Implementation of Co-Operative Diversity and Space Time Coding In Wireless Networks

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Abstract: A Wireless Ad-hoc network is an autonomous and self-organizing network without any centralized controller. Cooperative communication is a technique used to increase the reliability and the quality of service (QoS), coverage area range. Space time coding and spatial diversity schemes enhances the performance of the wireless networks. Such networks can be used in military communications and have lot of prospective for civilian applications, to include commercial and educational use, calamity management, road vehicular network etc. In this paper, Decode and Forward with Cooperative diversity and the Alamouti Space Time coding with cooperative diversity has been evaluated, which are primarily used to relay multiple-input multiple-output communications in distributed clustered two hop relaying network. In Decode and Forward Cooperative diversity, an Ad-hoc network consisting of a source, a destination and a third station as a relay is analyzed with Rayleigh flat fading channel by using different combining techniques. Combining techniques such as Equal Ratio Combining (ERC), Maximum Ratio combining (MRC) and Fixed Ratio Combining (FRC) with cooperative diversity have been compared. From the comparison of three combining techniques it is found that FRC improves system performance by reducing the BER. In Alamouti Space Time coding, a 2x2 Alamouti coding has been implemented with the cooperation of two relays with Stanford University Interim (SUI) channel. The data is modulated using Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). Simulation results show that, in order to achieve BER of $10^{-4}$ Cooperative diversity with DAF protocol at relay and FRC at the receiver reduces the SNR by 6dB as compared to that of a single link transmission. Alamouti Cooperative space time coding reduces the SNR by 8dB in order to achieve the BER of $10^{-4}$ as compared to that of Alamouti space time coding. The location of relay in between source and the destination has high influence on the performance of the network. MATLAB is used to evaluate the bit error rate for the Cooperative wireless communication.

Keywords: Cooperative Communication, MRC, FRC, ERC, Rayleigh, Decode And Forward(DAF), Alamouti Space Time Coding.

I. INTRODUCTION

Cooperative wireless network is a promising technology for future communication systems, because cooperation in ad hoc networks can save limited network resources including energy savings. Diversity in wireless communication network can be achieved by cooperative techniques, which is inherent in a wireless medium. The fundamental idea of cooperative networks is that the signals are transmitted to the destination with the help of single antenna relays, which provide the spatial diversity to the system. Using relays in wireless networks can potentially lead to significant capacity increment. The goal of the cooperative diversity is to increase the reliability, quality of service (QoS), coverage area range and the data throughputs as well as to improve the spectral efficiency of the wireless networks while prolonging the life of the nodes or user terminals by increasing energy efficiency. Emerging wireless applications such as sensor and wireless mesh networks have an increasing demand for small and low cost devices that are densely deployed over a wide area network. The development of the wireless network is hindered by the limited battery lifetime of devices and the scarce bandwidth shared by the large number of users. Therefore, many research efforts has been made in the field of wireless communication in order to maximize the system performance under the respective resource constrained environment. The effectiveness of these solutions could be limited by the uneven resource distribution among the users, which is especially true in highly dynamic and aggressive environments. If the users are willing to share their local resources and cooperate in transmitting each other’s message, these issues can be resolved. This is the essence of cooperative communication.

In a wireless transmission due to fading caused by multipath propagation, the signal quality degrades. To reduce such effects diversity can be used to transfer the different samples of the same signal over essentially independent channels. In this paper diversity is realized by using a third station as a relay. In [3], a decode-and-forward relaying scheme, was introduced. Later in [4, 5] a modified version for multipath...
fading channels was proposed for the single-antenna receiver case. Cooperative diversity for a simple three-terminal relay channel was first introduced in [6]. Although compared to MIMO full diversity gains are not achieved due to single antenna elements, data rate gains can be achieved compared to the non-cooperative cases [6]. By combining signals through different paths from different users in receiver node, both spatial diversity and user diversity are fully exploited, which dramatically enhances system performance in terms of reliability and throughput [7].

The capacity of the three-node network consisting of a source, a destination, and a relay has been analyzed. It was assumed that all nodes operate in the same band, so the system can be decomposed into a broadcast channel from the viewpoint of the source and a multiple access channel from the viewpoint of the destination. Many ideas that appeared later in the cooperation literature were first explained in [8]. The advantages of multiple-input multiple-output (MIMO) systems have been widely acknowledged, to the extent that certain transmit diversity methods like Alamouti signaling [7] have been incorporated into wireless standards. Although transmit diversity is clearly advantageous on a cellular base station, it may not be practical for certain other scenarios like wireless sensor networks, mobile ad-hoc networks etc. Specifically, due to size, cost, power or hardware limitations, a wireless agent may not be able to support multiple transmit and receive antennas [8]. In [11], a new terrain is proposed for SUI propagation model equations. It is based on the new woody cities found in the Amazon region. The parameter for the proposed terrain is obtained from the LS (least square) optimization based on 5.8 GHz path loss data.

Part I describes the user cooperation scenario, while Part II focuses on implementation issues and performance analysis. The rest of the paper is organized as follows. Cooperative communication, Relaying protocol, cooperative Space time coding are explained in section II. System model, channel model, receiver model and different combining techniques are explained in section III. Simulation results are given in section IV. Concluding remarks are given in section V.

II. COOPERATIVE COMMUNICATION

Cooperation in wireless networks has been proven to be an advantageous technique. In wireless communications cooperation is regarded as the sharing of the resources and encoding and decoding capabilities of the network users. Distributed terminals cooperate to relay signals to distant terminals. For practical reasons all the terminals in a given area of interest need not cooperate with other terminals. In a network consisting of cluster, only selected terminals of a cluster participate in the cooperative communication scheme. Cooperative diversity is a technique used to achieve spatial diversity in a network. Cooperative diversity is applied to achieve spatial diversity between the closely located and correlated antennas in MIMO communication. In cooperative communication transmit diversity and receive diversity can be achieved by using more than one cooperative transmitter and cooperative receiver respectively.

A. Cooperative Spatial Diversity and Multiplexing

A signal is said to be spatially diverted when it is being carried to the destination not only by one wireless channel, but by using multiple parallel independent channels. Hence in spatial diversity scheme [13] the information message is copied in space, time, frequency domain and is transmitted through all the possible independent fading channels $h_{ij}$ between the $i^{th}$ source and the $j^{th}$ destination of the wireless medium that are between the transmitter and the receiver. The multiple copies of the information to the receiver provides redundancy to the system since the probability that all copies experience deep fading is highly reduced. Cooperative spatial multiplexing occurs when independent wireless relays deliver different and spatially multiplexed portions of the information signal to the destination [13]. Cooperative spatial multiplexing takes the advantage of the spatial (uncorrelated channels due to dispersion of antennas) and frequency (orthogonal frequency channels) diversity gain of a multi terminal network to increase data rates and decrease outage probability [14] compared to traditional forwarding schemes.

B. Relaying Protocol

Amplify and Forward (AAF) or Decode and Forward (DAF) are the cooperative communication protocols. The protocol used here is DAF.

1. Decode and Forward (DAF):

Fig.1. Decode and Forward Relaying.

Fig.1 describes a simple Decode and forward relaying. The wireless transmission is rarely analogue and the relay has enough computing power, so DAF is usually preferred method to process the data in the relay. The received signal is first decoded and then re-encoded. So there is no amplified noise in the sent signal, as is the case using an AAF (Amplify and forward) protocol. The relay can decode the original message completely which requires a lot of computing time, but has numerous advantages. The decoded bits can be corrected if the source message contains error correcting code at the relay station. Or if there is no such code implemented a checksum allows the relay to detect if the received signal contains errors. Depending on the implementation an error free signals can be sent to the destination. But it is not always possible to fully decode the source message. The additional delay caused to fully decode and process the message is not acceptable, the relay might not have enough computing capacity or the source...
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message could be coded to protect sensitive data. In such a case, the incoming signal is just decoded and re-encoded symbol by symbol. So neither an error correction can be performed nor a checksum can be calculated.

C. Analysis of DAF Protocol

The transmitted signals are detected by cooperatively combining the received signal $y_{zd}$ from the source and $y_{rd}$ from the relay with the knowledge of the channel coefficients $h_{zd}$ (between the source and the destination) and $h_{rd}$ (between the relay and the destination). The combined signal at the MRC (maximum ratio combining) detector is given by

$$y = a_1 y_{zd} + a_2 y_{rd}$$

Equation (1)

In (1) the factors $a_1$ and $a_2$ are determined such that the SNR of the MRC output is maximized [39].

$$a_1 = \frac{\sqrt{P_x h_{zd}}}{N_0} \quad a_2 = \frac{\sqrt{P_x h_{rd}}}{N_0}$$

Equation (2)

Assuming that transmitted symbol ‘x’ in (1) and (2) has average energy of 1J, then the SNR at the output is computed as shown in equation (3).

$$SNR = \frac{P_x |h_{zd}|^2 + P_x |h_{rd}|^2}{N_0}$$

Equation (3)

In (3) $P_x$ is the transmitted power at the source, $P_x = P_2$ if the relay decodes the transmitted symbol correctly, otherwise $P_x = 0$. SER formulations for an uncoded system with M-PSK modulation is given by

$$\psi_{PSK}(SNR) \triangleq \frac{1}{\pi} \int_0^{(M-1)\pi/M} \exp \left( \frac{b_{PSK} \cdot SNR}{\sin \theta} \right) d\theta$$

Equation (4)

In (4) $b_{PSK} = \sin^2(\pi/M)$ [39], therefore the instantaneous SNR in (3), the conditional SER of the system with the channel coefficients $h_{zd}$, $h_{sr}$ and $h_{rd}$ can be written as

$$P_{PSK} = \psi_{PSK}(SNR)$$

Equation (5)

The probability of correct decoding is $1 - \psi_{PSK}(P_x |h_{zd}|^2/N_0)$ [39] and the probability of incorrect decoding is $\psi_{PSK}(P_x |h_{zd}|^2/N_0)$.

D. Cooperative Space Time Coding

Real time voice and image transmissions over a wireless network demand high data rates and quality of service (QoS). Space time coding was developed to increase both reliability and channel capacity. There are two broad categories of space time codes, which are targeted to increase reliability/QoS of MIMO communications and those developed to offer higher data rates. Alamouti is a scheme targeted to provide reliability and BLAST [15] is an architecture that offers high rates by providing spatial multiplexing. Alamouti proposed an algorithm that offers transmit diversity to increase reliability in flat fading channels. The technique is ideal for two transmission antennas and as many reception antennas as possible. The equations for a system with two transmission antennas and one reception antenna (2x1) and a system with two transmission and two reception antennas (2x2) were derived in [16]. The Alamouti space time coding scheme can achieve full spatial diversity gain (a gain of two for 2x1 scheme and a gain of four for 2x2 scheme) without decreasing the achieved data rates, since there is also a spatial multiplexing gain of order two which doubles the achieved data rates. Since two symbols are transmitted during second time slot, the reduction in the achieved rate that occurs because of the retransmission of the symbols at the second time slot is compensated.

E. Alamouti Cooperative 2x2 Space Time Coding

The Alamouti space time coding scheme for the system with two transmission antennas and two reception antennas with the relays are shown in Fig.2. The complex channel coefficient $h_{ij}$ are assumed to be constant across two consecutive symbol periods from $i$th transmission to $j$th reception antenna. Let $X_1$ and $X_2$ are the information symbols to be transmitted. The system during the first symbol period transmits $[X_1, X_2]$ and during the second symbol period transmits $[-X_1^*, X_1^*]$, where $X_1^*$ denotes the complex conjugate of $X_1$ and $T$ denotes the symbol transmission period as shown in Table 1. The channel coefficients $h_{ij}$ are assumed to be constant during two consecutive symbol periods [3].

$$h_{ij}(t) = h_{ij}(t + T)$$

Equation (6)

The system performance between the two independent user’s $s_1$ and $s_2$ are evaluated separately. Sources and relays are single antenna mobile terminals. The two source terminals are denoted as $s_1$ and $s_2$. The two relays are denoted as $R_1$ and $R_2$. The destination is assumed to be a dual antenna terminal. All terminals in the upper path are assumed to have same SNR at reception. All the terminals operates in half duplex mode and apply coherent detection to the received signal using a ML detector. The received signals at $R_1$ are:

$$r_1(t) = h_{11}(t) X_1(t) + h_{12}(t) X_2(t) + n_1(t)$$

Equation (7)

$$r_2(t) = h_{21}(t) X_1^*(t) + h_{22}(t) X_2^*(t) + n_2(t + T)$$

Equation (8)

At time instances $t$ and $t+T$ respectively.
In (7) \( n(t) \) represents noise at relay 1. \( r_1(t) \) and \( r_2(t) \) represent the received signals at \( R_1 \). The decoded signals are calculated in the decoder/ combiner of \( R_1 \) as:

\[
\hat{x}_2(t) = h_{12}(t) r_1(t) + h_{22}(t) r_2(t)
\]

(9)

\[
\hat{x}_2(t) = h_{12}(t) r_1(t) - h_{22}(t) r_2(t)
\]

(10)

At \( R_2 \) the received signals are:

\[
r_3(t) = h_{12}(t) X_1(t) + h_{22}(t) X_2(t) + n_2(t)
\]

(11)

\[
r_4(t) = -h_{12}(t) X_1^*(t) + h_{22}(t) X_2^*(t) + n_2(t+T)
\]

(12)

At time instances \( t \) and \( t+T \), respectively.

In (11) \( n_1(t) \) represents noise at relay 2. The decoded signals are calculated in the decoder/ combiner of \( R_2 \) as:

\[
\hat{x}_3(t) = h_{12}(t) r_3(t) + h_{22}(t) r_4(t)
\]

(13)

\[
\hat{x}_4(t) = h_{12}(t) r_3(t) - h_{22}(t) r_4(t)
\]

(14)

The estimated symbols are then sent to the maximum likelihood detector. Each relay namely \( R_1 \) and \( R_2 \) make separate estimations \([\hat{x}_2(t), \hat{x}_2(t)]\) and \([\hat{x}_3(t), \hat{x}_4(t)]\) respectively. The received signals at receive antenna 1 of destination are:

\[
d_1(t) = h_{11}(t) \hat{x}_2(t) + h_{21}(t) \hat{x}_2^*(t) + n_1(t)
\]

(15)

\[
d_2(t) = h_{11}(t) \hat{x}_2(t) + h_{21}(t) \hat{x}_2^*(t) + n_1(t+T)
\]

(16)

At time instances \( t \) and \( t+T \) respectively.

In (15) \( n_1(t) \) represents noise at receiver 1. At receiver antenna 2, the received signals are:

\[
d_3(t) = h_{12}(t) \hat{x}_3(t) + h_{22}(t) \hat{x}_4(t) + n_2(t)
\]

(17)

\[
d_4(t) = -h_{12}(t) \hat{x}_3(t) + h_{22}(t) \hat{x}_4(t) + n_2(t+T)
\]

(18)

Since the destination terminal is a dual antenna device. The estimates of the signals are calculated in the decoder/ combiner as follows:

\[
\hat{x}_1(t) = h_{11}(t) d_1(t) + h_{12}(t) d_1^*(t) + h_{21}(t) d_2(t) + h_{22}(t) d_2^*(t)
\]

(19)

\[
\hat{x}_2(t) = h_{11}(t) d_1(t) - h_{12}(t) d_1^*(t) + h_{21}(t) d_2(t) - h_{22}(t) d_2^*(t)
\]

(20)

The destination terminal decodes symbols using a maximum likelihood detector.

F. BER Analysis for Alamouti Cooperative Space Time Coding

The probability that the destination correctly decodes the symbol is equal to the probability that at least one antenna decodes it correctly, hence the probability of symbol error is the probability that both reception antennas decode wrongly. The bit error rate \( P_b \) for the BPSK modulation in AWGN conditions and with noise power spectral density \( \frac{N_o}{2} \) is calculated based on energy per bit to noise spectral density (PSD) ratio:

\[
P_b = Q\left(\sqrt{\frac{2E_b}{N_o}}\right)
\]

(21)

In (21) \( E_b \) is the energy per bit and can be represented as the signal power \( P_s \frac{E_b}{T_b} \), where \( T_b \) is the bit period. The noise transmission equivalent bandwidth for BPSK is \( B = \frac{N_o}{2} \), thus the noise power is \( P_n = N_oB = N_o/T_b \) and substituting in (21) gives

\[
P_b = Q\left(\sqrt{\frac{2P_s}{N_o}}\right)
\]

(22)

By defining \( SNR = \frac{P_s}{P_n} \), the bit error probability \( P_b \) is given by

\[
P_b = Q\left(\sqrt{\frac{2}{SNR}}\right)
\]

(23)

In Alamouti 2x2 cooperative space time coding, there is a receive diversity of order 2 and 4 at relay and receiver respectively. The bit error probability \( P_m \) at relay is given by

\[
P_m = Q\left(2\sqrt{SNR}\right)
\]

(24)

The bit error probability \( P_{bd} \) at receiver is given by

\[
P_{bd} = Q\left(2\sqrt{SNR}\right)
\]

(25)

For the computation of total error probability \( P_m \), sum of all error probabilities of all the possible cases are considered

\[
P_m = P_{bd} - P_{bd}(1-P_{br}) + P_{bd}P_{br}(1-P_{br}) + P_{bd}(1-P_{bd})P_{br} + P_{bd}(1-P_{bd})(1-P_{br})P_{br}
\]

(26)

\[
= P_{bd} - P_{bd}P_{br} - P_{bd}P_{br}^2 + P_{br}^2
\]

(27)

III. SYSTEM MODEL

There are numerous ways to implement diversity in a wireless transmission. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination may be too far away to get good signal quality. If antennas are placed close to each other then there will be interference between the signals. To get diversity, an interesting approach might be to build an ad-hoc network using another mobile station as a relay. The model of such a system is illustrated in Fig.3. The source \( S \), sends the data to the destination \( D \), while the relay station \( R \) is listening to this transmission. The relay sends this received data burst after successfully decoding, where the two received signals are combined. As proposed in [10], orthogonal channels are used for the two transmissions.

Fig.3. A Cooperative Communication model with one Relay.

The transferred data is a random bipolar bit sequence which is either modulated with Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). In Fig. 4 QPSK in fact consists of two independent (orthogonal) BPSK systems and therefore has double bandwidth compared to BPSK.
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Fig.4. a) BPSK, b) QPSK, I denotes the in phase channel, and Q the quadrature phase channel.

A. Channel Model

In a wireless network, the data is propagated through air in order to transmit the signals from one point to another. During propagation several phenomena will distort the signal. In this paper, thermal noise, path loss and Rayleigh fading are considered and illustrated in Fig. 5. Path loss and fading are multiplicative whereas noise is additive.

\[ y_d[n] = h_d[n] \cdot x_s[n] + z_{sd}[n] = d_{sd} \cdot a_{sd}[n] \cdot x_s[n] + z_{sd}[n] \]  

(28)

In (28) s,d denote the source respective to the destination in the selected single link transmission, \( x_s[n] \) is the transmitted symbol and \( y_d[n] \) is the received symbol.

Noize: The main sources of noise in a wireless network are interference and electronic components like amplifiers. The scalar \( z_{sd}[n] \) can then be simulated as the sum of a real and an imaginary noise vector, both Gaussian distributed, mutually independent and zero mean with variance \( \sigma_n^2 \). The total noise power will be \( N_o = 2\sigma_n^2 \).

Signal To Noise Ratio: The signal-to-noise ratio (SNR) is a widely used value to indicate the signal quality at the destination.

\[ \text{SNR} = \left( \frac{S}{N_o} \right) = \left| h_{sd} \right|^2 \cdot \frac{E[x_s^2]}{N_o} \]  

(29)

In (29) \( E[x_s^2] \) denotes the energy of the transmitted signal and \( N_o \) denotes the total power of the noise.

Path Loss and Fading: The signal is attenuated mainly by the effects of free-space path loss and fading, both included in \( h_{sd} = d_{sd}^{-1} \cdot a_{sd} \). The path loss \( d_{sd} \) is proportional to \( \frac{1}{R^2} \), where \( R \) is the distance between sender and receiver. As long as the distance between the sender and receiver does not change too much, it can be assumed to be constant for the whole transmission. The fading coefficient \( a_{sd} \) can be modelled as a zero mean, Complex Gaussian random variable with variance \( \sigma_{sd}^2 \). This means that the angle \( \angle a_{sd} \) is uniformly distributed on \([0, 2\pi)\) and the magnitude \( |a_{sd}| \) is Rayleigh distributed [10].

Receiver Model: The receiver detects the received signal symbol by symbol. In the case of a BPSK modulated signal the symbol/bit is detected as

\[ y_{d}[n] = \begin{cases} +1 & (\text{Re}[y_d[n]] \geq 0) \\ -1 & (\text{Re}[y_d[n]] < 0) \end{cases} \]  

(30)

For a QPSK modulated signal there are two bits transferred per symbol, which are detected as

\[ y_{d}[n] = \begin{cases} +1,+1 & (0^\circ \leq \angle y_d[n] < 90^\circ) \\ -1,+1 & (90^\circ \leq \angle y_d[n] < 180^\circ) \\ +1,-1 & (-90^\circ \leq \angle y_d[n] < 0^\circ) \\ -1,-1 & (-180^\circ \leq \angle y_d[n] < -90^\circ) \end{cases} \]  

(31)

Combining Techniques: There are more than one incoming transmission with the same burst of data, therefore the incoming signals have to be combined before they are compared. Different combining techniques used here are Equal Ratio Combining (ERC), Fixed Ratio Combining (FRC) and Maximum Ratio Combining (MRC).

Equal Ratio Combining (ERC): ERC is used if the channel quality is very complex to be estimated and also if the computing time is a critical point, where all the received signals can just be added up. This is the easiest way to combine the signals, but the performance will not be that good in return.

\[ y_{d}[n] = \sum_{i=1}^{k} y_{i,d}[n] \]  

(32)

As one relay station is used, equation (32) simplifies to

\[ y_{d}[n] = y_{s,d}[n] + y_{r,d}[n] \]  

(33)

In (33) \( y_{s,d}[n] \) denotes the received signal from the sender \( y_{r,d}[n] \) the received signal from the relay.

Fixed Ratio Combining (FRC): The incoming signals instead of just adding up as in the case of ERC they are weighted with a constant ratio, which will remain constant during the whole communication. A much better performance can be achieved, when fixed ratio combining is used. The ratio should represent the average channel quality and therefore should not take account of temporary influences on the channel due to fading or other effects. But influences on the channel, which change the average channel quality, such as the distance between the different stations, should be considered. The FRC can be expressed as

\[ y_{d}[n] = \sum_{i=1}^{k} d_{i,d}[n].y_{i,d}[n] \]  

(34)

In (34) \( d_{i,d}[n] \) denotes weightage of the incoming signal \( y_{i,d}[n] \). Using one relay station, the equation simplifies to
\[ y_{d}[n] = d_{s,d}[n] \cdot y_{s,d}[n] + d_{r,d}[n] \cdot y_{r,d}[n] \]  
\[ \text{(35)} \]

In (35) \( d_{s,d}[n] \) denotes the weightage of the direct link, \( d_{r,d}[n] \) the one of the multi-hop link. The best achievable performance of an FRC system is of interest. So the best ratio is approximated by comparing different possible values. The ratio is then used to compare with the other combining methods.

**Maximum Ratio Combining (MRC):** The Maximum Ratio Combiner (MRC) achieves the best possible performance by multiplying each input signal with its corresponding conjugated channel gain. This assumes that the channel phase shift and attenuation is perfectly known by the receiver.

\[ y_{d}[n] = \sum_{k=1}^{K} h_{s,d}[n] \cdot y_{s,d}[n] \]  
\[ \text{(36)} \]

In (36) \( h_{s,d}[n] \) represents the complex conjugate of the channel coefficient \( h_{s,d}[n] \). Using singlerelay system, this equation can be rewritten as

\[ y_{d}[n] = h_{s,d}^{*}[n] \cdot y_{s,d}[n] + h_{r,d}^{*}[n] \cdot y_{r,d}[n] \]  
\[ \text{(37)} \]

In (37), \( h_{s,d}^{*}[n] \) represent the complex conjugate of channel coefficient \( h_{s,d}[n] \) of the direct link and \( h_{r,d}^{*}[n] \) represents the complex conjugate of channel coefficient \( h_{r,d}[n] \) from relay. The performance of a two sender transmission with MRC at the receiver can be expressed [9] as

\[ P_{b} = \frac{1}{4} (1 - \mu)^2 (2 + \mu) \]  
\[ \text{(38)} \]

where,

\[ \mu = \sqrt{\frac{\text{SNR}_{\text{avg}}}{1 + \text{SNR}_{\text{avg}}}} \]  
\[ \text{(39)} \]

where, \( \text{SNR}_{\text{avg}} \) denotes the average signal-to-noise ratio.

**BER and SNR analysis:** The signal quality received at the destination depends on the SNR of the channel and the way the signal is modulated. The theoretical probability of a bit error is derived in [9] and can be written as follows:

For BPSK,  
\[ P_{b} = \frac{1}{2} (1 - \sqrt{\frac{\text{SNR}_{\text{avg}}}{1 + \text{SNR}_{\text{avg}}}}) \]  
\[ \text{(40)} \]

For QPSK,  
\[ P_{b} = \frac{1}{2} (1 - \sqrt{\frac{\text{SNR}_{\text{avg}}}{2 + \text{SNR}_{\text{avg}}}}) \]  
\[ \text{(41)} \]

where, \( \text{SNR}_{\text{avg}} \) denotes the average signal-to-noise ratio, defined as

\[ \text{SNR}_{\text{avg}} = \frac{1}{2} E(a^2) \]  
\[ \text{where, } E(a^2) = a^2. \]

To calculate the SNR of a multi-hop link using DAF, first the BER of the link is calculated which can then be translated to an equivalent SNR. To calculate the SNR, the inverse functions of those are used. For a BPSK modulated Rayleigh faded signal

\[ \text{SNR} = \frac{1}{2} [Q^{-1}(BER)]^2 \]  
\[ \text{(42)} \]

For a QPSK modulated signal

\[ \text{SNR} = \frac{1}{2} [Q^{-1}(BER)]^2 \]  
\[ \text{(43)} \]

**IV. SIMULATION RESULTS**

The decode and forward cooperative scenario for three terminals is simulated using Rayleigh flat fading model and Alamouti Cooperative scheme is simulated using SUI (Stanford University Interim) model [41]. The modified SUI channel models consist of a set of 6 typical channels used to simulate the IEEE 802.16 channel models. They are proposed for a scenario where the cell size is 7km, the BS (Base Station) antenna height is 30m, the receive antenna height is 6m, the BS antenna beam width is 120 degrees. Each modified SUI channel model has three taps. Each tap is characterized by relative delay (with respect to first path delay), a relative power, a Rician k-factor, and a maximum Doppler shift [12]. SUI channel 1 parameters are taken out from [12].

<table>
<thead>
<tr>
<th>Table II: Parameters of SUI-1 Channel</th>
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<tr>
<td>Channel</td>
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</tr>
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<td>Delay</td>
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The performance of Decode and Forward protocol is analyzed when direct link is used and also when relay is present. The signals are modulated either by Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). Different combining techniques such as Equal Ratio Combining (ERC), Maximum Ratio Combining (MRC) and Fixed Ratio Combining (FRC) are compared either by BPSK or QPSK. The performance of FRC is analyzed by giving different weightages. The effect of location of relay has been analyzed by placing the relay at different positions.

Fig.6. Different combining techniques are compared with BPSK.
The diversity is realized by building an ad-hoc network in which third station acts as a relay. The data is sent directly from the base to the destination or via a relay. Selection of combining method has a big effect on the error rate at the receiver. In Fig.6 and Fig.7 FRC (Fixed Ratio Combining) outperforms from ERC (Equal Ratio Combining), MRC (Maximum Ratio Combining) and also from single link transmission. In order to achieve the bit error rate of $10^{-4}$ the use of FRC at the receiver shows 6 decibels reduction in SNR (Signal to Noise Ratio) when compared to that of single link transmission. The use of ERC or MRC shows almost 2 decibels reduction in SNR as compared to that of single link transmission.

The FRC with different weightages to estimate the ratio that results in the best performance. Fig.8 shows that, best performance can be achieved when the ratio of 3:1 is used. Therefore the FRC with the ratio of 3:1 has been used to implement Decode and Forward protocol with Cooperative diversity with BPSK and QPSK as a modulation techniques.

Fig.8. FRC with different ratios.

Fig.9. Different positions of relay in between source and receiver.

Fig.9 shows simulation results with different positions of relay. To see the effect of the relay position, the relay is relocated from the optimum position between the sender and destination. If the relay is placed very close to the sender, the whole arrangement resembles approximately to a two sender system. The best performance is attained, when the relay is situated in the middle between the sender and the destination, or somewhat closer to the sending station. The preferred position of the relay is exactly at the Centre i.e. between the sender and the destination. If this is not possible, the relay should be closer to the sender than to the destination.

Fig.10. Alamouti Cooperative space time coding with BPSK for the SNR difference between two paths as 3db.
Fig.11. Alamouti Cooperative space time coding with QPSK for the SNR difference between two paths as 3db.

Fig.10 and Fig.11 shows that, Alamouti Cooperative space time coding out performs the Alamouti space time coding. In order to achieve the BER of $10^{-4}$ the use of Alamouti Cooperative space time coding shows 8 decibels reduction in SNR as compared to that of Alamouti space time coding.

V. CONCLUSION

In this paper the performance of Decode and Forward (DAF) Cooperative communication and Alamouti Cooperative space time coding have been analyzed. DAF shows reduction in bit error rate as compared to that of Amplify and Forward protocol as obtained in [1] when only one relay is used.. In order to achieve the bit error rate of $10^{-4}$ the use of DAF at the relay with FRC at the receiver and Alamouti Cooperative space time coding shows 6 and 8 decibels reduction in SNR (Signal to Noise Ratio) as compared to that of a single link transmission respectively. Cooperative schemes require network establishment, time synchronization and terminal localization for simultaneous receptions in order to eliminate the distributed cooperative algorithms in an environment where the terminals are randomly dispersed. The parameters such as achieved data rates, outage probabilities and power consumption are important to analyze cooperative diversity. The evaluation of these parameters with respect to Alamouti cooperative scheme will be the future scope.

VI. REFERENCES


