Dual Hop Relay with Cooperative Diversity and Relay Selection

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Abstract- *As wireless communication becomes more prevalent, the demand for higher data rates and uninterrupted connectivity is increasing. Future wireless systems are provisioned to be highly heterogeneous and interconnected. On one side, wireless ad hoc networks are emerging for a wide range of new applications, on the other side; infrastructure based broadband wireless systems are expanding to provide increasing number of services with ubiquitous coverage. Space-time coding is a MIMO technique which is well known for its ability to combat fading, increased system performance and capacity. Space time coding uses specially designed code matrix which enhance overall system performance than single antenna systems. Furthermore cooperative communication can benefit single antenna systems with the benefits of MIMO systems. Conjunction of cooperative communication with space time coding can provide capabilities to mitigate fading with increased system performance to a single antenna system. In this regard, this research work is focused towards the performance evaluation and enhancement of dual hop cooperative communication network with regenerative and non-regenerative relaying techniques. Log-likelihood ratio (LLR) based relay selection scheme is applied to cooperative diversity architecture and Bit Error Rate (BER) performance is compared with random, max-min and harmonic mean based relay selection schemes. Simulation of this research work is carried out on MATLAB 2010a, simulation results shows that application of diversity in cooperative communication networks enhance system performance by 12dB. Furthermore, LLR relay selection strategy enhance this performance by 4dB more.*

Keywords- *Cooperative Diversity, Cooperative-STBC, LLR Relay selection*

I. INTRODUCTION

Multiple Input Multiple output (MIMO) systems are proven to eliminate the impact of fading and increase system reliability while maintaining low bit error rates with the cost of increased system hardware and complexity. Space-time block coding (STBC) that employs multiple transmit antennas and single/multiple receive antennas has been regarded as a promising technique being able to offer significant improvement in link reliability and spectral efficiency [1,2].Unfortunately, these benefits are obtained by deploying multiple antennas on a terminal, which causes an increase in size and power consumption [3, 4]. Recently, cooperative relaying has been attracting a great research interest [5–8]. The main idea behind cooperative diversity systems is that the source and the destination terminals communicate with each other with the help of intermediate nodes called relay terminals. Various cooperative relaying schemes exist in literature and two of the most well-known are amplify-and-forward (AF) and decode-and-forward (DF) protocols. In AF relaying, the relay terminal transmits a scaled version of received signal without decoding the message. In DF relaying, the relay terminal decodes its received signal and then re-encodes it for transmission to the destination. Cooperative diversity scheme exploits the user diversity by receiving both the relayed signal and the direct signal at the destination node in contrast to direct transmission where a receiver receives and decodes only the direct signal. Several nodes equipped with one or more antennas form a group to cooperatively work as a transmit antenna array. Therefore cooperative diversity can be regarded as an alternative to multiple antennas distributed among multiple source nodes. Sendonaris *et al* and Laneman *et al* were first to investigate the application of user cooperation diversity to increase system throughput for cellular area network and wireless adhoc networks respectively [5-8]. The authors in [9] have proposed a two stage cooperative diversity protocol known as "Distributed space time block coding". In first stage of the protocol the transmitter sends the data to relay terminals which is then encoded through space time block codes and relayed to the destination in second stage. This protocol achieves maximum diversity order equals number of relay constraint to the amount of transmission power. The application of orthogonal and quasi orthogonal codes in cooperative relay networks have been investigated in [10], the authors have found that AF based schemes achieve higher diversity than DF-SC based cooperative diversity scheme. Equalization techniques for DSTBC-AF system were derived by authors in [11], they have extended the equalization methods for conventional space time system to cooperative space time systems for frequency selective channel. The authors in [12] have investigated diversity for a system having multiple antennas at source and destination and single antenna relay terminal with no CSI available at the destination. In [13] authors have given framework for cooperative diversity scheme using regenerative and non-regenerative relaying over slow Rayleigh fading channel. They have proposed simulation for cooperative downlink CDMA system and cooperative space time system with single antenna terminal and compare system performance for bit error rate. In [14], authors have considered a wireless relay network with multiple antenna elements deployed at relay nodes and imperfect channel state information is presented at the receiver end. They found that AF relaying techniques always achieves maximal diversity while in DF relaying, diversity increases with the number of antenna at the relay nodes. Similar work for wireless multi-hop network is presented in [15].

In this paper, LLR based relay selection scheme is applied to cooperative diversity network. The proposed system model is composed of cooperative relaying and space-time block coding scheme to provide the benefits of MIMO system in a virtual MIMO architecture. Rest of this paper is arranged as follows. System model for adopted system is presented in section-II, followed by Relay selection criteria in section-III. In section-IV simulation results have been presented and finally section-V concludes this paper.

II. SYSTEM MODEL

We consider cooperative communication system with a source (S), a destination (D), and I relay (R) nodes as shown in Figure 1. Every terminal operates in half-duplex mode and is equipped with a single antenna. The complex fading coefficient of Sr_i, r_iD are denoted by H_{sr_i} and H_{r_iD} respectively. Let us consider the magnitude of all available links follow Nakagami distribution with probability density function (p.d.f) given by:

$$p(x) = \frac{2m^m x^{2m-1}}{\Gamma(m)\Omega^m} * \exp(-\frac{mx^2}{\Omega})$$ (1)

Where $\Gamma(.)$ represents gamma function [], $\Omega = E(x^2)$ and $m = \frac{\Omega}{E(x^2-\Omega^2)} \geq 0.5$ is Nakagami-m fading parameter. $E(.)$ denotes statistical expectation operator. The data transmission between source to destination occurs in two phases i.e. source to relay transmission, relay to destination transmission. Let P be total transmission power available and N_0 denotes noise power spectral density and $S \in \mathbb{C}^{1\times N}$ be a complex-valued M-point constellation data obtained from MPSK or MQAM modulation scheme. Let $y_{SR_i} \in \mathbb{C}^{1\times N}$ denotes the received data at i^{th} relay with $H_{sr_i}, H_{r_iD} \in \mathbb{C}^{1\times N}$ and $n_{sr_i}, n_{r_iD} \in \mathbb{C}^{1\times N}$ being complex valued channel coefficient and AWGN noise with zero mean and N_0 variance present between source and i^{th} relay, i^{th} relay and destination.

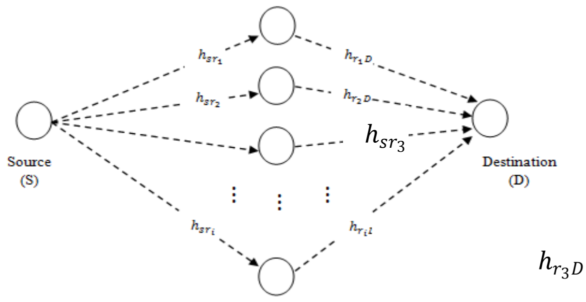


Figure 1: System Model

***Cooperative Diversity Scheme and Error Rate Analysis*:**

In Phase I, the source sequentially transmits S to the selected relays; hence, the data received at the i^{th} relay, $i \in \{1, 2\}$, can be written as:

$$Y_{sr_i} = \sqrt{\frac{P}{N_0}} * H_{sr_i} * S + n_{sr_i} \; \forall \; i = 1,2 \quad (2)$$

Second phase of data transmission follows either regenerative or non-regenerative transmission protocol with STBC encoding. In non-regenerative amplify and forward relaying technique, received signal from first phase of data transmission is amplified with channel gain given as: H_{Gain} =

$$\sqrt{\frac{P_b}{|H_{sr_i}|^2 * P_a + N_0}} \quad (3)$$

Then amplified signal will be:

$$s_i = H_{gain} * Y_{sr_i} \; \forall \; i = 1,2 \quad (4)$$

Where P_a and P_b are transmission power available for first and second phase respectively. s_i is then encoded by Alamouti's space-time code matrix given by :

$$x = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \quad (5)$$

Where $x \in \mathbb{C}^{2\times N}$ being Alamouti STBC encoded data. The Relaying phase starts with transmitting signals s_1, s_2 during first symbol period followed by transmission of signals $-s_2^*$and s_1^* from relay 1, 2 respectively as shown in figure-2.

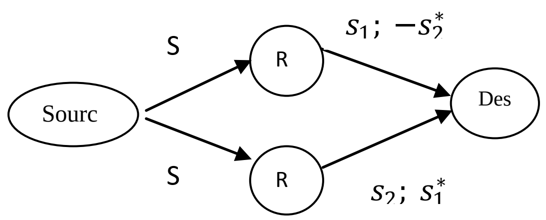


Figure 2: Cooperative Space-Time System

Assuming channel coherence time to be greater than symbol period, the received signals at the destination terminal from first relay is:

$$r_{r_1D} = (h_{r_1D}s_1 + h_{r_2D}s_2 + n_{r_1D}) \quad (6)$$

Similarly, the received signal from second relay will be: $r_{r_2D} = \left(-h_{r_1D}s_2^* + h_{r_2D}\, s_1^* + n_{r_2D}\right)$ (7)
Applying Maximal ratio combining at the receiver end, the combined signals will be:

$$\tilde{s}_1 = h_{r_1D}^* r_1 + h_{r_2D} r_2 = \left\{\left(\left|h_{r_1D}\right|^2 + \left|h_{r_2D}\right|^2\right) s_1 + h_{r_1D}^* n_{r_1D} + h_{r_2D} n_{r_2D}^*\right\} \quad (8)$$

$$\tilde{s}_2 = h_{r_2D}^* r_1 - h_{r_1D} r_2^* = \left\{\left(\left|h_{r_1D}\right|^2 + \left|h_{r_2D}\right|^2\right) s_2 - h_{r_1D} n_{r_2D}^* + h_{r_2D}^* n_{r_1D}\right\} \quad (9)$$

The combined detection estimates, $\tilde{s}_1$ and $\tilde{s}_2$ depends on their corresponding signals. To recover s_1 and s_2 for each of the transmitted signal the receiver needs to perform MLD $s_i^{'}(i = 1{,}2)$.

$$s_i^{'} = min\{|\tilde{s}_i - (|h_1|^2 + |h_2|^2)s_i|^2\} \quad (10)$$

The BER probability for proposed scheme can be calculated using the measurement of instantaneous SNR at destination node. Let P be total transmission power available and $\sigma_r^2 = \sigma_{sr}^2 + \sigma_{rD}^2$ be the variance of noise present between source to relay and relay to destination, then instantaneous SNR can be given as:

$$\gamma_\gamma = |h_{sr} * h_{rd}|^2 * P/\sigma_r^2 \quad (11)$$

Assuming channel coherence time to be greater than symbol period, the symbol error probability for instantaneous SNR γ_γ is given as:

$$P_e = Q(\sqrt{2\gamma_\gamma}) \text{, where } Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-k^2/2} dk = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right) for\ x \geq 0 \quad (12)$$

***Relay Selection Criteria*:**

The system consists of a two-hop network model where there is one source, one destination and L relays as shown in Figure-1. At the first time slot the source broadcasts the BPSK signal with amplitudes either $+\sqrt{E_s}$ or $-\sqrt{E_s}$ to the relays using equations (2). At the second time slot, the relays receive the transmitted signal from the source, the log-likelihood ratio (LLR) is calculated for each relay and it is given by:

$$\Delta = \ln \frac{P\left(r_{s,r_i}|h_{SR_i}, s=+\sqrt{E_S}\right)}{P\left(r_{s,r_i}|h_{SR_i}, s=-\sqrt{E_S}\right)} \quad (13)$$

Where the sign of Δ is the hard decision value and the magnitude represents the reliability of the hard decision which is used to choose the most reliable relay for detection. $P\left(r_{s,r_i}|h_{SR_i}, s = +\sqrt{E_S}\right)$ and $P\left(r_{s,r_i}|h_{SR_i}, s = -\sqrt{E_S}\right)$ are the probability density function (pdf) of the observation at the relays given the channel and the transmitted signal. Using (2) and knowing that the additive noise is AWGN and the channel is complex, then these probability density functions can be written as:

$$P\left(s = +\sqrt{E_S}|h_{SR_i}, r_{s,r_i}\right) = \frac{1}{2\pi\sigma^2} e^{\frac{-\left|\left(r_{s,r_i} - h_{SR_i}\sqrt{E_S}\right)\right|^2}{\sigma^2}} \quad (14)$$

$$P\left(s = -\sqrt{E_S}|h_{SR_i}, r_{s,r_i}\right) = \frac{1}{2\pi\sigma^2} e^{\frac{-\left|\left(r_{s,r_i} + h_{SR_i}\sqrt{E_S}\right)\right|^2}{\sigma^2}} \quad (15)$$

Substituting (14) and (15) into (13), the LLR in its simplest form is given by:

$$\Delta = \left|r_{s,r_i}\right|^2 + 2\sqrt{E_S} Re\{r_{s,r_i} h_{SR_i}^*\} + \left|h_{SR_i}\sqrt{E_S}\right|^2 - \left|r_{s,r_i}\right|^2 + 2\sqrt{E_S} Re\{r_{s,r_i} h_{SR_i}^*\} - \left|h_{SR_i}\sqrt{E_S}\right|^2 \quad (16)$$

Then, the magnitude of LLR $|\Delta|$ in its simplest form can by written as:

$$|\Delta| = \frac{4\sqrt{E_S}}{\sigma^2}\left|Re\{r_{s,r_i} h_{SR_i}^*\}\right| \quad (17)$$

Where $Re\{.\}$ represents the real part, $(.)^*$ represents the complex conjugate and $|.|$ represents the magnitude of the equation. Then the best relay pair can be given by:

$$K = \underset{K\epsilon\{1,2,\ldots L\}}{arg \max} |\Delta| \quad (18)$$

The relay pair obtained from eq.(18) is used to cooperatively send the source transmitted data through Space-Time coding scheme.

III. SIMULATION RESULTS

This research work is focused towards the development of dual hop cooperative diversity scheme based on the fusion of cooperative relaying scheme with orthogonal space-time block coding and LLR relay selection protocol. Simulation of proposed scheme is carried out over Nakagami fading environments under the influence of AWGN noise. SNR vs. BER analysis is used as a reference parameter for performance evaluation.

Figure 3: BER performance comparison of cooperative relaying and cooperative diversity

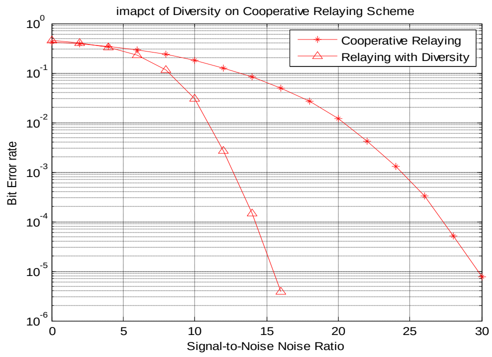


Figure 4: BER performance comparison of diversity and cooperative diversity with relay selection

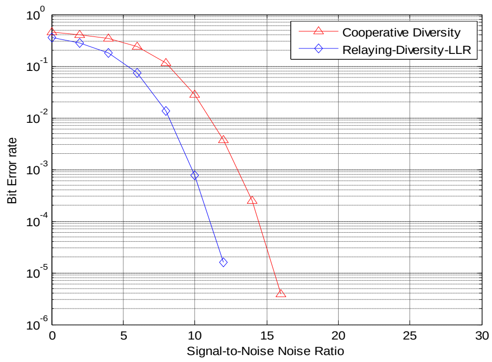
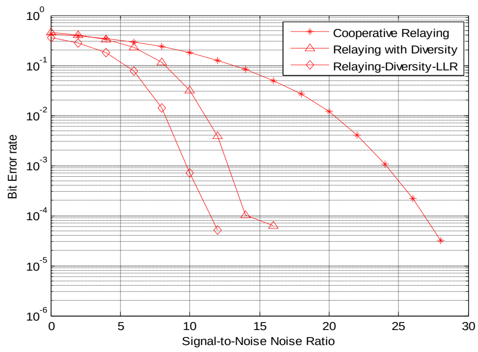


Figure 5: BER performance comparison of cooperative relaying, cooperative diversity and cooperative diversity with relay selection



Bit error rate performance of cooperative relaying, cooperative diversity and cooperative diversity with relay selection has been presented in Figure-5. Taking Zero (0) error as reference level, it can be observed that cooperative relaying technique achieves reference level at 28 dB, Cooperative diversity scheme at 16 dB and cooperative diversity with relay selection at 12dB. Clearly the performance of cooperative network is shown to be enhanced by 12dB through diversity and further 4dB is enhanced by LLR based relay selection.

IV. CONCLUSION

In this research Dual Hop Cooperative STBC system is developed for regenerative (decode and forward) and non-regenerative (amplify and forward scheme). This system architecture utilizes the benefits of cooperative communication and space time coding to provide array gain and diversity gain in single antenna communication system. To further enhance system performance, LLR based relay selection scheme is applied to the adopted system architecture. Bit error rate is considered as a performance evaluation parameter and Zero (0) BER is taken as reference level. Simulation results on the basis of Bit-Error-Rate vs. Signal-to-noise Ratio have been presented.

Finally the simulation results for cooperative relaying, cooperative diversity and cooperative diversity with relay selection has been compared and it is observed that cooperative diversity performs 12dB better than cooperative relaying scheme and cooperative diversity with relay selection provides 4dB better performance than cooperative diversity scheme.

On the basis of above observations it can be concluded that:

- Application of diversity in cooperative relaying i.e. applying Alamouti space time coding to cooperative relaying enhances system performance up to 12dB.
- Application of LLR relay selection in Cooperative diversity (Cooperative STBC) improves system performance by 4dB.

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