Enhancement of Transmission Reliability in Multi Input Multi Output (MIMO) Antenna System for Improved Performance

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Abstract

Broadband wireless communication systems have seen a considerable growth recently. This paper introduces basic concepts in multi-antenna wireless systems. Use of multiple antenna configurations instead of a single one has proven to be successful in enhancing data transfer rate, coverage, security and the overall performance of radio networks. The use of multiple antennas for diversity, including MIMO (Multiple Input Multiple Output), is one of the most promising wireless technologies for broadband communication applications. This paper will focus on the use of distributed MIMO antenna to obtain higher throughput and reliability. Different techniques like diversity, spatial multiplexing and beam-forming for improving transmission reliability are also addressed.

Keywords: MIMO, diversity, cooperative, Wireless communication.

1 INTRODUCTION

MIMO systems are characterized by having multiple antennas at both the transmitter and the receiver. The number of antenna elements at the transmitter and the receiver need not be the same. Multiple input multiple output system is a potential technology
that can be used to improve system performances such as coverage, capacity and data rates for broadband wireless networks. Various different multiple antenna techniques are available. These can be broadly classified into three categories. They are diversity techniques, spatial multiplexing techniques and beamforming. The diversity techniques intend to receive the same information bearing signals in the multiple antennas or to transmit them from multiple antennas. In the spatial multiplexing techniques, the multiple independent data streams are simultaneously transmitted by the multiple transmit antennas, thereby achieving a higher transmission speed. In beam-forming, multiple antennas can be used to transmit the same signal appropriately weighted for each antenna element such that the effect is to focus the transmitted beam in the direction of the receiver and away from interference, thereby improving the signal to noise ratio. A significant improvement in the coverage range, capacity and reliability can be provided by beamforming. The concept of cooperative diversity in wireless networks has been newly introduced. In such a strategy, when a node has some information to send, it cooperates with other single-antenna terminals to send its information to a certain destination, thus forming a virtual antenna array.

2 ANTENNA DIVERSITY TECHNIQUES

Antenna diversity technique is one of the wireless diversity schemes that use two or more antennas to improve the quality and reliability of a wireless link. Diversity techniques are used to remove degradation in the error performance due to unstable wireless fading channels which occurs due to multipath fading.

Two most commonly used antenna diversity techniques are receive and transmit diversities. They are described below:

2.1 Receive Diversity

Receive diversity is the most common form of spatial diversity which uses two receive antennas. Receive diversity requires a receiver that processes the Nr received streams and combines them. The two widely used receive diversity are Selection Combining (SC) and maximal ratio combining (MRC).

2.1.1 Selection combining

![Selection combining receive diversity](image-url)
A block diagram showing selection combining receive diversity technique is shown in Figure 1. The channel response is given by

\[
H = \begin{bmatrix}
h_1 \\
h_2 \\
\vdots \\
h_{Nr}
\end{bmatrix}
\]

-------- (1)

Selection combining is the simplest type of combiner. It estimates the instantaneous strengths of each of the Nr streams and selects the highest one. As it ignores the useful energy on the other streams, SC is suboptimal, but its simplicity and reduced requirements of hardware are the advantages that make it attractive in many cases.

2.1.2 Maximal ratio combining

A block diagram showing maximal ratio combining receive diversity technique is shown in Figure 2. The channel response is given by equation 1, same as selection combining. Maximal ratio combining combines the information from all the received branches in order to maximize the ratio of signal-to-noise power, which gives it its name. MRC works by weighing each branch with a complex factor \( q_i \) and then adding up the Nr branches, as shown in Figure 2. The complex factor \( q_i \) is given by,

\[
q_i = 1, 2, Nr
\]

where, \( |q_i| \) and \( \Phi_i \) are the magnitude and phase of \( i \)th branch, respectively.

![Figure 2: Maximal ratio combining receive diversity](image)

2.2 Transmit Diversity

A crucial drawback of receive diversity is that most of computational burden is on the receiver side, which may incur high power consumption for mobile units in the case of downlink. Transmit diversity is particularly useful for the downlink of
infrastructure-based systems. A block diagram of open loop transmit diversity system is shown in figure 3.

![Block Diagram of Open Loop Transmit Diversity System](image)

**Figure 3:** Open loop transmit diversity

### 3. SPACE TIME BLOCK CODES

Space–time block coding is a wireless communication technique used to transmit multiple copies of data stream across a number of antennas and to utilize the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must cross a potentially difficult environment with scattering, reflection, refraction and so on and may then be further ruined by thermal noise in the receiver, means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal.

### 4 BEAMFORMING

Beamforming is a powerful technique which can increase the link signal-to-noise ratio (SNR) by focusing the energy into desired directions. In this scheme, \( N_s = 1 \) and \( K = 1 \), resulting in the data rate \( R = 1 \). To enable beamforming, the number of transmit antennas and/or the number of the receive antennas should be greater than one. Beamforming are of two types, Receive beamforming and transmit beamforming.

#### 4.1 Receive Beamforming

With a single transmit antenna \( (N_t = 1) \) and multiple receive antennas \( (N_r > 1) \), beamforming can be realized at the receiver. Figure 4 shows the receive beamforming scheme. The source symbol \( s \) arrives at the antenna array at the receiver side through the wireless channel. The received signals from the multiple antennas are first weighted by a beamforming vector \( w \) and then are combined. After the receiver has acquired a channel estimate, it can set the beamforming vector \( w \) to its optimal value to maximize the received SNR.
4.2 Transmit Beamforming

Beamforming can also be realized at the transmitter. Similar to the receive beamforming scheme, the transmitting signal is precoded by a beamforming vector and then transmitted via multiple transmit antennas. The beamforming vector is selected based on the channel state information (CSI) to maximize the receive signal to noise ratio of the received signal.

5 CO-LOCATED AND DISTRIBUTED MIMO

In the above three basic schemes, the information transmitted via the multi-antenna channels is limited to one user. These schemes are called single-user multi input multi output systems (SU-MIMO). Because the multiple antennas provide extra spatial dimension, it is possible to transmit information of multiple users simultaneously in the same bandwidth, while the users are differentiated in the spatial domain. The technology that implements this scheme is called multi-user multi input multi output system (MU-MIMO). It is an attractive approach to increase spectral efficiency in wireless links.

MU-MIMO is an extended concept of space-division multiple access (SDMA), which allows a terminal to transmit (or receive) signal to (or from) multiple users in the same band simultaneously.

Traditionally, spatial diversity is achieved by using multiple antennas at the transmitter or receiver, where the antennas are packed together with spacing of the order of wavelength, referred to as co-located MIMO. However in practical systems the benefits of the co-located MIMO technique are limited.

To eliminate the drawbacks in co-located MIMO systems, a new technique named distributed MIMO was proposed and has attracted much attention. The major difference between the distributed MIMO and the co-located MIMO is that multiple
antennas at the front-end of wireless networks are distributed among widely-separated radio nodes.

In a distributed multi input multi output system, each node may be only equipped with one antenna. Many nodes at different locations transmit the same information to the receiver. In this manner, multiple nodes form a virtual antenna array that achieves higher spatial diversity gain. This kind of spatial diversity is referred to as user cooperation diversity or simply cooperative diversity. Distributed MIMO can provide full user cooperation diversity, and the data rate in the cooperative networks can be increased by using distributed space-time coding.

5.1 COOPERATION SYSTEMS

A cooperative wireless network consists of a source, a number of relays, and a destination, which is illustrated in Figure 5. In Figure 5 the source node \( S \) is intending to send information to the destination node \( D \). Other nodes in the networks could be selected as the helpers or relays for the transmission between the source and the destination. Assuming that the nodes \( \{R_1, R_2, ..., R_n\} \) are selected to be the helpers, these helpers are treated as relay nodes, which forward the signals from the source to the destination. The relays together with the source form a virtual transmit array to achieve the spatial diversity. Relays in a cooperation network are different from that in a relay network where the relays only forward signals from other nodes. In cooperation networks, any nodes could function as a source or a relay. When a node collects and transmits information, it works as a source. Otherwise, it can help other nodes as a relay.

Figure 5: A cooperative wireless network

The communication between the source and the destination proceeds in two phases: information sharing and cooperative transmission.
In the information sharing phase, the source broadcasts its information to the relays and the destination. This step is essential as the spatial diversity can only be achieved from the independent transmission of the same information. Through information sharing, all relays get the information from the source and enable an independent data transmission. In the second phase, the information is forwarded by the relays to the destination. In the meantime, the source could either transmit or remain inactive. Because the relays are randomly selected and they are usually separated far away from others, it is highly likely that the channels between each relay and the destination are uncorrelated.

In the cooperative transmission, multiple relays and a source node (that are equipped with a single antenna) form a virtual antenna array for a distributed MIMO system. This distributed MIMO provides the benefits of the cooperative system by overcoming the size limitation and ill-conditioned channel in co-located MIMO systems.

Co-channel interference is one of the serious problems in the cooperative wireless network. When the information is relayed to the destination, there exists co-channel interference in that the signals from different relays may interfere with each other at the destination.

Although the interference cancellation at the destination is a possible solution, the required algorithm is complex and the performance may not be very satisfying. The common cooperative approach is to avoid the interference by transmitting the relayed signals in orthogonal sub channels. The orthogonality could be acquired by using repetition-based strategy or by using distributed space-time coding (DSTC). For the repetition-based approach, the relays forward the signal in different time slots, i.e., in each time slot, only one relay transmits information, while the other relays stay inactive. This approach is easy to implement, but it results in poor bandwidth efficiency. By using DSTC, the relays can forward information in the same time slot. The orthogonality is constructed in both time and space domains. Although DSTC-based approach leads to a more complex network, the bandwidth is utilized more efficiently. Both repetition-based and DSTC-based cooperative strategies can achieve full spatial diversity, i.e., the order of the spatial diversity. However, the achieved diversity is not only decided by the cooperative strategies, but also determined by the methods or relay protocols. The different relay protocols are: Amplify-and-Forward, Decode-and-Forward and Selection Relaying.

6 CONCLUSION AND FUTURE SCOPE

The performance of wireless networks highly depends on multipath fading in terms of degradation. One of the most dominant methods to reduce the effect of fading is by using multiple antennas that provides high system stability. The combination of space diversity and spatial multiplexing is called Multiple-Input Multiple-Output (MIMO). Cooperative diversity, a substitute form of realizing MIMO, it has been newly proposed to recognize the diversity benefit in a distributed manner. Cooperative
V.W. Sonone, Dr. A.N.Gaikwad and Dr. N.B.Chopade

diversity method exploits the broadcast nature of wireless communication and creates a virtual antenna array system through cooperating nodes. This paper presents a detailed discussion of the latest distributed MIMO technologies in cooperative wireless networks, which includes the principle of cooperative wireless communications and the popular relay protocols. Distributed multi input multi output systems can provide full user cooperation diversity, and the data rate in the cooperative networks can be significantly increased by using distributed space-time coding.

The cooperative diversity network offers enhanced gain and considerably better performance. The cooperative MIMO scheme may have effective throughput in low SNR regime when compared to the conventional point-to-point system.

REFERENCES


Enhancement of Transmission Reliability in Multi Input Multi Output (MIMO)... 601


