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Performance Analysis of Cooperative Cognitive Radio Network with Optimum Combining

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Abstract: In this paper, cooperative cognitive radio network (CCRNs) with optimum combining has been analyzed. In the presence of CCI in secondary networks, CRNs systems is constrained by temperature limit (Q) which degrades the performance of throughput in primary networks. A new closed form of expression is been derived from probability density function (PDF) and cumulative distribution function (CDF) for best relay in order to achieve the improved performance of average bit error rate and ergodic capacity.

Index Terms: Co-channel interference (CCI), cognitive radio networks (CRNs), cooperative relaying system, optimum combining (OC).

1. INTRODUCTION

Wireless Communications has been making tremendous growth over the last few decades and it is anticipated to move forward in the future. Space diversity can be achieved by using multiple antennas, but in some applications implementation of many antennas are not all the time feasible or the destination is distant to get good signal quality. To cope up with this, an ad-hoc network is build up with the help of relay station to take the benefits of diversity. Such a model is known as Cooperative Relaying Network. The capacity and coverage of cellular networks can be extended using relays without increasing mobile transmit power or demanding extra bandwidth.

To provide better reliability in case of multipath fading, cooperative relaying communication has been deployed. Relays re-transmit the received signals depending on available CSI and allowable complexity on utilizing different relaying schemes**.** AF and DF are two relaying protocols of cooperative communication network [1]. Cooperative communication serves various advantages such as increases spectral and power efficiency improve network coverage and reduce the outage probability [4]. Different cooperative diversity techniques studied in [3]. To enhance the robustness and reliability of wireless networks, the cooperative protocols are integrated into conventional QoS mechanisms such as automatic-repeat-request (ARQ) protocols [8], [9]. In case of cognitive network the spectrum is managed with careful planning so as to maximize the number of users present in the spectrum [14]. A regulatory framework is used for assignment and allocation purpose.

In optimum combining (OC), the transmitting signals are received by the receiver antennas are first weighted and then combined at the output from which the signal-to-interference-plus-noise ratio is maximized [12]. From [7], even if numbers of antennas are smaller than the number of interferers, the optimum combining (OC) is superior of maximal ratio combining (MRC). To determine the performance of optimum combining analytical and computer simulation techniques are used when desired results and interfering signals are subject to flat Rayleigh fading.

Contributions

The main contribution of this paper is to derive the analytical expression for ergodic capacity and average bit error rate of optimum combining in cooperative cognitive radio system. To accomplish this, we derive a new expression of PDF and CDF for best relay by using order statistics selection scheme method. Further this PDF is used to evaluate the expression for average BER performance and ergodic capacity. This enables us to establish a mathematical analysis of the system under study.

The remaining paper is structured as follows. Section II concerns with the system overview of CCRNs. In section III expressions are obtained for the average bit error rate and ergodic capacity. The section IV discusses about the numerical results and lastly the paper is concluded in section V.

2. SYSTEM OVERVIEW

An underlay system of cooperative cognitive radio (CCRNs) is considered which co-exist with primary and DF cooperative communication based secondary network. In primary network, data is been transferred to the primary destination (PD) by the primary transmitter (PT), simultaneously in secondary network, data is been transferred to the secondary destination (SD) by the secondary transmitter (ST) in co-ordination with the primary transmission over the channel as depicted in Figure 1. Along with the transmitter and destination, secondary relays are also present denoted by R_i, $i = 1, 2, ..., L$. The secondary relays (SR_S) and secondary destination (SD) are affected by finite number of co-channel interference (CCI), M_i and N. For the protection of primary destination (PD) from the interferences which are harmful to the primary network, thus restricting the transmitted peak power, $P_P << Q$ [13]. In DF technique, relay decodes the message received from the secondary transmitter (ST), re-encodes and then forwards it to the secondary destination (SD).

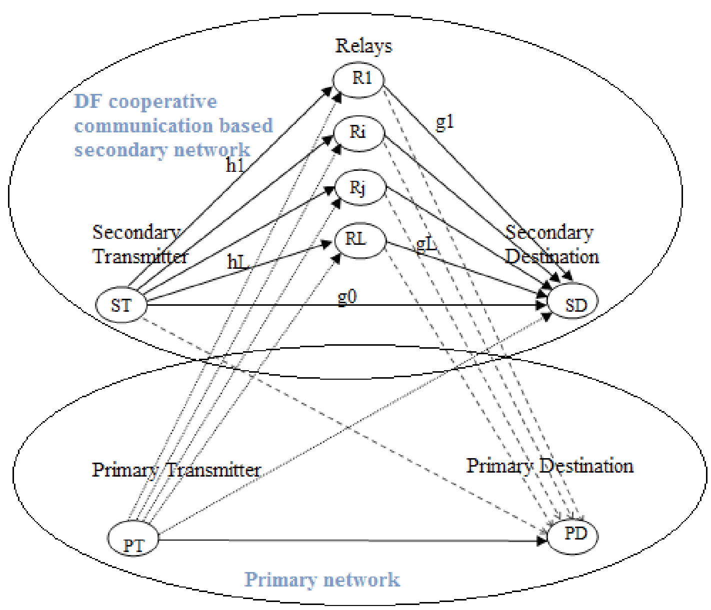

Figure 1: The system model of cooperative cognitive radio network [2], [5]

Cooperative communication categorized into two processes: Amplify and Forward or Decode and Forward [11]. AF protocol can be further split up into two phases. In the first phase, information is transmitted to the relays and the destination. In the second phase, relay received the transmitted signal from the source and further re-transmits it to the destination after amplification [15]. The incoming signal is amplified block wise. Then, the entire received signal combines at the destination by using OC technique.

In the first phase, source broadcast its signal to both destination and relay. Received signal from source to destination, $y_{S,D}$ and source to relay, y_{S,R_i} is given as

$$y_{S,D} = \sqrt{E_S g_0 d_0} + \sum_{j=1}^{N} \sqrt{E_{Ij} \alpha_{j,0} d_{j,0}} \tag{1}$$

$$y_{S,R_i} = \sqrt{E_S h_i d_0} + \sum_{j=1}^{N} \sqrt{E_{Ij} \beta_{j,i} d_{R_{j,i}}} \tag{2}$$

where, E_S and E_{Ij} are energies of received signal S and j^{th} interferer, respectively. d_0 and $d_{j,0}$ are the symbols transmitted by S and the j^{th} interferer, respectively which are assumed to be independent. $d_{R_{j,i}}$ represents the j^{th} interfering symbol at the i^{th} relay. The channel gain g_0, h_i and $\alpha_{j,0}$, $\beta_{j,i}$ resemble to the flat Rayleigh fading channels for S and j^{th} interferer.

In the second phase, relay amplifies noisy version of the signal received from the first phase and forward it to the destination. Received signal at D with respect to the i^{th} relay, $y_{R_i,D}$ is given as

$$y_{R_i,D} = \sqrt{E_R g_i d_0} + \sum_{j=1}^{N} \sqrt{E_{Ij} \alpha_{j,i} d_{j,i}} \tag{3}$$

where, $d_{j,i}$ is the j^{th} interferer at the destination. $\alpha_{j,i}$ and g_i are the channel gains. E_{Ij} represents the average received energy from the j^{th} interferer. It is assumed that $E_R = E_S$ and $E_{Ij} = E_I, j = 1, ..., N$.

3. PERFORMANCE ANALYSIS

In this section, we describe the best relay selection scheme, average bit error rate and ergodic capacity for the system under study.

A. Best Relay Selection

The best antenna selection [6] b_{R_i} is expressed as

$$b_{R_i} = \arg\max\{\gamma_{S,R_i}(t)\} \tag{4}$$

where, R_i, $i = \{1, ..., L\}$ and $\gamma_{S,R_i}(t)$ is the instantaneous SNR in time slot t. Now, the CDF and PDF of the SNR for the best transmit antenna is expressed by using the theory of order statistics such as

$$F_{\gamma_{bm,m}}(\gamma) = [F_{\gamma_{S,Ri}}(\gamma)]^S \tag{5}$$

$$f_{\gamma_{bm,m}}(\gamma) = S f_{\gamma_{S,Ri}}(\gamma)\, [F_{\gamma_{S,Ri}}(\gamma)]^{S-1} \tag{6}$$

The PDF and CDF of γ_{S,R_i} is given by (7) and (8) [2] where M denotes the co-channel interferer.

$$f_{\gamma_{S,Ri}}(\gamma) = M\left(\frac{\Omega_h e_s}{\Omega_\beta e_r}\right)^M \left(\frac{\Omega_h e_s}{\Omega_\beta e_r} + \gamma\right)^{-(M+1)} \tag{7}$$

$$F_{\gamma_{S,Ri}}(\gamma) = 1 - \left(1 + \frac{\Omega_\beta e_r}{\Omega_h e_s}\gamma\right)^{-M} \tag{8}$$

The best relay selection [6] b_m is expressed as

$$b_m = \arg\max\{\gamma_{bm,\,m}(t)\} \tag{9}$$

where, R_i, $i = \{1, ..., L\}$ and $\gamma_{bm,\,m}(t)$ is the instantaneous SNR of the cooperative network. Hence, the best relay is selected among R_i relays. Thus, the CDF and PDF of the best relay chosen among all R_i relays is given as

$$F_{\gamma_{br,\,r}}(\gamma) = [F_{\gamma_{bm,\,m}}(\gamma)]^L \tag{10}$$

The PDF can be achieved by differentiating CDF, we get

$$f_{\gamma_{br,\,r}}(\gamma) = Lf_{\gamma_{bm,\,m}}(\gamma)[F_{\gamma_{bm,\,m}}(\gamma)]^{L-1} \tag{11}$$

where, $F_{\gamma_{bm,\,m}}(\gamma)$ and $f_{\gamma_{bm,\,m}}(\gamma)$ are defined in (5) and (6). Substituting (5) and (6) into (10) and (11), we get

$$F_{\gamma_{br,\,r}}(\gamma) = [F_{\gamma_{S,\,Ri}}(\gamma)]^{SL} \tag{12}$$

$$f_{\gamma_{br,\,r}}(\gamma) = SLf_{\gamma_{S,\,Ri}}(\gamma)[F_{\gamma_{S,\,Ri}}(\gamma)]^{SL-1} \tag{13}$$

By substituting (7) and (8) into (13) the closed form expression of CDF and PDF for best relay in cooperative relaying network is obtained through order statistics selection scheme and given as:

$$F_{\gamma_{br,\,r}}(\gamma) = \left(\left(1-\left(1+\frac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}\right)^S\right)^L \tag{14}$$

$$f_{\gamma_{br,\,r}}(\gamma) = \frac{L \times M \times S\left(\gamma + \dfrac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{-1-M}\left(\dfrac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{M}\left(\left(1-\left(1+\dfrac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}\right)^S\right)^L}{1-\left(1+\dfrac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}} \tag{15}$$

Knowing $f_{\gamma_{br,\,r}}(\gamma)$ given by (15), we can derive the closed form expression for the average bit error rate and ergodic capacity as shown in *B* and *C*.

B. Average Bit Error Rate

In this, average bit error rate [10] performance P_e is calculated by integrating the pdf of variable node given by (13) from 0 to ∞

$$P_e = \frac{1}{2}\int_0^\infty erfc\left(\sqrt{\gamma}\right) f_{\gamma_{br,\,r}}(\gamma)\, d\gamma \tag{16}$$

$$P_e = \frac{1}{2}\left(L \times M \times S\right)\int_0^\infty Erfc\left(\sqrt{\gamma}\right)\left(\frac{\left(\gamma + \dfrac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{-1-M}\left(\dfrac{e_s\Omega_h}{e_r\Omega_\beta}\right)^{M}\left(\left(1-\left(1+\dfrac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}\right)^S\right)^L}{1-\left(1+\dfrac{\gamma e_r \Omega_\beta}{e_s \Omega_h}\right)^{-M}}\right) d\gamma \tag{17}$$

which can be evaluated using software such as Wolfram Mathematica, as given in (18), where $\eta = \frac{e_s \Omega_h}{e_r \Omega_\beta}$ and ${}_1F_1(.,.,.)$ is the generalized hyper-geometric function. Alternatively, (17) can be evaluated numerically.

$$P_e = \frac{1}{2} L \times M \times S \left(1 - (1+\gamma\eta)^{-M}\right)^{-1+L} \eta^M \left[-\frac{\eta^{\frac{1}{2}-M}\,\Gamma\left[-\frac{1}{2}+M\right] {}_1F_1\left[\frac{1}{2}, \frac{3}{2}-M, \eta\right]}{\Gamma[1+M]} + \frac{\eta^{-M} - \frac{\Gamma\left[\frac{1}{2}-M\right] {}_1F_1\left[M, \frac{1}{2}+M, \eta\right]}{\sqrt{\pi}}}{M} \right] \tag{18}$$

C. Ergodic Capacity

In this, first we derive the expression for the first moment of $f_{\gamma_{br,r}}$ which is given as

$$\mathbb{E}\{\gamma_{br,r}\} = \int_0^\infty \gamma\, f_{\gamma_{br,r}}(\gamma)\, d\gamma \tag{19}$$

where, $\mathbb{E}\{.\}$ is an expectation operator and the value of $f_{\gamma_{br,r}}$ is given in (13). Equation (19) is evaluated by using software Wolfram Mathematica. The ergodic capacity, $C_{\gamma_{br,r}}$ is defined as the maximum long term achievable rate and determined by averaging of instantaneous capacity over all possible channel states and is given as:

$$C_{\gamma_{br,r}} \approx \log_2(1 + \gamma\,\mathbb{E}\{\gamma_{br,r}\}) - \frac{\gamma^2 \sigma^2_{\gamma_{br,r}}}{2(1+\gamma\,\mathbb{E}\{\gamma_{br,r}\})^2} \tag{20}$$

where, the variance $\sigma^2_{\gamma_{br,r}}$ of $\gamma_{br,r}$ is also computed in Wolfram Mathematica software.

4. RESULTS AND DISCUSSION

This section presents the results for the cooperative cognitive radio network system. For the system model, number of relays L are taken as 2, 4, 8, 16 and interferers as M = 2, 4, 8, 16. We assume that $\Omega_h = \Omega_g = \Omega_\alpha = \Omega_\beta = 1$ and BPSK modulation scheme is considered. The results of average bit error rate and ergodic capacity for different number of relays (L) and co-channel interferers (M) are depicted in the cases below.

A. Relays $L = 2$ and varying interferences, M

Figure 2 shows the average bit error rate results for different number of CCI at relay $L = 2$. The average bit error increases from 0.061 for ($L = 2$, $M = 2$) to 0.143 for ($L = 2$, $M = 4$). At ($L = 2$, $M = 8$) error slightly increases to 0.233 and at ($L = 2$, $M = 16$) error rises from 0.233 to 0.307. From the Figure 2 it is clear that significant gain is achieved for the cooperative cognitive ratio network system when the number of interferers increases, which can be inferred from the Table 1.

Table 1
When the relays are fixed at $L = 2$ and the interferences are varied accordingly from $M = 2$ to 16

Number of relays (L)	*Number of interference (M)*	*Average bit error rate*
2	2	0.061
2	4	0.143
2	8	0.233
2	16	0.307

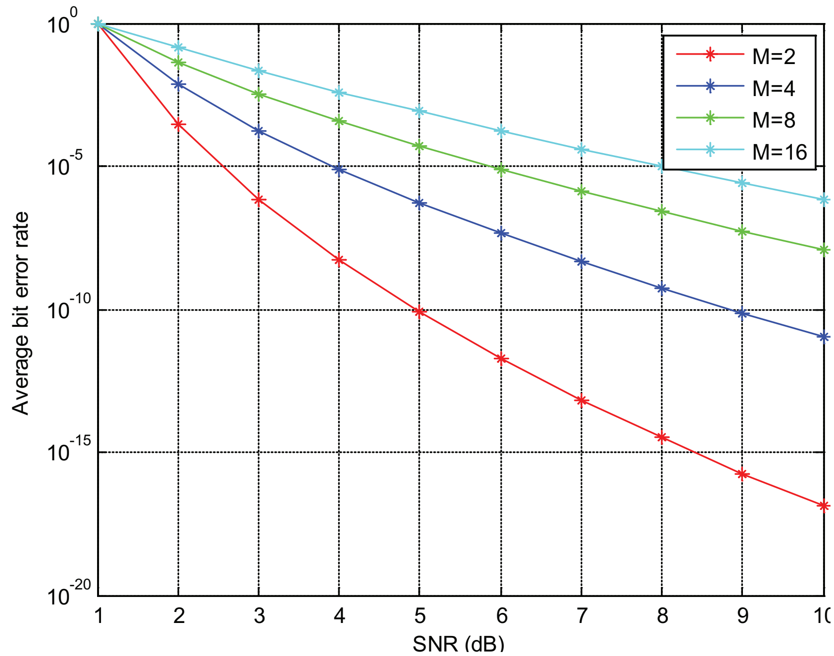

Figure 2: Average BER performance curves for different interferences at relay, $L = 2$

B. Interference $M = 2$ and varying relays, L

The average bit error rate performance for different number of relays at interferer $M = 2$ is analysed as shown in Figure 3. From the Table 2, it is clear that there is a rapid decrease in the bit error rate as the numbers of relays are increased from 2 to 16.

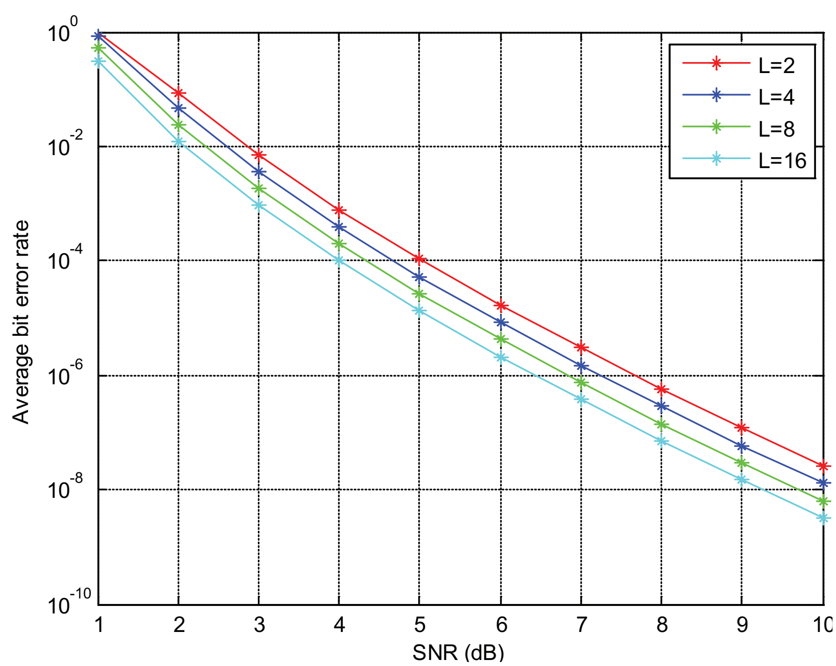

Figure 3: Average BER performance curves for different relays at interferences, $M = 2$

Table 2
When the interference are fixed at $M = 2$ and the relays are varied from $L = 2$ to 16

Number of relays (L)	*Number of interference (M)*	*Average bit error rate*
2	2	0.198
4	2	0.143
8	2	0.099
16	2	0.065

C. Relays $L = 2$ and varying interferences, M

Figure 4 shows the ergodic capacity for different number of interferers in cooperative cognitive radio network at relay, $L = 2$. From the Table 3, it can be seen that when ($L = 2$, $M = 16$) the ergodic capacity achieved is 5.184. At ($L = 2$, $M = 8$), capacity increases to 9.182. By taking $L = M$ i.e. ($L = 2$, $M = 2$) the capacity rises from 16.168 to 30.426. With a decrease in the number of interferers there is a significant increase in the ergodic capacity of the system.

Table 3
When the relays are fixed at $L = 2$ and the interferences are varied accordingly from $M = 2$ to 16

Number of relays (L)	*Number of interference (M)*	*Ergodic Capacity*
2	2	30.426
2	4	16.168
2	8	9.182
2	16	5.184

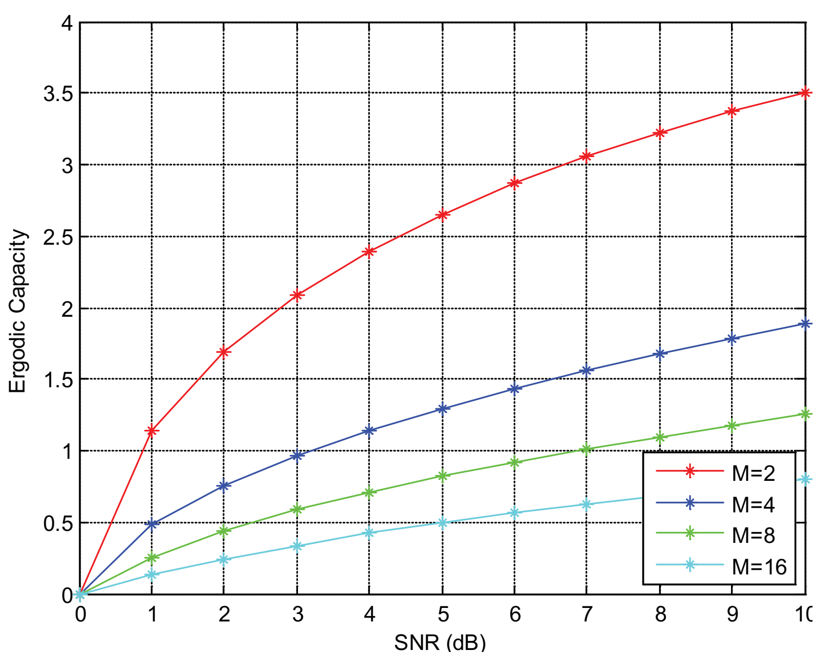

Figure 4: Ergodic capacity of cooperative cognitive radio network for different interference, M at relay, $L = 2$

D. Interference $M = 2$ and varying relays, L

Figure 5 shows the ergodic capacity for different number of relays in cooperative cognitive radio network at interferer, $M = 2$. From the Table 4, 30.426 capacity is achieved at ($L = 2$, $M = 2$) as the M increase to 4 and $L = 2$ our capacity also increases to 36.841. Now at ($L = 16$, $M = 2$) then the capacity rises to 48.517 from 42.830 when ($L = 8$, $M = 2$). We analyze that there is a significant increase in capacity as the number of relays increases.

Table 4
When the interference are fixed at $M = 2$ and the relays are varied from $L = 2$ to 16

Number of relays (L)	*Number of interference (M)*	*Ergodic Capacity*
2	2	30.426
4	2	36.841
8	2	42.830
16	2	48.517

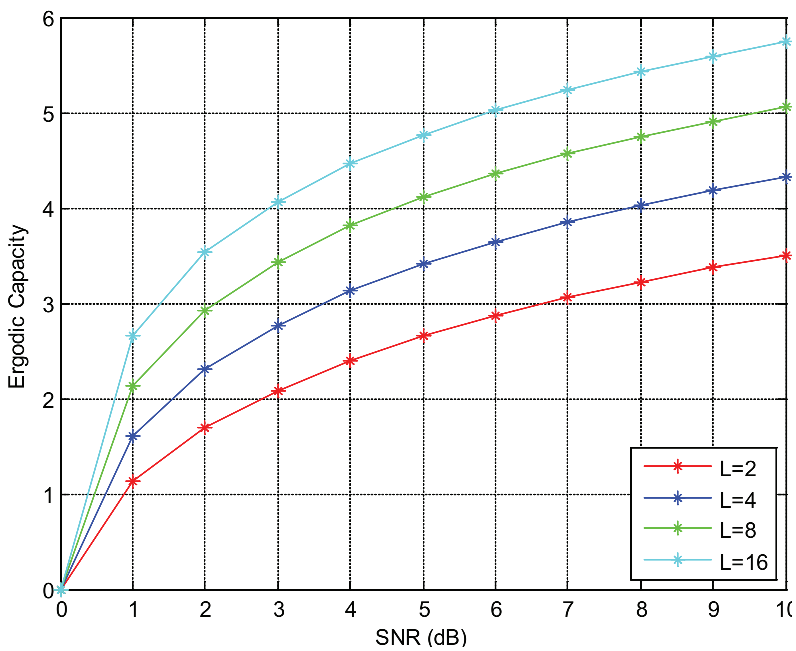

Figure 5: Ergodic capacity of cooperative cognitive radio network for different relays, L at interferer, $M = 2$

5. CONCLUSION

In this paper, optimized relay selection scheme for CCRNs has been discussed. From the proposed system, a closed form PDF and CDF has been derived by using selection scheme method and further utilized for evaluating the closed form expression for the average bit error rate in terms of confluent hyper-geometric function and ergodic capacity performance of CCRNs system. Based on this approach, performance of bit error rate with different interference and relays can be evaluated. With a significant decrease in the average bit error rate of the system and the capacity of the system increases; this is when the interferers in the system increases. Similarly, when the relays increase for the system the bit error rate decreases which lead to an increase in the capacity of the system. This is helpful in the present scenario where the number of users and the demand for the radio spectrum is increasing simultaneously. This is where the cognitive distribution comes into being.

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