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Capacity Analysis and Relay Coverage Investigations of Wireless Cooperative MIMOSystems

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Abstract: In this paper, the capacity analysis of cooperative amplify-and-forward multiple-input multiple-output (MIMO) relay system is investigated. The paper presents a comparative view of varies proposed link scenarios to study the effect relay location and coverage on the system performance under different power allocation techniques. In the presented model, a modified realistic Spatial Channel Model (SCM) stochastic propagation channel model is used assuming the cases of existence and none existence of low rank line-of-sight communication for outdoor open space. The channel is modeled for multi-clusers scattering environment which means that the signal will be transmitted with Angle of Departure (AOD) and will arrive at the receiver from multiple Angles of Arrival (AoA) each with angle spread (AS) that is a measure of the angle displacement due to the non-LOS propagation. The used relay has multiple antennas at both transmitting and receiving sides. The variation of the angle spread at the transmitter, relay and receiver is addressed as well. Also, different number multiple antennas in source, relay and destination nodes are considered.

Keywords: Relay MIMO, Realistic Channel Model, Amplify and Forward

1. INTRODUCTION

Applying multiple-input multiple-output (MIMO) to wireless relaying systems has attracted high interest recently [1-9]. Relaying is a means of improving the performance of infrastructure- based networks by increasing their coverage. Line-of-sight (LOS) scenario where the MIMO system exhibits a reduced performance since the LOS component overwhelms the multipath components in the received signal and this results that the system is incapable of acquiring high spatial multiplexing gain, which seriously affects the performance of the system. This is a low-rank line-of-sight communication environment in the outdoor open space, where there are less scattering objects and the channel matrix is in a low-rank state. The widely used Rayleigh channel model overestimates the performance of the channel compared with realistic models [1]. Therefore, Realistic models have to be applied in the simulation of these systems such as Spatial Channel Model (SCM) and the fading correlation model developed in [2]. Two hop single relay scenarios are investigated in [3] with relay either above rooftop or at ground level using both measurements and simulations. Techniques such as cross-polarized antenna or optimal power allocation to improve the performance in the channel are utilized when the relay is in the LOS propagation environment and the channel capacity degrades.

In [4] [5] and [6], various AF relaying schemes achieve full diversity in the number of antennas; their relative performance merits are determined by noise amplification at the relays and the exact configuration of the distributed array. it was shown that scattering relays can improve MIMO system performance if these are constrained by correlated propagation.

In [7], it was shown that double-directional geometry-based stochastic channel model based on ITU generic model has good accordance with the measurement data in both AF and DF relay modes. A typical urban micro-cell environment is assumed with 2.35GHz and bandwidth up to 50MHz. RS was fixed on the top of a travel trailer, BS was located on the rooftop of a 5-floor high. Antenna heights of MS, RS and BS are 1.8m, 7m and 22m respectively. Buildings on both sides of the routes are mostly 5 or 6 floors high. Line-of-sight propagation condition is the case in the backhaul link, and BS was clearly below the rooftops of the surrounding buildings.

In [8], another study on the effect of various factors on the capacity of MIMO relay system. The simulation results show that system capacity is greatly expanded by adding relay nodes. However, spacing between antenna arrays and direction angles at the transmitting and receiving ends, as well as relay node location, Rice K-factor and other factors all can produce certain effect on the capacity of the MIMO relay system. Therefore the correlation analysis in this paper is of

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application significance. However, the fading correlation model used is not the exact model with multi clusters scattering.

In [9], It is shown that the capacity of polarized MIMO relay system outperforms that of co-polarized MIMO system with constant signal to noise ration (SNR). The channel model for arbitrary polarized antennas can be derived from the model for co- polarized antennas by element wise multiplication with a matrix containing the polarization mismatch loss between the transmit and receive antenna pairs as well as the effect of azimuthal direction of the terminal in the cell. These previous efforts show that simulation of such systems and investigating its performance requires utilizing an accurate channel model, which is our aim in this paper.

Therefore the objective of this paper is to extend previous work in further investigating to the location of the relay, LOS existence between the relay and the source or the destination and the scattering clusters and fading in the channel influence on the capacity and data rates at the receiver using a more accurate and realistic channel model. In this paper the realistic fading correlation model presented in [2] was included in the channel model. This model is an enhanced modified version of the SCM channel model with capability of including different array types and polarization antennas. The center frequency of the simulation was set at 2.53 GHz. The results are compared with the published work in [3-7] for validation.

The paper is organized as follows. Generalized system model with MIMO relaying will be described as well as a brief description of the used realistic channel model in section II. Channel capacity equations are derived for different propagation scenarios in section III. In section IV numerical results are obtained pointing out the influence of the performance of MIMO relay system by relay location and LOS existence and channel parameters. Finally, the paper is concluded in section V.

2. SYSTEM MODEL

In the following we consider a MIMO channel between a transmitter and a receiver with one or two relay stations and all are equipped with multiple antennas.Figure 1 shows the general model for the system under investigation. Multiple antennas with number of elements at the source (S), the relay (R) and the destination (D) nodes in MIMO channels are (N_S, N_R andN_D) respectively. The variable physical dimensions of interest in the presented model include the height of the antenna towers for the source, the relay and the destination nodes are (h_S, $h_R$andh_D) respectively. The horizontal separation distance between the source and the relay is (d_{SR}) and between the relay and the destination nodes is (d_{RD}). The channel matrix between the source and relay is referred to as (H_{SR}) while the source to destination channel matrix is referred to (H_{SD}).

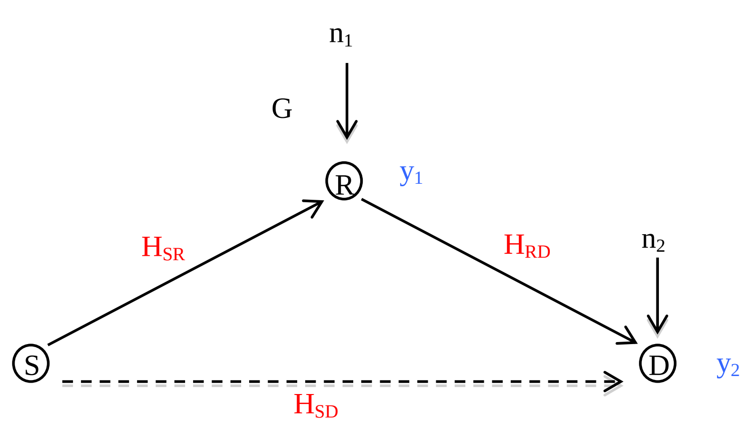

Figure 1. The Cooperative MIMO systems

Figure 2 depicts the mathematical model used in the simulation. This is a two-hop Amplify and Forward MIMO relay model with no Line of Sight path between the source and the destination. Thus, the Relay node's path is the only path available for this network. The system capacity formula is derived from the following expression of cooperative amplify-and-forward relay networks used in [3].

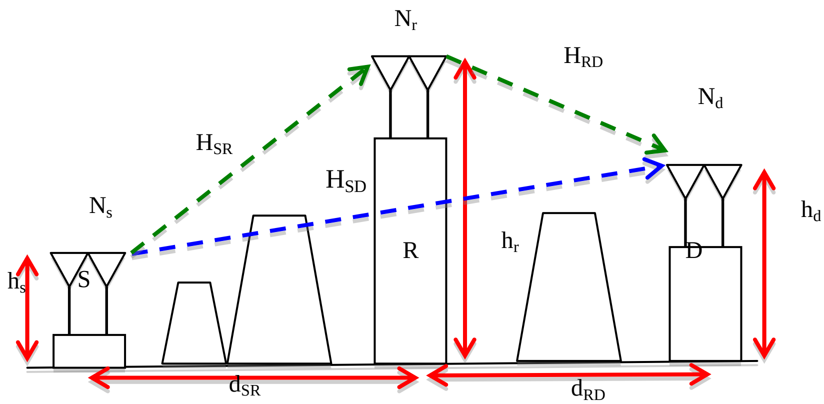

Figure. 2 Two hop AFMIMO Relay with h_{SD}=[0]

The MIMO channels (H_{ij}) between the source, relay and destination are modeled using a fadingcorrelation model [2] where the channel is modeled as,

$$\mathbf{H}(t) = \sum_{l=1}^{L-1} \mathbf{H}_l \, \delta(t - \tau_l) \tag{1}$$

where$\delta(t)$ is the delta function and H_l is the channel tap matrix with tap index l and delay (τ_l). Each H_l at one instance of time can be written as the sum of a constant LOS matrix and a variable Rayleigh non line of sight (NLOS) matrix. The correlated Rician Fading MIMO channel Matrix, (H_{ij}) with dimensions (Ni×Nj) at one instance of time can be modelled as a fixed (constant, LOS) matrix and a Rayleigh (variable, NLOS) matrix.

$$H_{ij} = \sqrt{\frac{K}{1+K}}\overline{H_{NLOS}} + \sqrt{\frac{K}{1+K}} R_r^{1/2} H_R R_t^{1/2} \tag{2}$$

where$H_{ij}$is either H_{SR}, H_{SR} or H_{SR}. $H_w$are zero mean and unit variance complex Gaussian random variables that presents the coefficients of the variable NLOS matrix. K is the Rician K-factor and R_r and $R_t$are the $N_i \times N_i$ and $N_j \times N_j$ correlation matrices that include all possible coefficients of spatial correlations between the channel links seen at transmit and receive elements respectively.

The path loss evaluation can be done by empirical models predicting the mean path loss as a function of various parameters e.g. distance, frequency, antenna height etc. In this paper, we consider Erceg empirical propagation model [10] for suburban areas to calculate path loss.

3. System Channel Capacity analysis

Assuming signal vector **x** is transmitted from the source. It passes through a relay-amplified double MIMO fading channel. Simply affected by a signal-propagation matrix **A**. simultaneously, noise vector **n**. includes the destination noises occur at the final receiver only and the relay noises that are amplified and transmitted over fading channels to the destination; we therefore use a matrix B to model this fact. We now aim at transforming each scenario and finding the matrices A and B and n components for each caseto follow the equation for the systems of interest.

$$\mathbf{y = Ax + Bn} \tag{3}$$

(1) Case 1: One Relay with no direct link between source and destination

First time slot at the destination

$$y1 = H_{SD}.x + n_1 \quad (4)$$

Second time slot at the destination

$$\begin{aligned} y_2 &= r1.G.H_{RD} + n_2 \\ &= (H_{SR}.x + n_1).G.H_{RD} + n_2 \\ &= H_{SR}.G.H_{RD}.x + G.H_{RD}.n_1 + n_2 \end{aligned} \quad (5)$$

At the destination (6)

$$y2 = [H_{SR}.G.H_{RD}]x + [G.H_{RD} \quad I]\begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$A = \begin{bmatrix} 0 \\ H_{SR}.G.H_{RD} \end{bmatrix} \text{and} B = \begin{bmatrix} 0 & 0 \\ H_{RD}.G & I \end{bmatrix} \quad (7)$$

(2) Case 2: One Relay with direct link between source and destination (with $H_{SD} \neq [0]$)

$$A = \begin{bmatrix} H_{SD} \\ H_{SR}.G.H_{RD} \end{bmatrix} \;,\; B = \begin{bmatrix} I & 0 & 0 \\ 0 & H_{RD}.G & I \end{bmatrix} \quad (8)$$

(3) Case 3: Two Relay with no direct link between source and destination (with h_{SD}=[0])

$$A = \begin{bmatrix} H_{SD} \\ (H_{SR1}.G1.H_{R1D} + H_{SR1}.G2.H_{R2D}) \end{bmatrix},$$

$$B = \begin{bmatrix} I & 0 & 0 & 0 & 0 \\ 0 & (H_{R1D}.G1) & (H_{R2D}.G2) & I & I \end{bmatrix} \quad (9)$$

Once the channel is modeled and A and B matrices are found then the capacity of the MIMO relay channel different scenario is obtained by substituting in the following equation [3].

$$C = 0.5.\log_2 \det\{I + (A\, R_x A^T)(BR_n B^T)^{-1}\} \quad (10)$$

where, Gaussian inputs x and, $R_x = E\{xx^H\}$is the covariance matrix of the transmitted signal vector, and$R_n = E\{nn^H\}$is the noise covariance matrix. For our considered system, we have $R_x = (P / Ns).\, I$, with P is the transmitted Power and G is the channel gain matrix.

4. Numerical Results and Discussions

The simulation is performed with 10000 channel realizations for each configuration. The ergodic capacity is used in the performance comparison. The ergodic capacity of a channel is the average of the information rate over the distribution of the elements of the correlated channel matrix H.

Figure 3 shows the system capacity CDF when varying the relay position in a 2D plane. As stated earlier the model consists of multiple antennas at the source, relay and destination and N_S, N_R andN_D are assumed to be 4. A distance of 800m separates the source and the destination. As seen, when the relay is located closer to the source, at d_{SR}=800 meters, the system capacity becomes more deterministic and has a low value compared to other relay positions. As the relay node is moved away from the source the system capacity increase taking its highest value when positioned half way between the source and destination. Moving the relay closer to the destination after that point reduces the system capacity till it drops below the value attained when positioning the relay closer to the source.

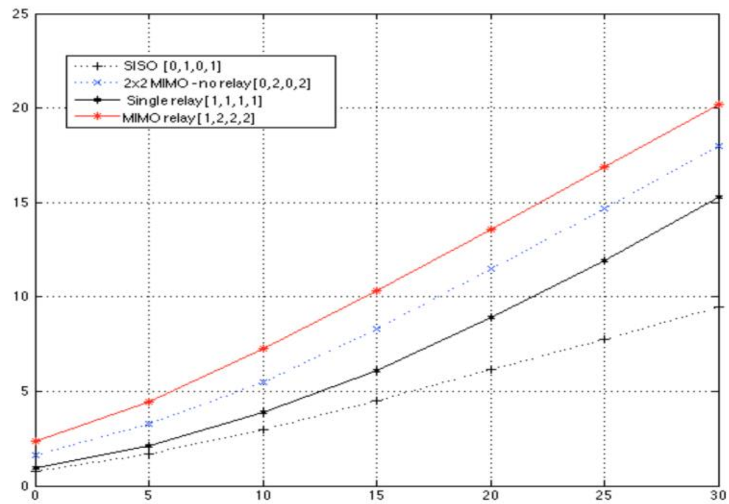

Figure. 3 The capacity of the relay channels for different cooperative AF schemes as a function of SNR compared to traditional SISO and MIMO no relay schemes.

Figure 4 shows the effect of the variation of the Angle Spread of the received signal at the relay, AS, on the system capacity while keeping all the other channel model parameters unchanged. The increase of the AS has a positive effect on the system capacity until a certain AS value when the system capacity holds on an upper limit. As the AS increases more scattering is expected at the receiver. Each added path acts like another point source of transmission and the over all effect is positive on the channel matrix rank. This increases the system capacity to a certain level. Then the system capacity does not respond to increased AS and assume relatively the same value. This is as if it is bounded by another factor in the model used.

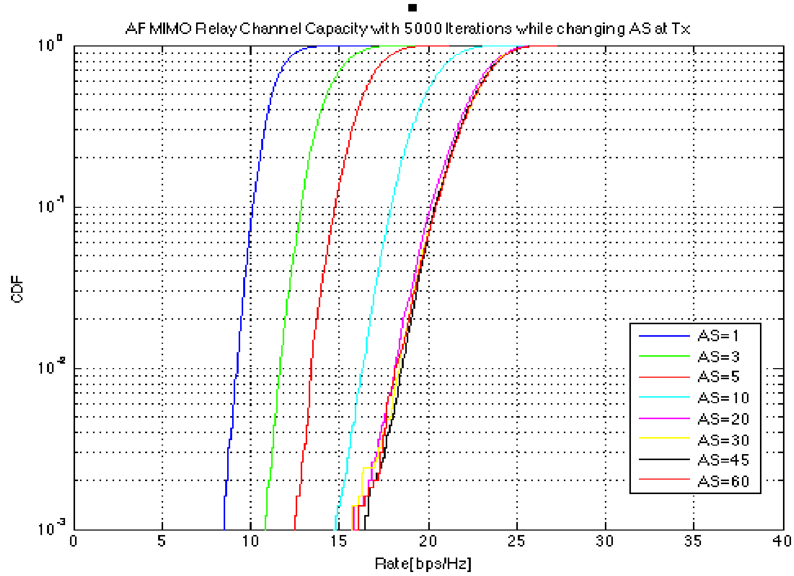

Figure 4. The CDF of the capacity of the relay channels for different AS values (fading correlation effect)

Figure 5 shows for case 1 scenario, the average Ergodic capacity of the relay channel with 4elements antenna at the relay versusrelay location(d_{SR}) that varies from 100 m to 1000 mand the source at the origin. Four cases are considered here, with LOS existence and NLOS scenario in the two links SR and RD. It's clear that LOS existence degrade the system performance by about 50% in some cases. As shown, best place to locate the relay is at the center between source and destination. Also, the location affects bothchannel characteristics and performance significantly.

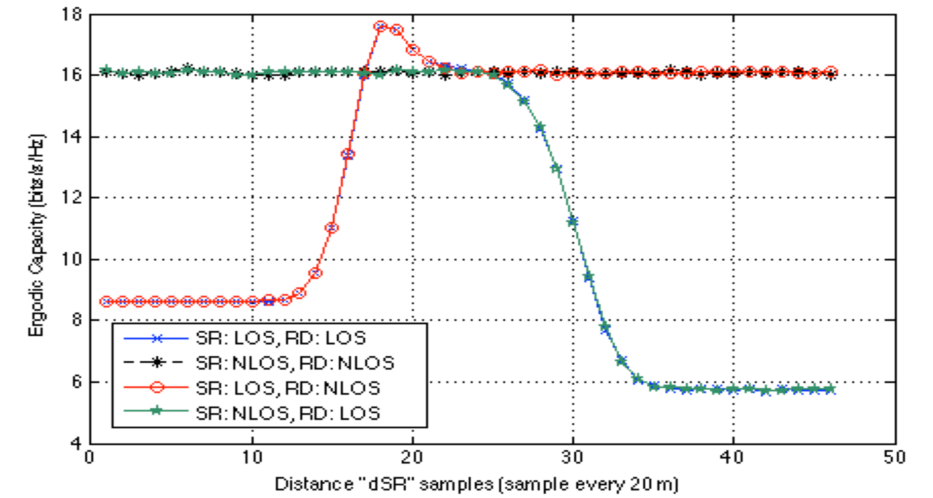

Figure 5 Ergodic capacity versus relay location

Figure 6 shows the channel capacity versus the Signal to Noise power Ratio (SNR) at S-D link with the relay located in the center of the distance between source an destination. The channel capacity in Fig. 6 is calculated for single input single output (SISO) is plotted for reference. No Relay (S-D) and MIMO Relay cases. Fig. 6 shows that the channel capacity for the relay MIMO using the path loss model is higher than both SISO and S-D cases. It is assumed that the power transmitted from the relay to the destination equals the power transmitted to the relay from the source. The power transmitted from source (Ps) is assumed to bedivided to (*q*.Ps) in the direction of Relay and (1-*q*).Ps, where q is the ratio of the power transmitted to the relay to the total transmitted power. As seen from the results as *q* increases the capacity increases as long as the relay-amplifying ratio is adjusted such that it is not less that the transmitted power from the source.

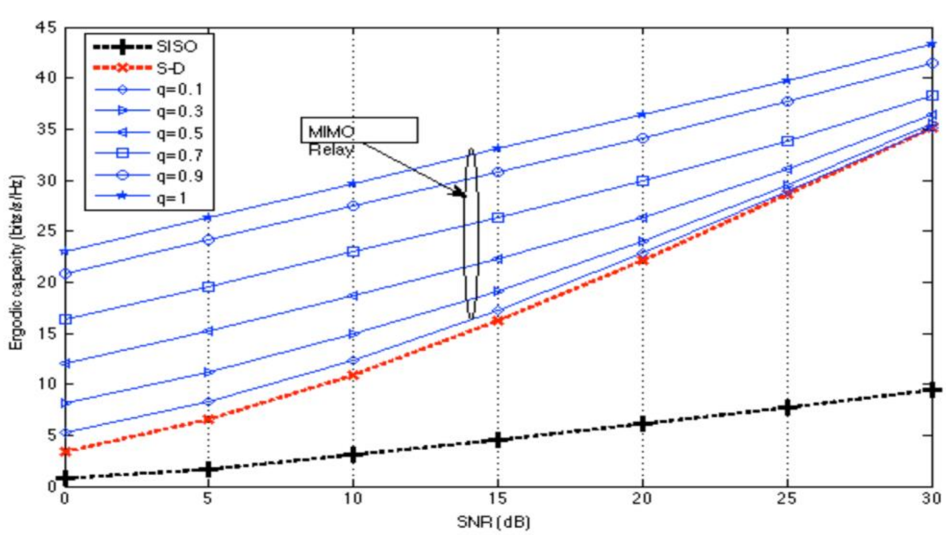

Figure 6. Channel capacity using the relay MIMO versus CNR.

5. Conclusion

The effect of the relay position, AS variation and transmitted power ratio between relay and destination directions on the AF MIMO relay system capacity with realistic channel models has been investigated in this paper. The system capacity will be highest when the relay is positioned at an equal distance from the source and destination. Moving the relay closer to the destination has a slightly better capacity rather than locating the relay closer to the source. The system capacity is then limited by other system parameters. Future work should include the effect of adding more multiple antenna relay nodes on the system capacity as well as finding the effect of varying the AoA and AoD at the

Relay and Destination on the system capacity. From the numerical results it is concluded that if the destination is far enough away from the source to make their central area NLOS to both of them, it is better to place the relay in the region close to source. The results are compared with the published work in [1-6] for validation and it is found in good agreement. Results, for a single relay node, showed placing the relay at an equal distance from the source and destination results in the highest system capacity. However, placing the relay closer to the destination with more power directed towards relay than the direct link results in higher system capacity. Study ofthe variation of angular spread of the received signal on the system capacity revealed that as expected the higher AS the higher the system capacity, however with higher AS exceeding a certain value system capacity remains unchanged.Therefore, for such scenarios using MIMO relays with increasing the number of relay antennas are highly recommended to improve the capacity.

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