# COMPARATIVE STUDY OF RELAY PROTOCOLS USING SIMULATION

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**ABSTRACT**

*Cooperative communication has gained a lot of interest due to its ability to exploit the spatial diversity or antenna diversity. The implementation of the cooperative relaying systems involves less hardware and low complexity but gives comparable performance and diversity gains to the actual multiple antenna systems. The aim of this paper is to compare various techniques used in cooperative relaying protocols. The performance is evaluated in terms of average symbol error under various ranges of signal-to-noise ratio (SNR) probabilities. A three node system i.e. source, relay and destination, placed on the edges of equilateral triangle, has been proposed using Maximal ratio Combiner (MRC) method by combining signals from source and relay at destination point. The transmission path is modeled as a frequency non-selective Rayleigh fading in the presence of additive white Gaussian noise (AWGN). The results show that at high SNR decode-and-forward performs well, while at low SNR amplify-and-forward works well. A selective relaying scheme called selective detect-and-forward is also simulated which shows better performance than its fixed counterparts for a wide range of SNR.*

**KEYWORDS:** *MIMO, Cooperative MIMO, Relay Techniques, Nodes, Additive White Gaussian Noise (AWGN).*

## INTRODUCTION

In communication systems, single path transmission shows performance degradation due to multipath propagation[1,2,3]. The transmissions of communication signals experience sever errors due to fading[4,5]. In such a situation the system performance can be improved if multiple paths are provided between the source node and the destination node. In multiple paths, it is more likely that all paths are in different fades simultaneously. The communication system error rate can be significantly improved by combining independently fading signals[2,3,5]. The technique in which multiple independent fading paths are provided to the signal is called diversity. In diversity technique the varying properties of wireless channel are exploited.

There are different types of diversity which include frequency, time, polarization, spatial and cooperative diversity[7]. Spatial diversity is achieved by providing multiple antennas at the transmitter end or receiver end or both. This type of diversity is sometimes termed as antenna diversity[6,8]. If these antennas are separated sufficiently, then the independent paths are achieved between different antenna pairs. Sufficient diversity is provided by a separation in terms of half of the carrier wavelength. In case multiple antennas are used for transmission, then it is termed as MISO i.e. Multiple Input Single Outputs[9,10,11].

The paper explains all models in detail considered for this research in the subsequent sections.

## RESEARCH MODEL USED

### SYSTEM MODEL

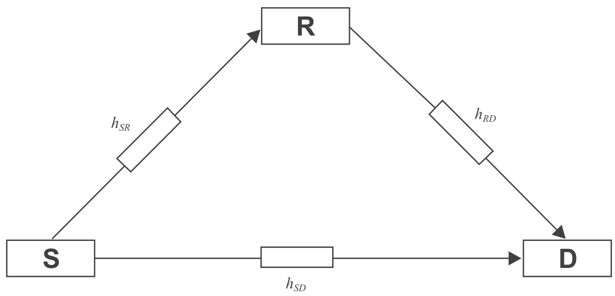


Figure 1: System Model

Figure 1 shows the generic system model that has been considered by various researchers[1,2,3].

The model consists of a single relay (R), the source node (S) and the destination node (D). All the nodes are placed at the edges of an equilateral triangle. The channel from source to relay is represented by $h_{SR}$, channel from relay to destination is represented by $h_{RD}$ while that of source to destination is represented by $h_{SD}$. The channel from source to destination is termed source uplink, source to relay is termed as inter-user channel while relay to destina-

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tion is called relay uplink channel. It is assumed here that all the nodes are working as half duplex with single transmit and receive antenna. It is further assumed that the relay node is perfectly aware about the inter-user channel conditions and the destination node is fully aware of all the transmission paths and fading conditions. Due to half duplex, the nodes can either transmit or receive the information at a given time. The relay and source node are placed in one cell, equivalent to a scenario when two mobile users are communicating in the same cell. The destination node is considered as the base station communicating with mobile users. This system model only considers the case of uplink i.e. from mobile node to a destination. Due to broadcast nature of transmission from source, a nearby relay node also receives the source transmission. The relay then process the information according to some diversity protocol and finally the information is forwarded to the ultimate receiver i.e. destination[2,5,6]. At the destination MRC combiner is used to combine the two signals i.e. directly from the source and from source via relay and extracts the required information from the signals[3,7,11].

## SIMULATION MODEL

MATLAB has been used as a tool for simulation using Monte-Carlo type simulation setup because it is considered the best suitable for random variables. $10^5$ bits are transmitted for error rate calculation, and the results are averaged for 50 iterations.

## CHANNEL MODEL

Channel model is shown in Figure 2. The wireless channel considered for this model is Frequency non-selective Rayleigh faded channel with Additive White Gaussian Noise (AWGN). All the channels are identically distributed, and independently modeled as complex Gaussian Random process. It has zero mean and variance equal to unity. Here the subscript ij represents the node pair. These nodes are connected through respective channels i.e. inter-user channel (SR), source uplink channel (SD), and relay uplink channel (RD). The noise is considered to be complex random process given by $Z = Zi + jZ_R$ .

$$y_{ij} = \sqrt{P_t} h_{ij} x + Z_{ij} \tag{1}$$

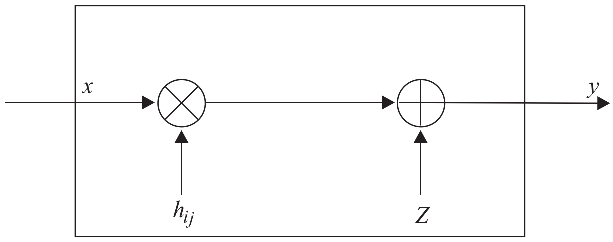


Figure 2: Channel Model

Here Zi represents real[12] while $Z_R$ imaginary part of noise. The noise follows Gaussian distribution having zero mean and variance[2].

The selected channel is slowly fading in which the fading co-efficient remains constant for one symbol period. Other wireless parameters such as path loss and shadowing effect are not considered for the sake of simplicity.

## SIGNAL MODEL

Binary Phase Shift Keying (BPSK) is used for the modulation of a signal. In simulation, the frequency up/down conversion of modulation is dropped and the base band signals are used hence equation reduces to:

$$x(t) = \begin{cases} A & for\ d_i = 1 \\ -A & for\ d_i = 0 \end{cases} \tag{2}$$

Here $d_i$ represents $i_{th}$ bit that is in the data sequence. This $i_{th}$ bit is generated by the source. Equation can be simplified as:

$$x(t) = \begin{cases} +A & for\ d_i = 1 \\ -A & for\ d_i = 0 \end{cases} \tag{3}$$

So that the transmitted signal can be taken from both source and relay as a sequence of 1's and -1's.

## RELAY MODEL

Figure 3 shows the block diagram of relay node used. The transmitted power of Relay is taken as normalized Pt=1, similar to the source transmitted power. The BPSK signal modulation model is also used by Relay. Likewise source transmission, relay signal is in the form of 1's and -1's. It is assumed here that relay is perfectly aware of inter-user channel. It detects the source signal and has the capability of to equalize the effects of inter-user channel. The signal


Figure 3: Relay Model

detected at the relay is further processed using some cooperation scheme. The signal is finally sent to the destination.

## COOPERATIVE STRATEGIES

Four types of cooperation protocols have been used and compared, three fixed and one selective cooperation protocol. There are two conditions, one in which the relay cooperates with a source in all conditions, it is termed as fixed relaying. Amplify-and-Forward (AF), Decode-and-Forward (DF) and Detect-and-Forward (Dtf) are fixed cooperation schemes[10,11,12,15]. The other scheme is when it cooperates conditionally; it is called selective or adaptive relaying. Selective Detect-and-Forward is adaptive scheme. For comparison, symbol error rates are used.

## SIMULATION RESULTS AND ANALYSIS

Monte Carlo simulation has been performed on various cooperation protocols. An equidistant arrangement is considered for simulation. Moreover, two symbol error rate (SER) reference curves are used for the sake of fair comparison. The SER curve is plotted against the Signal to Noise Ratio (SNR) on horizontal axis of the all the graphs. First one is the SER curve which represents the Single-input Single-output (SISO) scenario i.e. the direct transmission from source to destination without using intermediate path[1,2,10,16]. The second SER curve shows the second order diversity with two transmit antennas. To get a better picture of the analysis, all the selected cooperation protocols are compared with these two reference curves[16,17].

## WHEN ALL THE CHANNELS HAVE SAME AVERAGE SNR

Figure 4 and Figure 5 shows SER graphs of the relayed signal having same average SNR and the MRC combined signal having same SNR respectively for comparison. In Figure 4, signal has been relayed for all the protocols while Figure 5 shows the result of combined signal i.e. the combination of relayed signal with direct transmission employing MRC on the destination side. Figure 4 shows better relayed signal for DF as compared to AF and Dtf at mid-high SNR. Here it can be seen that none of the relayed signals show good performance. In Figure 5, these relayed signals are combined at destination using MRC. After the combination, the relayed signal and the direct transmission on the destination side shows better performance of AF and DF. Here, the Dtf does not shows significant performance as compared to other two protocols. Figure 5 shows that the performance of DF

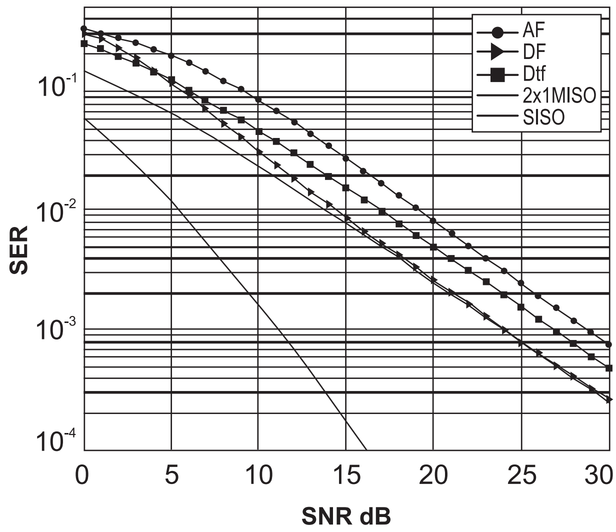


Figure 4: Relayed signal when all the channels have same average SNR

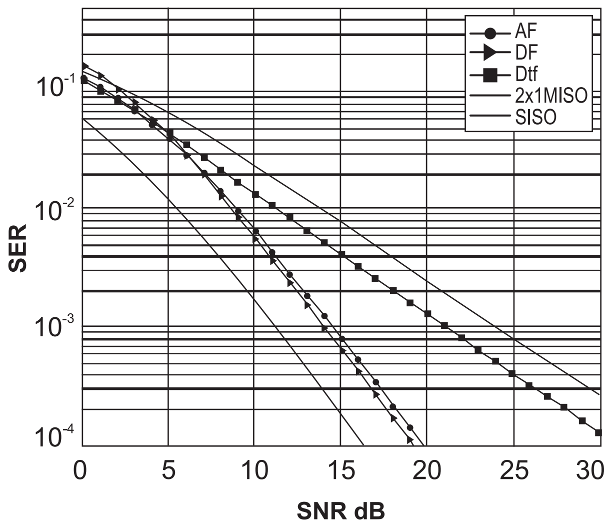


Figure 5: MRC combined signal when all the channels have same average SNR

is not significant at low SNR because at low SNR, the relay can decode the signal perfectly and the error remains in the signal. Furthermore, these errors propagate in the relayed signal and reaches destination, which, limits the benefits of DF at low SNR.

In Figure 5, it can be clearly observed that both AF and DF achieves full diversity and acts as diversity order 2,while for Dtf only first order diversity can be clearly observed. The other worth noting behavior is the performance of AF. Although this is a very simple protocol, but it gave similar performance compared to DF. The reason is that the combiner MRC is most suitable for AF[19,20,21].

## GOOD INTER-USER CHANNELS

Figure 6 shows an SER versus SNR graph showing the comparative analysis of the channels. The analysis is based on the assumption that both the relay and source are very near to each other or they are cooperating with each other in the same street. Better inter-user channel means less error propagation, hence greatly improving the performance of DF and Dtf. The figure shows full diversity gains for both AF and DF. Their error

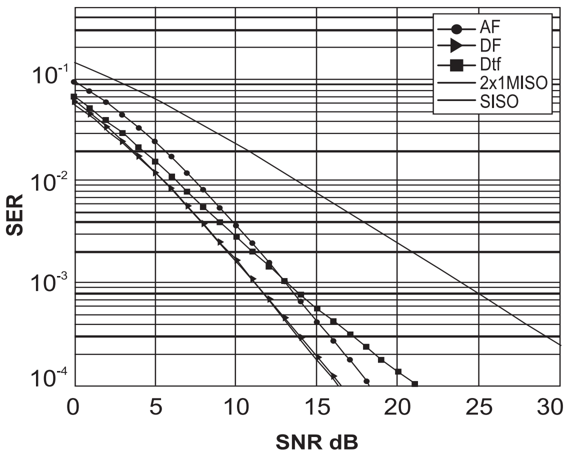


Figure 6: +10 dB advantage for inter-user channel as compared to other channels

rate curves perform similar to diversity order 2 (2×1 MISO). A simple protocol like Dtf also gives good performance because of good inter-user channel. The graph shows a 10 dB advantages in SNR for the inter-user channel as compared to other two uplink channels.

## POOR INTER-USER CHANNEL

Figure 7 shows the graph for a 10 dB weaker inter-user channel as compared to other two uplink channels. This scenario is based on the assumption of having an obstacle or building in between the source and relay. The analysis is based on the SNR values. Results shows when the inter-user channel is bad the performance of all the protocols degrades. DF and Dtf shows worse error rate curves because of unsuccessful decoding/detection at the relay. AF still shows better performance as compared to other two

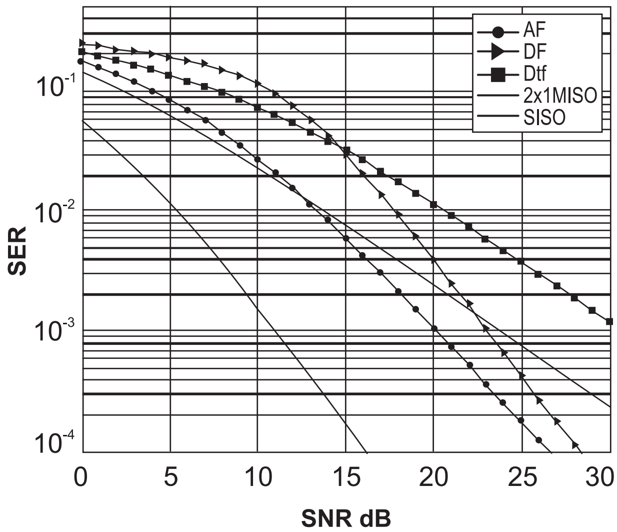


Figure 7: 10 dB worse inter-user channel as compared to other two channels

schemes. At low-mid SNR it can be seen that direct transmission curves (SISO) outperform other cooperation schemes. It can be concluded that both AF and Dtf fully depend upon the quality of inter-user channel. Worse inter-user channel means more error propagation in relayed signal; hence error propagates all the way to receiver which limits the benefits of cooperation.

Figure 7 shows worse performance for AF at low SNR. Low SNR means high errors and a noisy signal. AF amplifies the noise along with the signal. At low SNR the relay receives a very noisy signal. When this signal is propagated in second hop, it limits the benefits of cooperation. The performance of AF is still better than decoding and detection based protocols. This is due to the fact that AF considers the noise in amplification factor i.e. amplification factor is inversely proportional to the noise when considering received signal. Incase of worse, the direct path from source to destination should be preferred for communication.

**GOOD SOURCE UPLINK**

Figure 8 is based on a scenario when the source is very close to receiver (Base station) and there is almost no obstacle in their communicating path. In

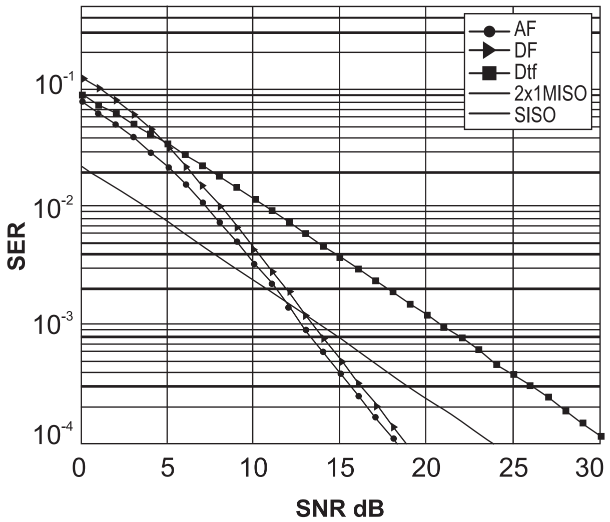


Figure 8: +10 dB advantage for source uplink as compared to other two channels

this case, it is assumed that a 10 dB advantage is given to the source uplink as compared to inter-user and relay uplink channel. Results show good performance for AF at high SNR, while at low SNR it outperforms DF and Dtf but it can be observed that none of the protocols give good diversity gains at low-mid SNR. The error curve for direct transmission (SISO) gives significant performance over cooperation protocols. AF cooperation scheme is still the best.

**POOR SOURCE UPLINK**

Figure 9 shows a 10 dB weaker source uplink channel as compared to other two channels. This scenario assumes when there is an obstacle between source and destination, making the source uplink weaker. In this case cooperation the relay gives significant performance. Results show higher error rates for direct transmission (SISO). Fairly good diversity gains are achieved due to diversity protocols for a wide range of SNR. In this case, DF outperforms AF and Dtf, even a low complexity protocol like Dtf provides significant diversity gains. Another worth noting point is the better performance of DF as compared to the theoretic curve for second order diversity (2×1 MISO). Apparently the result seems incorrect because DF cannot outperform second order diversity but the result is correct indeed. The curve for 2×1 MISO is simulated with the link that is 10 dB weaker than other two channels. The other two channels have 10 dB advantages over source uplink which justifies this unpredictable result.

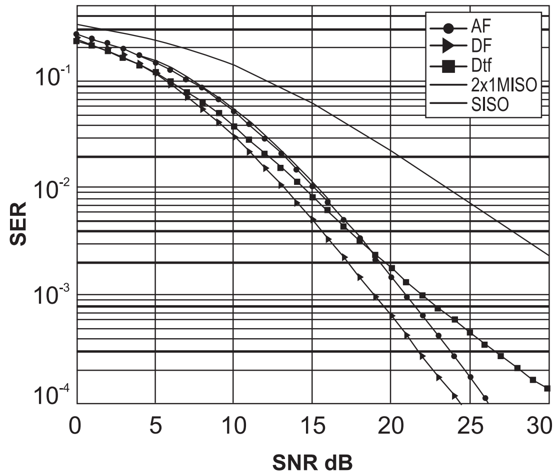


Figure 9: 10 dB worse source uplink channel as compared to other two channels

Thus a user with poor uplink can be considered a best candidate for cooperation. Such a user can greatly benefit from cooperation because with better inter-user and relay uplink channel the DF outperforms all other diversity protocols.

**GOOD RELAY UPLINK**

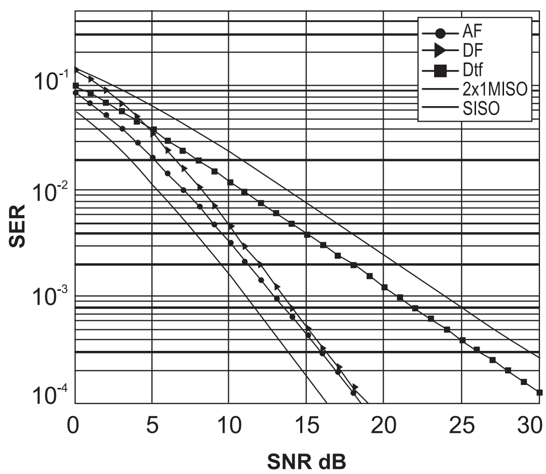


Figure 10: +10 dB advantage for Relay uplink as compared to other two channels

Figure 10 shows a graph of a 10 dB advantage for relay uplink as compared to other two channels. Result shows significantly improved performance in terms of SNR for AF and DF but the performance of Dtf can be considered as a coding gain. At low SNR, DF shows high error, which is due to the unsuccessful decoding. Although the overall performance of the AF provides better diversity gains than DF but still the applications which works at high SNR can select DF as better candidate.

## POOR RELAY UPLINK

Figure 11 shows the graph of a scenario of a 10 dB weaker link as compared to other two channels. Source uplink and inter-user channel shares the same channel conditions, means they have same average SNR. It is clear from the figure that DF is somewhat better than AF and Dtf. AF also shows good diversity gains at high SNR but Dtf shows little gain. The results show that none of the diversity protocols is giving good performance gain at low-mid SNR. The system which requires low power for its operation cannot benefit from these diversity protocols when the relay has poor uplink. However the applications that operates at high power, can still benefit from DF in this particular scenario.

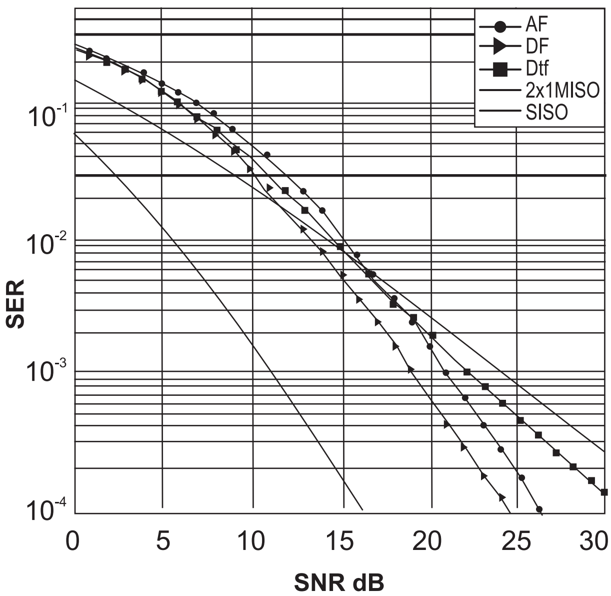


Figure 11: 10 dB worse relay uplink channel as compared to other two channels

The graph shown in Figure 11 depicts poor performance of DF at low SNR but a sharp improvement with increasing SNR. Significant improvement in performance of AF is observed as compared to DF from the very low range of SNR. Inspite of its simplicity, AF competes with DF at high SNR. A very low complexity protocol like DtF gives no performance gain except at very high SNR. The cooperative communication having a bad source uplink will get diversity gains with the help of a relay node with better uplink channels. A relay with poor uplink should not be involved in cooperation.

## SELECTIVE DETECT AND FORWARD (S-DTF)

In Figure12, SER based comparison has been shown for S-Dtf with all other previously discussed fixed relaying strategies. All the channels are assumed to have same average SNR for uplinks and inter-user channel. The adaptive or selective detect and forward error rate curve for S-Dtf is showing an outstanding performance for Dtf with selective relaying the superiority of Dtf over the fixed relaying. A diversity order 2 for S-Dtf is observed from the very low range of SNR. It can be deduced from the results that S-DtF attains full diversity and performs better than both AF and DF. This protocol has been designed on the basis of ideal detection. The relay only detects and forwards the correct received bits which means no error propagation in the relayed signal. This argument justifies the outstanding performance of S-Dtf. The practical performance of S-Dtf depends on its design and implementation in terms of strength or capability of error detection scheme used. In practice, the performance of S-Dtf is worse as compared to the abovementioned protocols.

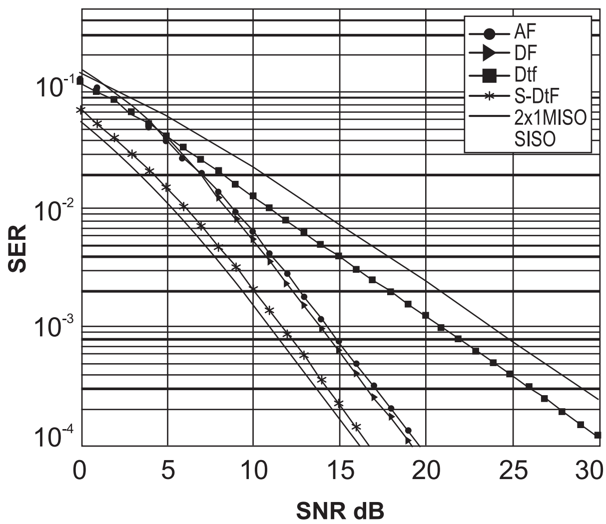


Figure 12: MRC combined signal for channels having same average SNR

**CONCLUSION.**

This research investigated different cooperative schemes for a generic relaying system. The aim is to understand the advantages and shortcomings of these relaying strategies in a MATLAB simulated environment. The basic emphasis of this analysis is to probe into various relaying techniques namely amplify and forward and decode and forward. Decode and forward is further simplified to detect and forward on the basis of level of difficulty and relay applications. The case study shows that AF and Df provide good results. AF provides promising diversity gains in most of the scenarios. DF performs poorly at low SNR but upgrades with improving channel conditions. DtF doesn't present significant gains in most of conditions. However the performance of DtF is improved by employing selective relaying.

**FUTURE WORK**

Comparison has been made for the various relaying techniques for three node model .i.e. source, destination and single relay. The analysis can further be extended to multiple node models. The actual GSM network can also be taken as a practical case study taking specific factors involved in that particular scenario. The technique investigated in this research is for the MRC and can be extended to investigate the other two techniques namely Fixed Ratio Combiner (FRC) and Equal Gain Combiner (EGC).

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