Design and Development of Multiple Input Multiple Output System in Cooperative Communication

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Abstract. Co-operative MIMO utilizes distributed antennas which belong to other users, while conventional MIMO i.e., single-user MIMO only employs antennas belonging to the local terminal. It can be described as a form of macro-diversity, used in soft hand over. Cooperative MIMO corresponds to transmitter macro-diversity. This paper provides a detailed insight into this highly noble and applicable field for next generation wireless systems because Co-operative MIMO improves the performance of a wireless network by introducing multiple antennas advantages, such as diversity, multiplexing, and beamforming. In this paper we are analyzing repetition based cooperative protocol (Detect and Forward) in conjunction with MIMO. We have derived the mathematical expressions for SNR, Outage Probability, and Capacity over a channel link. A comparison between SISO, MIMO and Co-operative MIMO has been carried out by evaluating and plotting various performance parameters such as SNR, Outage Probability and Capacity and verifying them.

Key words: MIMO, Detect and forward protocol, SNR, Outage Probability, Capacity, Mutual Information.

I. INTRODUCTION

The advantages of multiple-input multiple output (MIMO) systems have been widely acknowledged, to the extent that transmit diversity methods have been incorporated into wireless standards. Specifically due to size, cost, or hardware limitations, a wireless agent may not be able to support multiple transmit antennas. In this paper a technique known as Cooperative Communications in MIMO 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 cooperative wireless communication, the users can increase their effective quality of service (outage probability, SNR, capacity) via cooperation. In this each mobile has one antenna and cannot individually generate spatial diversity. However it may be possible for one mobile receiver to receive the other. Because the fading paths from two mobiles are statistically independent thus creating a “spatial diversity”[1]. The premise of cooperation is that certain allocation strategies for the power and bandwidth of mobiles lead to significant gain in the system performance. In this, each mobile transmits for multiple mobiles leading to
trade-offs in code rates and transmit powers.

II. CO-OPERATIVE SYSTEM PROTOCOLS

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

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

Amplify-and-forward transmission has been shown to be a viable transmission protocol for wireless networks incorporating distributed spatial diversity. A drawback of this relatively simple transmission protocol is identified as signal amplification, perpendicular noise at the relay[9] is also amplified. Perpendicular noise elimination is inherent in decode-and-forward relaying. Hence, Fair comparisons of amplify-and-forward relaying with decode-and-forward relaying are based on noise reduced amplify-and-forward relaying. In coded cooperation, two users form a partnership to transmit their information using both of their antennas. In a wireless channel, each user’s transmission is receivable, to different degrees, by the other users as well as the base station. Therefore, a mobile may receive and re-transmit the data of a partner to the base station, thus providing assistance to the original mobile. Because the two streams are received via independent fading paths, the spatial diversity will provide an improvement in overall reception.

III. SYSTEM MODEL

In order to analyze and evaluate the system, we will have to consider three different scenarios

3.1 SISO with Non Co-operation
3.2 MIMO without Co-operation
3.3 MIMO with Co-operation

We will have a detailed insight into each system considering each of them one by one

A. SISO with Non Co-Operative scenario

Fig 1 shows a system model for Single Input Single Output System Model. In this model, the wireless data transmission 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 [3].

Thus signal to noise ratio is represented as:-

$$SNR_T = \frac{P}{\sigma^2}$$ \hspace{1cm} (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

$$SNR_R = \frac{P}{\sigma^2} |h|^2$$ \hspace{1cm} (2)

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

$$I = \log_2(1 + SNR_R)$$ \hspace{1cm} (3)

In case of the static fading channel in SISO with additive white Gaussian noise channel where $y = x + \eta$, \hspace{1cm} (4)

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

$$C = \log_2 \left(1 + |h|^2 SNR_R \right)$$ \hspace{1cm} (5)

Probability of outage that the channel capacity is below a threshold ‘$R$’[4] is given as:-

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\[ P_t = P_t \left( \log_2(1 + SNR_t) \right) < R \]  

**B. MIMO without Co-Operation scenario**

MIMO systems are also referred as multiple-element antenna systems (MAEs). Fig 2. shows a MIMO system, where the data stream from a single user is demultiplexed into \( n_T \) separate substreams. The number \( n_\text{R} \) equals the number of antennas. Each substream is then encoded into channel symbols. The signal are received by \( n_\text{R} \) receive antennas. The general equation for MIMO with various transmits and receive antenna [5] are given by:

\[ y = hx + \eta \]  

\[ \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{1R} \\ h_{21} & h_{22} & h_{2R} \\ h_{31} & h_{32} & h_{3R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{bmatrix} \]  

MIMO model consists of ‘t’ transmitter and ‘r’ receivers with the full ‘t x r’ channel matrix \( h_\text{in} \) between [6].

Hence capacity will be defined as

\[ C = \sum_{n=1}^{N} \log_2 \left( 1 + \frac{E_{n} |h_n|^2}{\sigma^2} \right) \]  

Where \( N \) = number of channels and \( E_n \) is the energy allocated to the \( n^\text{th} \) channel.

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

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

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.

**C. MIMO with Co-Operation**

In this paper we have used Detect and Forward protocol[7] in which a user attempts to detect the partner’s bits and then retransmit the detected bits. Fig 3 shows that 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 subchannel. 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 subchannel 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 $P/M_n^w$, where $M_n$ are the number of users. Then the mutual information for the users can be given as

Let us consider a multiplex 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 $n^{th}$ BTS and $l^{th}$ being cell number can be written as

$$y_n = \sum_{m_n=1}^{M_n} \sum_{i=1}^{n} h_{nm_n} \times M_n^w x_{im_n} + Z_n$$  \hspace{1cm} (10)

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

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

$$P' = \frac{P}{M_n^w}$$  \hspace{1cm} (11)

And the SNR received at the receiver side is given by

$$SNR_r = \frac{P'}{\sigma^2}$$  \hspace{1cm} (12)

Hence the mutual information for the users can be given by

$$I = log_2(1 + \mu)$$  \hspace{1cm} (13)

where

$$\mu = \sum_{i=1}^{M_n} \sum_{j=1}^{M_n} P' \times (h_{ij})^2$$

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

$$P_{tr}[I < R] = P_r[\mu < 2^{R-1}]$$  \hspace{1cm} (14)

IV. PERFORMANCE ANALYSIS

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[8]. 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.

SNR V/S Gain

Fig 4 shows SNR v/s Gain (defined as Signal to Noise ratio) was plotted for three different models taking different powers where MIMO with Cooperation was observed with highest SNR value. SNR specifications
are important measurements used to describe the noise level in system in communication channel. It is the ratio of message signal power to noise power. Traditionally more is SNR better is the system.

![Plot of SNR vs Gain](image1)

**Outage Probability**

Fig 5 shows the outage probability graph. A system is said to be in outage for a particular channel if the total received power is below the threshold power level defined. The outage probability curves corresponded to three models mentioned above along with different SNRs. It can be observed that it varies inconsistently with three models in different SNR conditions. MIMO with Cooperation was observed with the best outage graph as compared to SISO and MIMO. Lesser the probability of outage in system better is the performance.

![Outage probability Plot](image2)

**Capacity**

Fig 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.

V. CONCLUSION

In this paper, the use of multiple antennas on both the transmitter and receiver side of a communication link have shown to greatly improve the spectral efficiency of wireless systems over SISO systems. Relaying of a weak signal by means of another node can improve link quality and the overall network capacity. Furthermore a group of nodes can cooperatively form a virtual multiple-input multiple-output (MIMO) system, which allows directing the radio beam spatially in the best direction. Cooperative communication techniques could become a promising foundation for future communication systems.

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Fig. 6. Capacity comparison in three different systems.

Subsequently, the co-operative networks have improved the overall capacity and efficiency of wireless systems. Three models were simulated having different curves for parameters such as SNR, Outage, and Capacity compared to the traditional model systems. MIMO with Co-operation was observed to be the best of three and thus having a wider area of application in future research.

REFERENCES