Volume 2 No. 7, July 2012 ISSN 2223-4985

International Journal of Information and Communication Technology Research

http://www.esjournals.org

Cooperative Diversity in Cognitive Relay Networks using Different Coding Techniques

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ABSTRACT

Cognitive radios (CR) represent new technique that can effectively improve the spectrum efficiency of future wireless networks. In this paper, the problem of cooperative relay in CR networks will be investigated for further improve network performance. A scenario in which a secondary transmitter can communicate with a secondary receiver via a direct communication link or a relay channel will be considered. Cooperative relay communications or cooperative diversity has emerged as a promising technique to combat fading in wireless communications. Two well-known cooperative diversity are known as Decode –And-Forward (DAF) and Amplify-And-Forward (AAF). In this paper, the DAF strategy will be considered, which achieves diversity by using Maximal Ratio Combining (MRC) and Fixed Ratio Combining (FRC). Convolutional Code (CC) and Low Density Parity Check (LDPC) will be investigated which is not clarified until now. The analysis of the system will be made. From simulation results; we can conclude that by using both of the direct and relay channels, the transmission performance of the secondary system can be improved significantly. Moreover, by exploiting the cooperative spectrum sensing technique for applications in relay based cognitive radio network, it is seen that detection probability increases by using relay channel. Comparisons between convolutional code for different rates will be made under using AWGN. Also, the effect of the positions of the relay will be studied. The best performance was achieved when the relay is at equal distance from the sender and the destination or slightly closer to the sender in the case of MRC and FRC.

Keywords- *Relay, Decode and Forward (DF), CC and LDPC.*

I. INTRODUCTION

Radio spectrum is one of the most scarce and available resources for wireless communications. Strictly conservative spectrum policies employed by regulated authorities have resulted in underutilization of the overall available spectrum. Measurements performed by, for example, the Federal Communications Commission (FCC) [1] in the United States and OFcom [2] in the United Kingdom have revealed that at any given time, a large number of spectrum bands are seldom or rarely occupied. CR is a promising technology to exploit such spectrum that is called white spaces or spectrum hole and has received significant interest in the research community [3],[4]. The complementary technique of cooperative diversity is a promising technique for providing the high data rate coverage required in future cellular and ad-hoc wireless communication networks [5]. In Cooperative Relaying, one of cognitive nodes is used to support signal transmission by using Decode-And-Forward relaying mode. Recently, the combination of relaying and cognitive radio techniques has been investigated [6, 7, 8, 9]. In addition to the advantages described above, cognitive relays could also be deployed as a means of minimizing the interference can used by secondary transmission to the primary licensee, while guaranteeing reliable communications for the secondary users [9]. Detection probability and bit error rate performance are widely used as a measuring to the characterization of the performance of communication systems. In this paper, we investigate error performance for decode and forward Cognitive Relay networks by using CC and LDPC will be investigated. The analysis of the system will be made. Error performance for Decode- And-Forward by using CC for different rates which is not clarified until now will be studied. A relay based cooperative spectrum sensing in cognitive relay networks with different coding technique will be proposed. The idea is to utilize relay nodes to convey the signal transmitted from the primary user to a cognitive coordinator, which will make estimation of the presence or absence of primary activates. The cognitive coordinator uses an energy detector to make the estimation which is used due to its simplicity of implementation and low complexities. In addition, it doesn't need any prior information about the primary users 'signals. The rest of this paper is organized as follows: Single Relay Cooperation is described is Section II. Cooperative Convolutional Code (CC) and LDPC transmission schemes will be discussed in Section III. Cooperative spectrum sensing with cognitive relay will be introduced in Section IV. In Section V, Simulation results will be made. Finally, Conclusions will be done in Section VI.

Volume 2 No. 7, July 2012 ISSN 2223-4985

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II. SINGLE RELAY COOPERATION

A. System Model

Figure 1 shows a single relay cooperative system. This figure considers the simplest model in which only one relay (R) helps the source (S) to communicate with the destination (D). The source S broadcasts the symbols to D that are also received by R, which forwards the decoded symbols to D. Because signals from S and R arrive through two different paths, If fading is present, one can (at least in principle) design a detector capable of collecting diversity up to order of two. In practice, terminals cannot transmit and receive at the same time and over the same frequency band; however, S and R can transmit over orthogonal channels. In this paper, we suppose a Time Division Duplex (TDD) mode, where data transmission consists of two slots. In slot 1, S broadcasts modulated symbol *x* with average power P_x. The received symbols at *R* and *D* are:

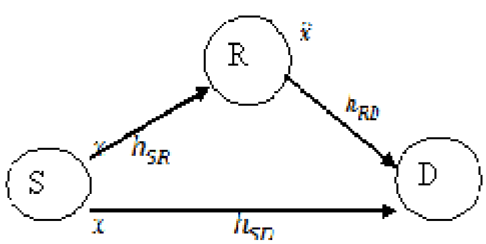

Figure 1. Block model for a single-Relay Cooperative system.

$$y_{SR} = h_{SR}x + z_{SR} \qquad (1)$$

$$y_{SD} = h_{SD}x + z_{SD} \qquad (2)$$

Where h_{SR} and h_{SD} denote the fading coefficients from S to R and D, which are modeled as $h_{SR} \sim CN(0,\sigma^2_{SR})$, $h_{SD} \sim CN(0,\sigma^2_{SD})$, with $\sigma^2_{SR} := E\{|h_{SR}|^2\}$ and $\sigma^2_{SD}: E\{|h_{SD}|^2\}$, respectively. Without loss of generality, we assume that the noise terms z_{SR} and z_{SD} have equal variances, N_0, and are modeled as $z_{SR} \sim CN(0,N_0)$, $z_{SD} \sim CN(0,N_0)$. In the uncoded DF protocol, R performs coherent ML demodulation as

$$\hat{x}_R = \arg \min_{x \in A_x} |y_{SR} - h_{SR}x|^2 \qquad (3)$$

Where $|A_x| = \Theta$ denotes the cardinality (size) of the Θ-ary constellation. Then, the detected symbol $\hat{x}_R$ is remodulated and subsequently transmitted during Slot II with the same average power P_x . The received symbol at D is

$$y_{RD} = h_{RD}\hat{x}_R + z_{RD} \qquad (4)$$

Where $\hat{x}_R$ is the remodulated symbol at R, h_{RD} denotes the channel coefficient from R to D ,$h_{RD} \sim CN(0,\sigma^2_{RD})$ with $\sigma^2_{RD} := E\{|h_{RD}|^2\}$, and $z_{RD} \sim CN(0,N_0)$ denotes the noise at D.

B. Relay Link Analysis

Define the instantaneous signal to noise ratio (SNR) at links S-R, R-D as $\gamma_{SR} := |h_{SR}|^2\bar{\gamma}$, $\gamma_{RD} := |h_{RD}|^2\bar{\gamma}$, and $\gamma_{SD} := |h_{SD}|^2\bar{\gamma}$, respectively, with $\bar{\gamma} = {}^{P_x}/_{N_0}$ denoting average SNR. Notice also that, errors at the destination occur either when the S-R transmission is received correctly and the R-D transmission is received in error, or when the S-R transmission is received in error and R-D transmission is received correctly. Hence, for any given modulation, the two hop S-R-D channel has end to end BEP that is given by

$$p^b_{eq}(\gamma_{SR},\gamma_{SD}) = [1 - p^b_{SR}(\gamma_{SR}(\gamma_{SR})]p^b_{RD}(\gamma_{RD})$$

$$+[1 - p^b_{RD}(\gamma_{RD})]p^b_{SR}(\gamma_{SR}) \qquad (5)$$

Where $p^b_{SR}(\gamma_{SR})$, and $p^b_{RD}(\gamma_{RD})$ are the conditional BEPs at both hops which we assume available at D. Due to possible errors at the relay, the S-R-D channel is clearly nonlinear and non- Gaussian. However, one can think of the BEP in (5) as the error probability at the receiver of an equivalent one-hop AWGN link whose output SNR γ_{eq} is

$$\gamma_{eq} := \frac{1}{\alpha}\{Q^{-1}[p^b_{eq}(\gamma_{SR},\gamma_{RD})]\}^2 \qquad (6)$$

Where $(x) := ({}^1/_{\sqrt{2\pi}}) \int_x^\infty \exp({}^{-t^2}/_2)\, dt$, and α is a constant that depends on the underlying constellation; e.g., α=2 for BPSK. This equivalent one-hop SNR γ_{eq} jointly accounts for the equality of both S-R and R-D links, and will guide the design of our novel demodulator. To this end, we establish the following property for γ_{eq} .

Property1: Upon defining $\gamma_{min} := \min\{\gamma_{RD},\gamma_{SR}\}$,it holds that γ_{eq} in (6) is bounded by

Volume 2 No. 7, July 2012 ISSN 2223-4985

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$$\gamma_{min} - \frac{3.24}{\alpha} < \gamma_{eq} \leq \gamma_{min} \qquad (7)$$

Property 1 upper-bounds the end-to-end equivalent SNR by the minimum of its single-hop SNRs. This is intuitively expected, because the BEP over the aggregate S-R-D link cannot exceed that of R-D or S-D. on the other hand, the lower bound in (7)implies that for a relatively large γ_{min} ,the constant 3.24/α can be negligible, showing that indeed γ_{min} can offer a tight approximation to γ_{eq}. Property 1 will come handy in our subsequent asymptotic analyses.

As recognized by [10, 11] in the context of AAF, knowledge of the S-D link quality (γ_{SR}) at D is possible by sending pilot symbols through R. In regenerative schemes such as DAF, one can acquire the S-R link quality by sending a pilot from S for the relay to estimate the S-R channel, and forward it to the destination via a second pilot whose power is so called according to the estimated channel coefficient. At the receiver, as in AAF, one again recovers the product of the two S-R and R-D fading coefficient.

C. Cooperative MRC

Consider combining the received y_{SD} and y_{RD} at the destination to obtain

$$\hat{x}_D = arg \min_{x \in A_x} \left| \begin{matrix} w_{SD} y_{SD} \\ + w_{RD} y_{RD} (w_{SD} h_{SD} + w_{RD} h_{RD}) x \end{matrix} \right|^2 \quad (8)$$

Where weights w_{SD} and w_{RD} are functions of h_{SD}, h_{SR}, and h_{RD} to be specified later . In a collocated multi-antenna setup, MRC employs weights $w_{SD} = h_{SD}^*$ and $w_{RD} = h_{RD}^*$, and is known to maximize the SNR at the combiner output. This would also be the optimal choice in our context if $\hat{x}_R = x$. However, since the fading link *S-R* causes detection errors at the relay, performance of the standard MRC is far from being optimal. Motivated by this, we fix $w_{SD} = h_{SD}^*$ to maximize γ_{SD}, and seek a weight w_{RD} to maximize the equivalent SNR γ_{eq} in the link *S-R-D*, instead of *R-D* alone. These considerations lead to the choice

$$w_{RD}(h_{SR}, h_{RD}) = \frac{\gamma_{eq}}{\gamma_{RD}} h_{RD}^* \qquad (9)$$

Combiner (8) with weights $w_{SD} = h_{SD}^*$and w_{RD} as in (9) constitutes what we term cooperative MRC(C-MRC). Consider the product $w_{RD} h_{RD}$, and define $|h_{eq}|^2 := \frac{\gamma_{eq}}{\bar{\gamma}}$. If one opts for MRC, $w_{RD} = h_{RD}^*$ and thus $w_{RD} h_{RD} = |h_{RD}|^2$. However, the weight (9) modifies the last product to $w_{RD} h_{RD} = |h_{eq}|^2$, which now jointly considers the *S-R* and *R-D* links. We also note from Property 1 that $\gamma_{eq} \approx \gamma_{min}$ at sufficiently high SNR. From this approximation, w_{RD} can be seen as either part of a conventional (one -hop) MRC (when $\gamma_{SR} > \gamma_{RD}$ or as a two hop weighted combiner (when $\gamma_{SR} < \gamma_{RD}$). I the first case, because the link *S-R* is better than *R-D*, the combiner places full confidence to the arriving symbols from R .In the placed on the link *S-R-D* by $|h_{eq}|^2$, instead of the link *R-D* alone by $|h_{RD}|^2$.

III. COOPERATIVE CC AND LDPC TRANSMISSION SCHEMES

A binary CC takes a stream of information bits and converts it into a stream of transmitted bits as using a shift register bank as shown as in Figure 2. Redundancy for recovery from channel errors is provided by transmitting more bits per unit time than the number of information bits per unit time. Maximum likehood decoding can be done using the Viterbi algorithm. In practice, the information stream is of finite duration and one typically appends a few termination bits to the input stream to bring the shift register bank back to the all zeros state, so that the CC is in effect used as a very long block code. Often CCs are used as inner codes with burst error correcting block codes as outer codes to form concatenated codes. Errors in Viterbi-like decoding algorithms for CCs tend to occur in bursts because they result from taking a wrong path in a trellis. The burst error correcting capability of the outer code is used to recover from such burst error patterns in the decoding of the inner code.

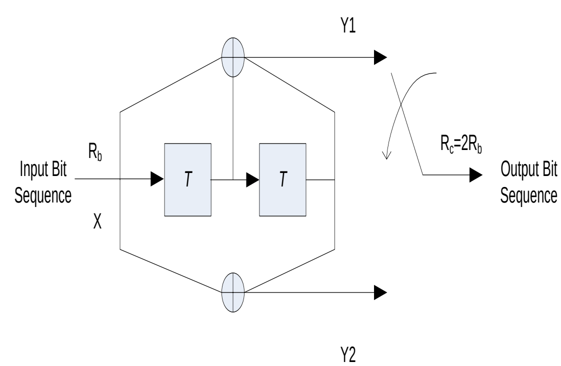

Figure 2: CC Transmission Scheme

Volume 2 No. 7, July 2012 ISSN 2223-4985

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The code rate r for a CC is defined as:

$$r = \frac{k}{n} \qquad (10)$$

Where k is the number of parallel input information bits and n is the number of parallel output encoded bits at one time interval. The constraint length k for the CC code is denoted by:

$$k = m + 1 \qquad (11)$$

Where m is the maximum number of stages (memory size) in any shift register. The shift registers store the state information of the CC and the constraint length relates the number of bits upon which the output depends. On the other hand, LDPC [12-13] block codes form a class of codes which approach the (theoretical) Shannon limit. LDPC block code is one *(n, k)* linear block code types, where sequence of K message bits be applied to a linear block encoder producing an n-bit code word. Where code word is divided into two parts, one of which is occupied by the message bits and the other is made by the parity bits. Clearly, we have the option of sending the message bits of a code word before the parity bit or vice versa. Where *1-by – (n-k)* parity vector b is given by:

$$b = mp \qquad (12)$$

$$c = m[b \vdots m]) \qquad (13)$$

Substituting Eq. (12) in Eq. (13) and factoring out the common message vector m, we get

$$c = m[p \vdots I_k] \qquad (14)$$

Where I_K is the *k- by- k* identify matrix, p is *k-by-(n-k)* coefficient matrix. Define the *k-by -n* generator matrix as

$$G=\begin{bmatrix} g_0 \\ g_1 \\ \vdots \\ \vdots \\ g_{k-1} \end{bmatrix} = \begin{bmatrix} g_{00} & g_{01} & \cdots & g_{0,n-k-1} & 1 & 0 & 0 & 0 \\ g_{10} & g_{11} & \cdots & g_{1,n-k-1} & 0 & 1 & 0 & 0 \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix}$$

(15)

$$c = mG \qquad (16)$$

There is another way of expressing the relationship between the message bits and parity-check bits of a linear block code. Let H denote an *(n-k)-by-n* matrix, which is defined as:

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & p_{00} & p_{10} & \cdots & p_{k-1,0} \\ 0 & 1 & 0 & 0 & \vdots & \vdots & & \vdots \\ \vdots & \vdots & \vdots & \vdots & p_{0,n-k-1} & \vdots & & p_{k-1,n-k-1} \end{bmatrix}$$

(17)

When a codeword $\boldsymbol{c}$ is transmitted and vector $\boldsymbol{r}$ is received, the difference between the two is called the error vector $\boldsymbol{e}$. i.e. $\boldsymbol{r} = \boldsymbol{c} + \boldsymbol{e}$ will be the input information for decoder. The traditional decoder depends on the syndrome. $s = H \cdot r$. Calculate the syndrome of $\boldsymbol{r}$. If the syndrome is $\mathbf{0}$, no error has occurred and $\boldsymbol{r}$ is a codeword but error has caused the syndrome to non zero. Furthermore the position of the error can locate by comparing the syndrome with the columns of the check matrix.

IV. COOPERATIVE SPECTRUM SENSING WITH COGNITIVE RELAY

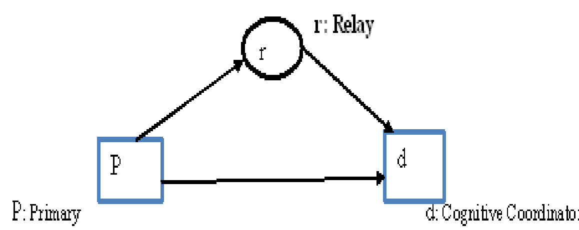

Figure 3 .Cooperative Networks with Cognitive Relay

We discuss a relay-based spectrum sensing [14, 15, 16] by using one relay, as shown in Fig.3.. As the primary user starts using the band, cognitive radios receive the signal of the primary user. Instead of making individual hard decision about the presence of the primary user, Relay-based cognitive radios simply decode and retransmit the noisy version of the received signals to the cognitive coordinator. The cognitive coordinator is equipped with the energy detector which compares the received signal strength with a pre-defined threshold based on the decision; the cognitive coordinator informs the cognitive radios the presence or absence of primary user's activities.

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V. SIMULATION RESULTS

In this section, computer simulation results are presented to evaluate cooperative diversity in cognitive relay networks under using different coding techniques over AWGN channel in terms of the average bit error probability (BEP). We assume that primary network uses OFDM modulation with 64 QAM and N=512 subcarriers. Energy detector is used to detect the presence or absence of the primary user signal.

Figure 4 shows the cooperative relaying over AWGN channel by using decode and forward relaying. We conclude that the improvement using relay channel with cooperative scheme is better than the case of no using relay channel.

Figure 5 illustrates the effect on the performance for decode and forward relaying mode by using CC for different rates. It is seen that bit error probability is decreased when the value of rate reduced because the rate is directly proportional with bit error probability.

Figure 6 demonstrates the comparisons between LDPC and CC transmission schemes. It is shown that bit error probability is reduced by using LDPC. This is because, LDPC add more redundancy than CC.

Figure 7 shows performance results of relay based cooperative spectrum sensing. It is seen that the probability of missed detection is greatly reduced by using relay channel for a given probability of false alarm.

Figure 8, 9 show the effect positions of the relay that is between sender and destination on performance of cooperative relaying in the case of MRC and FRC. It is shown that the best performance is achieved when the relay is situated in the middle between the sender and the destination, or slightly closer to the sending station.

VI. CONCLUSIONS

In this paper, we have analyzed bit error rate probability of cognitive wireless relay networks where a single source-destination pair is assisted by one relay channel employing regenerative decode and forward under using different coding techniques. It is shown that bit error probability is reduced by using CC and LDPC better than the case of no using relay channel. Moreover, the effects of the positions of the relay are studied on the performance of cooperative relaying where the best performance is achieved when the relay is situated in the middle between source and destination. Performance of cooperative relaying with CC and LDPC for different rates has been investigated. The relay based spectrum sensing with an energy detector for a cognitive radio network with AWGN channels has been discussed. It seen that the detection probability increases by using relay channel.

ACKNOWLEDGEMENTS

This work has been partially supported by the help of Egyptian Atomic Energy Authority. First and foremost all praises and thanks to Dr .Mona Shokair who gave me the ability and bestowed me with perseverance to write this paper.

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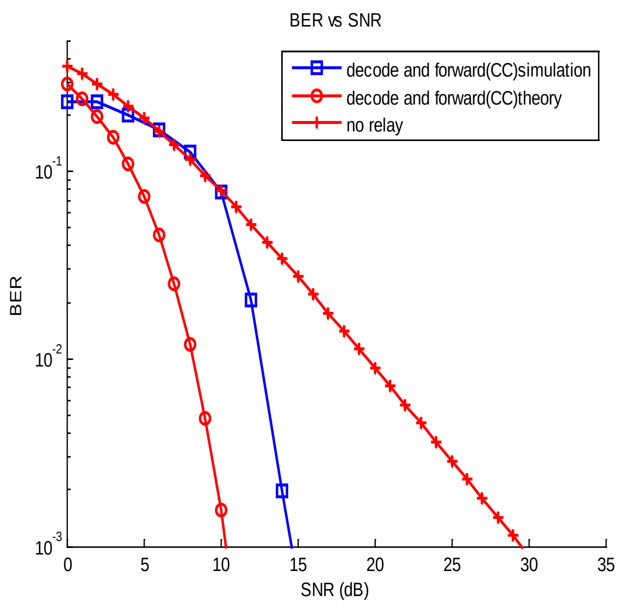

Figure 4: Comparisons of BEP for Cooperative Relaying with or without Relay Channel

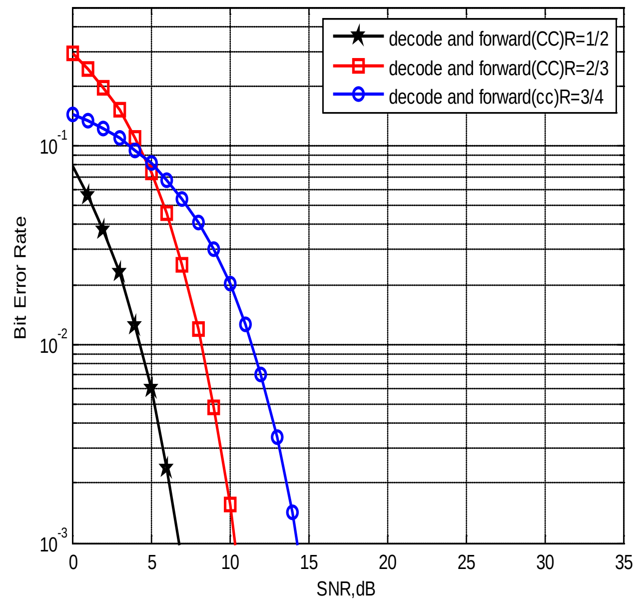

Figure 5: Comparisons of CC for Different Rates

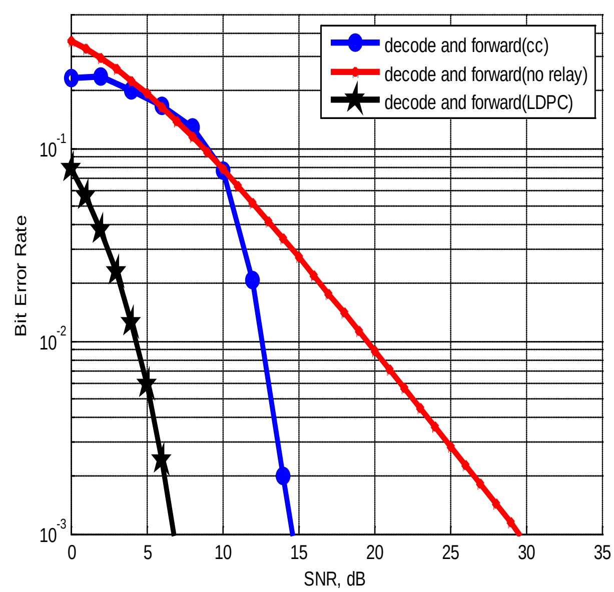

Figure 6: Comparison between LDPC and CC Transmission Schemes

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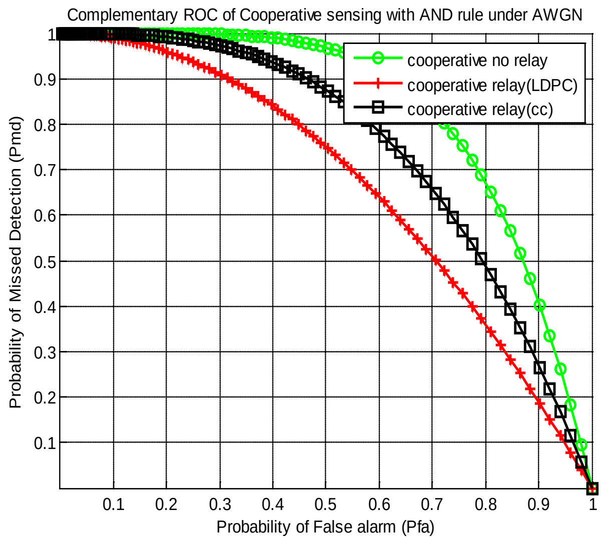

Figure 7 .Comparisons of Performance for Relay based Cooperative Spectrum Sensing

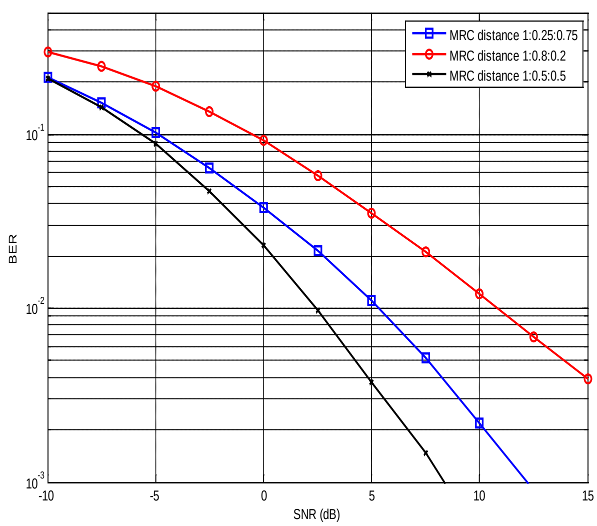

Figure 8 Comparisons for MRC when the Relay is located between Sender and Destination

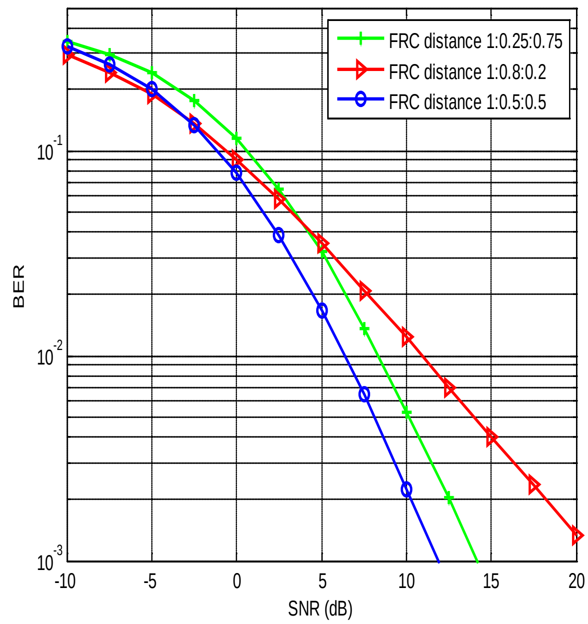

Figure 9 Comparisons of FRC when the Relay is located between Sender and Destination