Cooperative Multi-Antenna Relaying in Fixed Hybrid Relay Networks

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Abstract: - Co-operative communication using relays can achieve spatial diversity, which improves the link quality in a wireless network. In this paper, the performance of an infrastructure based multi-antenna adaptive decode-and-forward cooperative relay network in presence of a m-Nakagami fading channel using Low Density Parity check (LDPC) code has been investigated. The bit error probability (BER) and outage probability performance has been evaluated, when received signals are coherently combined at both the relays with multi-antenna and destination using Selection Combining (SC) and Maximal Ratio Combining (MRC) schemes respectively. The effects of number of relay antennas (L) and number of relays on the system performance have been studied. The impact of decoding threshold and 'm' parameter on bit error rate (BER) and outage probability have also been evaluated. Further a tradeoff between relay antennas and number of relay is also indicated.

Key-Words: - Low Density Parity check (LDPC) code, Amplify and forward (AD), decode and forward (DF), adaptive decode and forward (ADF), BER, outage probability, Log- likelihood ratio (LLR), end-to-end (E2E).

1 Introduction

In the past few years, wireless relay network has received significant attention and been extensively researched, for high data rate, large coverage area and quality-of-service (QoS). In the case, when the source is not able to communicate directly with the sink, intermediate nodes within the transmission range may be used to relay the information. There are two common strategies in relay networks. The first one, amplify and forward (AF), detects the transmitted symbols and forward them to the next terminal after scaling. It mainly compensates the negative impact of fading. The disadvantage of the AF strategy is that it will also forward any errors which occur at the relay. The second strategy, decode and forward (DF), detects the received symbols at the relay and generate fresh signal. Thus, it is able to correct errors at the relay and forwarding of erroneous symbols to the subsequent terminal is prevented. However the disadvantage of DF scheme has increased decoding complexity. Recently, the combination of these two schemes have been proposed to improve performance. Some adaptive schemes combining AF and DF relaying protocols have been proposed in the literature [1-3]. In [1-2], an adaptive DF-AF relaying protocol has been proposed in which the relay first tries to decode the received signal. If the decoding succeeds, it transmits the decoded signal using the DF protocol. However if the decoding fails, the relay simply amplifies the received signal. The computational complexity of this DF protocol is high since decoding is always performed at the relays. In [3], the relay estimates the BEP using log-likelihood ratios. If the estimated BEP is above a given threshold, the DF strategy is used. Otherwise, the relay amplifies the received signal since it contains no or only few errors.

The use of relays achieves cooperative diversity through node collaboration, as well as extends the coverage of networks without increasing transmits power [4-6]. In a wireless environment, signal transmission quality is always degraded due to channel fading and variation, which results in high bit error rate (BER). Through cooperation among the relay nodes, a virtual antenna array is formulated so as to achieve the spatial diversity gain by combining transmissions from all relays at the destination and using various combining methods. Multiple antennas appear as another enabling technology to dramatically increase the system capacity of cooperative networks. However, the deployment of multiple antennas at wireless terminals may not be feasible in some scenarios, especially when future terminals are expected to be small and light. As such, it is of great interest to adopt advanced antennas solutions at the relays instead of terminals. Multi-antenna based relay techniques are well studied; a number of promises in these schemes are documented in [7-11].

A mixed adaptive strategy is discussed for a single antenna cooperative relay network by using Low Density Parity check (LDPC) code in presence of Rayleigh fading [12]. It operates in either of the two modes; amplify-and-forward (AF) or decode-and-forward (DF) depending on channel condition. Thus it allows switching between the two schemes according to channel condition. In present work, we have extended our earlier work [12] by incorporating multi-antenna relay schemes in m-nakagami fading channel. The m-nakagami fading is chosen as it could represent various fading conditions in wireless channel. In this paper, we assume that the source and the destination terminals are equipped with a single antenna, while multi-antennas are deployed at the relays. More precisely our contributions in this paper are

- Evaluation of BER and outage performance of an infrastructure-based multi-antenna adaptive decodes-and-forward (ADF) cooperative relay network in presence of m-Nakagami fading.
- Assessing the impact of decoding threshold, number of antenna (L) and 'm' parameters on BER and outage performance.
- Evaluating the effects of number of relay antennas and number of relays on end-to-end BER and outage performance respectably. A trade-off between number of relay antennas and number of relays has been indicated.
- Development of a simulation test bed for carrying out the performance evaluation. A simulation test bed has been developed in MATLAB to assess the impact of number of relay antennas and relays on the overall BER and outage performance of the hybrid relay network. Our simulated results demonstrate that the deployment of multi-antennas at the relays can reduce the required number of relay and thus significantly reduce the system cost.

Section 2 introduces the system model of our work and notation used in the remainder of this paper. In Section 3, we describe the simulation model. Simulation results are discussed in Section 4. Finally, paper is concluded in Section 5.

2 System Model

The network architecture considered in present work is depicted in Fig. 1. The two-hop cooperative network architecture consists of N_R adaptive decode-and-forward (ADF)-based fixed relays each carrying L diversity antennas as shown in Fig. 1. The scenario considered here is referred to as symmetric network in contrast to an asymmetric one. The symmetric networks assume that all links (source-relay, relay-destination, and source-destination) experience independent but statistically identical (iid) channels with the same mean pathloss. The employed protocol operates as follows. In the first time slot, the source broadcasts a signal that is received by both the destination and relays. The destination stores this signal for future processing. The received L copies of signals at each relay are processed using Selection Combining (SC) diversity technique. In the second time slot, the set of adaptive decode and forward based relays transmit the received signal to the destination. We assumed that at the destination signals received from the source and relay paths are combined using Maximal Ratio Combining (MRC) scheme.

A node 'i' communicating general with another node 'j' constitute a link in the network. A node may correspond to the source, a relay or the destination. The signal received at node 'j', transmitted from node 'i' can be expressed as $r_{i,j} = h_{i,j}\, x_i + n_j$, where x_i is the signal emanating from node 'i', $h_{i,j}$ is the channel gain between node 'i' and node 'j' and n_j is the additive white Gaussian noise (AWGN). For a relay in a multi-antenna relay network, the input-output relation of the first hop, i.e., source (node S) to relays, can be expressed as

$$r_j = h_{s,j} x_s + n_j\,, \qquad j = 1, 2, \cdots, N_R, \tag{1}$$

where N_R is the total number of relays, r_j is the $L\times1$ received vector at the jth relay, $h_{s,r_i} = [h_{s,r_i}{}^{(1)}, ..., h_{s,r_i}{}^{(L)}]^T$ is the random channel vector with independent components which are also independent of the components in the $L \times 1$ AWGN noise vector denoted by n_j . For a coherent detection scheme, perfect recovery of phase and carrier is possible, therefore, each entry $h_{i,j}^{(l)}$ represents the magnitude of the fade sample which is assumed to follow the Nakagami distribution. It is also assumed that the channel state information for the relay-destination (R-D) links is available to the destination while, those of the source-relay (S-R) links are known to the respective relays. The destination does not require any knowledge of the S-R channels.

An ADF based single link single antenna relay network is analyzed in [12]. The multi-antenna based ADF single-link relay network, which is *a priori* foundation of our work is shown in Fig. 2. The received L copies of signals at the relay are processed using Selection Combining (SC) diversity technique. At the hybrid relay, this combined received signal is demodulated to obtain log-likelihood ratio (LLR) $L\{c_n/r_j\} = Log\dfrac{p(x_s = +1/r_j)}{p(x_s = -1/r_j)} = \dfrac{2r_j h_{s,r_j}}{\sigma_{s,j}}$ for the transmitted LDPC coded bits, where $\sigma_{s,j}$ is the variance of noise from source to relay channel. When DF is applied, $L\{c_n/r_j\}$ are given to a soft-input soft-output decoder to recover transmission errors that occurred during the transmission from the source to the relay using a code *C* which results in the soft outputs $L\{c_n/r_j, C\}$. The equivalent noise process has sample mean

$$\hat{\mu}_n = \frac{1}{N}\sum_{n=1}^{N}\left(1-\tilde{x}_{j,n}\hat{x}_{j,n}\right) \tag{2}$$

and sample variance

$$\hat{\sigma}_n = \frac{1}{N}\sum_{n=1}^{N}\left(1-\tilde{x}_{j,n}\hat{x}_{j,n}-\hat{\mu}_n\right) \tag{3}$$

where $\tilde{x}_{j,n}$ and $\hat{x}_{j,n}$ soft symbol and hard symbol estimates respectively[3].

The soft symbols transmitted from the relay, $\tilde{x}_{j,n}$ are normalized to have an average symbol energy of one by multiplying them with a normalization factor

$$\beta_j = \frac{1}{\sqrt{(1-\hat{\mu}_{n,j})^2 + \hat{\sigma}_{n,j}{}^2}} \tag{4}$$

In ADF strategy, combination of AF and DF is used. It includes a relay which is able to switch between AF and DF depending on channel condition. If the demapper at the relay provides LLRs $L\{c_n/r_j\}$ of the transmitted code bits, the bit error probability (BEP) of the received code word is estimated as [7]

$$\hat{P}_b = \frac{1}{N}\sum_{n=1}^{N}\frac{1}{1+e^{\left|L\{c_n/r_j\}\right|}} \tag{5}$$

Instead of the BEP, the word error probability could alternatively be used as a reliability measure [8]. Each relay estimates the bit error probability ($\hat{P}_{b,j}$) of the received code word using (5). If $\hat{P}_{b,j}$ exceeds a certain chosen decoding threshold ($P_{b,t}$) the DF strategy is used, otherwise $\tilde{x}_{j,n}$ is forwarded without decoding i.e. following AF scheme.

In the second hop (time-slot), a relay j forwards the pre-processed signal to the destination (node D) shown in Fig. 1. Depending on the channel only between a source node and a relay, the relay selects AF or DF as a more suitable relaying strategy. Thus signal received at the destination is expressed as

$$y_{j,D} = h_{j,D}\beta\tilde{x}_{j,n} + n_{D,n} = h_{j,D}\beta(1-\hat{\mu}_n)\hat{x}_{j,n} + n_E \tag{6}$$

We assumed that effective noise samples (n_E) at the destination are Gaussian distributed with variance [6]

$$\sigma_E = \left|\beta h_{j,D}\right|^2 \sigma_n{}^2 + \sigma_{D,n}{}^2 \tag{7}$$

where $\sigma_{D,n}$ is the variance of the noise between relay to destination.

We estimate the received signal bit using demapper and decoder circuit as shown in Fig. 2. Next we compare the received bits with corresponding transmitted bits and estimate the bit error rate (BER).

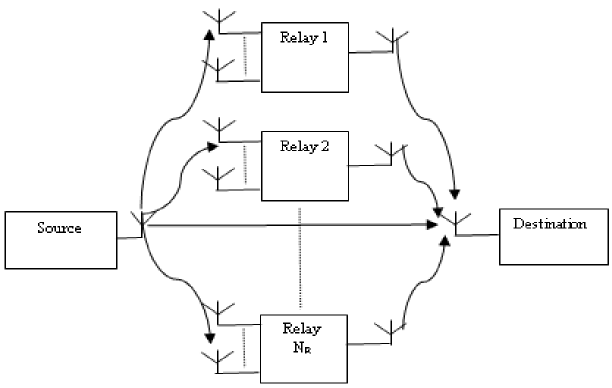

Fig.1 ADF protocol with multi-antenna cooperative relays.

Now we outline the evaluation of outage probability for the relay scenario presented above.To obtain the outage probability of hybrid relay scheme, we define the DF mode set ζ as the set of relays whose bit error probability (BEP) of the received code word ($\hat{P}_{b,j}$) exceeds a certain chosen decoding threshold ($P_{b,t}$). If the estimated BEP of the received code word ($\hat{P}_{b,j}$) at the relay exceeds a certain predecided or a chosen decoding threshold ($P_{b,t}$), the relay node is included in decoding set ζ. In other words, a relay 'j' belongs to ζ if the condition ($\hat{P}_{b,j} > P_{b,t}$) is satisfied. Otherwise, the relay is not included in DF mode set ζ, and consequently it uses the AF scheme. During the following N_R time slots, relays forward their signals to the destination in some predetermined order. We also assume that the destination uses maximal ratio combining (MRC) method to combine the signal received from source and relays. The mutual information between the source and the destination for hybrid relaying can be expressed as

$$I_{ADF} = \frac{1}{N_R+1} Log \left[\begin{array}{l} \sum_{j\in\zeta} \min\left(\left(\bar{\gamma}\left|h_{r_j,d}\right|^2 + \bar{\gamma}\left|h_{s,d}\right|^2 \right), \bar{\gamma}\left|h_{s,r_j}\right|^2 \right) \\ + \sum_{j\notin\zeta} \left(\frac{\bar{\gamma}\left|h_{s,r_j}\right|^2 \bar{\gamma}\left|h_{r_j,d}\right|^2}{\bar{\gamma}\left|h_{s,r_j}\right|^2 + \bar{\gamma}\left|h_{r_j,d}\right|^2 + 1} \right) + 1 + \bar{\gamma}\left|h_{s,d}\right|^2 \end{array} \right] \quad (8)$$

where $\bar{\gamma}$ is the transmitted SNR and $h_{s,d}$, h_{s,r_j} and $h_{r_j,d}$ are the fading coefficients of source to destination, source to 'j'th relay, and 'j'th relay to destination respectively.

The outage probability of hybrid relay scheme is given as:

$$P_{out,ADF} = \Pr\left[I_{ADF} < R \right] \quad (9)$$

where R is the bit rate of the channel.

We evaluate $P_{Out,ADF}$ of ADF scheme as given in (9) by simulation.

However if the relays work purely in DF or purely in AF mode, the outage probability will be evaluated in following ways:

The mutual information between the source and destination for DF relaying can be expressed as

$$I_{DF} = \frac{1}{N_R+1} Log \left(\begin{array}{l} 1+\bar{\gamma}\left|h_{s,d}\right|^2 \\ + \sum_{k=1}^{N_R} \min\left(\left(\bar{\gamma}\left|h_{r_j,d}\right|^2 + \bar{\gamma}\left|h_{s,d}\right|^2 \right), \bar{\gamma}\left|h_{s,r_j}\right|^2 \right) \end{array} \right) \quad (10)$$

Hence the outage probability of DF relay scheme is

$$P_{out,DF} = \Pr\left[I_{DF} < R \right] \quad (11)$$

The mutual information between the source and destination for AF relaying can be expressed as

$$I_{AF} = \frac{1}{N_R+1} Log \left[1+\bar{\gamma}\left|h_{s,d}\right|^2 + \sum_{k=1}^{N_R} \left(\frac{\bar{\gamma}\left|h_{s,r_j}\right|^2 \bar{\gamma}\left|h_{r_j,d}\right|^2}{\bar{\gamma}\left|h_{s,r_j}\right|^2 + \bar{\gamma}\left|h_{r_j,d}\right|^2 + 1} \right) \right] \quad (12)$$

The outage probability of AF relay scheme is

$$P_{out,AF} = \Pr\left[I_{AF} < R \right] \quad (13)$$

We also evaluate the outage for pure DF and AF cases by simulation following (11) and (13).

3 Simulation Model

The major steps of simulation model is described below

3.1 Source

- The information bits $U = \left[u_1 \ldots\ldots, u_k \ldots\ldots\ldots u_K \right]$ $u_k \in \{1,0\}$ are encoded by an FEC encoder to

form LDPC coded bits $C = [c_1....., c_n........c_N]$ which are mapped onto complex symbols $X = [x_1....., x_n........x_N]$.The complex symbols are transmitted to the relay.
- In the present study we restrict ourselves to BPSK modulation in this paper.

3.2 Relay
- The received L copies of signals at each relay are processed using Selection Combining (SC) diversity technique.
- Estimated BEP at the output of Selection Combiner (SC) is compared with BEP threshold (P_{bt}). If estimated BEP is above the threshold value, the AF technique is used. Otherwise DF strategy is utilized.
- All nodes take the decision about DF or AF independent of any other node. The decision depends on the BEP after SC combining which is a function of number of antenna (L), 'm' parameter of m-nakagami fading and chosen BEP threshold.

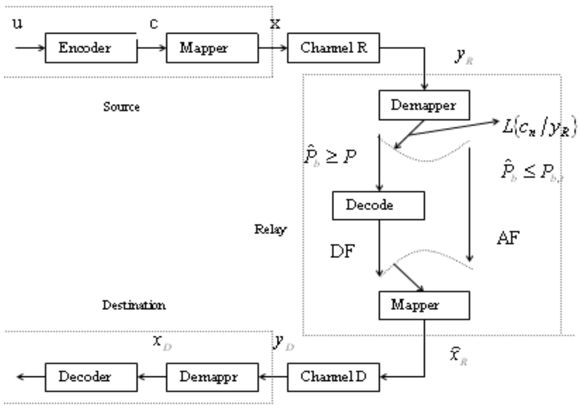

Fig.2 Multi-antenna based adaptive decode and forward for relay-link network.

3.3 Channel
- The channel between source and relay (multi input antenna) as well as relay (single output) and destination is assumed to be frequency-flat m-Nakagami fading channel.
- Samples of Rayleigh and Ricean fading envelops are generated initially. From such generated envelop, complex valued nakagami faded channel coefficients ($h_{S,j}$, $h_{j,D}$) are generated following [8].
- Additive white Gaussian noise (AWGN) samples, n_j, $n_{D,n}$ on both links are added to signal while the signal is transmitted through channel.
- We consider a quasi-static fading channel, for which the fading coefficients remain constant within one transmission block, but changes independently from one block to another.
- We also assume that the fading channels between source and destination, between source and each relay, and between each relay and destination are independent, but identically distributed.

3.4 Destination
- Using demapper and decoder circuit we estimate the received signal from noisy received signal [3].
- We compare the received bits with corresponding transmitted bits. An error counter is incremented for every erroneous bit. Finally error counter is divided by total number of transmitted bits to estimate the bit error rate (BER) or BEP.

3.5 Outage probability
- In phase 1, a source sends information to its destination, and the information is also received by the all relays at the same time.
- The received L copies of signals at each relay are processed using Selection Combining (SC) diversity technique.
- In phase 2, all the relays help the source by forwarding or retransmitting the information to the destination.
- We evaluate the BEP of received code word $\hat{P}_{b,j}$ for a k^{th} relay by simulation following steps in 3.4 and compare it with a chosen threshold $P_{b,t}$. If $\hat{P}_{b,j}$ exceeds $P_{b,t}$ the relay is included in the set of DF mode else it is included in the set of AF mode. This is repeated for all the available relays.
- In phase 3, the destination combines the signals that it receives from the source and all relays using MRC.
- We evaluate the mutual information between the source and destination for hybrid relay scheme following (8).
- We evaluate the mutual information (I_{ADF}) for a large number of times (N) and compare it

with R each time. We count the number of times (N_t) it exceeds R and estimate outage probability as $P_{out} = \frac{N_t}{N}$.

4 Result and Discussions

A simulation test bed is developed using MATLAB to evaluate the performance of cooperative multi-antenna fixed relay network exploiting hybrid ADF technique. The performance of the hybrid ADF technique is compared with that of pure AF and DF techniques. In the proposed scheme the information bits at the source are encoded using LDPC (Low density parity check) code with code rate 1/2 and decoded by an optimal soft-input soft-output symbol-by-symbol decoder. The channels between source and relay as well as relay and destination are modeled as frequency-flat those between channels. It is assumed that both the channels have identical average SNR values.

Fig. 3, Fig. 4 and Fig. 5 show the BER performance at destination node for the pure AF, DF as well as the mixed AF/DF strategies for a link with single antenna single relay under several condition of fading and BEP thresholds. The value of SNR where the switching from AF to DF or vice versa takes place depends on various parameters such as the decoding threshold *($P_{b,t}$)*,the parameter of *'m'* of m-Nakagami fading. Fig. 3 shows dependences of BER performance of the ADF strategy on m parameter of m-nakagami channel. It is seen that for lower value of 'm', the change from AF to DF occurs at a higher SNR for a fixed threshold *($P_{b,t}$)* at the relay. For example, as seen in Fig. 3, for a fixed threshold *($P_{b,t}$ =0.06)* with single antenna *(L=1)*, change from DF to AF occurs at SNR values of 8 dB, 6 dB and 4 dB respectively for the corresponding values of *m*=1, 1.5 and 3 respectively.

Fig. 4 shows that the BER performance of ADF strategy for various levels of threshold for a fixed '*m*' parameter. It is seen that performance of ADF lies in between that of AF and DF. AF and DF can be seen as special cases of ADF with decoding thresholds $P_{b,t}$= 0.5 (never decode at the relay) and $P_{b,t}$=0 (always decode at the relay) respectively. The BER performance of ADF and DF are quite similar in the low SNR range. It is seen that as SNR increases, BER performance of ADF degrades and finally it converges to the AF. The point where the BER of ADF leaves the AF/DF curve depends on the threshold value $P_{b,t}$ chosen at the relay. For a lower threshold, the change from AF to DF occurs at a higher SNR.

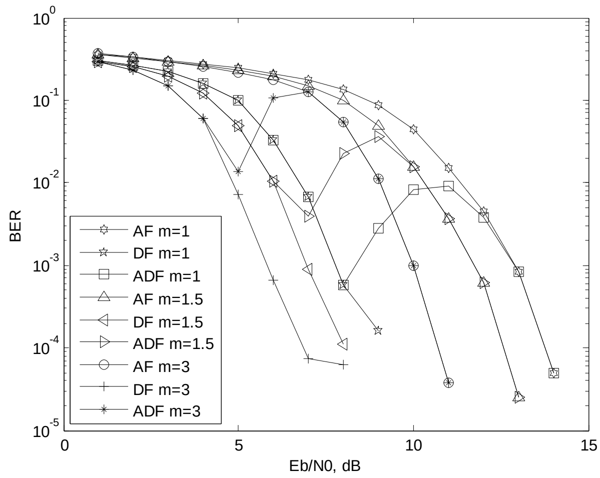

Fig.3 Bit error rate of various soft-forward relaying strategies for diffrent 'm' parameter of single antenna single relay network in a m-nakagami fading channel.

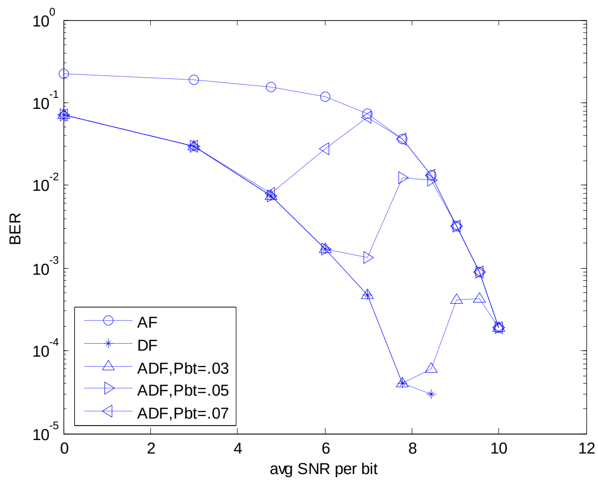

Fig.4 Bit error rate of different soft-forward relaying strategies when transmitting via one-relay link with single antenna.

Fig. 5 shows that impart of the number of antennas on hybrid ADF scheme in a single relay network for fixed $P_{b,t}$ and 'm'. It is seen that as the number of antenna at relay increases, the switching from AF to DF occurs at lower SNR. In case of fixed relay (infrastructure-based relay) switching from AF to DF associated with ADF strategy occurs at lower SNR value with increase in the number of antenna at a relay. It is seen that the BER performance of AF, DF as well as ADF improve with increase in number of antenna at the relay. Further, it is also seen that improvement in BER performance of AF with increasing number of antenna is significantly higher as compared to DF.

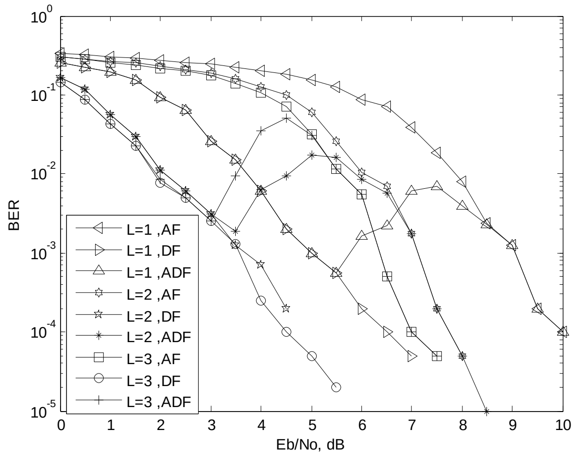

Fig.5 Bit error rate of different soft-forward relaying strategies for multi-antenna single relay network in a m-nakagami fading channel.

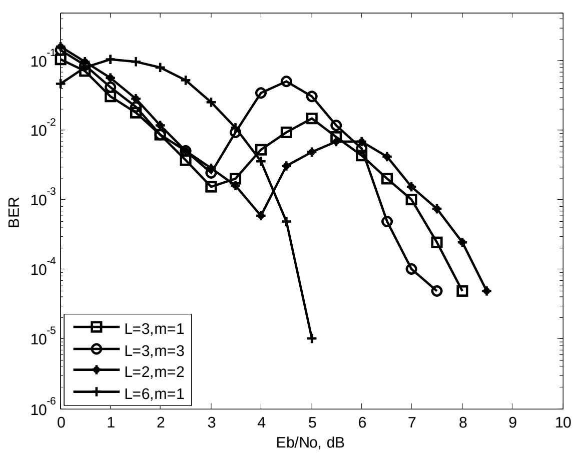

Fig.6 BER performance of MRC-based multi-antenna ADF relay in m-nakagami fading, number of antenna(N_R=1).

Fig. 6 shows the joint impact of two parameters *m* and *L* on the overall performance of relay network under study. BER performance which deteriorates with lower value of *m* (as seen in the Fig. 3) can be compensated by increasing *L* as revealed in the Fig. 6 for *L*=6, *m*=1 case. Thus higher L can be used to compensate the degradation in BER due to lower 'm' i.e. severe fading. It is also seen that switching from DF to AF associated with ADF strategy occurs at low SNR value for higher set of *L* and *m*. For example, as observed in Fig. 6 for *m*=3, *L*=3 and *m*=2, *L*=2 cases, the change from DF to AF occurs at SNR values of 3 dB and 4 dB respective respectively.

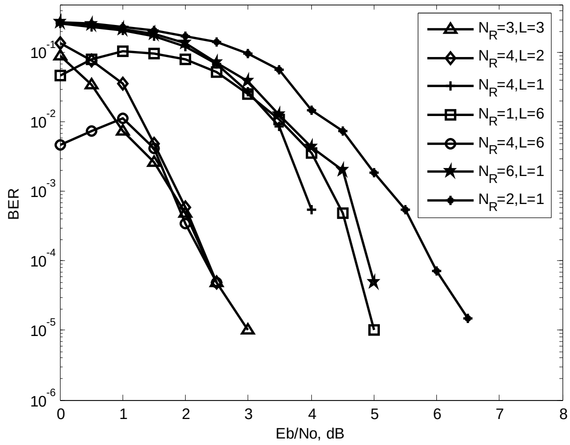

Fig.7 Comparison of network architectures demonstrating the impact of multiple antennas on relays in Rayleigh fading.

In Fig. 7, the end-to-end (E2E) BER performances under different network configurations (i.e. several values of N_R and L) are compared. This figure reveals three important aspects. First, we compare the performances achieved by different values of N_R while keeping L fixed. It can be seen that when *L* is fixed at *L*=1, no significant improvement is achieved as N_R changes from 2 to 6. However performance improvement due to increase in N_R starts from L=2 and significant improvement is seen in the case of L=*6*. This is because the correct soft symbols and hard symbols estimation probability at the relay increases as the value of *L* increases. This indicates that with large *L*, more relays will exhibit better performances over small number of relays. Further, when N_R is fixed, we compare the performances achieved by different higher values of *L*. A similar phenomenon is observed that the BER performance of the systems improves with higher values of *L* for higher values of N_R. Thus, the two parameters, N_R and *L*, have a close relationship with each other. Next, we consider three performance curves corresponding to the cases (N_R*=1, L=6*), (N_R*=6, L=1*) and (N_R*=3, L=3*). It is observed that performance of the system adopting (N_R*=3, L=3*) is the best while the performance of the system using (N_R*=6, L=1*) is better than that of (N_R*=1, L=6*). Hence it is seen that the use of multi-antennas at the relays (*L*) could reduce the number of required relay nodes (N_R). Moreover it is important to see that *L=2* for a given N_R is sufficient and any increase in *L* beyond this does not improve performance significantly.

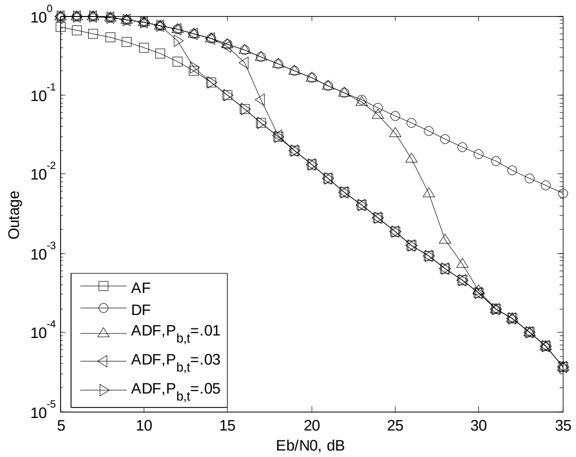

Fig. 8 Outage performance of different soft-forward relaying strategies with single relay single antenna.

Fig. 8 shows the outage performance at destination node for the pure AF, DF as well as the hybrid AF/DF strategies for a link using single relay with single antenna i.e. (N_R=1,L=1) under several BEP threshold. The outage performance of the DF strategy is worse than AF scheme as shown in Fig. 8. This occurs because the decoded signal at the relay may be incorrect. If an incorrect signal is forwarded to the destination, the decoding at the destination is also erroneous. So the mutual information between the source and the destination is limited by the mutual information of the weakest link between the S-R and the combined S-D and R-D. It is seen that outage performance of ADF lies in between that of AF and DF. The outage performance of ADF and DF are quite similar in the low SNR range. It is also seen that as SNR increases, outage performance of ADF improves and finally it converges to the AF. The point where the outage of ADF leaves the AF/DF curve depends on the threshold value $P_{b,t}$ chosen at the relay. If that threshold is lowered, the change from DF to AF occurs at a higher SNR.

Fig. 9 shows that the outage performance of multi-antenna single link ADF relay for various levels of threshold with fixed '*m*' parameter. It is seen that outage performance of AF and ADF schemes are quite similar throughout the SNR range at multi-antenna relay. This nature occurs because the multiple copies of received signals at multi-antenna relay are processed using Selection Combining (SC) diversity technique to improve the source-to-relay link. Therefore $\hat{P}_{b,j}$ cannot exceeds a certain chosen decoding threshold ($P_{b,t}$), i.e. AF strategy is used under such cases. It is also seen that performance of DF scheme is better than those of other two schemes (i.e. AF and ADF schemes). This is because; the channel between the source and the relay node is strong enough to allow successful decoding at the relay. It is also observed that the outage probability of ADF scheme does not depend on switching threshold ($P_{b,t}$) at higher value of L. This occurs because the hybrid scheme operates in AF mode over the entire range of SNR at higher value of L.

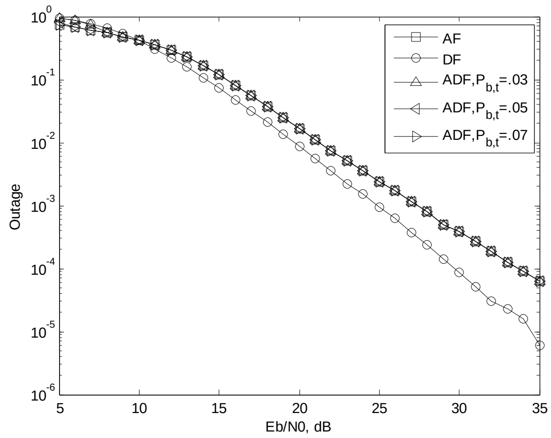

Fig. 9 SNR vs. outage probability curve for multi-antenna single relay network (i.e. L=2 and N_R=1).

Fig. 10 shows the outage performance of the ADF strategy for various '*m*' parameter of m-Nakagami fading channel at fixed levels of threshold ($P_{b,t}$) and number of antenna (L). It is seen that the outage performance of ADF strategy improves as the value of 'm' parameter increases.

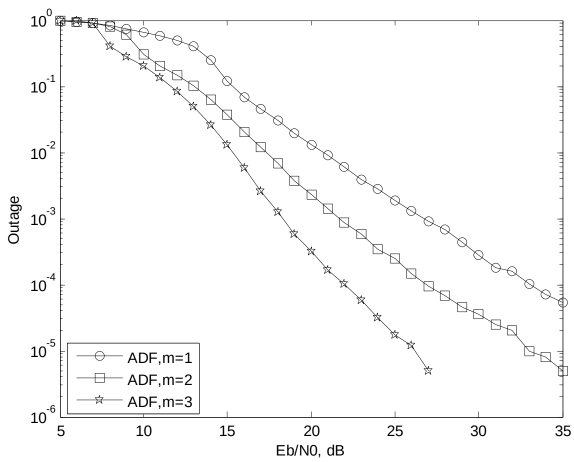

Fig. 10 ADF relaying strategies for diffrent 'm' parameter of single antenna single relay network in a m-nakagami fading channel.

Fig. 11 shows the outage probability versus SNR curve for variable number of relay. In this figure all the channel variances are assumed to be 1. In this case spectral efficiency R=1 is used. It is seen that the outage performance of ADF scheme improves with increase in the number of relays at high SNR. However at low SNR range the outage performance of ADF scheme decreases with increase in number of relay. So the outage performance of ADF scheme is better at high SNR range.

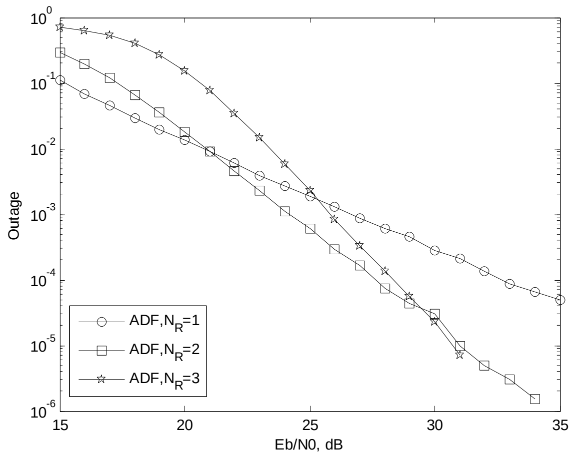

Fig. 11 Outage probability for a one-, two-, and three-node hybrid relay network.

5 Conclusion

Performance of an infrastructure based multi-antenna adaptive decode-and-forward cooperative relay network is investigated in presence of an m-Nakagami fading channel. This hybrid strategy allows a trade-off between decoder usage and error performance for links containing relays, which is useful for energy constrained self organizing networks. All relays take the decision about DF or AF mode of operation independent of any other relay, only depending on the decoding threshold. A relay with estimated bit error probability exceeding the decoding threshold operates in DF mode, otherwise it operates in AF mode. It is observed that by lowering the decoding threshold value, the relay is operated for most of the time in DF mode and thereby the performance is enhanced. It is also seen that the BER and outage performance of AF, DF as well as ADF improve with increase in number of antenna at the relay and 'm' parameter of m-Nakagami fading respectively. Further, lower value of 'm' (i.e., more severe fading environment) can be compensated by increasing the number of antennas. Switching the mode of relay operation from AF to DF associated with ADF strategy occurs at low SNR value with increase in number of antenna at a relay. Outage performance of AF and ADF schemes are quite similar over entire ranges of SNR for multi-antenna relay. It is also observed that outage performance of ADF scheme improves with increase in number of relay only for high SNR range. Further, the deployment of multi-antenna at relay nodes decreases the overall number of relays, but at the cost of increased processing complexity. Simulation results show that the use of multiple antennas at the relays helps to reduce the number of required relay nodes, thus significantly reduces the system cost. Further it is seen that two antennas for a given N_R is sufficient and any further increase in number of antennas beyond this does not improve the performance significantly. For a given number of relays, performance degradation due to severity of fading can be compensated by increasing number of antenna at each relay. It is possible to trade-off between number of antennas at each relay and number of relays in order to achieve a desired level of performance. The above study is useful in designing energy constrained relay network.

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