Performance Analysis of Cooperative Communication System with a SISO system in Flat Fading Rayleigh channel

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Abstract. In recent years cooperative communication has emerged as a promising technique to enhance system capacity, reliability and performances in resource-limited wireless environment. This paper presents performance analysis and comparison of a three node cooperative communication system with a single input single output (SISO) system in a flat fading Rayleigh channel with negative SNR. The simulations' results show that the system performance can be improved by using cooperative communication techniques even when the inter-user channel is not good. The performance metric used for analysis is BER at a particular direct link SNR.

Keywords: “SISO”, “Cooperative Communication”, “Rayleigh Channel”

1. Introduction

In wireless transmission the signal quality suffers severe degradations due to effects like fading caused by multipath propagation. To reduce such effects, diversity can be used to transfer the different samples of the same signal over essentially independent channels [1]. There are several approaches to implement diversity in a wireless transmission investigated by researchers. Multiple antennas can be used to achieve space diversity [2]. The advantages of multiple-input multiple-output (MIMO) systems have been widely acknowledged, to the extent that certain transmit diversity methods like Alamouti signaling [2] 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 [3]. To overcome these limitations of sensor networks Sendonaris et al. [4], [5] introduced the concept of cooperation among wireless terminals for spatial diversity. Authors concluded that user cooperation is able to effectively achieve robustness against fading. Cooperative communication generates this diversity in a different and interesting way. It should be noted that cooperative relaying is substantially different from traditional multihop methods. This traditional relay model in information theory is discussed in detail by Cover and El Gamal [6].

Cooperative communication systems exploit the spatial diversity gains inherent in multiuser wireless systems without the need of multiple antennas at each node. This is achieved by having the users relay each other's messages and, thus, forming multiple transmission paths to the destination. Cooperation in communication networks results when terminals use their power, time, and bandwidth resources to mutually enhance their transmissions which results in increasing capacity and multiplexing gain and also helps to combat the effects of fading. Thus single antenna station or nodes can also reap the benefits of a MIMO system.

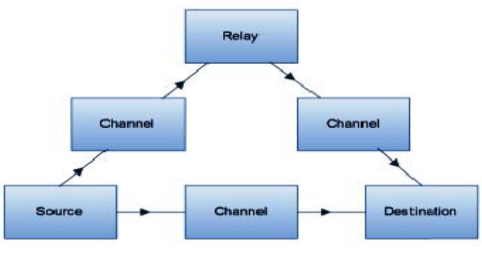

Fig. 1: A simple three node cooperative communication system.

2. System Overview

In any wireless system, it is desired to maintain a high quality link between the Source (S) and the Destination (D) nodes but in any practical system, issues like multipath fading, shadowing and distance may decrease the actual performance below acceptable limits. With the help of a cooperating Relay(R) node, performance can be improved by combining signals from this second path via the relay with those transmitted from the originating source [3]. The cooperative communication system consists of a source, relay, channels, and destination. The output of the source is transmitted through two different channels. One channel is from source to destination, the other is from the source to relay and then from relay to destination. The signal once received at the relay is then transmitted to the destination, possibly after applying some signal processing techniques on it. The processing of signal at the relay incurs some delay in the transmission of signal.

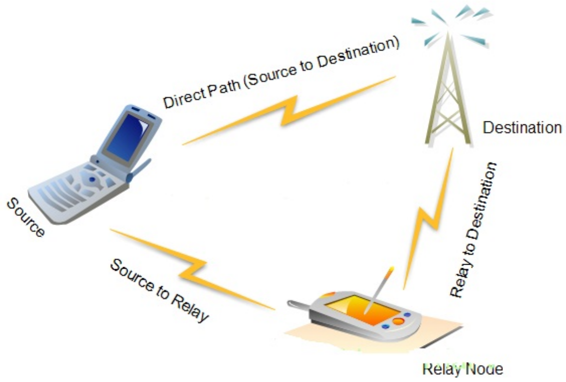

Fig. 2: Three node wireless cooperative network.

The source generates a stream of information bits. Typically, a random bit generator is employed in simulations. These bits are mapped onto symbols and optionally applied with pulse shaping. The output from the source is fed through a channel, for simulation purposes this paper discusses flat fading channel. The relay receives the signal and then retransmits it by using some cooperative diversity protocols. In this paper Amplify and forward, Detect and Forward and Decode and Forward techniques are discussed. The destination block takes the output from both channels and does optimal combining, two types of combining techniques have been used namely equal gain combining and maximal ratio combining, and then demodulate and estimate the received symbols into information bits. Typically, in a simulation environment, we simply count the number of errors that occurred to gather statistics used for investigating the performance of the system (Bit error probability). This paper discusses performance of three node cooperative model but the extension to four node network with two transmitters can be found in [5 - 15].

2.1. Amplify and Forward (AAF)

This method is often used when the relay has only limited computing time/power available or the time delay has to be minimized. The signal received by the relay is attenuated and needs to be amplified before it can be sent again [3].The major drawback of this protocol is that by doing amplification the noise in the signal is also amplified [7]. Thus the incoming analog signal is only multiplied with an amplifying factor and then retransmitted by the relay.

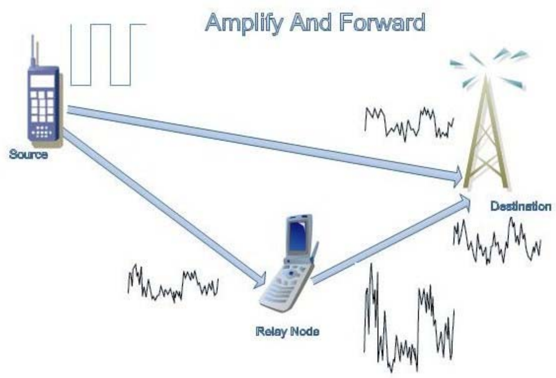

Fig. 3: Amplify and Forward technique.

2.2. Detect and Forward (DAF)

In this protocol the relay node receives the signal, demodulates it, detects the transmitted bits and then retransmits the estimate of the received symbols, obtained via hard detection, towards destination [8, 9]. It involves a lot of processing at the relay therefore it cause increase in time delay in detect and forward in comparison with amplify and forward.

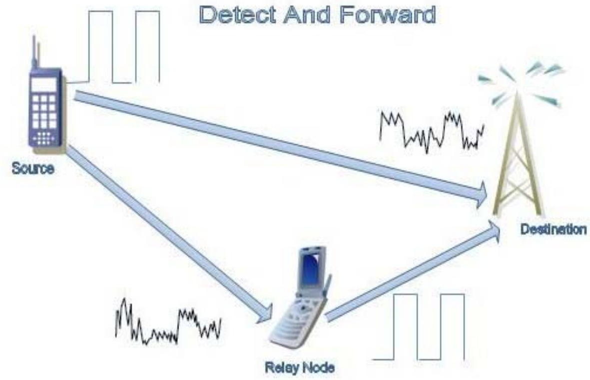

Fig. 4: Detect and Forward technique.

2.3. Decode and Forward (DeAF)

In decode and forward protocol the relay decodes the received packet and transmits a fresh codeword using either the same code as the one used at the source or a new one. In our simulations the fresh codeword transmitted by relay is same as the one used at the source. In decode and forward channel coding is used to correct the erroneous transmission. Thus processing and transmission delay at relay is longest in decode and forward protocol as compared to the other two protocols mentioned in the text.

In most of the research papers detect and forward and decode and forward are used interchangeably and both of them are believed to be one and same thing. But in this paper simulations are done in the way which differentiates between the two on the basis of channel coding i.-e. in detect and forward no channel coding is used while in decode and forward the source message contains an error correcting code, received bit errors might be corrected at the relay station. For our simulations we have used half (1/2) rate channel coding.

3. Methodology

The implemented cooperative system operates under Time Division Multiplexing (TDM) protocol where the Source transmits data during the first time slot and the Relay transmits during the second slot. In this paper, we assume that the transmission is half-duplex, i.e. nodes can not send and receive data simultaneously. The data transmitted during the first time slot is received by both the Relay and Destination nodes. During the second time slot, the Relay retransmits the data to the Destination node [10]. There are three major techniques for data retransmission and have been already described in the paper. The system described here uses all three schemes and then compare their performance on the basis of received BER of the signals received at destination. For our system we have used certain assumptions, which are numerated below:

- At the destination we have perfect knowledge of channel,
- The system is perfectly synchronized,
- The relay node is equidistant from both source and destination.
- Channel used is single tap flat fading channel with additive white Gaussian noise (AWGN) and the amplitude attenuation due to distance is also taken into account, as the distance increases the attenuation increases, amplitude (A) or power of signal decreases $A\alpha \, ^1\!/_d$.
- All the three channels are independent, as explained in [11] that it is observed that if two or more radio channels are sufficiently separated in space, frequency, or time, and sometimes in polarization,

then the fading on the various channels is more or less independent; i.e., it is then relatively rare for all the channels to fade together.

To ensure a fair comparison, we maintain the same total consumed energy per bit for both cooperative and non-cooperative scenarios. In other words, sum of the energy that transmitter and relay nodes consume in cooperative mode equals the energy of transmission in non-cooperative or SISO system as in [12].

4. Results and Analysis

The performance analysis of the point-to-point transmission had been investigated by many papers [13, 14], but in this paper we have analyzed the performance of cooperative communication techniques for single tap flat fading channels. This work deals with the analysis of error rate performance in which the direct link (source to destination link) has very low SNR. For simulations the transmit power and receive gain at each node were adjusted to provide a low-quality wireless link between S-D, a relatively good-quality link between S-R and R-D. Our simulation results show that even for negative SNR i.-e. the noise power of channel is greater than the transmitted signal power, of direct path cooperative protocols performs better than typical SISO system. Thus we can say that even when the source to destination channel is in outage we can communicate to destination by using cooperative strategies.

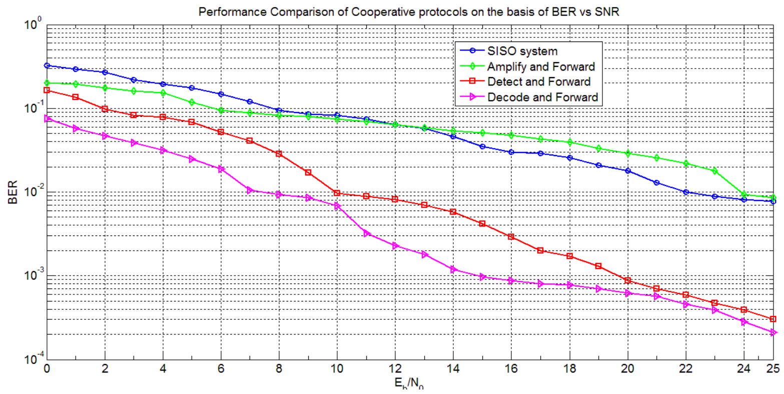

Fig. 5: performance comparison of SISO and Cooperative Strategies.

From the Fig. 5 we note that the SISO (blue) curve crosses amplify and forward (green) curve when the direct channel SNR is about 11.8 dB. This is because of the fact the SNR increases the channel effects on the signal become less hostile thus the signal received through direct path also become less erroneous. It should be kept in mind that the SNR of S-R and R-D is about 5dB while that of S-D is in the range of [0, 25]. So the signal received at relay is not very good, and in amplify and forward the noise is also amplified. Thus this signal when combined with a relatively better signal at the destination may distort the overall received signal and may affect the final detection. But even for comparatively high direct link SNR other two cooperative strategies outperform SISO system.

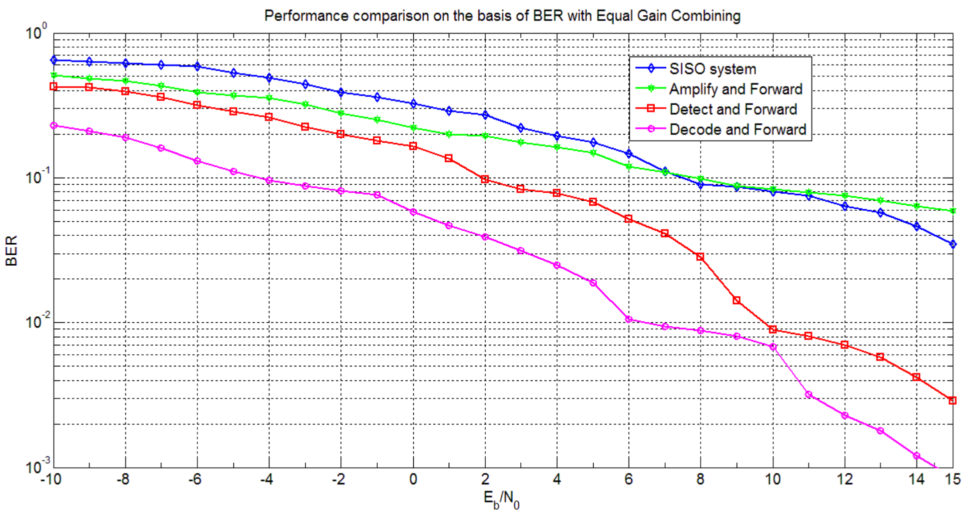

Fig. 6: Performance comparison of SISO and cooperative with Negative SNR of direct channel and EGC at the

destination.

In cooperative strategies we see that Detect and Forward gives better performance than Amplify and Forward but Decode and Forward out-powers all others and give the best performance even under hostile channel conditions. This is because for negative SNR scenarios where noise power is greater than signal power this amplification of noise in AAF can affect the signal badly. It should be noted that our amplifying factor is dependent upon the source to relay channel gain, channel variance and transmit power of the signal [9]. The difference in the performance of DAF and DeAF is due to the fact that bits if detected wrongly at the relay in DAF, it will be forwarded towards the destination without being corrected but in DeAF the erroneous bits are corrected at the relay with the help of channel coding used which in this case is convolutional coding. Thus these corrected bits are once again encoded before being transmitted to the destination.

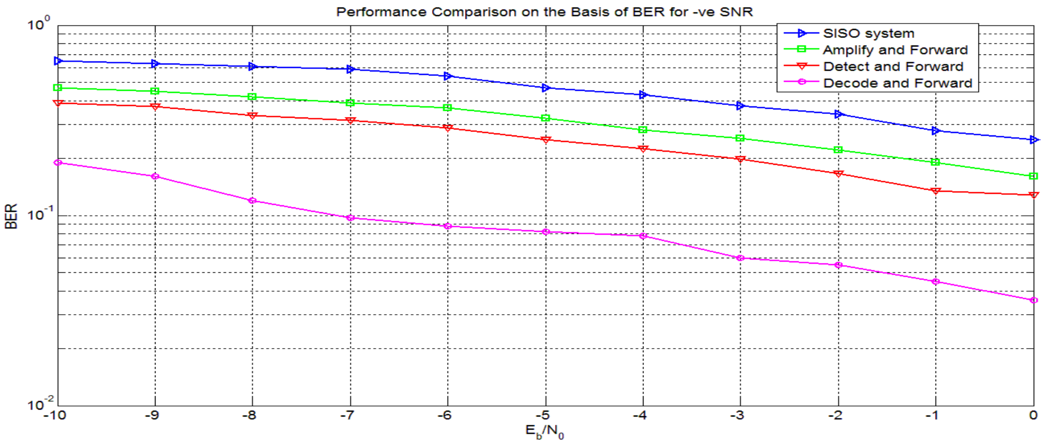

Fig. 7: Performance comparison curve with MGC at the destination.

The destination combines the signals coming from the source and the relays, enabling higher transmission rates and robustness against channel variations due to fading [7]. For cooperative strategies we have used two types of combining techniques.

4.1. Equal Gain Combining (EGC)

This is the easiest way to combine the signals, all the received signals can just be added up, but the performance will not be that good in return. This is usually done when channel quality could not be estimated [9]. Figure 6 shows the performance comparison of cooperative strategies with ECG at the receiver.

4.2. Maximal Ratio combining (MRC)

In maximal ratio combining (MRC) technique we multiply each input signal with its corresponding conjugated channel gain. This assumes that the channels' phase shift and attenuation is perfectly known by the receiver [9].

In figure 6 the SISO curve outperforms AAF curve at about the direct channel SNR of 7dB. This is so because for both the figures 6 and 7 the SNR for S-R and R-D is kept at 3.5dB, which means the communication conditions are very hostile and both the links available for the transmission of data are not very good.

From the comparison of figure 6 and 7 it is evident that the results of maximal ratio combining techniques for cooperative communication system are far better than those of equal gain combining, especially when one of the channels i-e S-D channel is very bad with very low SNR. It is because MRC gives weight to each signal in relation to its channel gain, assuming that the channel conditions are known at the receiver.

In Fig. 7 the direct link S-D channel is in outage, typically when channel conditions are so hostile no communication is possible, but we can see that cooperative strategies are performing fairly well especially DeAF shows a notable low BER considering extreme conditions of channel. If efficient signal processing techniques and error coding algorithms are used at relay the system performance can be improved further, the only drawback is that it will increase processing delay. But generally in data communications processing delay is not a big concern.

5. Conclusion and Future Work

The cooperative communication system shows a large improvement in measured BER as compared to the SISO or direct path using the same modulation/demodulation scheme. These measured results show that the spatial diversity introduced by a cooperative system can improve the system performance as compared to other traditional wireless systems. Thus it can be used in future wireless systems and adhoc networks to improve link reliability.

6. Acknowledgements

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