepts for Wireless Communication Applications

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ABSTRACT

The rapid developments occurring in the field of wireless communication technology are creating various challenges with respect to multiple antenna configurations. Recent advances in MIMO communications are very useful by spacing the antenna elements at the Tx and Rx such that angular spread is manifested which can be utilized in order to improve the link quality, reliability and spatial diversity. With an enormous amount of yearly publications, the field of multiple-antenna systems, often referred as multiple-input multiple-output (MIMO) systems,. Multiple antennas in MIMO systems can be utilized in order to achieve a multiplexing gain, an antenna gain, or a diversity gain, thus increasing the high bit rate, the signal-to-interference ratio, or the error performance of wireless systems, respectively. The main objective of this paper is to provide an overview of diversity techniques and MIMO technologies.

Keywords: *Diversity, Spatial multiplexing, 4G, MIMO.*

INTRODUCTION

The idea of using multiple antenna configuration instead of single antenna has proven to be successful in increasing data transfer rate, coverage, security and overall performance of radio networks. MIMO refers to antenna technology for enhanced wireless communications, where in multiple antennas are used at the transmitter and the receiver, all over a radio channel. Multiple antennas are used simultaneously for transmission and reception to minimize errors and to optimize the data speed.

MIMO is one among the various types of smart antenna technologies. MIMO techniques are used in variety of technologies such as Wi-Fi (Wireless Fidelity), WiMAX (Worldwide Interoperability for Microwave Access), Cellular Networks, Radio Frequency Identification (RFID), Ultra-wideband (UWB) etc. [1]. MIMO achieves space measurements in-order to improve wireless system's capacity, reliability and range. Without any additional bandwidth or transmitting power, it provides high coverage and increases the speed of data transfers. Apart from the requirement of high speed data transfers, there is an issue of quality control, which includes low error rate and high capacity. In order to maintain certain Quality of Service (QOS), an effect known as multipath fading effect is utilized [2]. Hence, multiple antennas can be used to reduce the error rate as well as, improve the signal-to-noise-plus-interference ratio of wireless systems and also improves the quality and capacity of a wireless transmission. Multiple antenna techniques are mainly divided into three categories namely, Spatial Diversity (SD), Spatial Multiplexing (SM) and Adaptive Antenna System (AAS).

DIVERSITY TECHNIQUES

Diversity technique is a powerful communication technique used to compensate for fading channel impairments. This technique is used as an effective solution to mitigate multipath fading signals and enhance the system capacity [3]. It is implemented by using two or more receive antennas.With an equalizer, diversity improves the quality and capacity of a wireless communication link without alerting the common air interface and devoid of increasing the transmitted power or bandwidth. The quality of wireless communication link mainly depends upon the three parameters, namely rate, range and reliability of transmission. The difference in equalization and diversity is that the equalizer technique [4] is used to reduce inter symbol interference, whereas diversity technique is used to reduce the fading effect on wireless communication.

According to the types of fading, diversity techniques are classified as small-scale fading and large-scale fading. Small-scale fading is caused due to multiple reflections from the surrounding object. To reduce this, microscopic diversity may be used. Large-scale fading is caused by shadowing due to variations in the environment profile. It occurs at a large distance from the base station. To reduce this, macroscopic diversity may be used [5].

Macroscopic diversity is also called as large scale diversity. The basic principle of macroscopic diversity is illustrated in figure 1. It is related with shadowing effects due to large obstacles (such as large buildings or hills or trees) between transmitter and receiver. Macroscopic diversity can be gained if there are multiple antennas at transmitter or receiver side that are spatially separated on a large scale.

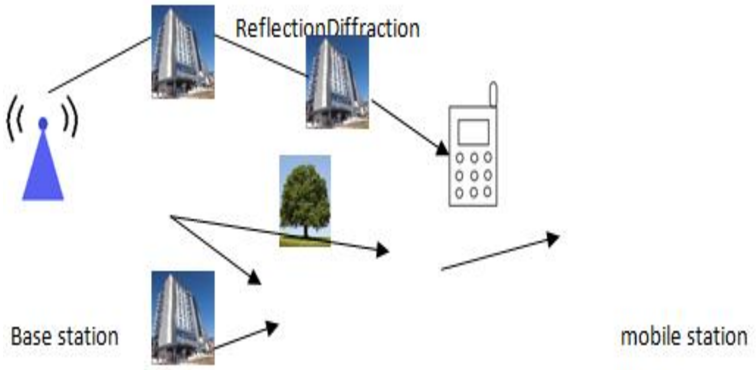

Figure1. *Macroscopic diversity*

Microscopic diversity is also called as small scale diversity, which is available in rich scattering environments with multipath fading. Microscopic diversity can be gained by using multiple co-located antennas [6]. Figure 2, illustrates microscopic diversity.

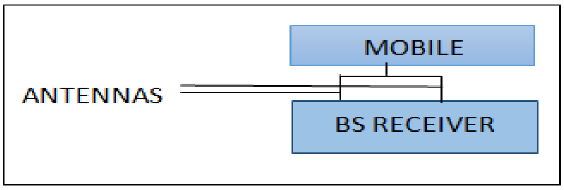

Figure2. *Microscopic diversity*

The common methods that can be used to combat small-scale fading are spatial diversity, temporal diversity, frequency diversity, angular diversity, and polarization diversity.

Spatial Diversity

Spatial diversity, also known as antenna diversity, is any one of several wireless diversity schemes that uses multiple antennas to improve quality and reliability of a wireless link [7]. Especially in densely populated areas and indoor environments, there is no clear line-of sight (LOS) between transmitter and receiver. Instead the signal is reflected along multiple paths resulting in time delays, phase shifts, attenuations, distortions that can destructively interfere with one another at the aperture of the receiving antenna. As a result, multipath fading effect [2] occurs on the transmission path. Figure 3, shows the basic principle of spatial diversity.

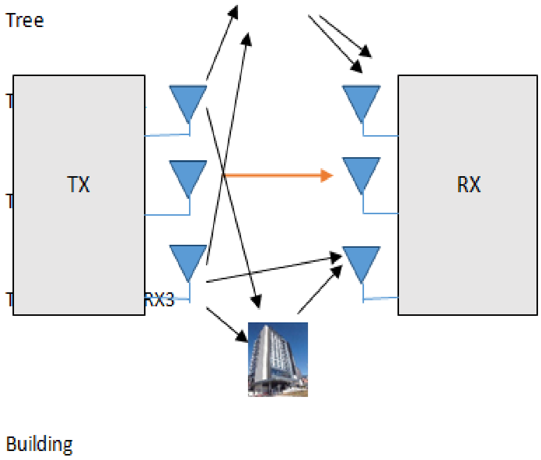

Figure3. *Spatial diversity*

The same signal is fed through single or multiple transmitter antennas, and the same signal is captured by single or multiple receiver antennas. In figure 1, several transmitter and receiver antennas are placed apart from each other. However, it can be observed in the figure that from transmitter TX2 there is a clear line of sight (LOS) to receiver RX2. In spite of multipath fading effect that occurred in other receivers, the receiver can get a fairly good signal [1].Spatial diversity techniques mainly aim at an improved error performance and can be used to enhance bit rates.

Temporal Diversity

In temporal diversity, the same signal is transmitted in multiple forms at different time slots. Time diversity continuously transmits information at time spacing that exceeds the coherence time of the channel. As the wireless propagation channel is time variant, the signals that are received at different times are uncorrelated. Temporal diversity is also called as time diversity. A modern implementation of time diversity involves the use of RAKE receiver for spread spectrum CDMA, where multipath channel provides redundancy in the transmitted message. Multiple repetitions of the signal will be received with multiple fading conditions, thereby providing for diversity [5].

Frequency Diversity

In frequency diversity, the same information signal is transmitted at two or more different frequencies using several frequency channels [5]. If these frequencies are separated by more than the coherence bandwidth of the channel, then their fading is independent.

Angular Diversity

In angular diversity, different antenna patterns can be achieved by using multiple antennas with or without spatial separation. Although, different types of antennas have different patterns, identical antennas can also achieve different patterns when they are placed close to each other.

Polarization Diversity

Polarization Diversity Depends On The Decorrelation Of The Two Receive Ports To Achieve Diversity Gain. The Two Receiver Ports Must Remain Cross Polarized [5]. Effective Diversity Can Be Obtained With Polarization Diversity Order Up To 6 And With A Correlation Coefficient Below 0.7. In Order To Keep The Correlation At This Level, Space Diversity At A Base Station Requires Antenna Spacing Of Up To 20 Wavelengths For The Broadside Case, And Even More For The Inline Case.

Spatial Multiplexing Techniques

In wireless communication systems, multiple antennas are capable of establishing parallel data streams. Spatial multiplexing involves splitting a high data rate signal into multiple low data streams, which are then transmitted from separate antennas on the transmitter side. This is done in order to improve the transmission rate and throughput [8].The spatial multiplexing is some time referred as direct transmission. The basic principle of spatial multiplexing scheme is illustrated in Figure 4. The information of the signal are represented in terms of bits. At the transmitter, the information bit sequence is fragmented into M sub-sequences, this process is called as demultiplexing. These sequences are modulated and transmitted over the transmit antennas. At the receiver, the transmitted sequences are separated by using a detection algorithm known as interference-cancellation type of algorithm

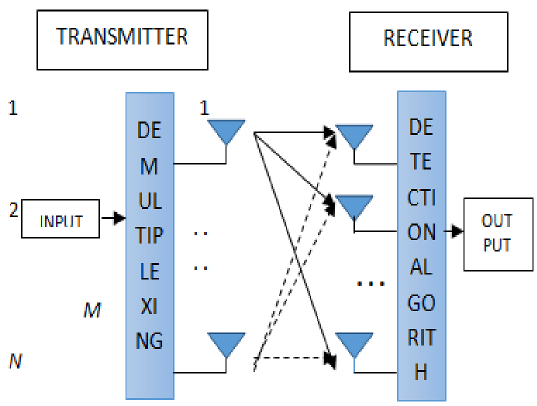

Figure4. *Basic principle of spatial multiplexing*

In the case of frequency-flat fading, there exists several choices for the detection algorithm at the receiver, which are characterized by different trade-offs between performance and complexity. The Bell Laboratories Layered Space-Time Architecture (BLAST) scheme is one of the detection strategies, originally designed for frequency-flat fading channels [6]. Layered space-time architecture exploit the spatial multiplexing gain by transmitting independently encoded data streams in diagonal layers using diagonal-BLAST (D-BLAST). For a certain time instant, the transfer of information between the encoded layers and the transmit antennas remain fixed, and is then changed in a modulo-M fashion. Figure 5, illustrates the diagonal transfer of the data associated to each layer, for a system with four transmit antennas.

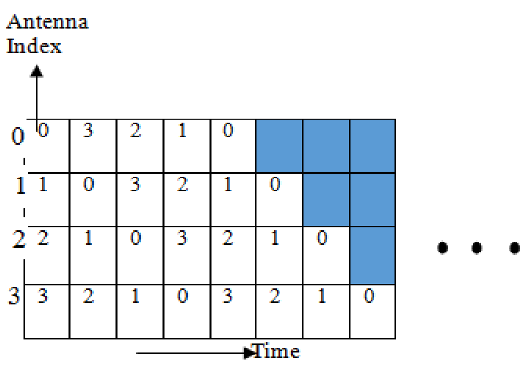

Figure5. *Transmit coding scheme in D-BLAST*

The vertical-BLAST (V-BLAST) architecture is a simplified version of D-BLAST. This scheme tries to reduce its computational complexity. As in D-BLAST, the information bit stream is divided into sub streams, and each can undergo its own channel coder. The layering is horizontal, i.e. all the symbols of the information bit stream are transmitted through the same antenna. Figure 6, illustrates the horizontal transfer of the data associated to each layer, for a system with four transmit antennas.

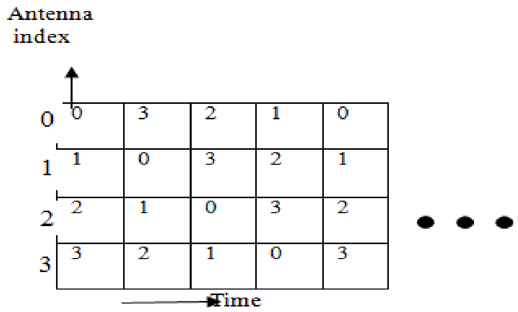

Figure6. *Transmit coding scheme in V-BLAST*

Multiple-Input Multiple-Output Technique

Multiple-input multiple-output (MIMO) is an antenna technology for wireless communications known to achieve large spatial multiplexing and diversity gains in multipath rich fading channels [9]. It uses multiple antennas at the transmitter and the receiver side to transmit more data at the same time. There are various other antenna technology like MISO (multiple-input single-output) and SIMO (single-input multiple-output) apart from MIMO technique.

SIMO

Single input multiple output is an antenna technology for wireless communications in which multiple antennas are used at the receiver and the single antenna is used at the transmitter. The antennas are combined at the receiver to minimize errors and optimize data speed. The various techniques that can be used to combine the received signals are maximal ratio combining (MRC), equal gain combining (EGC) and selection combining (SC) [8]. Figure 7, represent general SIMO system. Receive diversity technique [1] is used in SIMO system.

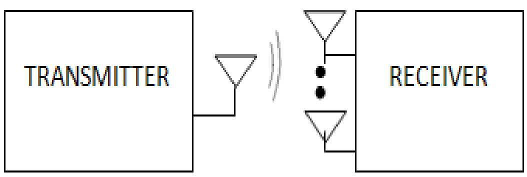

Figure7. *SIMO System*

MISO

Multiple input single output is an antenna technology for wireless communication that uses multiple antenna at the transmitter side and single antenna at the receiver side. In case of MISO, transmit diversity technique is used [1].

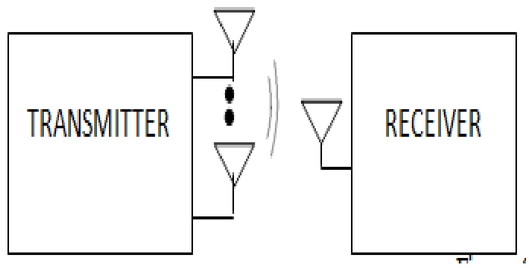

Figure9. *MIMO System*

MIMO

Multiple input multiple output is an antenna technology for wireless communications that uses multiple antennas at the transmitter side and the receiver side. MIMO techniques uses trans-receive diversity. By using MIMO technique we can increase the channel capacity and decrease the bandwidth requirement [1]. Channel capacity is increased by using spatial multiplexing techniques and the fading is completely eliminated by spatial diversity.

Multiuser MIMO

Multi-user MIMO (MU-MIMO) is a MIMO technology for wireless communication, in which a set of users or wireless terminals, each with one or multiple antennas communicate with each other. Here the antennas are distributed over several users, which are served at the same time on the same frequency band and separated by means of spatial processing. In contrast, Single-user (SU) MIMO assigns all spatial resources in a particular time on the same frequency band to the same user [11]. SU-MIMO provides high data rate for the single user and high throughput for a low signal to noise ratio.

MU-MIMO provides a methodology whereby spatial sharing of channels can be achieved. Using MU-MIMO capacity gain and multiplexing gain can be achieved and it provides a higher throughput when the signal to noise ratio is high. The two scenarios associated with MU-MIMO are uplink and downlink MU-MIMO [11].

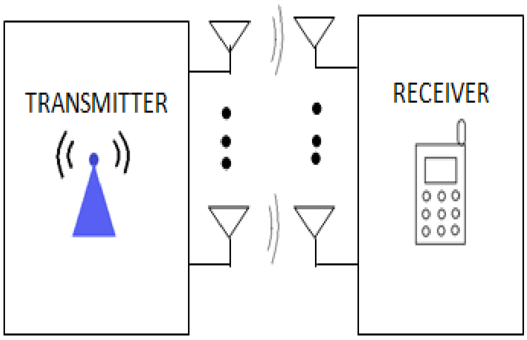

Figure10. *Single-user MIMO (SU-MIMO)*

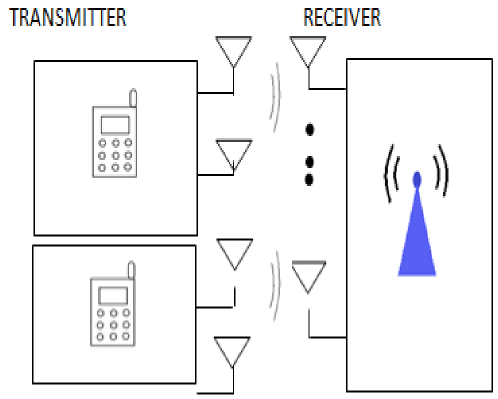

Figure11. *Multi-user MIMO (MU-MIMO)*

Applications of Multiple Antenna Techniques

Smart antenna technology can be added to any existing technology in order to improve its performance and spectral efficiency. As an ever growing technology, multiple antenna techniques are proved to be useful in the following areas [1], since it provides high coverage, channel capacity, data rate and improved spectral efficiency.

Wi-Fi (Wireless Fidelity)

It is a popular wireless networking technology that uses radio waves to provide wireless high speed network connections and internet. The main benefits that multiple antennas have to offer in case of Wi-Fi include interference mitigation for unlicensed band, uniform coverage, high data rates and increase in range.

Cellular Network

Cellular network is a communication network where the last link is wireless. The network is distributed over large area through cells, which includes a fixed location transceiver known as base station. These cells provide radio coverage over large area. WiMax, adaptive arrays and multi-beam antennas are used in cellular networks. In upcoming 4G technology, like in its predecessors WiMax and Long Term Evolution (LTE), OFDMA combined with MIMO will be used [1].

RFID (Radio Frequency Identification)

RFID uses electromagnetic fields to automatically read and capture information stored on a tag attached to the object. Smart antennas can be used in the readers to increase the response of RFID receivers [1].

Mobile Satellite TV

A multi beam antenna permits a low profile antenna that can track the received signal while the vehicle is in motion. Therefore when these types of antennas are used on top of some vehicles roof, satellite tracking is made fairly easy [1].

Conclusions

In this paper we presented an overview of the field of multiple antenna techniques for wireless communication systems and discussed a comprehensive overview of different diversity techniques used to compensate for fading channel impairments. High coverage, channel capacity, data rate and improved spectral efficiency are obtained by implementing MIMO Techniques on wireless communication systems. Substantial average cell throughput and capacity gain can be achieved with the adoption of MU-MIMO.

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