Hybrid Forwarding for General Cooperative Wireless Relaying in m-Nakagami Fading Channel

Chanchal Kumar De[1] and Sumit Kundu[2]

[1]Dept. of Electronics and Instrumentation Engineering
Dr. B. C. Roy Engineering College, Durgapur- 713206, India
[2]Department of ECE, National Institute of Technology, Durgapur
Durgapur- 713209, India
wrt2chanchal@rediffmail.com, sumit.kundu@ece.nitdgp.ac.in

Abstract

In this paper, an adaptive forwarding strategy for wireless networks using multiple relays in general cooperative link is analyzed. Two schemes, amplify-and-forward (AF) and decode-and-forward (DF) are investigated depending on channel conditions. Further a hybrid scheme employing multiple relays which allows switching between the two schemes according to channel condition is proposed. The bit error probability performance (BEP) for the proposed hybrid strategy has been evaluated in presence of m-nakagami fading. The simulation results are general as they hold for an arbitrary number of cooperating branches and arbitrary number of cooperating hops per branch. We have evaluated the BER performance for variable number of relays in multi-hop and multi-branch cooperative network. The impact of switching threshold and 'm' parameter on bit error rate (BER) is indicated. Further BEP performance is assessed using LDPC code.

Keywords- *Low Density Parity check (LDPC) code, Amplify and forward (AD), decode and forward (DF), adaptive decode and forward (ADF), BER, Log- likelihood ratio (LLR).*

1. Introduction

Cooperative relaying is a promising technique which helps to extend the communication range by forwarding data using one or several intermediate nodes. 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. When relays are used in wireless links between a source and a destination terminal, the total signal power used for transmission from source to destination is reduced [1, 2]. Serial relay transmission is used for long distance communication but it is suffers from multi-path fading. To increase the robustness against multi-path fading, parallel relay transmission can be used. In this topology, signal propagates through multiple relay paths in same hop and destination node combines the signals received via several relays with the help of various combining schemes. Performance will, thus, depend on the number of cooperating relay nodes as well as the processing operations at both relays and destination. It provides power gain and diversity gain simultaneously.

There are three 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 occurs 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. The disadvantage of DF scheme is decoding complexity. In the last strategy, decode and re-encode, the code word is decoded at the relay but a new code word differing from the source code word is constructed [2, 3]. It performs a kind of parallel channel coding but also suffers from the problem of error propagation.

A mixed adaptive strategy is discussed for a single relay network by using convolution code in presence of Rayleigh fading in [4]. It uses either of the i.e. two schemes 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. The hybrid scheme is analyzed under several fading condition in [5, 6] for serial and parallel relay network. In our present work we extend the concept of hybrid adaptive decode and forward scheme to provide a comprehensive analysis in general cooperative relay link network using LDPC (Low Density Parity Check) code. The simulation results are general as they hold for an arbitrary number of cooperating branches and arbitrary number of cooperating hops per branch. In this paper we have considered that the distance between two nodes is constant per branch. That means distance between source to destination increases with increasing the number of hops. The BER performance of the hybrid adaptive strategy in general cooperative relay network has been evaluated in presence of m-nakagami fading. The m-nakagami fading is chosen as it could represent various fading conditions in wireless channel. We have simulated the m-nakagami fading channel using MATLAB [10] which is used to assess the performance of relay schemes. The impact of number of relay on BER performance is depicted. The aims of the adaptive decode and forward scheme in multi-hop cooperative relay network is to prevent the negative effects of error propagation, reduce the decoding complexity and to save the energy resources. More precisely our contributions of this paper are

- BEP analysis of hybrid scheme employing LDPC code in single relay network in m-nakagami fading channel.
- Extension of the above analyses to multiple cooperative branch and multiple cooperative hops, relay systems.
- Impart of m-nakagami fading on hybrid scheme, switching threshold and number of multiple relays in general cooperative link network**.**
- Estimation of number of branches in multi-branch cooperative relay network to achieve a target BEP.
- Trade off between selection of number of branches and number of hops for achieving a desired BEP.

Section 2 introduces the system model of our work for a single link relay network and notation used in the remainder of this paper. In section 3 we extend these results to a general cooperation setups with multiple cooperating branches and multiple cooperating hops per branch. In Section 4, we describe the simulation model. Simulation results are discussed in Section 5. Finally, paper is concluded in Section 6.

2. Single Link Hybried Relay Network

Figure 1 shows the simplest model in which only one relay helps the source to communicate with the destination. It represents a transmission from a source node to a destination node via adaptive decode and forward (ADF) relays. Now we describe ADF based single-link relay network that has been proposed in [4], which is *a priori* foundation of our work. We consider the adaptive forwarding strategy for wireless networks with relays following [4] as shown in Figure 1. Here the binary information is encoded by an FEC encoder and these coded bits are mapped onto complex symbols. These symbols are transmitted from a source node to a destination node via a relay. The channel between source and relay as well as relay and destination is assumed to be frequency-flat m-nakagami fading and is described by complex valued channel coefficients $h_{R,n}$, $h_{D,n}$. Further we assume presence of additive white Gaussian noise (AWGN) on both links. For simulation purpose we restrict ourselves to BPSK modulation. Here information bits are encoded by using LDPC code. At the relay the received samples are represented by equation (1).

$$y_{R,n} = h_{R,n} x_n + n_{R,n} \tag{1}$$

It is demodulated to obtain log-likelihood ratios for the transmitted code bits. The log-likelihood ratios are

$$L\{c_n / y_R\} = Log \frac{p(x_n = +1 / y_R)}{p(x_n = -1 / y_R)} = \frac{2 y_R h_{R,n}}{\sigma_{R,n}} \tag{2}$$

where $\sigma_{R,n}$ is noise variance of source to relay channel. When DF is applied, $L\{c_n / y_R\}$ are given to a soft-input soft-output decoder to recover transmission errors which occurred during the transmission from the source to the relay using the code *C* resulting in the soft outputs $L\{c_n / y_R, C\}$. The equivalent noise process has sample mean

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

and sample variance

$$\hat{\sigma}_n = \frac{1}{N} \sum_{n=1}^{N} \left(1 - \tilde{x}_{R,n} \hat{x}_{R,n} - \hat{\mu}_n\right) \tag{4}$$

where $\tilde{x}_{R,n}$ and $\hat{x}_{R,n}$ soft symbol and hard symbol estimates respectively [4].

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

$$\beta = \frac{1}{\sqrt{(1 - \hat{\mu}_n)^2 + \hat{\sigma}_n{}^2}} \tag{5}$$

The received samples at the destination node are given as

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

Where n_E is the effective noise samples at the destination, which is Gaussian distributed with variance [2]:

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

From (6) the LLRs for the received BPSK symbols are

$$L\{c_n / y_D\} = Log \frac{p(x_n = +1 / y_D)}{p(x_n = -1 / y_D)} = \frac{2 y_D h_{D,n}}{\sigma_{D,n}} \tag{8}$$

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

Depending on the channel between a source node and a relay, AF or DF is chosen as a more suitable relaying strategy. In ADF strategy, combination of AF and DF is used. As seen from Figure 1 ADF strategy includes a relay which is able to switch between AF and DF. If the demapper at the relay provides LLRs $L\{c_n/y_R\}$ of the transmitted code bits, the bit error probability (BEP) of the received code word is evaluated using [7]

$$\hat{P}_b = \frac{1}{N}\sum_{n=1}^{N}\frac{1}{1+e^{|L\{c_n/y_R\}|}} \tag{9}$$

The BEP could be used as a parameter for choosing an appropriate relay strategy in hybrid scheme. If $\hat{P}_b$ is too large, i.e., above a certain switching threshold ($P_{b,t}$) the DF strategy is used, otherwise $\tilde{x}_{R,n}$ is forwarded without decoding. Instead of the BEP, the word error probability could alternatively be used as a reliability measure [8].

We apply this concept of ADF strategies in general cooperation setups with multiple cooperating branches and multiple cooperating hops per branch. Further we use LDPC as channel encoding scheme in contrast to convolution coding used in [4].

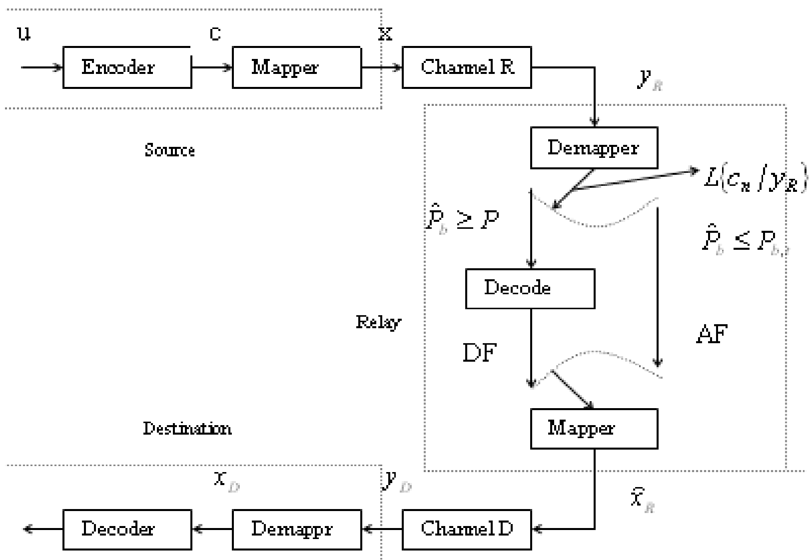

Figure 1. Adaptive Decode and Forward Based on Relay-link Network

3. General Cooperation Scenarios

In this section, we apply the general framework of scenarios. For simplicity in simulation, we confine ourselves to BPSK modulation.

3.1 Adaptive Decode and Forward Based Multihop Relay Network

Before discussing cooperative scenario, we first analyze the case of serial relay where N relays $R_1,\ldots,R_N$ are placed in cascade as depicted in Figure 2. In this technique, signals propagate through N number of channels/hops before arriving to the final destination.

Intermediate nodes relay the signal from one hop to the next. Here distance between two intermediate nodes is constant. So coverage area is increased by using N-hop relays. In our scheme as shown in Figure 2, the binary information is encoded by an LDPC channel encoder and these coded bits are mapped onto complex symbols. These symbols are transmitted from one terminal to next terminal in presence of m-nakagami fading and additive white Gaussian noise (AWGN). Each relay calculates the bit error probability ($\hat{P}_b$) of the received code word using equation (9). If ($\hat{P}_b$) exceeds a predefined threshold $P_{b,t}$, the DF strategy is used. Otherwise soft symbol ($\tilde{x}_{R,n}$) is forwarded without decoding. Such a mixed strategy may save energy which would have been spent unnecessarily for the decoding process if $\hat{x}_{R,n}$ contains no or only few errors (which are likely to be corrected at the destination). All the hops are assumed to be independent but not necessarily identically distributed.

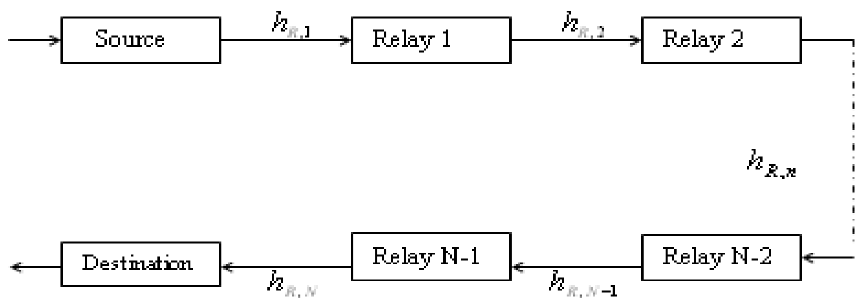

Figure 2. Adaptive Decode and Forward based N- hop Serial Relay Network

3.2 Adaptive Decode and Forward Based Multibranch Cooperative Relays Network

We now generalize our model to the multi-branch cooperation setup as depicted in Figure 3. We have M relays R_1,...,R_M, forming M branches besides the direct link S − D. Each R_m, m =1,..., M, processes symbols as a single relay R does in case of a single-relay network. We assume that all relays transmit over mutually orthogonal channels (M+1-time slots, for example) [8-9]. As shown in Figure 3, it includes one source, N relays in parallel and one destination. We consider a quasi-static fading channel, for which the fading coefficients remain constant within one transmission block, but change independently from one block to another. We also assume that the fading channels between the source and destination, between the source and each relay, and between each relay and the destination are independent.

The cooperative strategy which could be employed in present case of a parallel relay scheme has two phases. In the first phase, the source transmits same information data to the adaptive decode and forward relays and the destination. In the second phase, the set of relays transmit the received signal to the destination. At the destination signals received from the relay paths and direct path are combined using Maximal Ratio Combining (MRC) scheme. All relays take the decision about DF or AF independent of any other relay, only depending on the local parameter $P_{b,t}$. The selection of the value of $P_{b,t}$ depends on the channel code, modulation scheme, channel, energy consumption, network setup, and QoS requirements. Using this relay strategy we can improve the quality of serial and parallel relay network system.

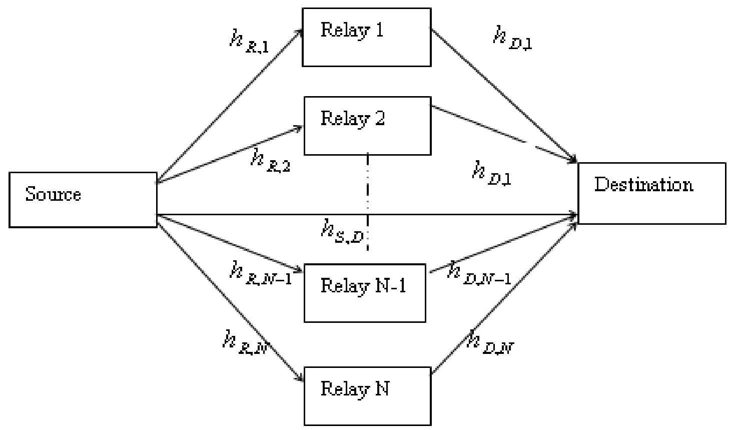

Figure 3. Adaptive Decode and Forward Based Two-hop Parallel N-relays Network

3.3 Multihop,Multibranch Cooperative Network

Combining two schemes as presented in Sections 3.1 and 3.2, we now present a scheme for multi-hop and multi-branch cooperation as shown in Figure 4. If we consider a single row (branch) of this model then it acts as a multi-hop (i.e. serial relay) network as shown in Figure 2. Further considering a single column of this generalized cooperative network the network becomes a multi-branch cooperative network (i.e. parallel relay network) as shown in Figure 3. Let us consider a cooperative system with M +1 branches $\{B_0, B_1, . . . B_M\}$ as depicted in Figure 4. Without loss of generality, let B_0 denote the direct link. Branch B_m consists of N_m relays and $R_{m,n}$ denotes the nth relay in branch $B_m \forall$ n =1,...,N_m and N_0 =0. Where $h_{m,n}$ denotes the fading coefficient of the link between $R_{m,n}$ and $R_{m,n-1}$.

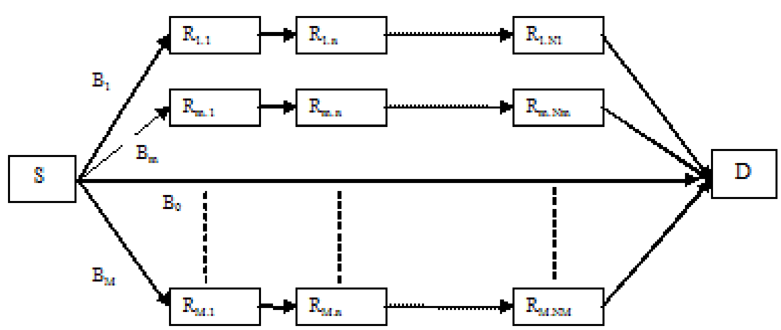

Figure 4. Block Model for Multihop and Multibranch Cooperation

4. Simulation Model

We now present the algorithms used in simulation. The simulation has been developed using MATLAB.

4.1 Source

- The information bits $U = [u_1.....,u_k........u_K]\ u_K \in \{1,0\}$ are encoded by an FEC encoder to form 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.
- For the ease of presentation we restrict ourselves to BPSK modulation in this paper.

4.2 Relay

- Depending on the channel between a source node and a relay, AF or DF may be a more suitable relaying strategy.
- All nodes take the decision about DF or AF independent of any other node, only depending on the bit error probability (BEP) of the received code word $\hat{P}_b$.
- This local parameter $\hat{P}_b$ is mainly dependent on LLRs value of received symbols. So we have calculated the LLRs value using demapper.
- Then a set of relays compare local parameter $\hat{P}_b$ with respect to chosen threshold $P_{b,t}$ and decide for AF or DF, then retransmits it.

4.3 Channel

- The channel between source and relay as well as relay 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 ($h_{R,n}$, $h_{D,n}$) are generated as described in [10].
- Additive white Gaussian noise (AWGN) samples $n_{R,n}$, $n_{D,n}$ on both links are added to signal as it is transmitted through channel.
- We consider a quasi-static fading channel, for which the fading coefficients are assumed to be 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.

4.4 Destination

- Using demapper and decoder circuit we calculate the estimated signal from noisy receive signal.
- Finally we compare the received bits with transmitted bits. An error counter is incremented for erroneous bits. The error counter is divided by total number of transmitted bits to obtain the bit error rate (BER).

5. Results and Discussion

A simulation test bed is developed using MATLAB to evaluate the performance of general multihop and multi-branch relay network exploiting hybrid ADF technique. The performance of hybrid ADF technique is compared with those of pure AF and DF techniques. In the proposed hybrid scheme the information bits 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 channels. It is assumed that both the channels have same SNR (Eb/N0) values. Further it is also assumed that the distance between two nodes within the branch is constant. However distance between source to destination is fully dependent on number of relays in multi-branch relay network system.

Figure 5 and Figure 6 show the BER performance at destination node for the pure AF and DF as well as the mixed AF/DF strategies for a link with single relay. Fig. 5 shows that the impact of 'm' parameters of m-nakagami channel on BER performance of the ADF strategy. The value of SNR where the BER of ADF leaves the AF/DF curve depends on both the threshold value $P_{b,t}$ and the parameter of 'm'. As the 'm' parameters is lowered keeping the threshold at a fixed level, the change from AF to DF occurs at higher SNR. For example, as seen in Fig. 5, for a fixed threshold ($P_{b,t}$ =0.06), 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 i.e. SNR values of 4dB, 6dB and 8dB for m=3, 1.5 and 1.

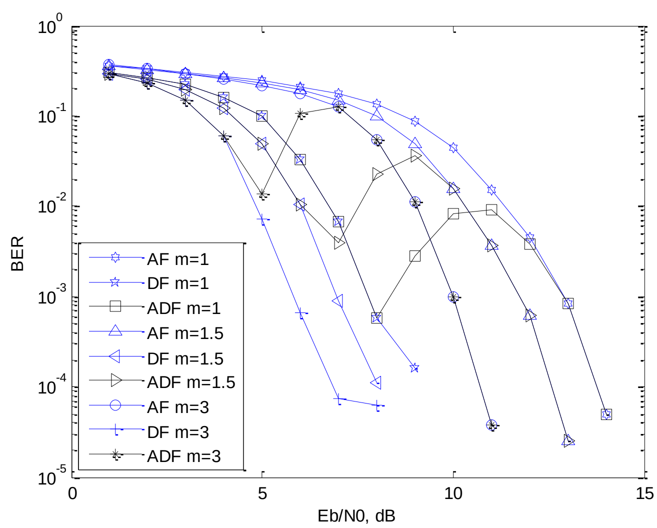

Figure 5. Bit Error Rate of Different Soft-forward Relaying Strategies for Different 'm' Parameter of Single Relay Network in a m-nakagami Fading Channel

Figure 6 shows that the BER performance of the ADF strategy for various levels of threshold ($P_{b,t}$) when 'm' is fixed. It is seen that the 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. However as SNR increases, BER performance of ADF degrades and finally converges to that of 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. If the threshold is lowered, the change from AF to DF occurs at a higher SNR.

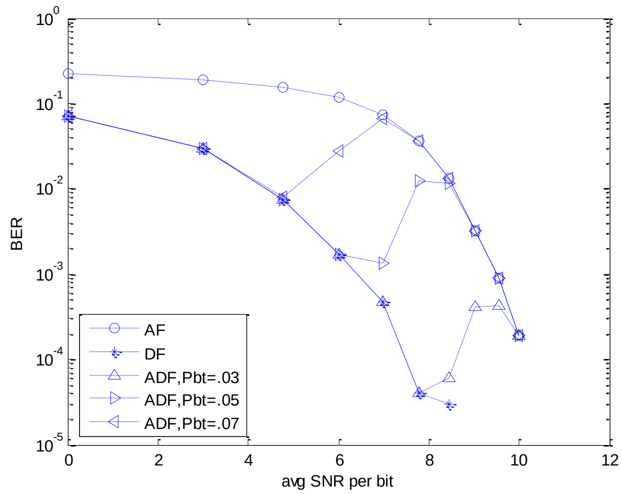

Figure 6. Bit Error Rate of Different Soft-forward Relaying Strategies when Transmitting via a One-relay Link

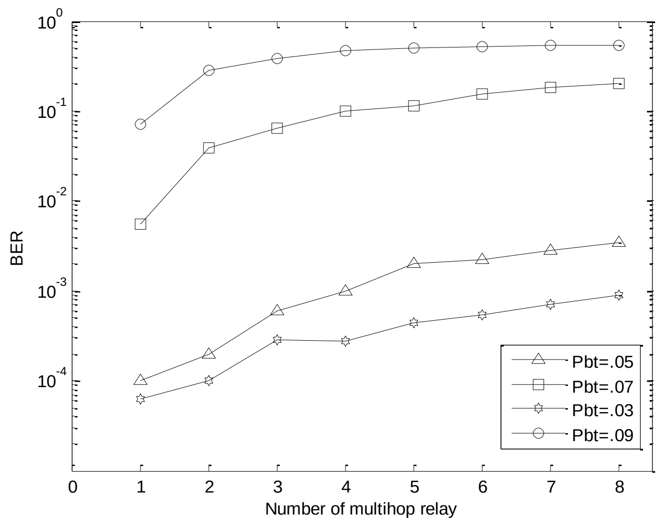

Figure 7. Comparative BER Performance at the Destination Node Considering Variable Number of Multihop Relays with Different Threshold

Figure 7 depicts the comparative BER performance at the destination node considering different number of relays in N-hop serial relay network. In multihop relay network, the BER performance of ADF strategy degrades with increase in number of relays as seen in Figure 7. This nature occurs because; increasing the number of hops (with fixed hop length) between source to destination increase the source-to-destination (S-D) distance in contrast to a fixed S-D distance. This help to enhance the coverage area but the performance degrades due to cumalative effects of fading in increased number of hopes. However it is also seen that beyond a certain number of relay the BER does not change significantly with further increase in number of relays. This nature occurs because; beyond a certain distance (i.e. number of hops) BER reaches a maximum level depending on a particular SNR and switching threshold. It is also observed that in ADF strategy, the impact of BER performance is more pronounced in low switching threshold as compared to high switching threshold.

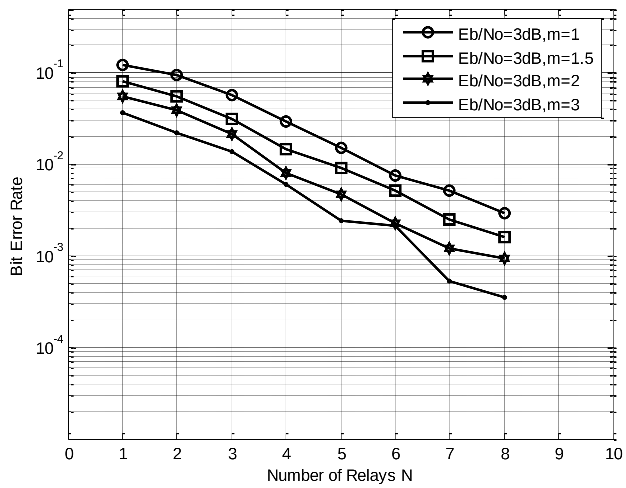

Figure 8. Comparative BER Performance of ADF Schemes at the Destination Node Considering Variable m Parameter in Multibranch Cooperative Relay Network

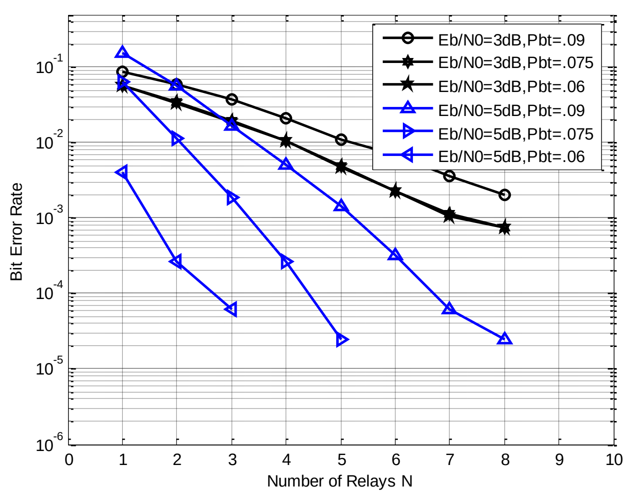

Figure 9. Comparative BER Performance of ADF Schemes at the Destination Node Considering Variable Threshold Value in 2-hop M branch Relay Network

Figure 8 and Figure 9 depict the comparative BER performance at the destination node considering variable number of relays in 2-hop M branch relay network. In contrast to serial relay, it is observed that BER performance improves with increase in number of relays. However it is also seen that BER performance of ADF strategy is improved with increase in 'm' parameter as seen in Figure 8. Figure 9 shows that the BER performance of ADF strategy under parallel relay scheme degrades with increase in switching threshold ($P_{b,t}$). It is also observed that in case of ADF strategy, the impact of switching threshold ($P_{b,t}$) is more pronounced in high SNR as compared to low SNR. However it is also seen that below a certain switching threshold ($P_{b,t}$) the BER performance of ADF scheme does not change with further decrease in switching threshold ($P_{b,t}$) for a particular SNR in Figure 9. For example BER performance of ADF strategy merges for two cases of switching thresholds ($P_{b,t}$=0.075 and 0.06) and remain unchanged at 3dB SNR for any switching threshold ($P_{b,t}$) ≤ .075 as in Figure 9. However it varies appreciably at 5dB SNR for various decoding threshold value.

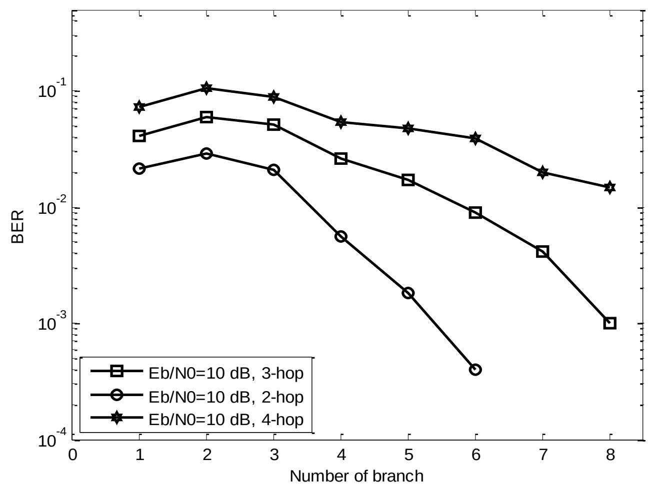

Figure 10. BER Performance Comparison for Multibranch and Multihop Cooperation using ADF Scheme

The comparative BER performance is depicted at the destination node in Figures 10 and 11 for the general cooperative link. This simulation results hold for an arbitrary number of cooperating branches and arbitrary number of cooperating hops per branch**.** However it is seen that BER performance of ADF strategy degrades with increased number of hops for same number of branches. It is also seen that BER performance of ADF strategy improves with increased number of branch for same number of hops. Thus it allows a tradeoff between selection of number of branches and number of hops for achieving a desired BER as shown in Figure 10. As seen in Figure 11 the BER performance of ADF strategy degrades after 12 dB since mixed AF/DF strategy follows the DF scheme upto 12dB SNR. After 12dB for a particular decoding threshold ($P_{b,t}$= 0.04), ADF strategy shift from DF to AF. In the range of 12dB SNR the BER performance of ADF strategy is very poor for higher switching threshold in multihop relay network as shown in Figure 7. So we can overcome this problem by decreasing the switching threshold as mention in Figure 7. Then the decoding threshold selection is one of the important challenges in multihop cooperative relay network. Further, for a given switching threshold the performance could be improved by appropriate choice of number of hops and branches in the network. For example, 2-hop and 3-branch network is outperforming than other three combinations at switching threshold ($P_{b,t}$= 0.04) in Figure 11.

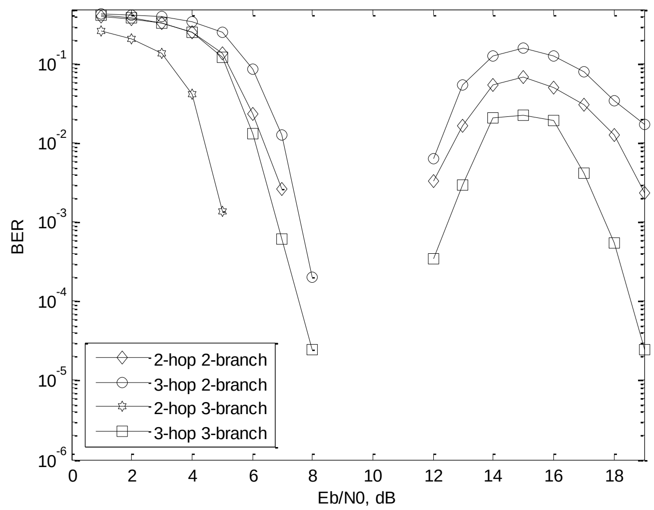

Figure 11. BER Performance Comparison for Multibranch and Multihop Cooperation using ADF Scheme

6. Conclusion

In this paper a hybrid AF/DF strategy based multi hop and cooperative relay network is investigated in presence of m-nakagami fading. The strategy allows a trade-off between decoder usage and error performance for links containing relays, which is useful for energy constrained self organizing networks. It is seen that the BER performance of DF is better than that of AF over the entire ranges of SNR in relay network. It is also observed that by lowering the switching threshold value, the relay is operated for most of the time in DF mode and thereby the performance is enhanced. It is seen that the BER performance of ADF strategy degrades with increase in switching threshold. However it is also seen that below a certain switching threshold ($P_{b,t}$) the BER performance of ADF scheme does not change with further decrease in switching threshold ($P_{b,t}$) for a particular SNR. In multihop relay network the BER performance of ADF strategy degrades with increase in number of relays which is same as number of hops. In multi-branch cooperative relay network the BER performance of ADF strategy improves with increase in number of relays which is same as number of branches. So it allows a tradeoff between selection of number of branches and number of hops for achieving a desired BER. Further BER performance does not change significantly beyond a certain number of relays for multihop relay network. In cooperative network the BER performance of hybrid scheme is improved with increase 'm' parameter. Our proposed network and assessment results are useful for designing relay based energy constrained cooperative network whose nodes are distributed randomly.

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Authors

Chanchal Kumar De received his B. Tech degree from the Haldia Institute of Technology, India, in 2004 and the M. Tech degree from West Bengal University of Technology, India in 2007, all in Electronics and Communication Engineering (ECE). He is currently Assistant Professor in Electronics & Instrumentation Engineering department at Dr. B. C. Roy Engineering College (BCREC), Durgapur, India. Before joining BCREC in February 2008, he was with the ECE Department as Lecturer at Bankura Unnayani Institute of Engineering since February 2005. His research interests include cooperative relay networks, cognitive radio networks. He has published 3 research papers in various Internationals Conferences.

Sumit Kundu received his B.E. (Hons.) degree in Electronics and Communication Engineering in 1991 from NIT, Durgapur, India and M.Tech. degree in Telecommunication Systems Engineering and Ph.D. in Wireless Communication Engineering from IIT Kharagpur, India, respectively. He has been a faculty in the department of ECE, National Institute of Technology, Durgapur since 1995 and is currently an Associate Professor there. His research interests include radio resource management in wireless networks, Wireless Ad Hoc and sensor networks, and Cognitive Radio Networks. As of today, he has published hundred (100) research papers in various journals and conferences. He is a member of IEEE (Communication Society) and is a reviewer of several IEEE journals.