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Research Article

Capacity Enhancement in Multiple Input Multiple Output Wireless Communication Systems

Jyoti, Manoj Kumar# and Jyoti Singla^

#ECE, MDU, BDES Group of Institute, JB knowledge Park, Manzawali, Faridabad, India
^ECE,Govt polytechnic, Uttawar ,India

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Abstract

With the abrupt increase in use of wireless communicating devices, the requirement of larger amount of data transmission is anticipated. Multiple Input Multiple Output antenna systems are becoming popular by providing increased channel capacity. This improvement in channel capacity is achieved by systematically combining various multipath components. This paper describes the multipath behaviors of the channel, multiple antennas configuration at one end and finally the multiple antennas at both the transmitter and receiver ends. Later, the increase in channel capacity has also been remarked.

Keywords: *Beamforming, channel capacity, MIMO, multipath*

1. Introduction

The ability to send large volumes of data is crucial in modern era of communications. With the increasing use of wireless LAN technology the demand for data services has further increased. The bandwidth of wireless communication systems is often limited by the cost of the radio spectrum required. With the advent of new technologies, wireless communication systems have been made more spectrally efficient through the use of intelligent error detecting and correcting coding techniques. But the primary limitation of bandwidth does not change. Multiple Input Multiple Output (MIMO) communication systems are under extensive research over the past years, due to their ability to greatly increase spectrum efficiencies. (Sanchez-Fernandez *et al*, 2018). In contrast to existing wireless systems incorporating one transmitting and one receiving antenna, MIMO systems use arrays of antennas at both ends of the communication link. All the antennas are operating at the same frequency at the same time. Using multiple antennas adds the spatial diversity into the communication system, which can be effectively used to tackle the problem associated to multipath propagation. In wireless system, like point to point radio links, the electromagnetic waves do not simply propagate from the transmit antenna to the receive antenna. Rather they bounce and scatter from objects and take multiple paths; this effect is known as multipath propagation. When the travelling electromagnetic wave strikes an object in the propagating path, they yield multiple scattered components that are randomly distributed as shown in fig 1. This effect is regarded as an impediment to the accurate transmission of data in wireless links. (Lohan *et al*, 2005) MIMO systems exploit the generated multipath components by using the rich scattering environment to increase the spectral efficiency of the wireless system.

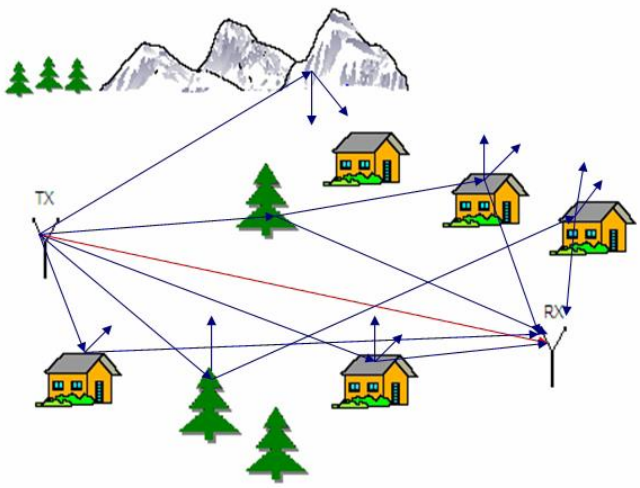

Fig 1: Multipath Environment

In digital mobile radio multipath can be used to improve transmission quality. Each additional transmission path used by a transmitter to reach a receiver increases the reception performance and

*Corresponding author's ORCID ID: 0000-0000-0000-0000
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improves the SNR. Multipath reception eases the effects of the large receive level fluctuations taking place in a channel. The probability that several channels are impassable at the same time is far smaller than if only one channel is used. Alternatively, frequency hopping and suitable coding techniques can also be used to reduce effect of impairments in transmission.

2. Single Input Multiple

Single Input Multiple Output (SIMO) uses one transmitting and several receiving antennas. It is also often referred to as receive diversity. The transmit signal of an antenna reaches a receiver with multiple antennas. There are various ways of evaluating these antenna signals. With switched diversity, the receiver always evaluates only the strongest receive signal and discards the weaker signals. Performance is best improved by maximum ratio combining; here, sum of all signals is evaluated. Furthermore, other alternate option for SIMO is MISO that implies for multiple input single output. It uses several transmitting antennas and one receiving antenna. (Raut *et al*) In a Multiple Input Multiple Output, "N" transmitting antennas and are used to provide signals to M receiving antennas. Graphically all these systems can be expressed as shown in fig 2.

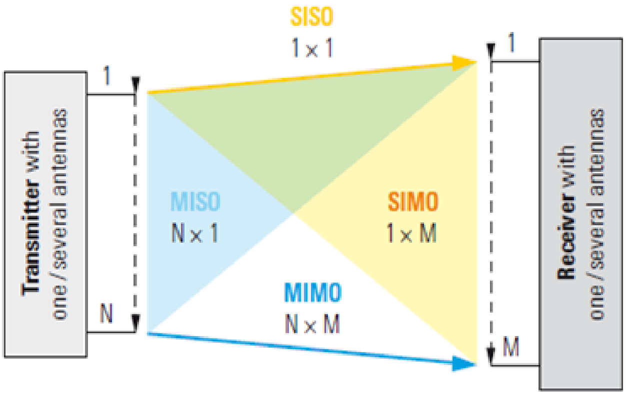

Fig 2: The different diversities at a glance

A. Ray Tracing

Multipath results in multiple copies of the same transmitted signal arriving at the receiver, at different times. Due to random time delays, the generated random phase delays may result in scattered signals combining destructively at the receiver. Thus multipath environment needs to be modeled to carry out any simulation. This is done using ray tracing. Ray tracing is performed by calculating the path taken by a ray of light from a light source to the reference point. (Kulakowski *et al*, 2006) At frequencies higher than greater than approximately 900MHz, the radio waves travels approximately in a straight line i.e. travel along localized ray paths.

B. Beamforming

Beamforming can be accomplished by using different types of arrays, like planar, linear and circular arrays. Here, a linear array has been shown in the fig 3. The principal behind beamforming is to introduce different power and phase weightings to each of the antennas in the array. This is done in such a way, so as to generate constructive interference in the desired direction. (Akay *et al*, 2005)

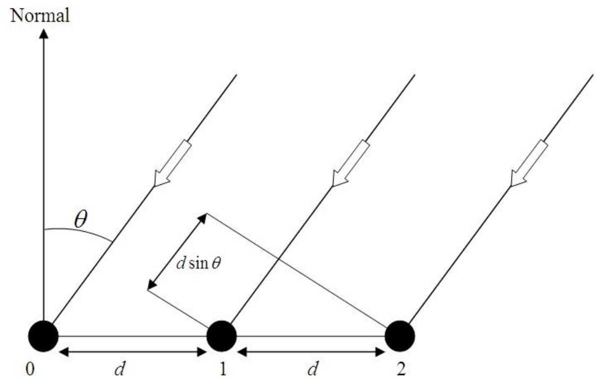

Fig 3: Linear Beamforming Array

A linear array shown in fig 3 has elements that are uniformly spaced with distance d in between. The incident wave on the array is at an angle θ with the normal. The wave arrives earlier at element 2 than at element 1 or 0. By resolving the vectors in horizontal and vertical components, the distance between each element is given by dsinθ, and therefore the phase delay between two adjacent elements will be the time it takes the incident wave to travel the distance dsinθ. The spacing between the elements of beamforming array must be large enough so as to achieve independent fading. In case of inappropriate spacing, there will be a loss of spatial diversity. By applying different phase and power weightings to the transmitting linear arrays desired beamforming can be produced. The average signal-to-noise ratio (SNR) is increased using beamforming that focuses energy in desired directions. However, in many practical multipath environments, the signals are too severly scattered to be effectively recovered, thus beamforming may not be as effective.

3. Multi Input Multi Output

MIMO exploits multipath components to enhance the wireless received signal. MIMO systems consist of multiple transmitters and multiple receivers. For he effectiveness of MIMO systems, a rich multipath scattering environment is required to create independent propagation channels that offers multiple parallel sub channels at the same frequency, thus providing higher capacities over the same bandwidth. The fig 4 shows a MIMO transmission system consisting of three transmitting antennas and three receiving antennas. The channel 'H' is conceded to be a rich scattering environment. Also, here multi antenna spatial diversity is used at both ends of the link in MIMO, treating the multiplicity of the different scattering paths as separate parallel sub channels.

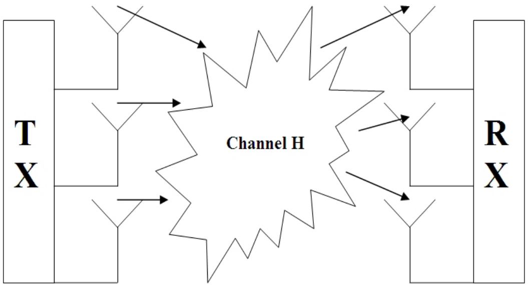

Fig 4: Three element MIMO system

A. MIMO Transmission

A MIMO transmission channel, demonstrating data transmission is as shown in fig 5.

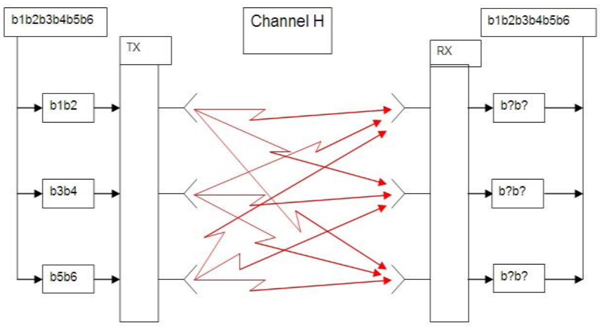

Fig 5: Data transmission in MIMO systems

The fig 5 demonstrates data transmission in a MIMO system. Consider the 6-bit data stream, this data stream is broken down (demultiplexed) into N equal rate data streams, where N signifies the number of transmitting antennas. Each of the lower bit rate sub streams are transmitted from one of the antennas. As all antenna are transmitting at the same time and at the same frequency, thus transmitted data mix together in the channel. As all sub streams are transmitted at the same frequency, it improves the spectrum efficiency of the system. Each receiving antenna picks up all of the transmitted signals superimposed upon one another. If the channel 'H' is a sufficiently rich scattering environment then each of the superimposed signals will have propagated over slightly different paths and hence carries different spatial signatures. These spatial signatures are due to the spatial diversity at both ends of the link and hence create independent propagation channels. Each transmits and receive antenna pair can be treated as parallel sub channels (i.e. Single Input Single Output channel). Since the data is being transmitted over multiple parallel channels; one channel for each antenna pair, thus the channel capacity increases in direct proportion to the number of transmits-receive pairs.

B. The MIMO Channel H

Since each of the receive antennas detects all of the transmitted signals, there are N×N independent radio wave propagation paths for N transmit and N receive antennas. Hence, the channel can be represented as an N×N matrix. Again using a 3×3system as an example, the matrix as specified by equation (1) is obtained.

$$H=\begin{pmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{pmatrix} \tag{1}$$

Each of the elements in the channel matrix is an independent propagation path. Here, h_{ij} represents the path from transmit antenna "i" to receive antenna "j". Hence, the system can be represented as the following equation.

$$r = Hs + n$$

Where s=Transmitted signal vector, H=Channel Matrix, n=noise and r =received signal vector. Each element of the channel matrix in the complex form represents the power of the signal and associated phase delay. The complex form of the elements of the channel matrix 'H' represent the attenuation and phase delay associated with that propagation path. The received signal can be decoded using Gaussian Elimination method.

C. Gaussian Elimination

Gaussian elimination is a method, which can be used to determine the transmitted signal at receiver. Ignoring any noise in the channel, the system equation is simplified to r=Hs. This states that the received signal is equal to the transmitted signal multiplied by the channel matrix. Here, it is believed that the receiver has full acquaintance to the channel properties and hence knows the channel matrix. Gaussian elimination is a systematic procedure used to solve sets of linear equations. This approach works by reducing the equations to triangular form as they can be more easily solved using back substitution.

D. Singular Value Decomposition (SVD)

Singular value decomposition (SVD) is a set of techniques for solving sets of linear equations and matrices that are singular or very close to singular. The SVD theorem states that any M ×N matrix H whose number of rows M is greater than or equal to its number of columns N, can be written as the product of an M × N column-orthogonal matrix U, an N × N diagonal matrix D with positive or zero elements (the singular values), and the transpose of an N×N orthogonal matrix V.

E. Channel Capacity

The prospective improvement in MIMO spectral efficiency comes from the analysis of channel capacity in a multi-antenna communication system.

F. Channel Capacity

The channel capacity or spectral efficiency of a communication system over power constraint white Gaussian channels is defined as

$$C = \log(1+SNR)$$

where C is in the unit of Hz. This definition relates the spectral efficiency to signal to noise ratio (SNR) of the communication channel. When either transmitter or receiver uses multiple antennas to suppress multipath fading, the channel capacity is given by

$$C = \log(1+n \cdot SNR)$$

where n is the number of antennas and SNR is averaged over n radio links. Although multiple antennas are used, channel capacity or spectral efficiency is still in the logarithmic nature of slow growth with the increase of number of antennas.

G. Channel Capacity for MIMO

Channel capacity for MIMO system is expressed as

$$C \approx m.\log(1+SNR)$$

where m is the number of antennas in the smaller of the transmitter and receiver sides. (Bjornson *et al*, 2013) Hence, it is evident that the spectral efficiency for a MIMO system is increased linearly with the increase of the number of antennas. Multiple parallel channels are formed to deliver more data traffic streams simultaneously.

Conclusion

Multiple Input Multiple Output channels offer diversity gain, array gain, multiplexing gain a co–channel interference cancellation gain. Thus MIMO systems offer a promising solution for future generations of wireless communicating wireless networks. As described, a MIMO channel exploits the multi path components for better quality reception. Moreover it also enhances the channel capacity by a factor of number of antennas deployed.

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