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PERFORMANCE EVALUATION OF RELAYING SCHEMES FOR WIRELESS COMMUNICATION SYSTEMS

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Abstract-The evaluation of MIMO (multiple-input multiple-output) Relay wireless system is carried out and compared against the performance of a SISO (single-input single-output) Relay wireless system. The encoding scheme used in MIMO is Alamouti coding and decoding is done by the Maximum Likelihood (ML) detector. A comparison is made between the SISO non-regenerative amplify-and-forward (AF) and regenerative decode-and-forward (DF) relaying schemes. The plots of bit error rate (BER) versus signal to noise ratio (SNR) are simulated by incorporating Rayleigh fading condition in the presence of additive white Gaussian noise(AWGN) using MATLAB.

Keywords: MIMO Relay; Alamouti coding; Maximum Likelihood (ML) detector; Rayleigh fading.

1. INTRODUCTION

Explosion in data rate has resulted in an increased dominance of wireless over wired communication systems. However, the spectrum has remained the same. This has led to congestion and has put a limit on the data rate. Therefore, there is a need to increase the capacity of communication systems for which different methods have been proposed. One such method for the 4G technology is the MIMO (multiple-input multiple-output) wireless system which uses multiple antennas at the transmitter and receiver. It offers significant increase in data throughput and link range without additional bandwidth or transmit power. It achieves a larger capacity by higher spectral efficiency i.e. more bits per second per hertz of bandwidth and spatial diversity (reduced multipath fading) leading to higher link reliability through spatial multiplexing and space-time coding, respectively.

Spatial multiplexing in MIMO systems yields a linear (in the minimum of the number of transmit and receive antennas) increase in capacity. The corresponding gain is realized by simultaneously transmitting independent data streams in the same frequency band. Under conducive channel conditions (such as rich scattering), the receiver exploits differences in the spatial signatures of the multiplexed streams to separate the different signals, thereby realizing a capacity gain. Diversity is a powerful technique to mitigate fading and increase robustness to interference. Diversity techniques rely on transmitting the data signal over multiple (ideally) independently fading paths (time/frequency/space). Spatial (i.e. antenna) diversity is particularly attractive when compared to time/frequency diversity since it does not incur an expenditure in transmission time/bandwidth. Space-time coding is used to exploit spatial diversity gain in point-to-point MIMO channels[1].

Alamouti[2] introduced the MIMO scheme allowing to transmit at two antennas with the same data rate as on a single antenna but increasing the diversity at the receiver from one to two in a flat fading channel. ML decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space-time block code and gives a maximum likelihood decoding algorithm which is based only on linear processing at the receiver[3].

In the relay-based communication system, a source communicates with a destination with the help of other nodes or relays. The use of relays (fixed) increase coverage and link capacity in regions where there is significant shadowing without requiring large transmit powers. Because of the ease of implementation, fixed relays are a low cost and low complexity solution to meet the requirement of high data rate communication far from the base station. The capacity and reliability of the relay channel can be further improved by using multiple antennas at the nodes. The benefits of relaying combined with the advantages of multiple antennas make the MIMO relaying technique powerful to achieve high sum capacity with the reliability. All nodes operate in half-duplex mode in MIMO relaying[4].

The paper is organised as follows. Section II deals with a 2x2 MIMO system. Section III discusses the relaying schemes used. Section IV describes the method of simulation. In section V, the bit-error performance of AF and DF SISO relaying methods with binary phase-shift keying (BPSK) is presented. Also a comparison between DF relaying schemes for SISO and MIMO is put forth. Section VI draws the conclusions for this paper.

2. MIMO

Figure 1: 2x2 MIMO

In most situations, the wireless channel suffers attenuation due to destructive addition of multipaths in the propagation media and to interference from other users. The channel statistic is significantly often Rayleigh which makes it difficult for the receiver to reliably determine the transmitted signal. The idea behind MIMO is to exploit the presence of, in the optimum, independent multipath fading. In reality, however, correlation between the different propagation paths lowers the achievable link capacity[5]. For all practical purposes, the primary requirement for diversity improvement is that the signals transmitted from the different antennas be sufficiently uncorrelated (less than 0.7 correlation)[2].

Figure1 shows a 2x2 MIMO wireless system having two transmit antennas and two receive antennas where h_0, h_1, h_2 and h_3 are the channels between the transmit and receive antennas. The signal to be transmitted is modulated, encoded, filtered and sent over the channel. It is assumed that the channel experienced by each transmit antenna is independent of the channel experienced by the other transmit antennas. The channel is known at the receiver[6]. AWGN is added to the transmitted signals in the Rayleigh channel.

Data transmission over bandlimited channels requires pulse shaping to eliminate or control intersymbol interference (ISI). Nyquist filters provide ISI-free transmission. In practical applications, the overall magnitude response of the Nyquist filter is split evenly between the transmitter and receiver. The phase response of the receiving filter compensates for the transmitting filter phase so that the overall filter has a linear phase. The spectrum of the square-root raised-cosine filter is investigated in[7]. When the impulse response of the filter is truncated, the overall impulse response has a reduced ISI.

The MIMO model which is to be realized at the receiver is of the form

$$y = hx + n \quad (1)$$

where y is the matrix at the receiver, h is the Rayleigh channel coefficient matrix, x is the matrix of transmitted signals and n is the matrix of random, complex, zero mean, unit variance noise signals. The transmitted signal is encoded using the Alamouti Space-Time Code[2] in which the information bits

are first modulated using an M -ary modulation scheme. The Space-Time Code matrix is,

$$s = \begin{bmatrix} s_0 & -s_1^* \\ s_1 & s_0^* \end{bmatrix} \quad (2)$$

The signal is transmitted both in space (across two antennas) and time (two transmission intervals). The two equations are,

$$\begin{aligned} s_0 &= [s_0, -s_1^*] \\ s_1 &= [s_1, s_0^*] \end{aligned} \quad (3)$$

where s_0 is the information sequence from the first antenna and s_1 is the information sequence from the second antenna. The signals passing through the multipath environment are assumed to fade according to the Rayleigh distribution.

The received signal at the two receive antennas (rx_0 and rx_1) are r_0, r_1, r_2 and r_3 where r_0 and r_2 are the received signals at time t at rx_0 and rx_1 respectively while r_1 and r_3 are the received signals at time $(t+T)$ at rx_0 and rx_1 respectively. n_0, n_1, n_2 and n_3 are complex random variables representing receiver thermal noise and interference [2].

$$\begin{aligned} r_0 &= h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= -h_0 s_1^* + h_1 s_0^* + n_1 \\ r_2 &= h_2 s_0 + h_3 s_1 + n_2 \\ r_3 &= -h_2 s_1^* + h_3 s_0^* + n_3 \end{aligned} \quad (4)$$

The combiner[2] in Figure 2 builds the following two signals that are sent to the maximum likelihood detector:

$$\begin{aligned} \tilde{s}_0 &= h_0^* r_0 + h_1^* r_1 + h_2^* r_2 + h_3^* r_3 \\ \tilde{s}_1 &= h_1^* r_0 - h_0^* r_1 + h_3^* r_2 - h_2^* r_3 \end{aligned} \quad (5)$$

The ML detector is used to determine at the receiver the probabilities of what the transmitter sent and select the one or more most likely transmissions. The decoded signal is then demodulated and the BER is calculated.

Figure 2: Two-branch transmit diversity scheme with two receivers

3. RELAYING SCHEMES

Adding relays in a cell reduces the signal transmission distances, resulting in lower propagation loss and higher average SINR to the mobile users. This guarantees stronger and more stable receiving signals, especially for the mobile users near the edge of the cell and improves the overall system capacity.

Figure 3: SISO Relay

In the SISO relay as shown in figure 3 the source terminal communicates with the relay and destination terminals during the first time slot. In the second time slot, both the relay and source terminals communicate with the destination terminal. h is a complex valued random variable with unit power channel gain between any two terminals.

Figure 4 shows a MIMO wireless single relay which provides significant improvements in data rate and reliability compared with single-antenna systems.

Figure 4: MIMO Relay

The transmission schemes at the relay node can be amplify-and-forward (AF) or decode-and-forward (DF). In AF, the relay amplifies the Alamouti encoded signal and performs simple operation of *unitary* linear transformation and then forwards the received signal without performing any decoding or demodulation, and accordingly the phase of signals from all the relay nodes are randomly combined at a destination node. This has the big advantage[8] that the relay needs no or only partly knowledge about the structure and coding scheme of the signal. This allows for easy upgrade of a mobile communication network regarding e.g. new coding schemes, without also having to upgrade the relay station. In the DF case, the relay decodes and demodulates the signal prior to re-encoding and retransmission. This has the main advantage that the transmission can be optimized for both links, separately[8]. If a relay node correctly decodes, it will forward the source data in the second phase of the cooperation protocol; otherwise, it remains idle. This can be achieved by setting an SNR threshold at the relay node, and the relay will only forward the source data if the received SNR is larger than that threshold [9].

4. METHOD OF SIMULATION

Figure 5: Simulation Methodology for MIMO Relays

The simulation is done by specifying the various parameters that are used namely the length of the signal, number of iterations, number of bits/symbol, type of modulation implemented, the SNR range for which BER is calculated. The input signal is then split between the two transmit antennas. Each split signal is individually modulated. Data is encoded using Alamouti's 2x2 space-time block code. The encoded signal is upsampled by a factor of $N=4$ and passed through the selected pulse shaping filter before transmission. Sender side pulse shaping is combined with a receiver side matched filter to achieve optimum tolerance for noise in the system. The pulse shaping is equally distributed to the sender

and receiver filters. The filters' amplitude responses are thus pointwise square-roots of the system filters. The transmitted signal is thereafter fed to the channel where it is subjected to AWGN. The received signal at each receive antenna is a linear superposition of the two transmitted signals.

For the DF relaying case, the received signal at the relay is filtered, down sampled and fed to the ML detector. The ML detector tries to retrieve the original signal with the least error. After demodulation, the signal is again split between the two relay transmit antennas, further modulated, coded and retransmitted. At the receiver, the performance of DF MIMO relay is evaluated from the plot of BER versus SNR for BPSK under flat fading channel conditions.

5. SIMULATION RESULTS

Figure 6 displays the simulated behaviour of the uncoded bit error rate of a basic SISO communication system for BPSK and shows 6.78% and 66.19% improvement in the performance of the DF and AF SISO relaying schemes, respectively, over SISO. Also AF SISO relaying scheme shows a lower and hence better BER of 74.77% compared to DF SISO relaying scheme for lower values of SNR as the signal at the AF relay is sent at all times unlike DF relay where the signal is retransmitted only if it is decoded correctly.

The SNR versus BER graph has been plotted for a DF SISO and MIMO relaying communication system using Binary Phase Shift Keying in figure 7. Simulation results show that BER is less for DF MIMO relaying scheme as compared to DF SISO relaying scheme for a given SNR which clearly indicates that MIMO relaying is preferred over SISO relaying on account of its superior BER.

Figure 6: Comparison between SISO and AF and DF SISO relaying schemes

Figure 7: Comparison between DF SISO and DF MIMO relaying schemes

6. CONCLUSIONS

AF SISO relaying scheme shows a marked improvement over DF SISO relaying scheme as reflected in the reduced BER. Also DF MIMO relaying has an improved performance over DF SISO relaying scheme.

7. FUTURE SCOPE

Performance of AF MIMO relaying and AF SISO relaying schemes can be studied. Also an analysis of AF and DF MIMO relaying schemes can be made. The above procedure can also be tested for three hops and thus the relaying distance can be increased.

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