Performance Analysis for DAF Cooperative Communication with different combining and modulation techniques.

Mohammed Mahboob Ali[1], Ms Kamakshi M B[2]

1.Mohammed Mahboob Ali
Student, Dept. of Telecommunication Engineering
R. V. College of Engineering
Bangalore, India

2. Ms Kamakshi M B
Assistant Professor, Dept. of T.E
R. V. College of Engineering
Bangalore, India

***Abstract*—Cooperative communication has been proposed in order to increase the reliability and the quality of service (QoS), coverage area range, and the data throughputs as well as improve the spectral efficiency of the wireless networks while prolonging the life of the nodes or user terminals by increasing energy efficiency. In this paper an Ad-hoc network consisting of a source, a destination and a third station as a relay is analyzed. Different combining techniques such as Equal Ratio Combining (ERC), Maximum Ratio Combining (MRC) and Fixed Ratio Combining (FRC) has been compared. The signal is modulated using either by Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). The channel consists of path loss and Rayleigh fading which are multiplicative components and thermal noise which is additive. Decode and forward protocol has been used at the relay. The location of relay in between source and destination has high influence on the performance of the network. MATLAB is used throughout to evaluate the bit error rate for the cooperative wireless communication.**

Keywords—Cooperative communication, MRC, FRC, ERC, Rayleigh, BPSK, QPSK, Decode and forward(DAF)

I. INTRODUCTION

Cooperative wireless networks are the promising technology for future communication systems because cooperation in ad hoc networks can save limited network resources, including energy savings. Diversity in a wireless communication networks 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 increases. The goal of cooperative diversity is to increase the reliability and the quality of service (QoS), coverage area range, and the data throughputs.

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 exposited 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, but 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].

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. Proposed model, channel model, relaying protocol, performance analysis are explained in section II. Different combining techniques are explained in section III. Simulation results are given in section IV. Concluding remarks are given in section V.

II. PROPOSED MODEL

There are numerous way 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 is just too

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far away to get good signal quality, if antennas are placed closed 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 1

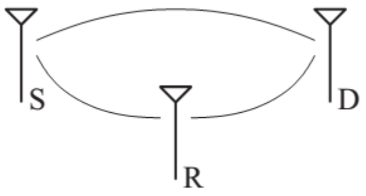

Fig. 1. A Cooperative Communication model with one Relay.

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.

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. 2 QPSK in fact consists of two independent (orthogonal) BPSK systems and therefore has double bandwidth compared to BPSK.

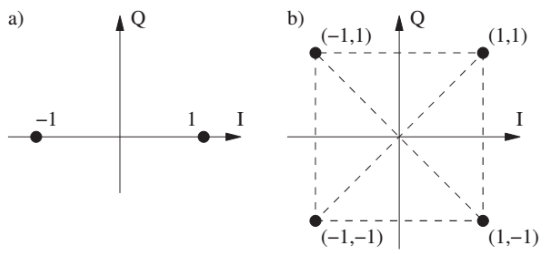

Fig. 2. a) BPSK, b) QPSK, I denotes the in phase channel, and Q the quadrature phase channel.

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. Within this paper, thermal noise, path loss and Rayleigh fading are considered, as illustrated in Fig. 3. Path loss and fading are multiplicative, noise is additive.

$$y_d[n] = \underbrace{h_{s,d}[n]}_{attenuation} \cdot x_s[n] + z_{s,d}[n] = \underbrace{d_{s,d}}_{path\ loss} \cdot \underbrace{a_{s,d}[n]}_{fading} \cdot x_s[n] + \underbrace{z_{s,d}[n]}_{noise} \quad (1)$$

In (1) s, d denote the source respective the destination in the selected single link transmission, $x_s[n]$ is the transmitted symbol and $y_d[n]$ the received symbol.

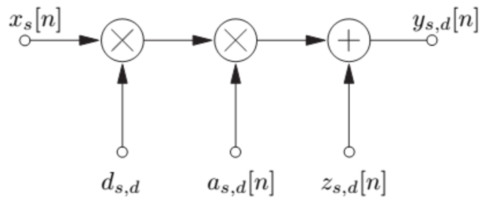

Fig 3. Channel model: path loss $d_{s,d}$, fading $a_{s,d}[n]$ and noise $z_{s,d}[n]$.

1) Noise

The main sources of noise in a wireless network are interference and electronic components like amplifiers. The scalar $z_{s,d}[n]$ 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 σ_n^2. The total noise power will be $N_o = 2\,\sigma_n^2$.

2) Signal to noise ratio

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

$$\text{SNR} = \left(\frac{S}{No}\right) = \frac{|h_{s,r}|^2 \zeta}{N_o} \quad (2)$$

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

3) Path Loss and Fading

The signal is attenuated mainly by the effects of free-space path loss and fading, both included in $h_{s,d} = d_{s,d} \cdot a_{s,d}$. The path loss $d_{s,d}$ 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 power of the received signal is attenuated proportional to $\frac{1}{R^4}$.

The fading coefficient $a_{s,d}$ can be modelled as a zero mean, Complex Gaussian random variable with variances $\sigma_{s,d}^2$.This means that the angle $\angle a_{s,d}$ is uniformly distributed on $[0\ 2\pi)$ and the magnitude $|a_{s,d}|$ is Rayleigh distributed [10].

B. 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

$$\widehat{y_d}[n] = \begin{cases} +1 & (\text{Re}\{y_d[n]\} \geq 0) \\ -1 & (\text{Re}\{y_d[n]\} < 0) \end{cases} \quad (3)$$

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

$$\widehat{y_d}[n] = \begin{cases} [+1,+1] & (0^\circ \leq \angle y_d[n] < 90^\circ) \\ [-1,+1] & (90^\circ \leq \angle y_d[n] < 180^\circ) \\ [+1,-1] & (-90^\circ \leq \angle y_d[n] < 0^\circ) \\ [-1,-1] & (-180^\circ \leq \angle y_d[n] < -90^\circ) \end{cases} \quad (4)$$

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C. Relaying protocol

The cooperative transmission protocols used in the relay station are either Amplify and Forward (AAF) or Decode and Forward (DAF). The protocol used here is DAF.

1) Decode and Forward (DAF)

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, it 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 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.

D. 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

For BPSK, $$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{SNR_{avg}}{1+SNR_{avg}}}\right) \quad (5)$$

For QPSK, $$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{SNR_{avg}}{2+SNR_{avg}}}\right) \quad (6)$$

Where, SNR_{avg} denotes the average signal-to-noise ratio, defined as $SNR_{avg} = \frac{\zeta}{2\sigma^2} E(a^2)$. 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 BSPK modulated Rayleigh faded signal this will be

$$SNR = \frac{1}{2}[Q^{-1}(BER)]^2 \quad (7)$$

For a QPSK modulated signal this will change to

$$SNR = [Q^{-1}(BER)]^2 \quad (8)$$

III. COMBINING TECHNIQUES

There is 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).

A. 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.

$$y_d[n] = \sum_{i=1}^{k} y_{i,d}[n] \quad (9)$$

As one relay station is used, so the equation simplifies to

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \quad (10)$$

In (10) $y_{s,d}[n]$ denotes the received signal from the sender $y_{r,d}[n]$ the received signal from the relay.

B. 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

$$y_d[n] = \sum_{i=1}^{k} d_{i,d}[n].y_{i,d}[n] \quad (11)$$

In (11) $d_{i,d}[n]$ denotes weightage of the incoming signal $y_{i,d}[n]$.

Using one relay station, the equation simplifies to

$$y_d[n] = d_{s,d}[n] \, . \, y_{s,d}[n] + d_{s,r,d}[n] \, . \, y_{r,d}[n] \quad (12)$$

In (12) $d_{s,d}[n]$ denotes the weightage of the direct link, $d_{s,r,d}[n]$ the one of the multi-hop link. The best achievable performance of a 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.

C. 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.

$$y_d[n] = \sum_{i=1}^{k} h_{i,d}^*[n].\, y_{i,d}[n] \quad (13)$$

In (13) $h_{i,d}^*[n]$ represents the complex conjugate of the channel coefficient $h_{i,d}[n]$.

Using a one relay system, this equation can be rewritten as

$$y_d[n] = h_{s,d}^*[n] \, . \, y_{s,d}[n] + h_{r,d}^*[n] \, . \, y_{r,d}[n] \quad (14)$$

In (14) $h_{s,d}^*[n]$ represent the complex conjugate of channel coefficient $h_{s,d}[n]$ of the direct link, $h_{r,d}^*[n]$ represent the

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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

$$P_b = \frac{1}{4}(1-\mu)^2(2+\mu) \quad (15)$$

Where,

$$\mu = \sqrt{\frac{SNR_{avg}}{1+SNR_{avg}}}$$

Where, SNR_{avg} denotes the average signal-to-noise ratio and given in (6).

IV. SIMULATION RESULTS

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.

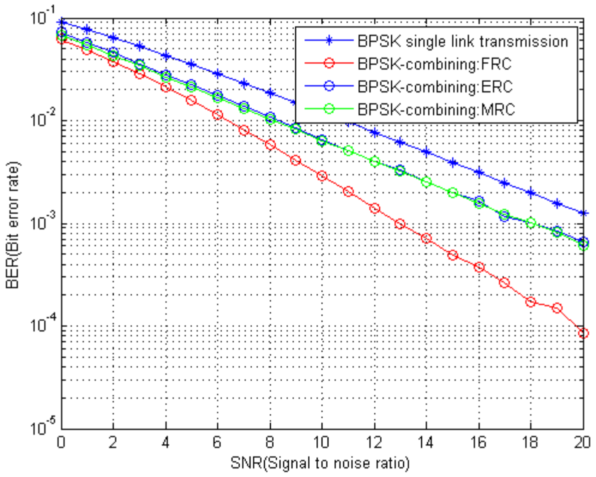

Fig. 3 Different combining techniques are compared with BPSK.

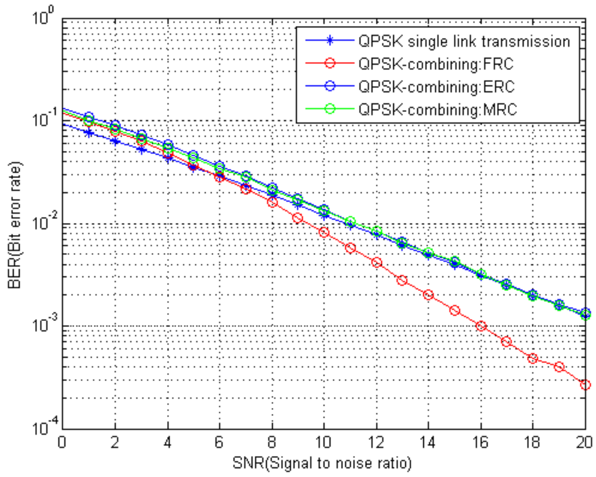

Fig. 4 Different combining techniques are compared with QPSK.

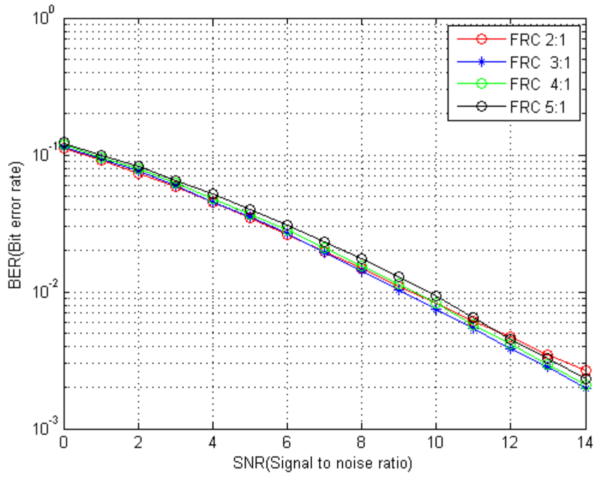

Fig. 5 FRC with different ratios.

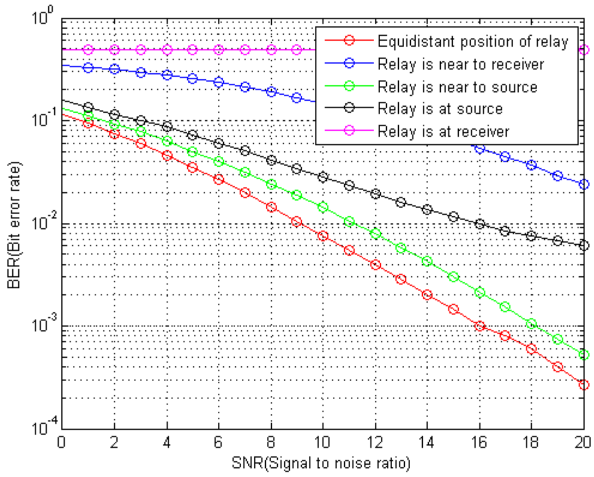

Fig. 6 Different positions of relay in between source and receiver.

Fig 3 and fig 4 shows the graph of plot for direct link and multi hop with different combining techniques with BPSK and QPSK as modulation techniques respectively. FRC shows the best performance in combining techniques with the ratio 3:1. The ratio 3:1 shows the best performance in Fig. 5. Fig. 6 shows the best results can be achieved when relay is placed at the same distance from source and destination.

V. CONCLUSION

In this paper the performance of Decode and Forward (DAF) Cooperative communication has 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 future the performance of DAF Cooperative communication can be analyzed by using transmit diversity and also it can be enhanced by using more than one relay such a system shows high level of diversity.

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