Performance of Multiple Antennas Cognitive Relay Networks

Eman Sadik
Faculty of Electronic Engineering,
Menoufia University, Egypt

Mona Shokair
Faculty of Electronic Engineering,
Menoufia University, Egypt

Said Elhalafawy
Faculty of Electronic Engineering,
Menoufia University, Egypt

ABSTRACT
Cognitive relay networks (CRNs) combine cognitive radio technique and cooperative relay technology. Cognitive radio offers a tempting solution to increase spectrum usage efficiency by proposing opportunistic usage of frequency bands between primary and secondary users. Many techniques are used to improve the performance of the cognitive relay networks. One of these techniques is using multiple antennas at relay. Another technique is using multiple antennas at the receiver of the system which exist at the energy detector (ED) which is not clarified until now. Adaptive relay protocol (ARP) will be used. Analysis of this system will be made. Moreover different combining techniques will be applied.

Keywords
Cognitive Relay Networks, Cooperative Relay, Multiple Antennas.

General Terms
Transmission protocols and spectrum utilization.

1. INTRODUCTION
Cognitive radio is used to designate intelligent communication networks that can adapt changes occurring in the surrounding environment [1]. Furthermore, Haykin [2] defined cognitive radio as an intelligent wireless communication system able to adapt some parameters (such as transmit-power, carrier-frequency, etc.) with two main goals: highly reliable communications and efficient utilization of the radio spectrum [3].

Cognitive radio network can be divided into three protocols interweave, underlay, and overlay protocols [4], [5]. In the interweave protocol, the unlicensed users (also referred as secondary users) detect the radio spectrum holes and communicate over them without causing interference to the licensed users (primary users). In the underlay protocol, the secondary users are allowed to transmit simultaneously with the primary users; provided that the received SUs signal power levels at all PUs receivers are kept below predefined threshold. In the overlay protocol, the SUs aid the PUs transmission by cooperative communication techniques and the secondary users can transmit concurrently with the primary users. In our system, overlay protocol is used.

In schemes for cooperative communications that is used in [6]–[8], where one or more nodes help the communication between source and destination by acting as relays, achieve spatial diversity even in a network composed of single antenna devices. In [7], Laneman et al presented two protocols of cooperative communications: amplify and- forward (AF) and decode-and-forward (DF). In the AF protocol, the relay amplifies the received signal and forwards it to the destination. In the DF protocol, the relay tries to decode the source message and then re encodes and forwards it to the destination. The disadvantages of these two techniques of relay come with the fact that the AF relay amplifies the noise, which degrades the signal quality. On the other hand, the DF relay causes error propagation in case of incorrect decoding of the information symbols [9]. These protocols will be used in this paper.

Another critical issue in cognitive radio is to reliably and quickly detect the presence or absence of primary user signal. The existing spectrum sensing techniques can be divided into three categories: energy detection, matched filter detection and cyclostationary detection. Among them, energy detection has been widely applied since it doesn't require any prior knowledge of primary signals and has much lower complexity than the other two schemes [10]. This type of detector will be used in the system which will be suggested in this paper.

In this paper, AF, DF relay protocols and ED with multiple antennas are adopted to improve the performance of cognitive relay networks. In addition, the relation between SNR and SER under different combining techniques will be investigated and it will be shown what relaying protocol is better, AF or DF? Moreover, adaptive relay protocol (ARP) is used to overcome the disadvantages of these two relay protocols. Moreover, improving the performance of the system is investigated by analysis of usage energy detector with multiple antennas and usage of two separate energy detectors, each one has a single antenna with various decision rules.

The reminder of this paper is organized as follows: Section II describes the system model for the analysis of cognitive relay networks. Analysis of primary user detection is illustrated in Section III. Simulation results are made in Section IV. Finally, conclusions are made in Section V.

2. SYSTEM MODEL

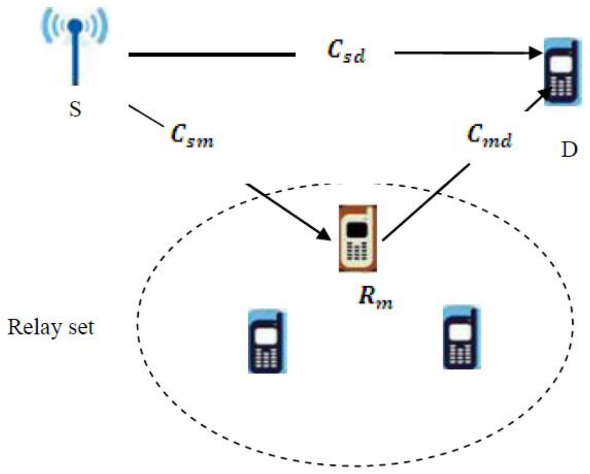

Figure 1: Channel model for cognitive relay network.

Cognitive relay system is illustrated in Figure 1, where S and D denote the source and destination respectively. The relay set represents those M available and randomly located SUs, which can act as a relay for S. Here only one relay node is used to help the link, which may provide the most throughput enhancement for the link. The common channels of S and D will be reserved for the usage of direct link, which is denoted by channel set C_{sd}. Assume that node R_m is selected as a relay, the channels used by R_m for receiving and transmitting should not be included in C_{sd}, which can bedenoted as channel set $C_{sm}$and C_{md} respectively. A channel in $C_{sd}$is called a direct channel, and a pair of channels, which transmit the same C_{sm}data from S to D through R_m, including a source-to-relay (SR) channel in $C_{sm}$and a relay-to-destination (RD) channel in C_{md}, could be called a relay channel[11].

2.1 Amplify-and-Forward Protocol

In the proposed scheme in Fig.1, the AF relay amplifies the received signal and forwards it to the destination. Suppose that S occupies V channels for sending, K of which for direct communication and the other V -K for relay links. As a result, there are K channels in C_{sd}, which can be denoted as C_{sd}^k, k = 1, 2,...,K. The number of channels in C_{sm} and C_{md} are both V-K, we use C_{sm}^i, i =1,2,...,V-K and C_{md}^j, j=1,2,…,V-K to denote them respectively.

While the primary system is always transmitting, the communication of the cognitive system is occurred in two time slots. Assume that the channel state information (CSI) is stable during a frame. For a direct link, the received signal at D can be written as [11],

$$y_{sd}^k = \sqrt{p_s^k} g_{sd}^k x_s^k + \sqrt{p_p^k} g_{pd}^k x_p^k + n_d^k. \quad (1)$$

For simplicity of the previous equation, it becomes,

$$y_{sd} = \sqrt{p_s} g_{sd} x_s + \sqrt{p_p} g_{pd} x_p + n_d. \quad (2)$$

2.2 Decode-and-Forward Protocol

Based on the DF cooperation protocol [12], the received signals r_{sd} and r_{sm} at the mobile-relay (MR) and the mobile-destination (MD), during the first time slot can be written as,

Where x_s^k is the transmitted information of the cognitive source S on channel C_{sd}^k, and x_p^k is the transmitted signal of a certain PU on this channel. If there isn't any PU transmitting on C_{sd}^k then $x_p^k = 0$. $p_s^k$and p_p^kdenote the transmit power from S and the PU respectively. g_{sd}^k and g_{pd}^krepresent the instantaneous channel gains from S and the PU to D, respectively, both of which include the path loss and fading effects. n_d^k is the additive white Gaussian noise (AWGN) at D on channel C_{sd}^k, assume the AWGN at all users has the same power of N. Since the primary signal received at D can be perfectly cancelled, the signal-to-noise ratio (SNR) of the direct channel C_{sd}^k is $SNR_{sd}^k = p_s^k G_{sd}^k / N$, where G_{sd}^k is the power gain of C_{sd}^k. Similar definition can also be applied to other links in [11].

For relay node R_m, suppose that the information received on channel $C_{sm}^i$is transmitted on channel C_{md}^i. The received signal at $R_m$on C_{sm}^iduring the first time slot can be written as,

$$y_{sm}^i = \sqrt{p_s^i} g_{sm}^i x_s^i + \sqrt{p_p^i} g_{pm}^i x_p^i + n_m^i. \quad (3)$$

For simplicity of the previous equation, it becomes,

$$y_{sm} = \sqrt{p_s} g_{sm} x_s + \sqrt{p_p} g_{pm} x_p + n_m. \quad (4)$$

The primary signal is first detected and cancelled, and then the remaining signal is amplified and retransmitted. Thus, the transmitted signal on C_{md}^ican be written as,

$$x_m^i = \left(\sqrt{p_s^i} g_{sm}^i x_s^i + n_m^i\right) / \sqrt{p_s^i G_{sm}^i + N}. \quad (5)$$

It can be easy reduced to,

$$x_m = (\sqrt{p_s} g_{sm} x_s + n_m) / \sqrt{p_s G_{sm} + N}. \quad (6)$$

The received signal at D on C_{md}^j during the second time slot can be written as,

$$y_{md}^j = \sqrt{p_m^j} g_{md}^j x_m^j + \sqrt{p_p^j} g_{pd}^j x_p^j + n_d^j. \quad (7)$$

Which it can be easy given by,

$$y_{md} = \sqrt{p_m} g_{md} x_m + \sqrt{p_p} g_{pd} x_p + n_d. \quad (8)$$

The primary signal can also be cancelled at D. Then the SNR of the cooperative relay channel can be written as,

$$SNR_m^{ij} = \frac{p_s^i p_m^j G_{sm}^i G_{md}^j}{N(p_s^i G_{sm}^i + p_m^j G_{md}^j + N)}. \quad (9)$$

For simplicity, the previous equation becomes,

$$SNR_m = \frac{p_s p_m G_{sm} G_{md}}{N(p_s G_{sm} + p_m G_{md} + N)}. \quad (10)$$

$$r_{sm} = \sqrt{p_s} g_{sm} x_s + n_{sm}. \quad (11)$$

$$r_{sd} = \sqrt{p_s} g_{sd} x_s + n_{sd}. \quad (12)$$

Then, the relay decodes its received signal and uses the power p_p for relaying. The received signal r_{md} at the D is given by,

$$r_{md} = \lambda(\sqrt{p_p} g_{md}\, x_s + n_{md})\,. \quad (13)$$

If the symbol is correctly decoded, λ = 1; otherwise, λ = 0. If MRC method is used at the D, the output SNR at the destination can then be calculated as,

$$\gamma_{MRC} = p_s \mid g_{sm} \mid^2/N_{sd} + \lambda p_p \mid g_{md} \mid^2/N_{md}\,. \quad (14)$$

2.3 Cooperative Relay Scheme

The basic idea of cooperative relay scheme is illustrated in Fig.2. Suppose there is a data transmission from source(S) to destination (D), and there is only one common channel (channel l) between them. Meanwhile, a neighbor relay node (R) has many channels: channel 2 common with S and another channel 3 common with D. As a result, R could be involved as a helper in the transmission by dividing a frame into two time slots: in the first time slot, S sends data to R on channel 2, and in the second time slot, R transmits the data to D on channel 3. The communication on channel 1 between S and D is continued all the time. In this way, the data rate is increased between S and D, and spectrum resources are efficiently utilized [12].

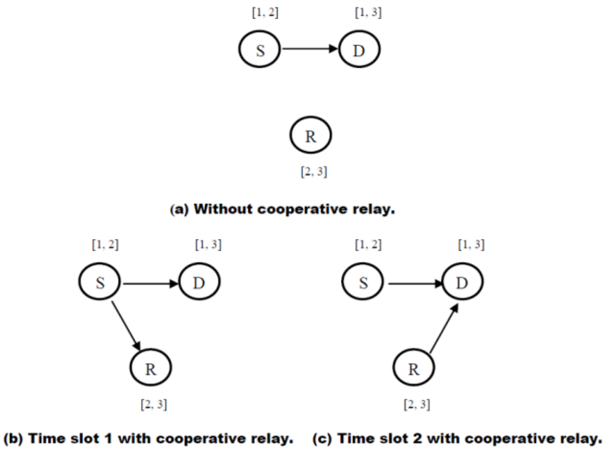

Figure 2: An example for cooperative relay.

3. ANALYSIS OF PRIMARY USER DETECTION

Spectrum sensing is the basic and important operation in cognitive radio to find the unused spectrum. Energy detector is a popular sensing method, because it doesn't require any information about PU signal. Energy detector uses squaring device followed by an integrator, the output of that gives the decision variable. This variable is then compared with a threshold and if it is above the threshold then the result of the detector is that primary user is present [13]. Figure 3 shows the block diagram of Energy detector.

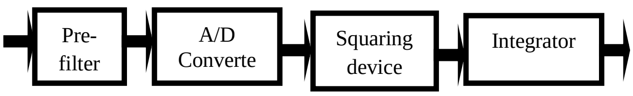

Figure 3: Block Diagram of Energy Detection.

Let s(t) be the primary user signal that is transmitted over a channel with gain h and additive zero-mean white Gaussian noise n(t). Let W denote the signal bandwidth, and T be the observation time over which signal samples are collected, so chosen that the time-bandwidth product, Λ = TW, is an integer. The goal is to determine whether a signal is present (hypothesis H_1) or not (hypothesis H_0) [14]. Under these two hypotheses, the received signal is given by

$$H_1: r(t) = h\, s(t) + n(t),$$
$$H_0: r(t) = n(t). \quad (15)$$

Let N_0 be the two-sided noise power spectral density. A modified energy detector is considered that differentiates between hypotheses H_1 and H_0 based on the normalized quantity, $E = E_r/N_0$, where E_r is the energy of the received signals under the two hypotheses [14].

Under H_0,

$$E=\frac{1}{N_0}\int_0^T n(t)^2\, dt=\frac{1}{2N_0 W}\sum_{i=1}^{2\Lambda} n_i^{\,2}. \quad (16)$$

Where n_i are the samples obtained by sampling n (t) at the Nyquist frequency 2W, i.e. we have

$$n(t) = \sum_{i=1}^{2\Lambda} n_i \mathrm{sinc}(2Wt-i),\ 0 < t < T, \text{ or } n_i = n(i/(2W)). \quad (17)$$

For the modified energy detector, with η as the detection threshold, the probability of detection (p_d) and probability of false-alarm (p_f) are defined by,

$$p_d = \mathrm{Prob}[E > \eta | H_1], \quad (18)$$

$$p_f = \mathrm{Prob}[E > \eta | H_0]. \quad (19)$$

Then, we can obtain the following closed-form expressions,

$$p_d = Q\Lambda(\sqrt{2\rho}, \sqrt{\eta}), \quad (20)$$

$$Pf = \Gamma(\Lambda, \eta/2)/\Gamma(\Lambda). \quad (21)$$

Where Γ (.,.) is the incomplete Gamma function and QΛ(a, b) is the generalized Marcum-Q function

For cooperative spectrum sensing, let N denote the number of users sensing the PU. Each user makes its own decision regarding whether the PU present or not, and forward it's binary (0, 1) decision to the collaborative decision. If one of decision fusion the AND rule is considered here to make collaborative decision; in this case, if all of the local decisions sent to the decision maker are one, the final decision is one[15]. The cooperative probability of detection using AND rule is

$$p_{d,AND} = pr\{\text{Fusion decision} = 1 | H_1\} = \prod_{i=1}^{N} p_{d,i}. \quad (22)$$

The cooperative probability of false alarm using AND rule is

$$p_{f,AND} = pr\{\text{Fusion decision} = 1 | H_0\} = \prod_{i=1}^{N} p_{f,i}. \quad (23)$$

The cooperative probability of misdetection using AND rule is

$$p_{m,AND} = 1-(p_{d,AND}). \quad (24)$$

If one of decision fusion the OR rule is considered to make collaborative decision; in this rule, if one of the local decisions sent to the decision maker is logical one, the final decision is one[15]. The cooperative probability of detection using OR rule is given by,

$$p_{d,OR} = pr\{\text{Fusion decision} = 1 | H_1\} = 1-\prod_{i=1}^{N}(1-p_{d,i}). \quad (25)$$

The cooperative probability of false alarm using OR rule is denoted by,

$$p_{f,OR} = pr\{\text{Fusion decision} = 1 | H_0\} = 1-\prod_{i=1}^{N}(1-p_{f,i}). \quad (26)$$

The cooperative probability of misdetection using OR rule is

$$p_{m,OR} = 1 - (p_{d,OR}). \quad (27)$$

4. SIMULATION RESULTS

In this section, the numerical results supporting the analysis of cognitive relay network are presented. Here, the relay network is demonstrated consisting of a source, a destination and M cognitive relay nodes. The performance of cognitive relay network is illustrated using QPSK modulation with AWGN and Rayleigh fading channels. Assume that, the number of symbols N is equal to 10^6.

In the following, the effect of many parameters will be studied as follows:

4.1 Effect of various combining techniques

Figure 4compares SER at different combining techniques with amplify and forward cooperative protocol. Numerical results are obtained by transmitted power of source$p_s = \frac{p_t}{2}$ and transmitted power of relay$p_r = \frac{p_t}{2}$.As shown in this figure; MRC technique has better performance than EGC and SGC techniques as it has the lowest symbol error rate.

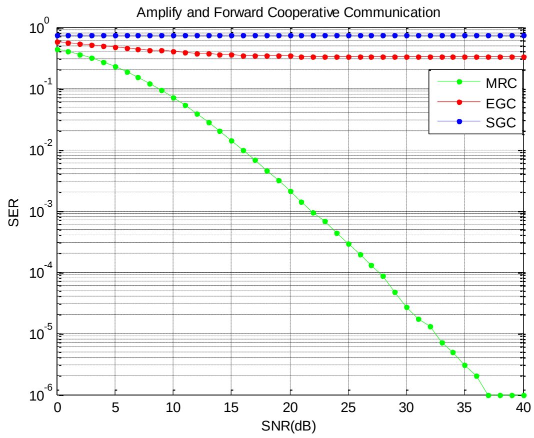

Figure 4: SER at different combining techniques with amplify and forward cooperative protocol.

4.2 Effect of different relay transmission protocols

Figure 5 shows the simulation of direct link, AF and DF protocols. From this figure, it can be conclude that significant improve performance is observed by using DF protocol than using AF or direct link. For instance, at SNR=22dB, the SER approximately 10^{-3}at AF protocol, $10^{-2.6}$ at DF protocol and 10^{-2} at direct link.The numerical results indicate that AF relay outperforms the DF relay under QPSK modulation in terms of signal to noise ratio (SNR) and symbol error rate (SER) which was explained by the error propagation effect in the DF relay protocol outweighing the noise amplification of the AF relay protocol.

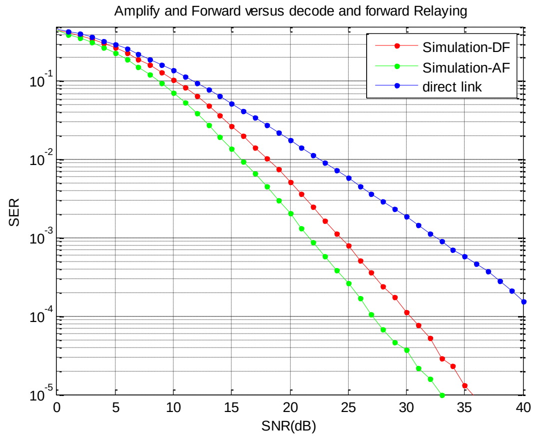

Figure 5: SER comparison between direct link, amplify and- forward (AF) and decode-and-forward (DF) protocols.

Figure 6 depicts the capacity using all the relay schemes (AF, DF, and ARP), which adaptive relay protocol (ARP) is one of the solutions to minimize the disadvantages of AF and DF relay technique as mentioned in the introduction. ARP can execute AF and DF based on the quality of signal (SNR) that triggers the switching between AF and DF relay protocol.

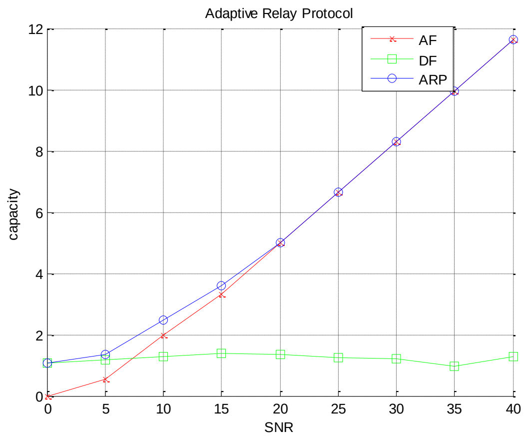

Figure 6: Achieved capacity for different SNR in adaptive relay protocol (ARP).

4.3 Effect of using energy detector with multiple antennas

The effect of the multiple antenna processing techniques through the detection probability for a pre-specified probability of false alarm at given SNR is illustrated in Figure 7. As shown in this figure, the diversity gains offered by four antennas processing in energy detection achieve the best probability of detection.

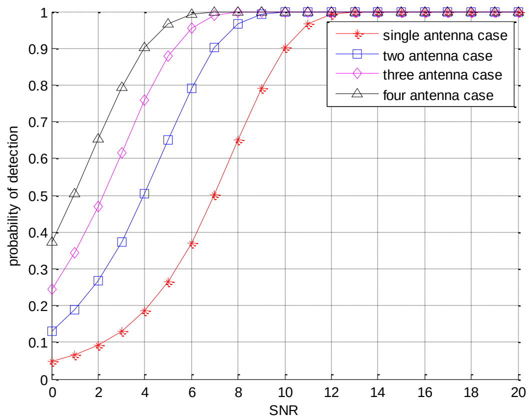

Figure 7: Detection performances with multiple antennas processing.

4.4 Effect of using more than one energy detectors at the receiver

The performance of a receiver using single energy detector with 2 antennas compared to another receiver using two energy detectors, each one has a single antenna using OR rule is illustrated in Figure 8.From the figure, it is found that; the performance of OR-rule is approximately same as that of the conventional energy detector with two antennas.

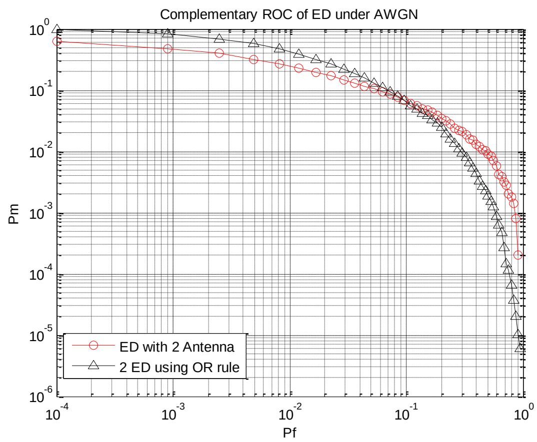

Figure 8: comparisons between the performance of receiver using one and two EDs.

4.5 Effect of different decision rules

Figure 9 shows simulative results of two antennas aided energy detector in terms of complementary receiver operating characteristics (ROC) curve. A relationship between the probability of misdetection (p_m) and probability of false alarm (p_f) is drawn in the figure. This figure shows that the OR rule achieves better performance than AND rule.

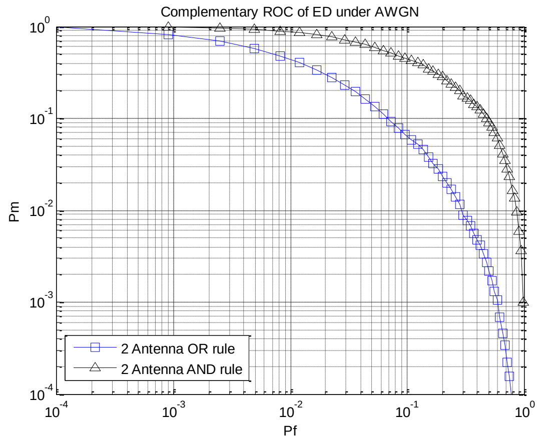

Figure 9: complementary ROC curve of proposed sensing with various decision rules.

5. CONCLUSIONS

In this paper, the cooperative communication protocols are presented: amplify-and-forward protocol, in which the relay amplifies the received signal and retransmit it to the destination and decode-and-forward protocol, in which the signal is decoded, re encoded and forwarded to the destination. It has been shown that using the AF protocol achieve better performance of the cognitive relay networks than using the DF protocol. Moreover, adaptive relay protocol is used to overcome the disadvantage of AF and DF protocols. In addition, enhancement the performance of cooperative spectrum sensing by using ED with multiple antennas than ED with single antenna and proposed sensing with different decision rules which OR rule has the better performance than AND rule.

6. ACKNOWLEDGMENTS

I am grateful to my supervisors and my husband who helped me to complete this research.

7. REFERENCES

[1] J.Mitola and G. Q. Maguire, “Cognitive Radio: Making Software Radios More Personal”, IEEE Personal Communications, vol. 6, no. 4, pp. 13-18, Aug.1999.

[2] S.Haykin, “Cognitive Radio: Brain-empowered Wireless Communications”, IEEE Journal on Selected Areas in Communications, vol. 23,no. 2, pp. 201-220, Feb. 2005.

[3] S. Mafra and E.Fernandez, “Cooperative Cognitive Radio Protocol Exploiting Primary Retransmissions in Nakagami-m Fading”, IEEE Conference Publications, pp. 771 - 775, Aug. 2012.

[4] A. Goldsmith, S. Jafar, I. Maric and S. Srinivasa, “Breaking Spectrum Gridlock With Cognitive Radios: An Information Theoretic Perspective”, Proceedings of the IEEE, vol. 97, no. 5, pp. 894-914, May 2009.

[5] S. Srinivasa and S. A. Jafar, “The Throughput Potential of Cognitive Radio: A Theoretical Perspective”, IEEE Communications Magazine, vol. 45, no.5, pp. 73-79, May 2007.

[6] R. A. Tannious and A. Nosratinia, “Cognitive Radio Protocols Based on Exploiting Hybrid ARQ Retransmissions”, IEEE Transactions on Wireless Communications, vol. 9, no. 9, pp. 2833-2841, Sep.2010.

[7] J. N. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior", IEEE Transactions on Information Theory, vol. 50, no. 12, pp. 3062-3080, Dec.2004.

[8] A. Nosratinia, T. E. Hunter, and A. Hedayat, "Cooperative Communication in Wireless Networks", IEEE Communications Magazine, vol. 42, no. 10, pp. 74-80, Oct. 2004.

[9] H. soury, F. Bader, M. Shaat and M. Slim Alouini, "Near Optimal Power Allocation Algorithm for OFDM-Based Cognitive Using Adaptive Relaying Strategy" , 7th International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications (CROWNCOM), pp. 212-217, Jun.2012.

[10] M. Hossain, S. Ahmed, S. Hossain and I. Abdullah, "Performance of Cooperative Spectrum Sensing for Different Numbers of CR Users in Cognitive Radio", International Journal of Science and Researches, vol.1, issue.3, pp. 145-149, Dec.2012.

[11] X. Liu and B.Zheng, "A New Scheme for Power Allocation in Cognitive Radio Networks Based on Cooperative Relay", IEEE International Conference, pp. 861 - 864, Nov. 2010.

[12] F. Gong, J.Ge and N. Zhang, "SER Analysis of the Mobile-Relay-Based M2M Communication over Double Nakagami-m Fading Channels", IEEE Communications Letters, vol.15, no.1, Jan.2011.

[13] R. S. Babu and M. Suganthi, "Review of Energy Detection for Spectrum Sensing in Various Channels and its Performance for Cognitive Radio Applications", American Journal of Engineering and Applied Sciences, pp. 151-156, Aug. 2012.

[14] A. Pandharipande and J. -P. M. G. Linnartz, "Performance Analysis of Primary User Detection in Multiple Antenna Cognitive Radio", Proceedings of the IEEE, pp. 6482-6486, Jun.2007.

[15] S. Hossain, S. Hossain and I. Abdullah, "Performance Analysis of Cooperative Spectrum Sensing in Cognitive Radio", International Journal of Innovation and Applied Studies,vol.1, issue.2, no.2, pp. 236-245, Dec. 2012.