Improvement in Link Reliability via Space Time Block Coding Technique for the LTE Advanced Wireless Communication System in Rayleigh Fading Environment

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Abstract

This paper presents highly robust space time block coded (STBC) multiple-input multiple-output (MIMO) system. This has been very popular in long term evolution (LTE) and LTE-A (LTE-Advanced) plans. STBC along with MIMO has tremendous potential for link reliability in physical layer. Also looking at various methods of combining signals at receiver gives motivation to the use of MIMO in LTE systems. This work discusses the combinations of multiple antennas at either transmitter and or receiver and shows that increase in number of antennas gives rise to bit error rate (BER) which is one of the important measure of link reliability. To show the conclusion, 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.
Keywords: Multiple Input Multiple Output, Space Time Block Code, Turbo Coding, Diversity

I. INTRODUCTION

Cellular networks are currently experiencing a tremendous growth of data traffic. A ten to seven teen fold increase of global mobile data traffic between 2012 and 2017 is predicted by several studies [1–3]. A few notable statements of Cisco's Visual Networking Index [3], illustrating these trends, are:

- Mobile data traffic in 2012 was nearly twelve times the size of the entire Internet in 2000.
- Average smart phone usage grew 81 percent in 2012.
- Smart phones represented only 18 percent of total global handsets in use in 2012, but represented 92 percent of total global handset traffic.

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, [4] which provides performance close to the Shannon limit.[5] 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. [6][7] Space-Time Codes (STC) were first introduced by Tarokh et al. from AT&T research labs [8] in 1998 as a novel means of providing transmit diversity for the multiple-antenna fading channel. In the year 1999 orthogonal designs were presented by Tarokh et al. [9] Previously, multipath fading in multiple antenna wireless systems was mostly dealt with by other diversity techniques, such as temporal diversity, frequency diversity and receive antenna diversity, with receive antenna diversity being the most widely applied technique. However, it is hard to efficiently use receive antenna diversity at the remote units because of the need for them to remain relatively simple, inexpensive and small. Therefore, for commercial reasons, multiple antennas are preferred at the base stations, and transmit diversity schemes are growing increasingly popular as they promise high data rate transmission over wireless fading channels in both the uplink and downlink while putting the diversity burden on the base station. Alamouti coding scheme has made revolution by giving the space time block coding. [10]

The space time coding scheme by Tarokh et all [8,9] is essentially a joint design of coding, modulation, transmit and receive diversity and has been generalization of other transmit and receive diversity schemes. This paper aims to give a literature survey of the design and diversity results of STBCs in Rayleigh fading.

Paper is organized like this. Section II gives basics of system model. Section III describes Space Time Block Codes. 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.

II. SYSTEM MODEL

Consider a mobile communication system where the base station is equipped with n transmit and the remote unit is equipped with m receive antennas (see Figure 1). At each time slots *t*, signals are transmitted simultaneously through *n* transmit antennas. The channel is flat-fading and the path gain from transmit antenna i to receive antenna j is denoted by hi,j. The path gains are modeled as samples of independent complex Gaussian random variables with variance 0.5 per real dimension, i.e. $h_{i,j} \sim N(0,1)$, as we assume that signals received at different antennas experience independent fading. In this report, we will consider modeling the path gains in both slow and fast Rayleigh fading. For slow fading, it is assumed that the path gains are constant during a frame of length L and vary from one frame to another, i.e., channel is quasi-static.

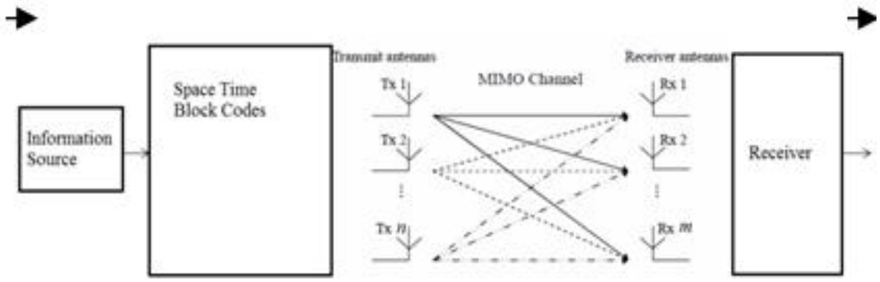

Fig. 1: System block diagram [11]

At time t, the signal , received at antenna j is given by (1) where the noise samples are i.i.d. zero mean complex Gaussian with variance per dimension. The average energy of the symbols transmitted from each antenna is normalized to one, so that the average power of the received signal at each receive antenna is n.

It is assumed that channel state information is only available at the receiver, who uses it to compute the decision metric (2) over all code words and decide in favor of the code word that minimizes the sum.

III. SPACE TIME BLOCK CODES

In 1998, Alamouti [10] proposed a simple transmit diversity scheme (see Figure (2)), which improves the signal quality at the receiver on one side of the link by simple processing across two transmit antennas at the opposite end.

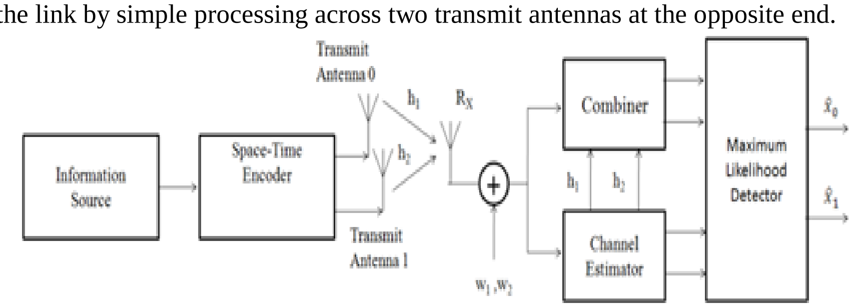

Fig. 2: Alamouti's STBC coding scheme [10]

At a given symbol period, two signals are simultaneously transmitted from the two antennas, namely c1 from the first antenna, Tx1, and c2 from the second antenna, Tx2. In the next symbol period, signal is transmitted from Tx1 and signal is transmitted from Tx2, where ∗ denotes complex conjugation. Following is the symbol matrix as per Alamouti scheme.[10] (3)
If we assume that the fading is constant across two consecutive symbols, we can write (4)
where *T* is the symbol period. The received signals are

$$r1 = r(t) = h_1c_1 + h_2c_2 + \eta_1 \quad (5)$$

$$r2 = r(t+T) = -h_1c_2^* + h_2c_1^* + \eta_2 ,$$

where r_1 and r_2 are the received signals at time t and $t + T$. The combiner combines the received signals as follows: (6) and sends them to the maximum likelihood detector. Maximum likelihood detector decides on base of minimum Euclidean distance the one who is received out of those transmitted. Several combining techniques are developed to effectively combine the received signals from many received antennas. Alamouti further extended this scheme to the case of 2 transmit antennas and m receive antennas and showed that the scheme provided a diversity order of 2m.

IV. GENERAL CONSTRUCTION

Tarokh et al. [8], [9] later generalized Alamouti's transmit diversity scheme to an arbitrary number of transmit antennas, and presented more complex space-time block codes akin to Alamouti's. These codes require no channel state information at the transmitter, achieve maximum-likelihood decoding through linear processing at the receiver, and exhibit maximum diversity. For real signal constellations (such as PAM), they are known to provide the maximum possible transmission rate allowed by the theory of STC [6]. For complex constellations, STBCs can be constructed for any number of transmit antennas, and they provide full spatial diversity and half of the maximum possible rate allowed by the theory of STC.

An STBC is defined by a p × n transmission matrix G, whose entries are linear combinations of and their conjugates, and whose columns are pairwise-orthogonal. In the case when $p = n$ and $\{c_i\}$ are real, G is a linear processing orthogonal design which satisfies the condition that $G^T G = D$, where D is a diagonal matrix. Without loss of generality, the first row of G contains entries with positive signs; if not, one can always negate certain columns of G to arrive at a positive first row. Equation (7) include the 2 × 2 and 3 × 4 design. In this design, G_2 stands for full rate and G_3^c stands for rate half code. (7)

Transmission using a generalized orthogonal design is similar to the case when $p = n$, except that now kb bits are sent during each p transmissions. Since p time slots are used to transmit k symbols, the rate R of this coding scheme is defined to be $kb/pb = k/p$. The diversity order remains nm.

A. Channel Model:

This paper considers multiple-input multiple-output (MIMO) Gaussian broadcast channel in which the Base Station (BS) has Nt antennas and each of the users or User Terminals (UT) have 1 antenna each. The channel output yk at user k is given by:[12] (8)

where models Additive White Gaussian Noise (AWGN), is the vector of channel coefficients from the kth 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 . 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:

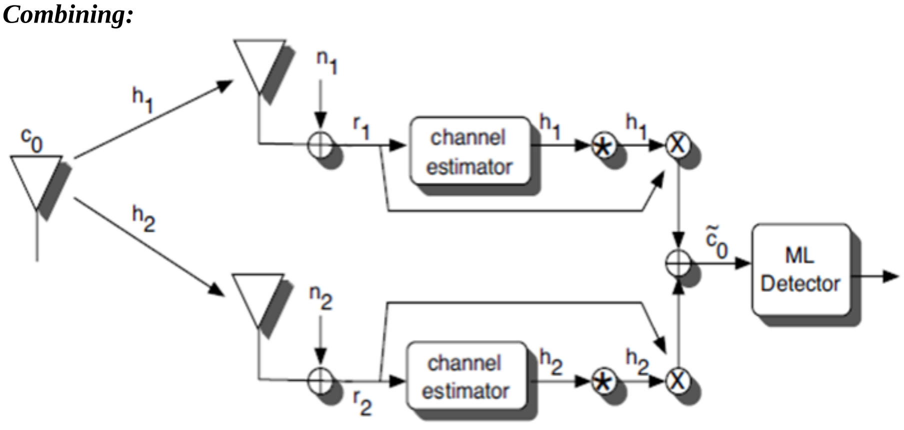

Fig. 3: Maximum Ratio Combining with 1 Tx and 2 Rx antenna [13]

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 (9) and the combined signal is (10) The maximum likelihood detector decides signal x_i , where h_i represents the channel parameters .

Note that the MRC signal in (10) 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 (11)
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.

V. 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. Quadrature Amplitude Modulation (QAM) is considered for all the simulations. Simulations are carried out using 4 QAM and 16 QAM modulations for the system specified in section II. In all simulations, receiver with MRC combining technique is considered.

Figure 4 shows the simulation results of STBC Alamouti based 2 x 2 and 2 x 1 multiple antenna combinations. It can be observed from the figure that as the number of antennas increase, BER improves.

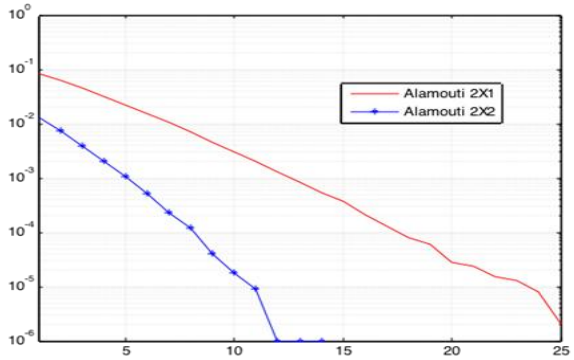

Fig. 4: BER Plot for Alamouti 2 x 1 with 16 QAM

Figure 5 gives the result of comparison of 4 QAM and 16 QAM using 2 x 1 and 2 x 2 antenna configurations.

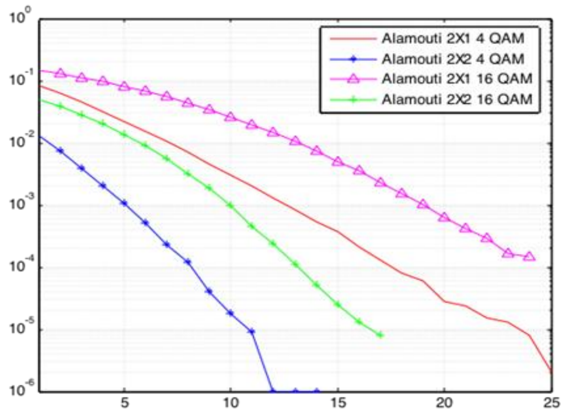

Fig. 5: Comparison of Alamouti STBC for 4 Qam and 16 QAM

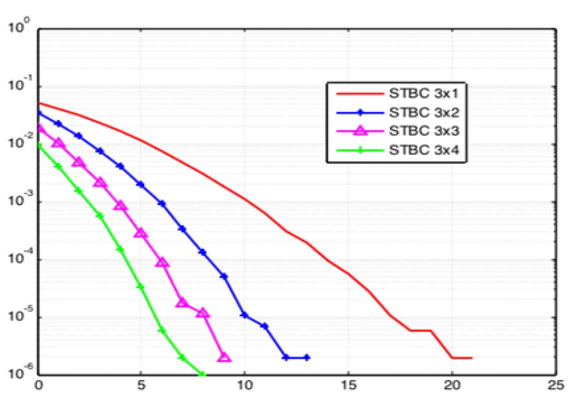

Fig. 6: Comparison of 3 x m MIMO for 4 QAM

Figure 6 gives comparison of various MIMO systems having 3 transmit and 1 to 4 receive antennas. It has been observed that as the receive antenna increases, BER improves.

VI. CONCLUSION

Simulation results of figure 4 shows that using two transmit antennas and one receive antenna provides diversity order less than that of two transmit antenna and two receive antennas. Due to this BER for 2 x 2 is better than 2x1.

Also from Figure 5 it is observed that transmit 4 QAM is better than 16 QAM for any fix combination of either MISO (Multiple Input Single Output) or MIMO. But by looking to all graphs it is observed that the best result is achieved for the case of 2x2 with 4 QAM modulation. Results are not good with 16 QAM and 2x1, but if diversity increases from 2 to 4, i.e. for the case of 2x2, 16 QAM, we get better performance compared to 2x1 4 QAM. This is mainly because of diversity advantage.

Figure 6 compares the MIMO combinations starting from 3x1 to 3x4 antennas. That is figure 6 gives comparison of different receive antennas relative to 3 transmit antennas. This is for half rate STBC codes. Due to this, performance of all combinations is better than that of either figure 4 or figure 5 results. But in all, as diversity order increases, BER improves.

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