

Throughput Analysis in Cooperative Spectrum Sensing Network using an Improved Energy Detector

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Abstract— In this paper, we have analyzed the performance of an average channel throughput analysis using an improved energy detector (IED) under non-fading environment (AWGN channel) in cooperative spectrum sensing (CSS) network. The performance analysis is evaluated using different fusion rules ($k=1+n$ and $k=M-n$) at fusion center (FC). The error rate is considered in reporting channel (R-channel) to show the effect of an error on the average channel throughput. Our simulation results gives the analysis of an average channel throughput for various values of detection thresholds, number of secondary users (M), and error rates in R-channel using different fusion rules at FC. The average channel throughput performance comparison between error free and error present in R-channel is provided using the MATLAB simulations. Finally, we have calculated an optimal number of secondary users to maximize the average channel throughput for different fusion rules.

Keywords— cooperative spectrum sensing, cognitive radio, improved energy detector, optimization, average channel throughput.

I. INTRODUCTION

In present days, the usage of radio spectrum have become crowded due to increase in the number of communication networks and services. Statistics related to an underutilized radio spectrum are shown in [1]. Cognitive Radio (CR) technique is introduced for the proper utilization of radio spectrum [2]. The concept of CR network introduces the secondary users (SUs) to make an efficient uses of radio spectrum without interfering primary users (PUs) activity. SUs are also called as cognitive radio users (CR users). Hence, with the help of SUs, vacant bands present in the given radio spectrum can be accurately detected. Spectrum sensing (SS) [3] is a useful task to monitor the radio spectrum periodically. There are different detection techniques are available in the literature, among all detection schemes, conventional energy detection (CED) [4] scheme is frequently used due to low complexity and non-coherent in nature. An identification of PU is limited using SS technique because of single SU is present in the network and also due to multipath fading effect. These drawbacks can be eliminated by taking the cooperation

of multiple SUs in the CR network. These multiple CRs are individually sense the PU activity; this concept is called as cooperative spectrum sensing (CSS) [5]. The CSS technique provides better immunity to multipath fading, mainly it eliminates the hidden terminal problem, and moreover it improves the detection performance. From the literature, it can be found that CSS network with an improved energy detection (IED) scheme [6] will further improve the detection performance of PU. An IED scheme uses and measures the received signal amplitude with an arbitrary positive power (p) rather than a squaring device used in CED. Sometimes, it is required to optimize the network parameters to achieve the better performance with the minimum number of network components and to reduce the complexity of the network. Optimization of CSS network parameters using an IED scheme over imperfect reporting channel (R-channel) is discussed in [7].

It is also important to optimize the number of CRs to maximize the average channel throughput value to improve the detection performance of PUs. Due to the fading effect, PUs are not detected accurately, hence, this may cause severe interference problem with SUs. This problem can be overcome and PUs are accurately detected if the sensing time of each SU user is increases, but it reduces the throughput value of the network. Hence, there is a trade-off between sensing time and throughput of the network [8]. Hence, average channel throughput value will be increased by performing sensing and transmission at a time [9]. In [10], throughput maximization is considered over an erroneous control channel using CED scheme. Total error value is minimized using an IED scheme over an erroneous control channel in [11]. The above stated papers are driven us to evaluate the performance of average channel throughput and maximization of network utility function (NUF) using an IED scheme over AWGN channel. An optimum number of SUs are also calculated to maximize the channel throughput with an error rate in R-channel.

Our contribution to the existing literature with this paper is, maximization of network utility function and average channel throughput using CSS network with IED detection scheme

over AWGN channel. Fusion rules like $k=1+n$ and $k=M-n$ (n : arbitrary positive integer) are used at fusion center (FC) to decide the activity of PU. We have considered the error rate in R-channel to show the effect of an error on the performance of average channel throughput and network utility function. The performance comparison between error free R-channel and error rate present in R-channel also provided using the simulation.

Remaining sections of the paper are arranged as follows: In section-2, proposed model of CSS network is addressed. Section-3 describes about the complete analysis of an average channel throughput analysis. Simulation results are addressed in section-4, and conclusions are given in section-5.

II. SYSTEM MODEL

An IED scheme operation is similar to the CED scheme as described in [4]. The main difference between these two detectors (CED, IED) is, earlier one measures the energy of the received signal using non-linear device called squaring device and later one operates on the arbitrary power (p) of the received signal. With the aid of this additional function in the IED scheme, detection performance will be improved.

Fig.1 shows the proposed model of CSS network with M number of SUs, a FC and a PU. The channel present between PU and SUs is called as sensing channel (S-channel), in this channel each CR senses the information about the PU. The information associated with each SUs is passed to the FC through R-channel (which lies between SUs and FC). FC collects the total information from all SUs and decides the existence of PU using fusion rules ($k=1+n$ and $k=M-n$). Each CR uses an IED scheme to decide the availability of PU. Two hypotheses are defined in the literature to decide the absence and presence of PU as H_0 and H_1 respectively. The received signal at i -th CR can be written as [4]:

$$y(t) = \begin{cases} n_i(t) & : H_0 \\ h_i * s(t) + n_i(t) & : H_1 \end{cases} \quad (1)$$

In above expression, $s(t)$ represents the received signal at the input of the receiver, $n_i(t)$ is the noise value at i -th CR. AWGN noise (Additive white Gaussian noise) is considered in the network which is uniformly distributed over each CR. h_i is the fading coefficient which is occurred due to fading effect in the channel. Missed detection, false alarm, and detection probability expressions for an IED scheme are given as follows [13]:

$$p_{f,i} = \frac{\Gamma(b_0, \lambda_i / a_0)}{\Gamma(b_0)} \quad (2)$$

$$p_{d,i} = \frac{\Gamma(b_1, \lambda_i / a_1)}{\Gamma(b_1)} \quad (3)$$

Where a_0, a_1, b_0 , and b_1 can be expressed as follows;

$$a_0 = \frac{2^{p/2}}{L} \frac{\sqrt{\pi} \Gamma\left(\frac{2p+1}{2}\right) - \Gamma^2\left(\frac{p+1}{2}\right)}{\sqrt{\pi} \Gamma\left(\frac{p+1}{2}\right)} \quad (4)$$

$$b_0 = b_1 = L \frac{\Gamma^2\left(\frac{p+1}{2}\right)}{\sqrt{\pi} \Gamma\left(\frac{2p+1}{2}\right) - \Gamma^2\left(\frac{p+1}{2}\right)} \quad (5)$$

$$a_1 = (1 + \gamma_i)^{p/2} a_0 \quad (6)$$

$\Gamma(\cdot)$ and $\Gamma(\cdot, \cdot)$ are complete and incomplete gamma functions. λ_i is the detection threshold, L is the sample value, and p is the positive power of received signal.

Effective probabilities for a given network are calculated by considering the error rate in R-channel, the expressions for effective false alarm and detection probabilities with an error rate are given in [13] as;

$$p_{fe} = p_f(1 - p_e) + p_e(1 - p_f) \quad (7)$$

$$p_{de} = p_d(1 - p_e) + p_e(1 - p_d) \quad (8)$$

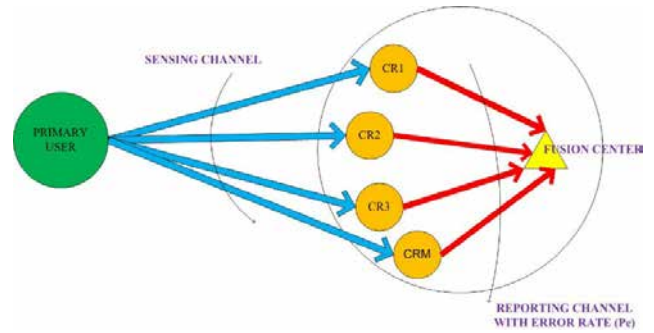


Figure 1. Proposed model of cooperative spectrum sensing network.

The information transferred to the FC through R-channel is in the form of binary decisions (either 0 or 1). Final decision about the PU is taken at FC using the following expression with the error rate in erroneous reporting channel.

$$P_{F,k} = \sum_{l=k}^M \binom{M}{l} p_{fe}^l (1 - p_{fe})^{M-l} \quad (9)$$

$$P_{D,k} = \sum_{l=k}^M \binom{M}{l} p_{de}^l (1 - p_{de})^{M-l} \quad (10)$$

In above expression k is number of selected SUs form available SUs (M). Expression for the average channel throughput (C_{avg}) for the proposed CSS network is given in [12] as;

$$C_{avg,k}(M) = \varphi_0 + \varphi_1 P_{D,k}(M) - \varphi_2 P_{F,k}(M) \quad (11)$$

where

$$\varphi_0 = P_1 \left(\tilde{C}_p + \tilde{C}_s \right) + P_0 C_s \quad (12)$$

$$\varphi_1 = P_1 \left(C_p - \tilde{C}_p + \tilde{C}_s \right) \quad (13)$$

$$\varphi_2 = P_0 C_s \quad (14)$$

C_s and $\tilde{C}_s$ are the throughputs of the secondary system in the presence and absence of PU respectively. C_p and $\tilde{C}_p$ are the throughputs of the primary system in the presence and absence of SU respectively. Final expressions for average channel throughput for different fusion rule ($k=1+n$ and $k=M-n$) are given in [10] as;

$$C_{avg,1+n}(M) = \varphi_0 + \varphi_1 P_{D,1+n}(M) - \varphi_2 P_{F,1+n}(M) \quad (15)$$

$$C_{avg,M-n}(M) = \varphi_0 + \varphi_1 P_{D,M-n}(M) - \varphi_2 P_{F,M-n}(M) \quad (16)$$

III. CALCULATION OF AN OPTIMAL NUMBER OF SECONDARY USERS

Average channel throughput value can be increased with the increment of number of SUs (M) in the network. Increased number of SUs makes larger delays in deciding the activity of PU. Hence, we need to calculate an optimal number of SUs which are exactly contributing towards the improvement of channel throughput. Final expressions for an optimal number of SUs (M^*) for a given CR network to maximize the average channel throughput using $k=1+n$ fusion rule at FC is given in [12] as;

$$M_{1+n}^* = \left\lceil \frac{\ln(\varphi_1/\varphi_2) + (n+1)\alpha}{\beta} + n \right\rceil \quad (17)$$

$$\alpha = \ln \frac{1 - P_{fe}}{P_{fe}}, \quad \beta = \ln \frac{1 - P_{fe}}{P_{me}} \quad (18)$$

If we substitute $n=0$ in eq. (17), it gives an optimal number of SUs expression when hard decision logic called **OR-Rule** is used at FC. The expression for an optimal number of SUs to maximize the channel throughput using **OR-rule** is;

$$M_{OR}^* = \left\lceil \frac{\ln(\varphi_1/\varphi_2) + \alpha}{\beta} \right\rceil \quad (19)$$

Similarly, expressions for an optimal number of SUs (M^*) for a given CR network to maximize the average channel throughput using $k=M-n$ fusion rule at FC is given in [12] as;

$$M_{M-n}^* = \left\lceil \frac{(n+1)\beta - \ln(\varphi_1/\varphi_2)}{\alpha} + n \right\rceil \quad (20)$$

For $n=0$, eq. (20) matches with an optimal number of SUs expression when hard decision logic called **AND-logic** is used at FC. The expression for an optimal number of SUs to maximize the channel throughput using **AND-rule** is

$$M_{AND}^* = \left\lceil \frac{\beta - \ln(\varphi_1/\varphi_2)}{\alpha} \right\rceil \quad (21)$$

Expressions for α and β are given in eq. (18). With the help of above expressions, simulation results are plotted to calculate an optimal number of SUs for different detection threshold values using $k=1+n$ and $k=M-n$ fusion rules at FC.

IV. RESULTS AND DISCUSSIONS

Fig.2 is drawn between average channel throughput versus detection threshold values using $k=1+n$ fusion rule at FC. The performance is evaluated using an IED scheme over AWGN channel for different values of SUs and error rates in R-channel. The performance comparison between error free R-channel and imperfect R-channel (i.e. error rate in reporting channel) is provided in the simulation to show the effect of an error rate on average channel throughput value.

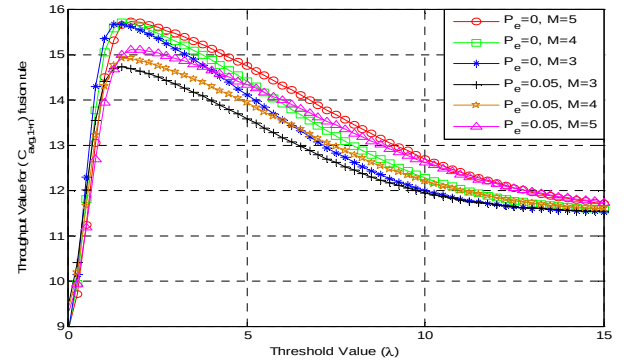


Figure 2. C_{avg} versus λ for different values of ($P_e = 0, 0.05$) and ($M=3, 4, 5$) using $k=1+n$ fusion rule at FC.

It can be observed from fig.2 that throughput value is maximum with error free R-channel and performance decreases as the error rate increases in R-channel. It can also be observed that initially throughput value increases at lower values of λ , and it reaches to the maximum point after that it decreases at higher values of λ . Finally, throughput value increases as the cooperation among the SUs are increases using $k=1+n$ fusion rule at FC. The above graph is simulated

for following network parameters: SNR=10dB, $p_e = 0$ & 0.05, $k=1+n$ ($n=2$) fusion rule, $C_s=10$, $\overline{C_s}=5$, $C_p=20$, $\overline{C_p}=10$ and $M=3, 4$ & 5.

Similar analysis which was explained in fig.2 is carried out in fig.3 also considering $k=M-n$ fusion rule at FC. Fig.3. also deals with the calculation of average channel throughput using an IED scheme over AWGN channel in CSS network. Above mentioned simulation parameters are used in this simulation also to get this fig.3. In this case also, throughput value decreases with the increment of error rate in reporting channel. As the number of SUs are increases, throughput value decreases using the $k=M-n$ fusion rule at FC.

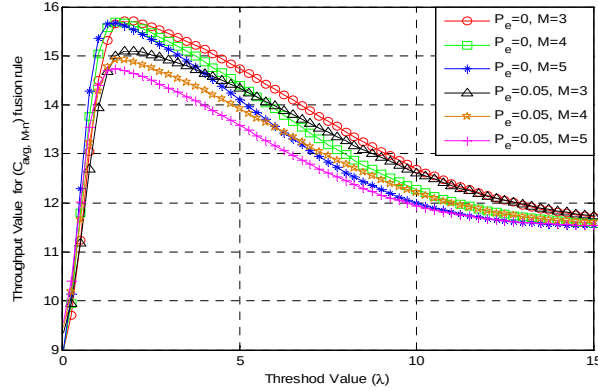


Figure 3. C_{avg} versus λ for different values of ($p_e = 0, 0.05$) and ($M = 3, 4, 5$) using $k=M-n$ fusion rule at FC.

Initially throughput value increases with threshold and later on it decreases with the increment of threshold value. For higher values of λ , channel throughput value decreases as the number SUs (M) are increases. Similarly, for lower values of detection threshold, average channel throughput value increases with the number of SUs. From above lines, we can justify that number of SUs (M) plays an important role to analyze the performance of average channel throughput value.

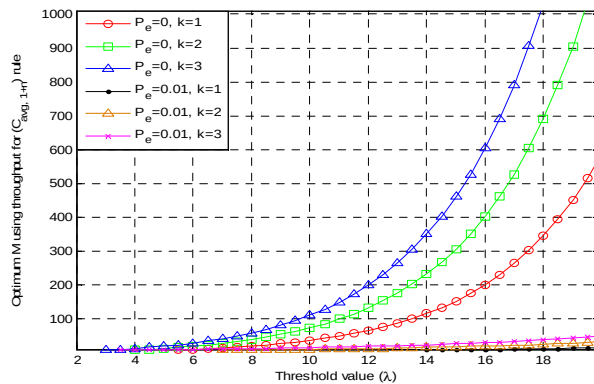


Figure 4. Optimum value of number of secondary users versus λ using $k=1+n$ fusion rule at FC.

Fig.4 is drawn between an optimum number of secondary users (M) versus different threshold values using $k=1+n$ fusion rule at fusion center. In fig.4, comparison between error free and error rate present in R-channel is provided. An optimal value of M is more with error free R-channel compared to error rate present in R-channel. It is also observed that as k value increases, optimal value of M also increases. We can conclude from fig.4 that for lower values of λ , the optimum value of SUs is very less and it increases with λ . If we introduce an error rate in R-channel, optimum value of number of CR users value drastically decreases. Hence, error rate plays an important role in deciding the number of SUs using different fusion rules at FC.

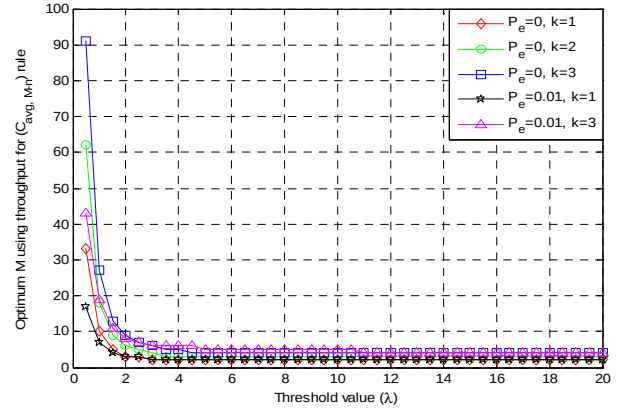


Figure 5. Optimum value of number of secondary users versus λ using $k=M-n$ fusion rule at FC.

Fig.5 is a plot between an optimum number of secondary users (M^*) versus λ using $k=M-n$ fusion rule at FC. In this fig.5 comparison between error free and error rate present in R-channel is provided. The optimal value of M is more with error free R-channel compared to error rate present in reporting channel. It can be observed from the simulation that as λ value increases, optimum value of number of CR users value decreases. When the error rate is introduced in R-channel, optimum value is further reduces.

V. CONCLUSIONS

The average channel throughput performance is analysed using an improved energy detector over AWGN environment in cooperative spectrum sensing network. An optimal number of secondary users are also calculated to maximize the average channel throughput using different fusion rules ($k=1+n$ and $k=M-n$ rules) at FC. The performance of average channel throughput is analyzed for various values of detection thresholds, number of secondary users (M) in the network and the error rate in R-channel using the fusion rules. The effect of an error rate on average channel throughput also shown using the simulations. From the analysis, we can conclude that number of secondary users and error rate in reporting channel

plays an important role to decide the average channel throughput value.

REFERENCES

- [1] Federal Communications Commission, "Notice of proposed rulemaking and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies," ET Docket No. 03-108, (2005).
- [2] J. Mitola and J. Maguire, G.Q., "Cognitive radio: making software radios more personal," *Personal Communications, IEEE*, 6, 13-18, (1999).
- [3] D. Cabric, S. Mishra, and R. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in *Conference Record of the Thirty-Eighth Asilomar Conference on*, 1, 772-776, (2004).
- [4] F. F. Digham, M.-S. Alouini, and M. K. Simon, "On the energy detection of unknown signals over fading channels," in *Proceedings of the International Conference on Communications (ICC '03)*, 5, 3575-3579, (2003).
- [5] G. Ganesan and Y. G. Li, "Cooperative spectrum sensing in cognitive radio networks," in *Proc. IEEE Symp. New Frontiers Dynamic Spectrum Access Networks (DySPAN'05)*, 137-143, (2005).
- [6] Y. Chen, "Improved energy detector for random signals in gaussian noise," *Wireless Communications, IEEE Transactions on*, 9, 558-563, (2010).
- [7] A. Singh, M. R. Bhatnagar and R. K. Mallik, "Optimization of cooperative spectrum sensing with an improved energy detector over imperfect report-ing channel," in *Proceedings of IEEE VTC Fall*, (2011).
- [8] Y.-C. Liang, Y. Zeng, E. Peh, and A. T. Hoang, "Sensing-throughput tradeoff for cognitive radio networks," *Wireless Communications, IEEE Transactions on*, 7, 1326-1337, (2008).
- [9] S. Stotas and A. Nallanathan, "On the throughput and spectrum sensing enhancement of opportunistic spectrum access cognitive radio networks," *Wireless Communications, IEEE Transactions on*, 11, no. 1, 97-107, (2012).
- [10] N. Bhanavathu and M. Khan, "On throughput maximization of cognitive radio using cooperative spectrum sensing over erroneous control channel," *conference on communication NCC*, (2016).
- [11] N. Bhanavathu and M. Khan, "On cooperative spectrum sensing with improved energy detector over erroneous control channel," *IEEE conference on wireless comm. and networking conference, WCNC*, (2016).
- [12] H. Hu, H. Zhang, Y. Chen and J. Jafarian, "Energy efficient design of channel sensing in cognitive radio networks," *Computers and Electrical Engineering*, 42, 207-220, (2015).

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