Performance Evaluation of Efficient Cooperative Multiple Input Multiple Output System Wireless Communication

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Abstract: In this paper, a novel technique known as Cooperative Communication in MIMO has been incorporated. This technique allows single antenna mobiles to have the benefits of MIMO systems. Numerical analysis and mathematical modeling is done for SISO with no cooperation, MIMO with no cooperation and MIMO with cooperation or Cooperative MIMO. Expressions for SNR, Outage probability and capacity over a channel link have been derived and simulated. A critical comparative analysis has been carried out between SISO with no cooperation, MIMO with no cooperation and Cooperative MIMO by evaluating and plotting various performance parameters. It has been demonstrated that Co-operative MIMO exhibits better performance in comparison to other two mentioned schemes.

Key–Words: MIMO, Detect and forward protocol, SNR, Outage Probability, Capacity, Mutual Information

1 Introduction

The rewards of multiple-input multiple output (MIMO) systems have been extensively recognized, to the degree that transmit diversity methods have been incorporated into wireless standards. Explicitly owing to size, expenditure or hardware constrains, wireless instrument may not be able to sustain multiple transmit antennas. In this paper a technique known as *Cooperative Communications in MIMO* [1] have been incorporated which allows single antenna mobiles to have the benefits of MIMO systems. In this the single antenna mobiles can “share” their antennas in a multi user scenario in a manner that creates virtual MIMO systems. In this, each mobile transmits for multiple mobiles leading to trade-offs in code rates and transmit powers [1]. The forthcoming paper is organized as follows. Section 2 gives a brief introduction about cooperative system Protocols. Section 3 discusses the considered system models in detail. Section 4 analyzes the performance of the systems in detail. Section 5 concludes the paper.

2 Co-operative System Protocols

In wireless communication there are three types of Cooperative Communication protocols namely [2]:

1. Amplify and Forward
2. Detect and Forward
3. Coded Cooperation

Amplify and Forward cooperative protocol transmission is the most simple and practical protocol. It is easy to implement but a major drawback is associated with it i.e. along with the signal amplification perpendicular noise amplification also takes place, which is unwanted. This problem is overcome by decode and forward relaying as this relaying scheme inherently eliminates the perpendicular noise. In coded cooperation, two mobile device affiliate with one another to collectively transmit the data. They use their resources collectively to achieve this. Since, the data is received via independent fading paths spatial diversity is achieved [5].

3 System Model

In order to analyze and evaluate the system, following system models have been considered.

3.1 SISO with No Co-operation

3.2 MIMO with No Co-operation

3.3 MIMO with Co-operation

We will consider each of the specified model one by one. SISO with No-Cooperation is a simple example of point-to-point communication. Further, MIMO with No-Cooperation is evaluated. This is an example of simple Multiple Input Multiple Output system. After, their comparison with one another third model i.e. MIMO with Co-operation is considered. The detailed insight into each system will help us in evaluating them and conclude which is the best among them.

3.1 SISO with No Co-operation Scenario

Figure 1: Point to point communication consisting of single base station and mobile station.

Figure 1 shows a Single Input Single Output System model, where the wireless data transmission in between the user and home base station is in the form of point to point communications. Let P be the total transmission power and signal to noise ratio as SNR_T at the transmitting side with additive white Gaussian noise (AWGN) noise power and N_0 as single sided noise power spectral density [4]. Thus signal to noise ratio [5] is represented as:

$$\mathrm{SNR}_T = \frac{P}{\sigma^2} \tag{1}$$

where $\sigma^2 = N_0$ is Additive White Gaussian Noise.

The channel gain is h, so the instantaneous SNR at the receiving side is

$$\mathrm{SNR}_R = \frac{P}{\sigma^2}|h|^2 \tag{2}$$

Assuming the static fading during the whole transmission duration, the maximum mutual information over the link can be expressed as:

$$I = \log_2(1 + \mathrm{SNR}_R) \tag{3}$$

In case of the static fading channel in SISO with additive white Gaussian noise channel where

$$y = x + \eta \tag{4}$$

the channel capacity in bits/s/Hz is given by,

$$C = \log_2(1 + |h|^2 \mathrm{SNR}_R) \tag{5}$$

Probability of outage that the channel capacity is below a threshold 'R' [4] is given as:

$$P_r = P_r[(\log_2(1 + \mathrm{SNR}_R)) < R] \tag{6}$$

3.2 MIMO with No Co-operation Scenario

MIMO systems are also referred as multiple-element antenna systems (MAEs). Figure 2 depicts a MIMO system [5], where the data stream from a single user is demultiplexed into n_T separate substreams. The number n_T equals the number of antennas. Each sub stream is then encoded into channel symbols. The signal are received by n_R receive antennas [7]. The general equation for MIMO with various transmits and receive antenna [8] are given by:

$$y = hx + \eta \tag{7}$$

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{1t} \\ h_{21} & h_{22} & h_{2t} \\ h_{r1} & h_{r2} & h_{rt} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_t \end{bmatrix} + \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_r \end{bmatrix}$$

MIMO model consists of 't' transmitter and 'r' receivers with the full '$t \times r$' channel matrix h in between [9].

N parallel channels operating in MIMO systems with AWGN of variance (σ^2) have been considered. The capacity over the link grows only as $\log_2$ at high SNR but linearly at low SNR. In order to combat this some power some power has been provided to weaker channels hence increasing the overall sum capacity, because in channel with lower noise power more energy will be allocated whereas in channel with large noise power the energy allocated is low. If energy is allocated, the sum of allocated energy and the effective noise power will be constant

Hence capacity will be defined as

$$C = \sum_{n=1}^{N} \log_2\left(1 + \frac{E_n |h_n|^2}{\sigma^2}\right) \tag{8}$$

where N = number of channels and E_n is the energy allocated to the nth channel.

If the channel to each user is changing with time it likely that, at any time instance one user has a good channel. By transmitting energy on that channel, overall Capacity can be achieved in a multi user situation.

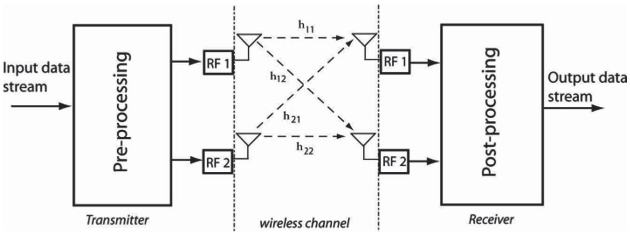

Figure 2: MIMO block diagram showing a 2×2 system.

This new form of diversity is known as *Opportunistic beamforming*.

Finally, if the channel is not available at the transmitter, clearly the best distribution scheme is to spread the energy evenly between all the transmitters and is given by

$$C = \sum_{n=1}^{N} \log_2 \left(1 + \frac{E_s}{N\sigma^2}\right) \tag{9}$$

where $E_n = \frac{E_s}{N}$.

Defining R as data rate measured in bit/sec/Hz (Threshold value), the outage probability over the link can be expressed as

$$P_r[C < R] = P_r\left(\sum_{n=1}^{N} \log_2 \left(1 + \frac{E_n|h_n|^2}{\sigma^2}\right) < R\right) \tag{10}$$

Where the threshold value has been selected in a manner if the total received power is below this level then the system is said to be in outage for this particular channel and the probability is called outage probability.

3.3 MIMO with Co-operation

As discussed in Section 2, this relaying scheme eliminates the perpendicular noise which is an inherent feature of Amplify and Forward Cooperative Protocol. This scheme is easier to implement in comparison to Coded Cooperative protocol.

We have used *Detect and Forward protocol* [1] in which a user attempts to detect the partner's bits and then retransmit the detected bits. Figure 3 shows a MIMO with Co-operation scenario where the partners may be assigned by base station via scheduling algorithm, including the orthogonality pairing, random and so on and the paired users can be allowed to transmit the signals in the uplink using the same frequency resources, which could not only improve the spectrum utilization but also effectively reduce the noise disturbance between the paired users via the different attenuation in each individual sub channel. Besides this the transmission channels, which is used by different paired users, cannot seem to be correlated each other so that they are easy to recognize at the receiver, and thus it can improve the uplink throughput for the system dramatically.

Following are the steps for pairing algorithm in MIMO via cooperation:

1. If home base station detects the first user in the system, it will randomly allow a sub channel to this user.

2. Keep on detecting, if the other users are not found. If the other user is found, home base station should select these two users to form a pair in order to form a cooperative transmission.

3. Repeat step 1 and 2 for more no of users.

Let P be the total transmission power and be equally divided to allocate the users. The transmit power of each user scales as "P/M_n", where M_n are the number of users. Then the mutual information for the users can be given as

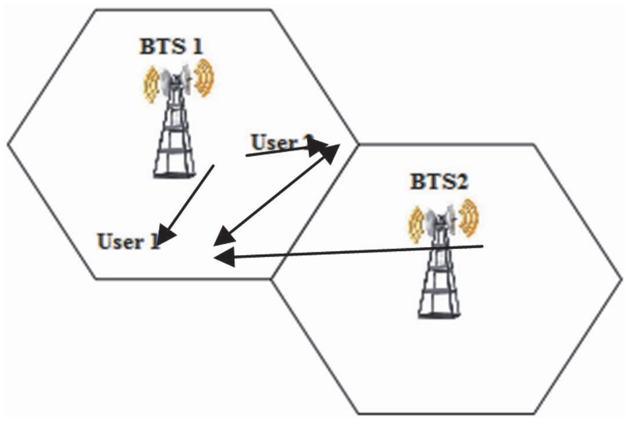

Figure 3: MIMO with Co-operation consisting of several BTS and mobile stations.

Let us consider a muticell network comprising of n co-operative base stations assigned with same carrier frequency. Each cell serves M_n users. The base stations are equipped with M_a antennas each. Due to lack of space, we mostly consider base stations side interference control. The base station can assume any geometry; however, strongly structured cell models can help the theoretical analysis of co-operation.

In the uplink, the received signals at the nth BTS

[10] and lth being cell number can be written as

$$y_n = \sum_{M_n=1}^{M_n} \sum_{i=1}^{n} h_n l M_n x_{lM_n} + Z_n \qquad (11)$$

Let P be the total transmission power and be equally divided to allocate the users. The transmit power of each user scales as P/M_n where M_n are the number of users. Therefore power allocated to each user can be written as

$$P' = \frac{P_t}{M_n} \qquad (12)$$

And the SNR received at the receiver side is given by

$$\text{SNR}_R = \frac{P'}{\sigma^2} \qquad (13)$$

Hence the mutual information for the users can be given by

$$I = \log_2(1 + \mu) \qquad (14)$$

Where $\mu = \sum_{i=1}^{M_n} \sum_{j=1}^{M_a} P'(h_{(i,j)})^2$.

The outage probability for a given power and rate at the receiver can be given by

$$P_r[I < R] = P_r[\mu < 2^{(R-1)}]\,. \qquad (15)$$

4 Performance Analysis and Numerical Results

Co-operation b/w wireless users have been proposed to achieve spatial diversity in applications. To understand in a more general context we examine the SNR, Outage probability in detect and forward protocol where capacity is defined as the maximum mutual information over a link.

Numerical analysis was simulated and compared using three comparison parameters SNR, outage probability and link capacity [7]. In this section simulation results were carried out to verify the analysis of different models presented in the above sections. The performance of three models is simulated. Results of *Outage Probability, Channel Capacity and SNR* were simulated in the form of curves using semilogy command. Here an *Additive White Gaussian Noise* channel is considered.

4.1 Gain vs. SNR

Figure 4 shows Gain vs. SNR for SISO with no cooperation and MIMO with no cooperation. Figure 5 shows for SISO with no cooperation and Cooperative MIMO.

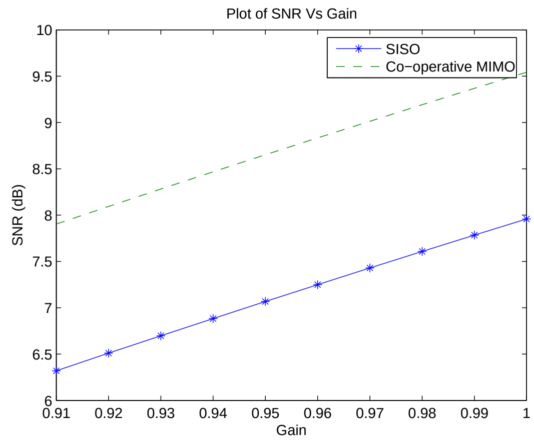

Figure 4: SNR comparison in SISO and Cooperative MIMO System.

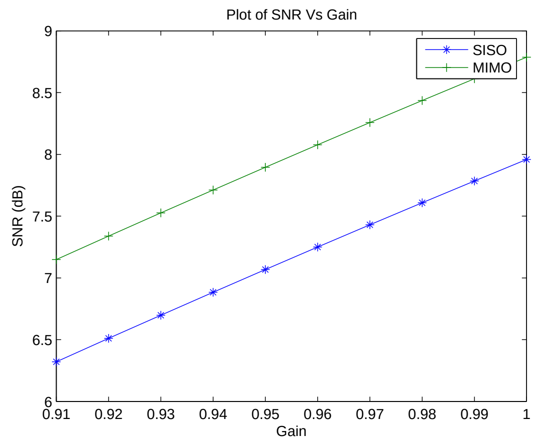

Figure 5: SNR comparison in SISO and MIMO System.

It is observed from simulation and numerical results that for same gain the SNR of Cooperative MIMO is highest. This is depicted elaborately in Table 1. SNR specifications are important measurement as they describe the noise level in a communication system. More is the SNR better is the system

4.2 Outage Probability

A system is said to be in outage for a particular channel if the total received power is below the threshold power level defined. Figure 6 and Figure 7 show the

Table 1: SNR vs. Channel Gain in different Systems

Channel Gain	SISO	MIMO	MIMO with CO-OP
0.91	6.30	7.10	7.90
0.92	6.51	7.33	8.09
0.93	6.69	7.52	8.28
0.94	6.88	7.71	8.46

plot between SNR and outage probability. Figure 6 compares the outage probability for SISO with no cooperation and MIMO with no cooperation where as Figure 7 compares the outage probability for SISO with no cooperation and Cooperative MIMO. It can be observed that it varies inconsistently with three models in different SNR conditions. MIMO with cooperation was observed with best outage graph as compared to other two schemes. Lesser the probability of outage in system better is the performance. Same is depicted in Table 2. We observe from the graphs that Cooperative MIMO provides highest gain.

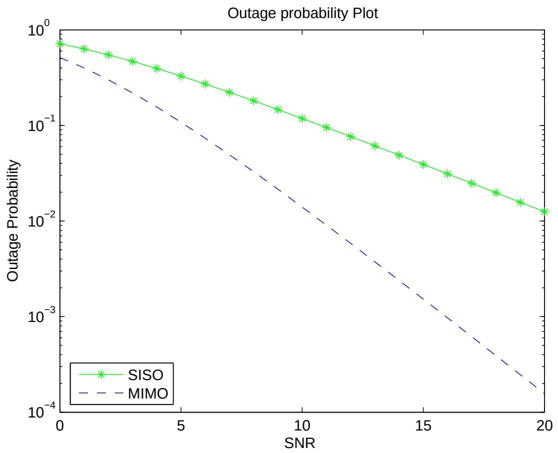

Figure 6: Outage probability comparison in SISO and MIMO system.

Table 2: Outage Probability vs. SNR

SNR(dB)	SISO	MIMO	MIMO with CO-OP
1	0.716	0.367	0.262
2	0.548	0.167	0.090
4	0.394	0.061	0.024
6	0.271	0.019	0.005

4.3 Capacity

Figure 6 shows capacity as a measure of efficiency of a system model including SISO, MIMO and MIMO with Co-operation. The capacity is defined as the maximal of the mutual information between the transmitted and received signal. Here the system capacity curves as the function signal to noise ratio. It was observed that with increase in power the link capacity increases. Multiple antennas provide MIMO transmission for cooperative transmission and thus improve the channel capacity. It is observed from the graphs that Cooperative MIMO provides highest capacity in comparison to SISO and Cooperative MIMO.

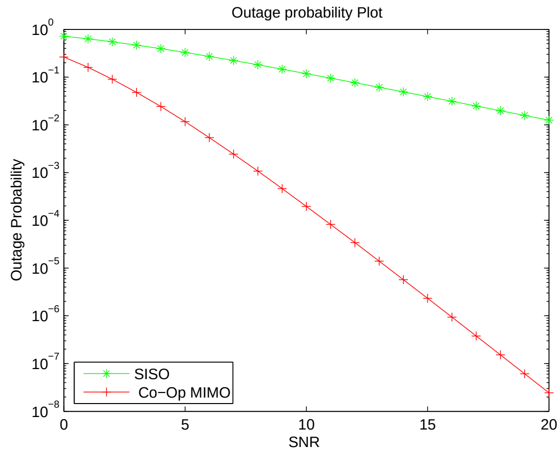

Figure 7: Outage probability comparison in SISO and Cooperative MIMO system.

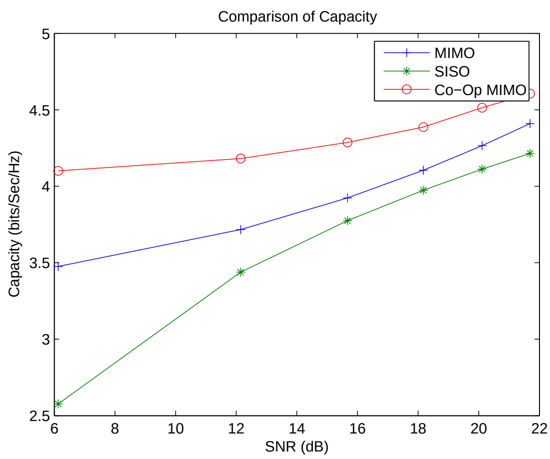

Figure 8: Capacity comparison in three different systems.

Ergodic Capacity

The capacity over AWGN is

$$C = B * \log_2(1 + SNR) \quad (16)$$

Let $SNR = \gamma$.

Table 3: Capacity vs. SNR

SNR(dB)	SISO	MIMO	MIMO with CO-OP
6	2.5	3.46	4.01
12	3.4	3.7	4.1
16	3.7	3.9	4.2
18	3.9	4.1	4.4

Taking bandwidth B as 0.5 for simulation purposes and SNR is the signal to noise ratio at the receiver. If the capacity hen anticipated over a fading channel, makes SNR a random variable. So the ergodic capacity is the average of C over the PDF of gamma:

$$C = \int_0^\infty \log_2(1+\gamma)P(\gamma)dy \qquad (17)$$

C is termed as average capacity. The rate over the channel is constant and for each transmitted symbol a fraction of all the information is received at the receiver. This formula gives the maximum of information transmission rate in the average and that is why it is called “ergodic” [10].

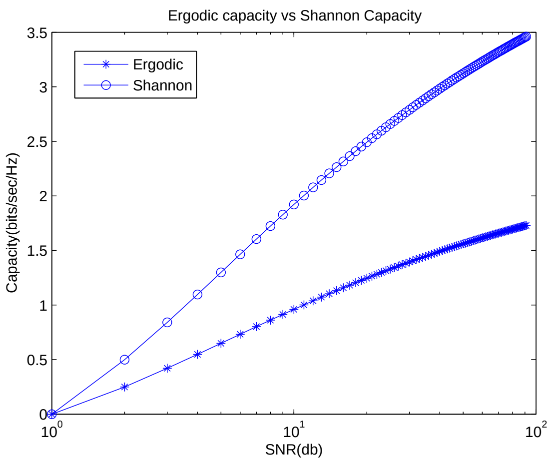

Figure 9: (Ergodic capacity and Shanon Capacity) Vs.SNR

5 Conclusion

For a gain of .92, Cooperative MIMO showed an improvement of 22% in SNR in comparison to SISO with No Cooperation and 9% improvement in comparison to simple MIMO with Cooperation. Outage Probability also showed much improvement for Cooperative MIMO, when compared to SISO or MIMO without Cooperation. When we analyzed capacity we observed Cooperative MIMO showed an increase of 12% in capacity at SNR of 12 db and 7% increase in comparison to simple MIMO. Thus ,MIMO with Cooperation was observed to be better than the other two schemes.

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