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PERFORMANCE COPARISON OF ERGODIC CAPACITY FOR MIMO

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ABSTRACT

Multiple-Input Multiple-Output (MIMO) technology is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. Spatial Modulation is one of the techniques that can significantly increase the capacity of MIMO channel by increasing the number of transmit antennas. This paper studies the ergodic capacity of the MIMO systems and feedback based communication with multiple antennas, such as the transmit diversity, the receive diversity, the Maximum Ratio Combining in a Rayleigh channel. In the basic form of Spatial Modulation, only one out of N_t and N_r available antennas is selected for transmission and receiver in any given symbol interval. This paper proposes to use more than one active antenna to transmit and receive several symbols simultaneously. This would increase the spectral efficiency and decreases BER (bit error rate) at the receiver.

KEYWORDS: Transmit and Receive Antenna Diversity, Beamforming (Spatial Selection), BER.

INTRODUCTION

MIMO technology takes advantage of a natural radio-wave phenomenon called multipath. With multipath, transmitted information bounces off walls, ceilings, and other objects, reaching the receiving antenna multiple times via different angles and at slightly different times. In the past, multipath caused interference and slowed down wireless signals. MIMO technology takes advantage of multipath behavior by using multiple, smart transmitters and receivers with an added spatial dimension, to dramatically increase performance and range. MIMO makes antennas work smarter by enabling them to combine data streams arriving from different paths and at different times to effectively increase receiver signal-capturing power. Smart antennas use spatial diversity technology, which puts surplus antennas to good use. When there are more antennas than spatial streams, the antennas can add receiver diversity and increase range.

The method employing training sequences is a popular and efficient channel estimation method. A number of training based channel estimation methods for MIMO systems have been proposed. However, in most of the presented works independent identically distributed Rayleigh channels are assumed. This assumption is rarely fulfilled in practice, as spatial channel correlation occurs in most of propagation environments. An MMSE channel estimator for MIMO-OFDM was developed and its performance was tested under spatial correlated channel. However, a very simple correlated channel model was used. These investigations neglected the issue of antenna array used at the receiver side. In practical cases there is a demand for small spacing of array antenna elements at least at the mobile side of MIMO system. This is required to make the transceiver of compact size. However, the resulting tight spacing is responsible for channel correlation. Also, the received signals are affected by mutual coupling effects of the array elements.

SYSTEM MODEL

Let us consider a wireless communication system having N number of antennas at the transmitting side and M number of antennas at the receiving side. When there is no antenna selection, $L_t = N$ and $L_r = M$. The below figure is block diagram representing the simple model for MIMO communication.

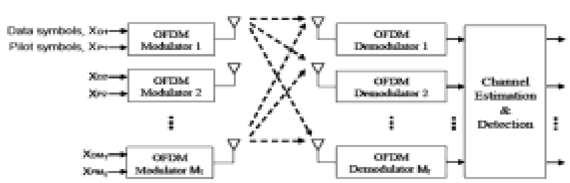


Fig. 1 Block Diagram of Simple Model for MIMO system

The incoming data is encoded by the space-time encoder. The output of the encoder is fed into a serial-to-parallel converter that converts the input stream into N parallel streams. The resulting N streams are modulated using Orthogonal Frequency Division Multiplexing (OFDM) and are transmitted from N transmit antennas simultaneously.

For a MIMO system with N_t transmit and N_r receive antennas, a narrowband time-invariant wireless channel can be represented by $N_t \times N_r$ deterministic matrix $H \in C^{N_t \times N_r}$. Consider a transmitted symbol vector $X \in C^{N_t \times 1}$, which is composed of N_t independent input symbols $x_1, x_2, \ldots, x_{L_t}$. Then, the received signal $Y \in C^{N_r \times 1}$ can be rewritten as follows:

$$y = \sqrt{\frac{E_x}{N_t}} Hx + z$$

Where $\mathbf{z} = \left(z_1, z_2, \ldots, z_{L_r}\right)^t \in C^{N_r \times 1}$ is a noise vector, which is assumed to be zero-mean circular symmetric complex Gaussian.

It is assumed, unless otherwise stated, that the sub channels fade independently, and the CSI is known exactly at the receiver, but not at the transmitter. In quasi-static fading (slow fading), the fading coefficients are assumed to be constant over the entire frame and change independently from one frame to another. In block fading, it is assumed that the fading coefficients remain constant over a block of consecutive symbols and change independently from one block to another within the same frame. It is easy to see that quasi-static fading is a special case of block fading. When the channel is modeled as fast fading, it normally refers to a fully-interleaved block fading channel where consecutive symbols in a frame, after de-interleaving at the receiver, see independent fades. For all three cases, the channel is assumed to be flat fading, which is the case when the coherence bandwidth of the channel is much larger than the transmission bandwidth.

SPATIAL MULTIPLEXING AND CAPACITY

As mentioned earlier, in a wireless fading channel with sufficiently rich scattering, it is possible to achieve capacities with MIMO systems that were unthinkable even a decade ago. When the wireless channel has sufficient degrees of freedom, the data streams transmitted from multiple transmit antennas can be separated, thus leading to parallel data paths. The capacity of the radio channel under these conditions grows with $\min(M_t, M_r)$, that is, linearly with the number of antennas. In this section we discuss antenna selection in light of MIMO system capacity in the presence of spatial multiplexing.

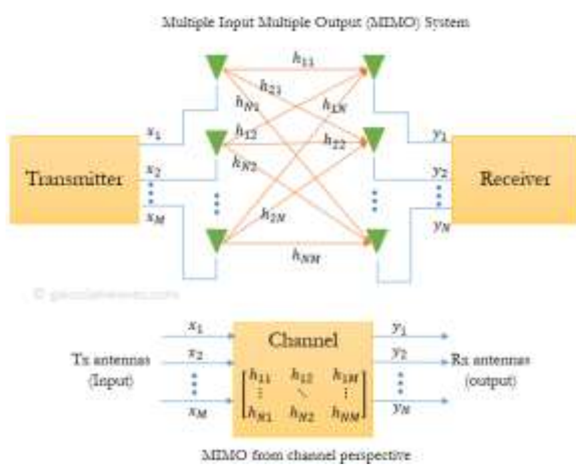


Fig. 2 MIMO Channel Matrix

Consider a multiple-antenna system with M_t transmit and M_r receive antennas. The channel matrix H is an $M_r \times M_t$ complex valued matrix. We assume a block fading model in which the channel statistics can be Rayleigh or Rician, and the system experiences additive Gaussian noise at the receive antennas. The object is to select the best L_r out of M_r antennas at the receive side and the best L_t out of M_t antennas at the transmit side so that the resulting system capacity is maximized. Assuming equal power transmission from antennas, the capacity as a function of the channel matrix is

$$\mathrm{C} = \log_2 \det\left(\mathrm{I} + \frac{\rho}{\mathrm{L_t}}\hat{\mathrm{H}}^{\dagger}\hat{\mathrm{H}}\right)$$

Where ρ is the receive SNR, $\hat{\mathrm{H}}$ is the $\mathrm{L_r} \times \mathrm{L_t}$ selected channel matrix, I is the $\mathrm{L_t} \times \mathrm{L_t}$ identity matrix, and $\hat{\mathrm{H}}^{\dagger}$ is the Hermitian of $\hat{\mathrm{H}}$. The ideal antenna selection technique chooses $\hat{\mathrm{H}}$ out of H such that the expression above is maximized.

Ergodic capacity implies that it is a result of infinitely long measurements. Since the process model is Ergodic, this implies that the coding is performed over an infinitely long interval. Hence, it is the Shannon capacity of the channel. The Ergodic capacity is the median of the CDF curve and it is expressed as:

$$C = \in \left\{\sum_{i=1}^{r} \log_2\left(1 + \frac{\rho}{M_t}\lambda_i\right)\right\}$$

RECEIVE ANTENNA SELECTION

For the case of receive antenna selection, assume we have $\mathrm{M_t} = \mathrm{L_t}$ transmit antennas and transmit RF chains, $\mathrm{M_r}$ receive antennas, and $\mathrm{L_r}$ receive RF chains, where $\mathrm{L_r} < \mathrm{M_r}$. Therefore, the problem is to choose $\mathrm{M_r} - \mathrm{L_r}$ rows of matrix H to be discarded and arrive at matrix $\hat{\mathrm{H}}$, such that the capacity is maximized. A simple exact solution to this problem is lacking. The only known exact solution is by exhaustive search, which is time consuming. In the following we study two approximate solutions. Applying the Taylor expansion of $\log x$, we find that at low SNR, capacity is proportional to $\| \hat{\mathrm{H}} \|2$ (with higher-order terms being negligible). Therefore, at low SNR the antenna selection algorithm can simply maximize the norm of the (selected) channel matrix. Thus, at low SNR, antenna selection for diversity gain and antenna selection for capacity both follow the same strategy. In other circumstances, norm-based selection may not be optimal. Nevertheless, norm-based selection may be used because of its low computational complexity and known statistics. In an attempt to achieve near-optimal selection, Gorokhov suggested a decremental selection algorithm where, starting from the full channel matrix, the rows of H are discarded one by one so that at each step the capacity loss is minimized. Further work showed that an incremental algorithm (instead of a decremental one) leads to less complexity and has almost the same capacity as optimal selection. An outline of the incremental selection algorithm (for high SNR) is as follows. Start by selecting the row vector with highest norm. At each selection step, project each remaining row vector on the orthogonal complement of the span of the previously chosen vectors, and choose the one whose projection has the largest magnitude. Continue until exactly $\mathrm{L_r}$ antennas are selected. Successive selection is a greedy algorithm for maximizing capacity. As a result, successive selection may not be strictly optimal. However, simulations show that the ergodic capacity of successive selection is indistinguishable from the true optimum. Also, it is shown that successive selection provides the full diversity of the original MIMO system.

TRANSMIT ANTENNA SELECTION

In the context of spatial multiplexing (maximizing capacity), transmit antenna selection has many similarities with receive antenna selection. The main difference, as mentioned earlier, is that in the case of transmit selection, a feedback path must exist to inform the transmitter which antennas to select. This feedback, in effect, gives the transmitter some information about the state of the channel. It is well known that the capacity of a wireless channel with transmit-side channel state information (CSI) is generally higher than without it. In other words, there is some excess capacity generated by the transmitter knowledge of the channel. When the transmitter is fully aware of the channel coefficients, the maximum capacity available in the channel will be attained (through a water-filling strategy). The feedback required by antenna selection is, of course, only a small fraction of the full channel state information. Full channel state information involves several complex-valued variables, but for transmit selection only on the order of $\mathrm{O}(\mathrm{L_t} \log \mathrm{M_t})$ bits of feedback information is necessary. Very interestingly, this minimal amount of feedback is sufficient to capture a considerable fraction of the optimal capacity with full CSI. The excess capacity provided by transmit antenna selection is quantified and analyzed in.

SIMULATION RESULTS

MIMO Channel Capacity: Mathematical Analysis & MATLAB Simulation

Detail study of mathematical analysis for MIMO channel is carried out and channel capacity calculations are done for channel capacity with or without the knowledge of CSI at transmitter. The channel capacity is also calculated for

SISO, MISO and random MIMO channel. The MATLAB simulation is carried out for ergodic capacity of MIMO channel as shown in fig.1. Apart from this the ergodic capacity calculations for different SNR values are done for various antenna configurations and the same is verified in MATLAB as shown in fig.2. To study the closely spaced systems for MIMO antenna selection, correlated fading is also important factor, therefore the ergodic capacity calculations are done for correlated channel. It is observed that there is a reduction in the channel capacity due to channel correlation as shown in fig 3.

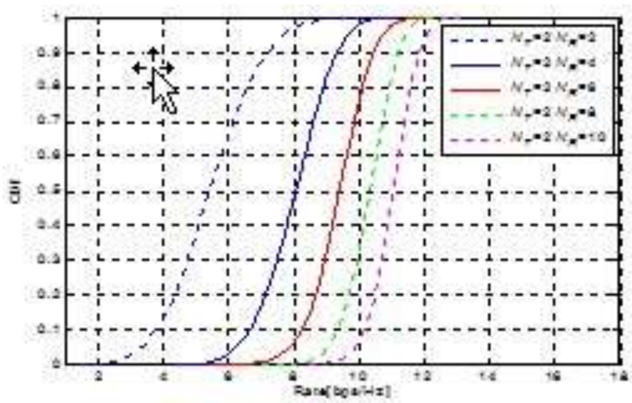
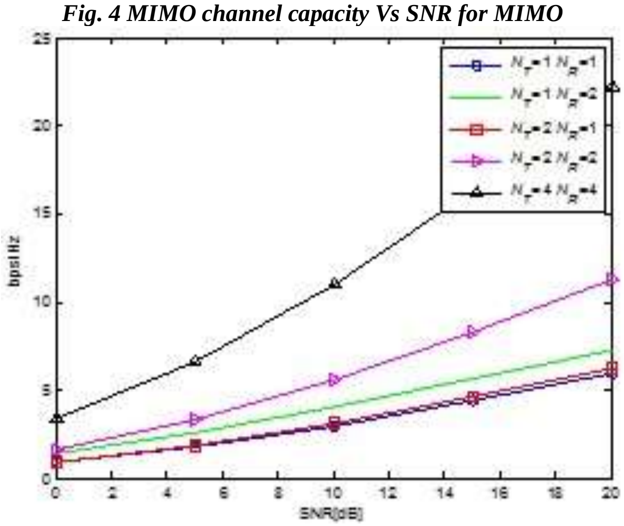


Fig. 3 MIMO channel capacity for SNR=10dB for MIMO configurations

This reduction in the channel capacity is to be considered while designing the technique for antenna selection.

Fig. 4 MIMO channel capacity Vs SNR for MIMO



Performance of Space Time coding in MIMO

Recent publications focus the importance of Antenna Selection (AS) at Transmitter end being simple for implementation than the receiver side AS but it requires the knowledge of Channel State Information (CSI) at transmitter. Therefore the first focus is on achieving antenna diversity gain at transmitter side using Space Time Coding. The performance comparison of Space time Block Codes (STBCs) for maximum-likelihood -decoding technique with full-rate and full-diversity, which also offer large coding gain, for the Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO) and Multiple Input Multiple Output (MIMO) systems is carried out in Rayleigh fading channel.

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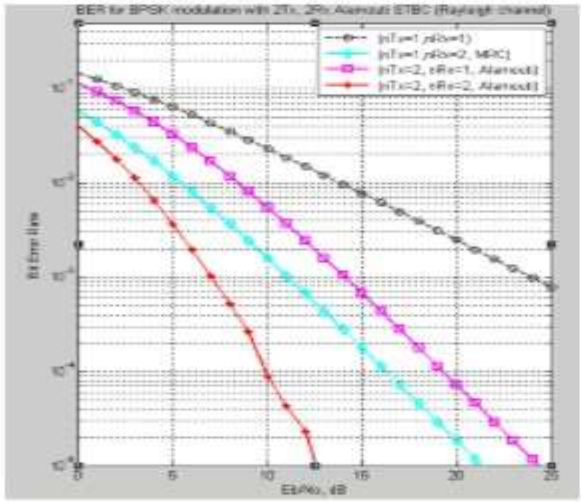

Fig. 5 BER for BPSK modulation with 2Tx, 2 Rx Alamouti STBC with Rayleigh channel

Identical performance is seen as MRC if the total radiated power is doubled from that used in MRC. This is because, if the transmit power is kept constant, this scheme suffers a 3-dB penalty in performance since the transmit power is divided in half across two transmit antennas. No need for complete redesign of existing systems to incorporate this diversity scheme.

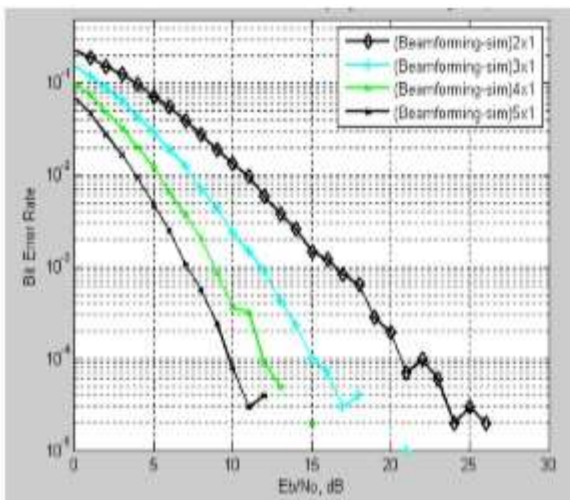

Fig. 6 BER for QPSK modulation with 2Tx, 2Rx Alamouti STBC with Rayleigh channel

Hence, it is very popular as candidates for improving link quality based on dual transmit antenna techniques, without any drastic system modifications. This can be further extended for multiple transmitting antennas as well as perfect MIMO systems in combination and can results better performance compare to conventional SISO systems.

CONCLUSION

In this paper, we have studied the various Antenna Selection techniques in MIMO system with Maximum Ratio Combining, the impact of Antenna Selection on channel capacity and Antenna Selection techniques based on received SNR which uses different space time coding techniques. We have seen systems with Maximum Ratio Combining schemes achieve full diversity order when transmitting over a memory less, flat-fading Rayleigh channel with independent entries. It is observed that there is a reduction in the channel capacity due to channel correlation for closely spaced systems in MIMO. Simulation results construct a beam forming vector that guarantees full diversity order.

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