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Effect of Impaired Channel Information on the Efficiency of Mimo Antenna

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Abstract: Effect of impaired channel information on received SNR over Multiple Input Multiple Output (MIMO) channel was investigated. MIMO channel was converted into equivalent independent parallel channels through Singular Value Decomposition (SVD) of the channel matrix. Levels of degradations of MIMO channel efficiency due to impairments in the available channel information at the transmitter and the receiver has been shown through simulations. It has been observed in the simulation that maximum received SNR is obtained when transmitted signal distribution among transmit antennas and received signal combination is matched with channel gains of the equivalent parallel channels.

Key words: MIMO, SVD, matrix, distribution, antenna, SNR

INTRODUCTION

Multiple Input Multiple Output (MIMO) antenna promises high spectral efficiency in wireless communication. Its higher spectral efficiency compared to Single Input Single Output (SISO) and Multiple Input Single Output (MISO) has been demonstrated. If the MIMO link consists of N_T transmit antennas and N_R receive antennas and the $N_R \times N_T$ channel matrix with i.i.d Gaussian entries is perfectly known to the receiver, it has been proved that the ergodic capacity increase is min (N_R, N_T) bits per second per hertz for every 3dB increase at high Signal-to-Noise Ratio (SNR) (Debah and Muller, 2005).

MIMO capacity can be significantly increased if the channel characteristics is known at the transmitter. However as channel matrix elements are random variables (which may be characterized by Rayleigh distribution) and hold constant values over a small time period (of the order of symbol time), it is difficult to provide transmitter with channel information through feedback from receiver. Typically, feedback interval will be larger than symbol time.

In this study, we study the effect of insufficient availability of channel information on MIMO characteristics. In the next section, a general model for NLOS MIMO channel is presented. A description of channel information based signal distribution at transmission is discussed and information based signal combination at reception. Simulation strategy and results are also discussed in this study, respectively.

NLOS MIMO CHANNEL

NLOS MIMO channel (Fig. 1) is characterized by an array of TX antenna, an array of RX antenna and the scattering medium (Kermoal *et al*., 2002). Transmitted signals are scattered by multiple scatterers and arrive at receive antennas through multiple paths. Resulting multi-path MIMO channel $H \in C^{NR \times NT}$ can be written as a $N_R \times N_T$ channel matrix,

$$H = \begin{bmatrix} h_{11} & h_{12} & \dots & h_{1N_T} \\ h_{21} & h_{22} & \dots & h_{2N_T} \\ \vdots & \vdots & \vdots & \vdots \\ h_{N_R} & h_{N_R} & \dots & h_{N_R N_T} \end{bmatrix}$$

N_T and N_R are the number of transmit and receive antennas, respectively. The transmission coefficient h_{ij} is the complex gain from transmit antenna j to receive antenna i. Because of rich scattering through Rayleigh fading channels, these entries can be estimated using Rayleigh distribution (Ratnarajah *et al*., 2003). The transmitted signals are denoted by the signal vector $X(t) = \{x_1(t), x_2(t), \dots, x_{NT}(t)]^T$ where $x_j(t)$ is the transmitted signal from the j-th transmit antenna.

The received signals are represented by $Y(t) = \{y_1(t), y_2(t), \dots, y_{NT}(t)]^T$. The relation between transmitted and received signals can thus be expressed by $Y(t) = H(t)X(t)$.

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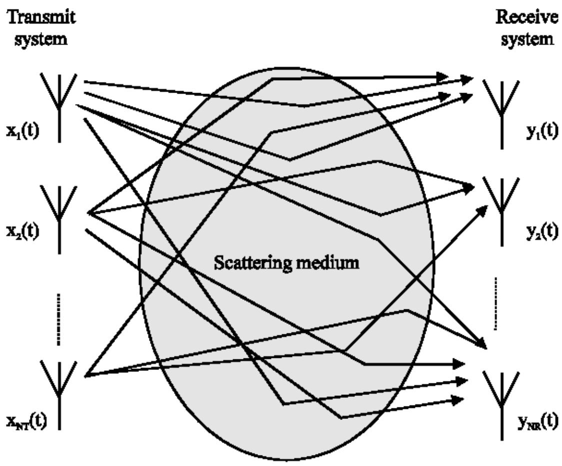

Fig. 1: MIMO setup

SIGNAL DISTRIBUTION AT TX

The total transmitted power is distributed among transmit antennas. If x(t) is the total transmitted signal, transmitted signal through j-th antenna is, $x_j(t) = \alpha_j x(t)$, where the weight vector, $\alpha(t) = \{\alpha_j(t)\}$, $j = 1,2,...N_T$ specifies the fractions to be transmitted through the corresponding antennas. The $N_T \times N_R$ MIMO channel can be converted to equivalent independent parallel channels through Singular Value Decomposition (SVD) of the channel matrix H (Jankiraman, 2004; Raghavan and Akbar, 2006).

$$H = UDV^H$$

Where U and V are $N_R \times N_R$ and unitary matrices and D is a diagonal matrix. The diagonal entries in D can be thought of as channel gains in the corresponding parallel channels. For simplicity, say $N_R \times N_T$. Signal distribution at transmission is optimized if equivalent weight for j-th channel is proportional to the j-th diagonal element in D (Hen, 2006). The weights $\alpha(t)$ can be found from the following equation.

$$\begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1N_T} \\ v_{21} & v_{22} & \cdots & v_{2N_T} \\ \vdots & \vdots & \cdots & \vdots \\ v_{N_T1} & v_{N_T2} & \cdots & v_{N_TN_T} \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_{N_T} \end{bmatrix} = \begin{bmatrix} d_1^* \\ d_2^* \\ \vdots \\ d_{N_T}^* \end{bmatrix}$$

where, d_j is the j-th diagonal element in D and $v_{i,j}$ are the elements of the V^H. These optimizing weights are normalized with the constraint,

$$\sum_{j=1}^{N_T} |\alpha_j|^2 = 1$$

SIGNAL COMBINATION AT RX

Received signal is constructed by combining signals from receive antennas

$$y(t) = \sum_{i=1}^{N_R} \beta_i(t) y_i(t)$$

where, weight vector $\beta = \{\beta_i(t)\}$, $i = 1,2....N_R$ specifies contributions from corresponding receive antennas. Similar to the transmission case, optimizing weight vectors are found from the following equation.

$$\begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{N_R} \end{bmatrix}^T \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1N_R} \\ u_{21} & u_{22} & \cdots & u_{2N_R} \\ \vdots & \vdots & \cdots & \vdots \\ u_{N_R1} & u_{N_R2} & \cdots & u_{N_RN_R} \end{bmatrix} = \begin{bmatrix} d_1^* \\ d_2^* \\ \vdots \\ d_{N_R}^* \end{bmatrix}^T$$

where, $U = [u_{ij}]$ is found from SVD decomposition $H = UDV^H$ and d_i is the i-th diagonal element in D. Finally $\beta = \{\beta_i(t)\}$, is normalized as

$$\sum_{i=1}^{N_R} |\beta_i|^2 = 1$$

SIMULATION STRATEGY

Through simulation, we estimated degradation in MIMO performance to due to imperfect information of H at transmitter as well as at receiver. A MIMO size of 2×2 was assumed. During estimating effect of imperfect information at transmission, the weight vector at receiver was kept at [0.5, 0.5]. Similarly during estimation of the effect at receiver, the weight vector at transmitter was kept at

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix}$$

Each element h_{ij} of channel matrix H was a complex number with two independent random variables having Gaussian distribution (Ratnarajah *et al*., 2003). Degraded versions of H were made available to transmitter and receiver. For each level of degradation at transmitter, a large number of iterations were run. During each iteration, a channel matrix H was calculated from the random variables; degraded version was calculated as H + ΔH, where ΔH is a 2×2 matrix with complex entries. Each entry consisted of two Gaussian distributed random variables with variance scaled to present level of degradation. For a fixed total transmit power, for various levels of degradation in channel information at transmitter, received average SNR levels were computed. Similar calculations were made for different degradation levels of channel information at the receiver.

SIMULATION RESULTS

As expected, reduced received SNR was observed when imperfections were introduced in channel information at transmitter. Normalized average SNR versus normalized error in channel information available at the transmitter is shown in Fig. 2. As seen in the figure, maximum SNR was obtained when transmitter had full information of channel matrix H and thus weight vector

$$\alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix}$$

was fully matched with diagonal matrix D. As error in channel information increased, average SNR decreased.

Similar results were obtained for different levels of error in channel information at the receiver. Maximum SNR was obtained when receiver has full information of the channel. Gradually decreased SNR levels were obtained with increased levels of errors in the channel information. Normalized average SNR versus normalized error in channel information available at the receiver is shown in Fig. 3.

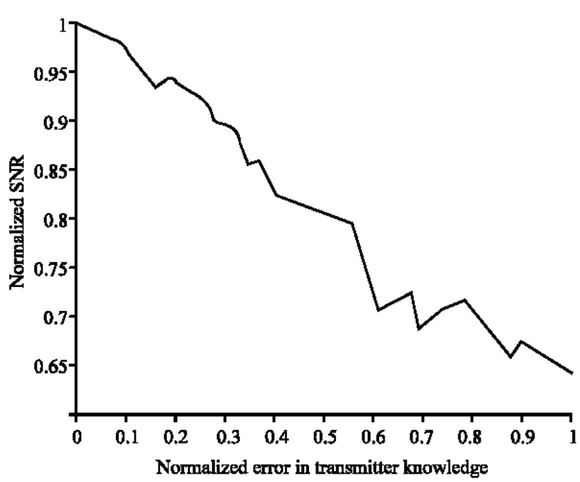

Fig. 2: Normalized SNR vs normalized error in channel information at transmitter

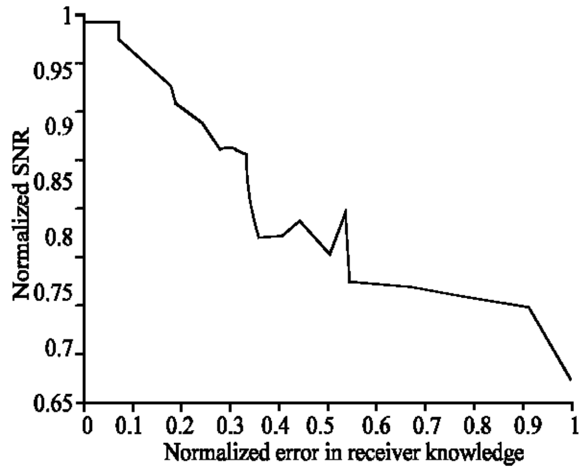

Fig. 3: Normalized SNR vs normalized error in channel information at receiver

CONCLUSION

Effect of impaired channel feedback on received SNR over MIMO channel has been investigated. Simulation results show signal distribution at the MIMO transmitter and signal combination at the MIMO receiver based on improper channel information can significantly degrade received SNR and thus channel capacity/covered distance. Channel estimation is a complex procedure; especially timely information availability to the transmitter is very difficult. Where there is a trade-off between system complexity and channel information availability to the transmitter/receiver, the results presented in this study may help by providing levels of MIMO performance degradation at various levels of information impairments

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