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RESEARCH ARTICLE

EXPLOITATION OF DIVERSITY GAIN IN MULTIPLE-INPUT MULTIPLE-OUTPUT ANTENNA FOR WIRELESS COMMUNICATION CHANNEL

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ABSTRACT

Recently multiple-input multiple-output (MIMO) is very popular in long term evolution (LTE) plan. Advancement is done in GPRS and UMTS technology at physical layer by introduction of multiple antennas at either receiver or transmitter. This has increased the reliability of the link to great extent compared to conventional coding techniques. This paper discusses and compares methods related to different combinations of MIMO. Comparison has been done among the system having one transmit and multiple receive antennas and one receive and multiple transmit antennas. It is found that multiple antennas provide diversity gain and as the number of antennas increases either in transmitter or in receiver side, it provides diversity gain. This greatly improves the performance of wireless communication channel in Rayleigh faded environment.

INTRODUCTION

Wireless communications undergoes a dramatically change in recent years. More and more people are using modern communication services, thus increasing the need for more capacity in transmission. Since bandwidth is a limited resource, the strongly increased demand in high transmission capacity has to be satisfied by a better use of existing frequency bands and channel conditions. This can be done by increasing the link reliability. Many good coding techniques are developed and are used in recent wireless communication standards. One of the popular coding is Turbo codes, (Berrou *et al*., 1993) which provides performance close to the Shannon limit. (Forney, 1966) Other way to fulfill the requirement is by using multiple antennas at transmitter and or receiver end. These types of systems are called Multiple-inut multiple-output (MIMO) systems. (Talatar, 1999; Foschini and Gans, 1998) There are two gains related to MIMO systems: diversity gain and spatial multiplexing gain. In this paper we concentrate in diversity gain using multiple antennas (Stege *et al*., 2000).

In wireless communication channels line of site (LOS) path is rare between transmitter and receiver.

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Since there is no LOS path, signal will reach the receiver via several different paths due to several phenomena like reflection. This is referred to as multipath propagation. Due to this, signal that reaches the receiver undergo Rayleigh fading (Proakis, 2000). Due to this statistical behavior channel gain may sometimes become very small and reliable communication can not be possible. To compensate this, diversity technique is developed which increases the reliability of the link.

The main requirements of future wireless communications system is improved link reliability with high speed. The hostile propagation medium suffers from fading and interference from other users. (Proakis, 2000) The use of multiple antennas at both ends of a wireless link promises significant improvements in terms of spectral efficiency and/or link reliability. Several space time coding and space frequency coding techniques are developed to fulfill these requirements. (Alamouti, 1998; Hottinen *et al*., 2003; Paulraj *et al*., 2004; Mietzner *et al*., 2009) Authors suggests different techniques of multiple antennas in space time and space frequency. Different diversity techniques are developed that provides link reliability (Patel and Shah, 2011).

Paper is organized like this. Section II gives basics of wireless channel. Section III gives basics of MIMO channels. Performance comparison of MIMO channels with turbo codes is described in section IV. Simulation results are explained in section V and conclusion is drawn in section VI.

Wireless Channel

In wireless communication, radio propagation refers to the behavior of radio waves when they are propagated from transmitter to receiver. In the course of propagation, radio waves are mainly affected by three different modes of physical phenomena: reflection, diffraction and scattering. (Goldsmith, 2005) The fading phenomenon can be broadly classified into two different types: large-scale fading and small-scale fading.

Received signal in the propagation environment for a wireless channel can be considered as the sum of the received signals from an infinite number of scatters. By the central limit theorem, the received signal can be represented by a Gaussian random variable. In other words, complex Gaussian random variable, $n_1 + jn_2$,

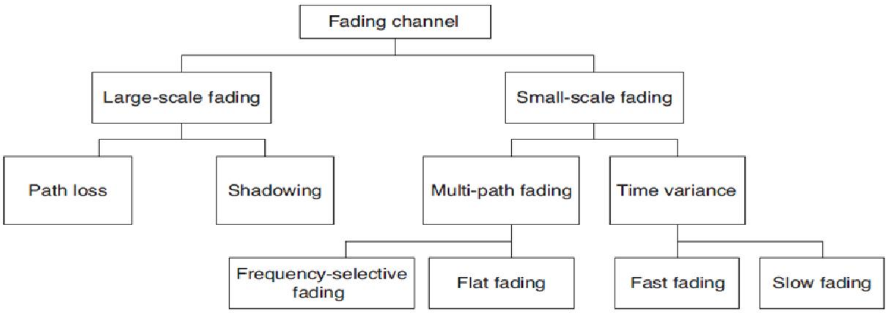

Fig. 1. Classification of fading channels (Cho *et al.*, 2010)

where n_1 and n_2 are the independent and identically-distributed (i.i.d.) Gaussian random variables with zero mean and variance σ^2. Let X denote the amplitude of the complex Gaussian random variable $n_1 + jn_2$, such that $X = \sqrt{n_1^2 + n_2^2}$. Then, note that X is a Rayleigh random variable with the following probability density function (PDF):

$$f_X(x) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \quad \text{...............(1)}$$

where $2\sigma^2 = E\{X^2\}$. Furthermore, X^2 is known as chi-square (X^2) random variable.

In the LOS environment where there exists a strong path which is not subject to any loss due to reflection, diffraction and scattering, the amplitude of the received signal can be expressed as $X = c + W_1 + jW_2$ where c represents the LOS component while W_1 and W_2 are the i.i.d. Gaussian random variables with a zero mean and variance of σ^2 as in the non-LOS environment. It has been known that X is the Rician random variable with the following PDF.

$$f_X(x) = \frac{x}{\sigma^2} e^{-\frac{x^2+c^2}{2\sigma^2}} I_0\left(\frac{xc}{\sigma^2}\right) \quad \text{............(2)}$$

where $I_0(.)$ is the modified zero order Bessel function of the first kind. Note that equation (2.2) can be represented in terms of the Rician K factor defined as

$$K = \frac{c^2}{2\sigma^2} \quad \text{.........(3)}$$

In case where LOS component does not exist, (i.e. K = 0), equation (2.2) reduces to the Rayleigh PDF equation (2.1) as in the NLOS environment. As K increases, equation (2.2) tends to be the Gaussian PDF. Generally it is assumed that $K \sim -40dB$ for the Rayleigh fading channel and K > 15 dB for the Gaussian channel.

MIMO Systems

The MIMO systems have multiple transmitting and receiving antennas. A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scattering environment. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain.

Let us assume that the number of transmitting antennas is M, and the number of receiving antennas is N. We will first look at the capacity of different antenna systems in order to see the dramatic increase in capacity obtained by using MIMO systems.

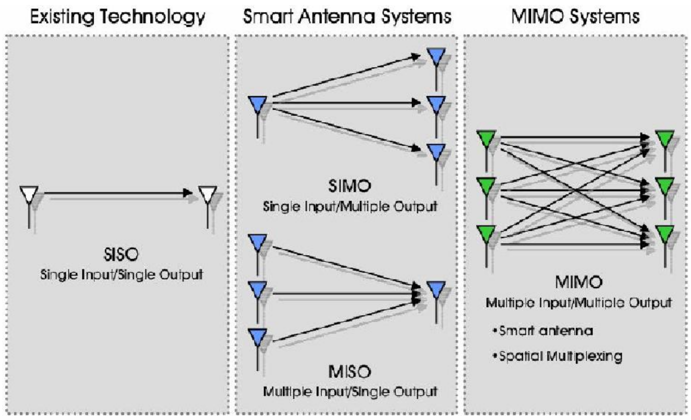

Fig. 2. Different types of MIMO systems

Multiple-Input, Multiple-Output (MIMO) – Same signal transmitted by each antenna.

The MIMO system can be viewed in effect as a combination of Multiple-Output Single-Output (MISO) and Single-Input Multiple-Output (SIMO) channels. In this case, it is possible to get approximately an MN-fold increase in the SNR yielding a channel capacity equal to:

$$C \approx B \cdot \log_2 \left(1 + MN \cdot SNR_0\right) \quad \ldots\ldots\ldots\ldots\ldots(4)$$

Thus, we can see that the channel capacity for the MIMO system is higher than that of MISO or SIMO. However, we should note here that in all four cases the relationship between the channel capacity and the SNR is logarithmic. This means that trying to increase the data rate by simply transmitting more power is extremely costly.

Multiple-Input, Multiple-Output (MIMO) - Different signal transmitted by each antenna.

Our assumption here is that we have N receive and M transmit antenna, so that all the transmitted signals can be decoded at the receiver. The big idea in MIMO is that we can send different signals using the same bandwidth and still be able to decode correctly at the receiver. Thus, it is like we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$C_{\text{single}} \approx B \cdot \log_2 \left(1 + \frac{N}{M} \cdot SNR_0\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

But, since we have M of these channels (M transmitting antennas), the total capacity of the system is

$$C \approx M \cdot B \cdot \log_2 \left(1 + \frac{N}{M} \cdot SNR_0\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Thus, as we can see from (6), we get a linear increase in capacity with respect to the number of transmitting antennas. So, the key principal at work here, is that it is more beneficial to transmit data using many different low-powered channels than using one single, high-powered channel.

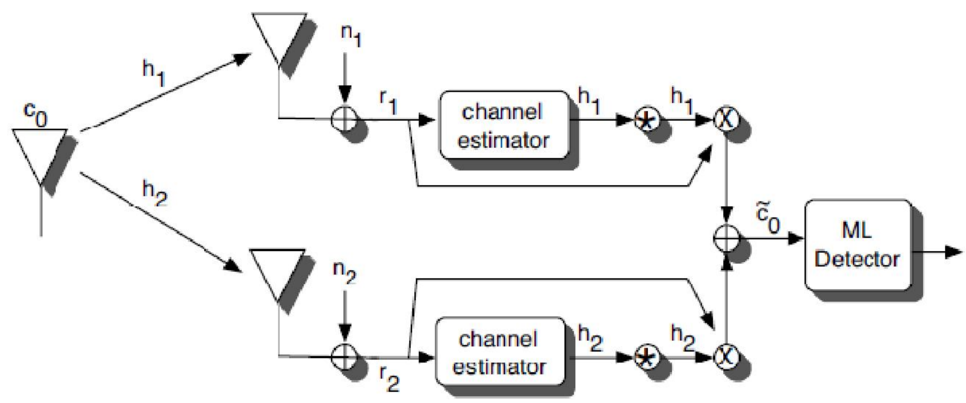

Fig. 3. Maximum Ratio Combining with 1 Tx and 2 Rx antenna (Cho *et al*., 2010)

a. CHANNEL MODEL

This paper considers multiple-input multiple-output (MIMO) Gaussian broadcast channel in which the Base Station (BS) has N_t antennas and each of the users or User Terminals (UT) have 1 antenna each. The channel output y_k at user k is given by: (Alex and Jalloul, 2008)

$$y_k = h_k^H x + n_k,\ k = 1, \cdots, K \quad \ldots\ldots\ldots\ldots(7)$$

where $n_k \sim CN(0,1)$ models Additive White Gaussian Noise (AWGN), $h_k \in \mathbb{C}^{N_t}$ is the vector of channel coefficients from the k[th]user antenna to the transmitter antenna array and x is the vector of channel input symbols transmitted by the base station. The average power constraint for channel input is $E(\|x\|_2^2 \leq SNR)$. We assume the channel state, given by the collection of all channel vectors, varies in time according to a block-fading model, where the channels are constant within a block but vary independently from block to block. The entries of each channel vector are i.i.d. Gaussian with elements ~$CN(0, 1)$. Each user is assumed to know its own channel perfectly.

b. MAXIMUM RATIO COMBINING

Figure 3 represents the concept of Maximum ratio combining (MRC). MRC is considered to be one of the best combining techniques at receiver. In the case of maximum ratio combining, the resulting received signals are

$$\begin{aligned} r_1 &= h_1 x_0 + w_1 \\ r_2 &= -h_2 x_0 + w_2 \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots(8)$$

and the combined signal is

$$\begin{aligned} \tilde{x}_0 &= h_1^* r_1 + h_2^* r_2 \\ &= (\alpha_1^2 + \alpha_2^2) x_0 + h_1^* w_1 + h_2^* w_2 \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots(9)$$

The maximum likelihood detector decides signal x_i , where h_i represents the channel parameters.

Note that the MRC signal $\tilde{x}_0$in (9) is equivalent to the resulting combined signals of the transmit diversity scheme, except for a phase difference in the noise components which do not affect the effective SNR. This shows that the diversity order from

Alamouti's two-antenna transmit diversity scheme is the same as that of the two-branch MRC.

c. Receive Diversity

Considering the Additive White Gaussian Noise (AWGN) equation for receive diversity can be defined as

$$P_b = \frac{1}{2} erft\left(\sqrt{\frac{NE_b}{N_0}}\right) \quad \text{...................... (10)}$$

Where E_b is energy per bit, N_0 is noise power and *erfc*() is complementary error function and N is number of receive antenna.

MIMO Performance Gain

The use of multiple antennas in the receiver and/or in the transmitter basically provides the following advantages.

- Array gain: Array gain is an increase in average received SNR obtained by coherently combined signals transmitted from multiple antennas or received by multiple antennas. In order to get array gain channel knowledge at the transmitter or receiver is required.
- Diversity gain: Diversity gain refers to improved link reliability in space, time, frequency or polarization. Diversity gain can be exploited in the case of independently fading multiple channels experienced by different antennas in order to mitigate the effect of multipath fading. Diversity gain is expressed in terms of order, which is characterized by the slope of error probability performance curve.
- Spatial multiplexing gain: Multiplexing gain corresponds to the increased data rate due to the ability to transmit multiple parallel data streams over MIMO channel without increasing the bandwidth or total transmit power. The capability to support multiple streams depends on the rank of the channel matrix H.

Simulation Results

Simulation is carried out by considering MIMO systems described in section III. It is assumed that the channel state information is completely available at receiver. Also perfect synchronization and zero carrier offset is assumed at the receiver. Here comparison is made among different combinations of input and output antennas. Rayleigh fading is implemented in all systems. It is assumed that the antennas are uncorrelated with one another.

Figure 3 gives the result of comparison of transmit and receive diversity. For the binary phase shift keying (BPSK) modulation over flat fading channel. For transmit diversity, we use two transmit antennas and one receive antenna (2x1 notationally), while for receive diversity we employ one transmit antenna and two receive antennas (1x2 notationally).

Figure 4 gives comparison of various MIMO systems with single input single output, orthogonal STBC (OSTBC), Alamouti, Maximum Ratio Combining techniques. As the diversity order increases, BER improves.

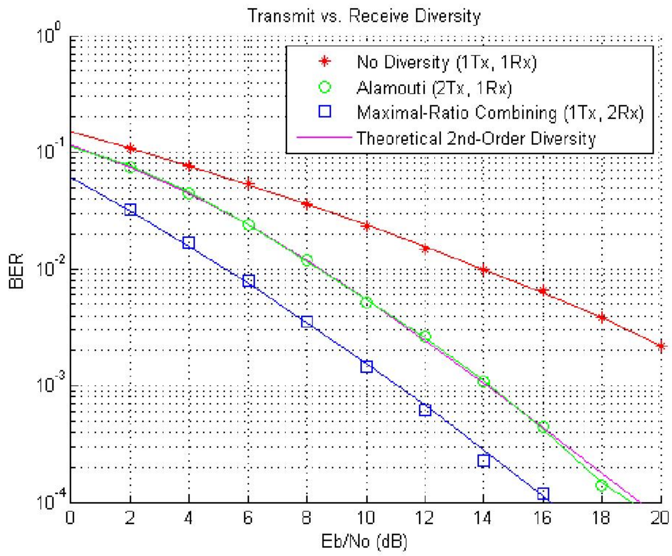

Fig. 3. Transmit and Receive Diversity for N_t x N_rMIMO

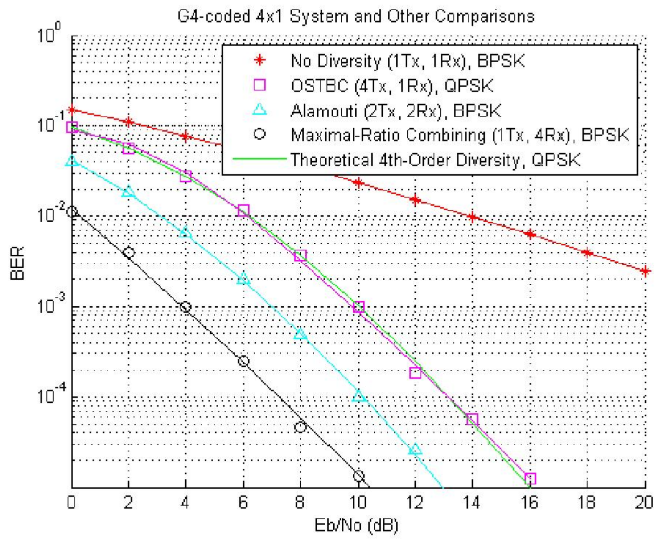

Fig. 4. Comparison of various diversity schemes

Conclusion

Simulation results of Figure 3shows that using two transmit antennas and one receive antenna provides the same diversity order as the maximal-ratio combined (MRC) system of one transmit antenna and two receive antennas.

Also observe that transmit diversity has a 3 dB disadvantage when compared to MRC receive diversity. This is because we modelled the total transmitted power to be the same in both cases. If we calibrate the transmitted power such that the received power for these two cases is the same, then the performance would be identical. The theoretical performance of second-order diversity link matches the transmit diversity system as it normalizes the total power across all the diversity branches.

Figure 4 shows that the increase in number of transmit antenna either at transmitter or at receiver improves the diversity gain.

As expected, the similar slopes of the BER curves for the 4x1, 2x2 and 1x4 systems indicate an identical diversity order for each system.

Also observe the 3 dB penalty for the 4x1 system that can be attributed to the same total transmitted power assumption made for each of the three systems. If we calibrate the transmitted power such that the received power for each of these systems is the same, then the three systems would perform identically. Again, the theoretical performance matches the simulation performance of the 4x1 system as the total power is normalized across the diversity branches.

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