Maximization of Network Utility Function in Co-Operative Spectrum Sensing using Energy Detection Scheme

M. Ranjeeth and S. Anuradha
Department of Electronics and Communication Engineering, National Institute of Technology, Warangal − 506004, Telangana, India; ranjithmamidi2001@gmail.com, anuradha@nitw.ac.in

Abstract
Spectrum Sensing (SS) is the best technique to identify the vacant bands present in the radio spectrum. Co-operative Spectrum Sensing (CSS) concept is introduced to overcome the drawbacks present in the SS network and CSS improves the detection probability though the fading and shadowing effects are present in the environment. It is necessary to maximize the network utility function and minimize the total error probability rate for the better usage of the CSS network. In this paper, performance is evaluated by maximizing network utility function and minimizing the total error probability rate with the Conventional Energy Detection (CED) scheme in AWGN channel. An imperfect Binary Symmetric Channel (BSC) having an error probability rate (r) is considered in the CSS network reporting channel. Finally, comparison between perfect and imperfect reporting channel, effect of error rate on utility function and total error are described.

Keywords: AWGN Channel, Cooperative Spectrum Sensing, Energy Detection, Error Probability Rate, Network Utility Function

1. Introduction
Now a days, the rapid increasing of communication services leads to scarcity of radio spectrum. According to the fixed spectrum allocation policy, the utilization of the licensed spectrum is less and it varies from 15% to 85%\(^1\). For efficient spectrum utilization, the concept called Cognitive Radio (CR) was first introduced in 1999 by J. Mitola-III\(^2\), where the Secondary Users (SUs) also called as CRs, opportunistically utilize the temporarily unused spectrum in the absence of Primary User (PU). Spectrum Sensing (SS) is an essential function in CR networks for SUs to identify the vacant licensed spectrum bands. Due to the shadowing and fading present in the nature, the detection performance of SS may be significantly compromised. Fortunately, these problems can be mitigated by allowing concept called CSS with the help of multiple CR users in the network. It is proved that SS can be performance can be improved with an increase of the number of CRs in cooperation\(^3\). It is necessary to optimize the network parameters to get an optimized performance of CSS network. Optimization of number of CR users, threshold value (\(\lambda\)) and total error value are discussed using Conventional Energy Detection (CED) scheme in\(^4\). Optimization of the number of CR users has been considered using network utility function and minimization of total error rate in AWGN and Rayleigh fading channel is considered in\(^5\). Optimization of CSS network by maximizing the network utility function and minimizing the total error rate are evaluated in AWGN channel using CED scheme with the help of binomial distribution function at Fusion Center (FC) in\(^6\). Most of the available literature is based on parameter optimization of CSS network by considering perfect sensing and reporting channels. But, in\(^7\), optimization of CSS network parameters with an Improved Energy Detector (IED) over imperfect reporting channel (R-channel) is evaluated, this paper does not deals with the network utility function.
Hence, these papers are drive us to do the optimization of CSS network by maximizing the network utility function and minimization total error rate with imperfect Binary Symmetric Channel (BSC) having an error probability rate (r) in R-channel.

Finally, this paper deals with optimization of CSS network parameters using the CED detection scheme. In the proposed CSS network consist of multiple CRs and in which each CR senses the spectrum individually, using CED scheme identifies the PU presence or absence. The sensing information moved to the FC through R-channel and global decision about PU is taken at FC. An imperfect R-channel is considered in CSS network to maximize the network utility function and minimize the error probability rate. We have provided the simulation results to describe how an error probability rate (r) is effects on network utility function and total error rate, performance comparison between perfect and imperfect R-channel is also provided. All the simulations are evaluated for AWGN channel.

Remaining sections of the paper are divided as follows: Section-2 describes the proposed cooperative spectrum sensing network, network utility function and total error probability rate calculations are provided. Simulation results and their explanations are provided in section-3. Finally, section-4 deals with conclusions.

2. System Model

The proposed model of CSS network consists of sensing channel and reporting channel as shown in Figure 1. In sensing channel, each CR performs local spectrum sensing independently about PU. In reporting channel, each CR sends its sensing results to the FC. Finally, FC makes a final decision to decide whether the PU is present or not. For $i^{th}$ CR with CED, missed detection and false alarm probability expressions over AWGN channel is given in:

$$P_{d,i} = P(r > \lambda | H_1) = Q_m(\sqrt{2\gamma_i \sqrt{\lambda_i}})$$

$$P_{f,i} = P(r > \lambda | H_0) = \frac{\tau(u, \beta_i^2)}{\tau(u)}$$

$$P_{m,i} = 1 - P_{d,i}$$

Where, $\lambda_i$ and $\gamma_i$ denotes the detection threshold and instantaneous SNR values.

The total error probability value can be calculated using following expression:

$$P_e = P(H_1 | H_0)P(H_0) + P(H_0 | H_1)P(H_1)$$

$$= P_{f,i}P(H_0) + P_{m,i}P(H_1)$$

where $P(H_1)$ denotes the probability of presence of PU and $P(H_0) = 1 - P(H_1)$.

$$-\mu_2 P_{m,i}(R) P(H_1) - \mu_2 K$$

Figure 1. Co-operative spectrum sensing network.

### 2.1 Network Utility Function

The expression for maximize the network utility function of CSS network is given in:

$$-\mu_2 P_{m,i}(R) P(H_1) - \mu_2 K$$

The above mentioned closed form of network utility function expression is a combination of three parts, in which first part gives the information regarding the amount of usage of spectrum. Sometimes, PUs are not detected accurately this may cause interference problem (PUs with SUs), this interference information is given by the second part of above expression. Finally, third parts represent the utilization of resources in the network, and are the cost functions for the three sections. The network utilities increases with the cooperation SUs and eliminating the factors like penalties and resources that are used while sensing the spectrums.

3. Results and Discussion

Simulation results are provided with the help of mathematical expressions. This section deals with network utility function and total error rate over AWGN channel with the following simulation parameters: $P(H_1)=0.3$, $P(H_0)=0.7$, $\mu_1=0.2$, $\mu_2=0.8$, $\mu_3=0.005$, $\text{SNR}=10\text{dB}$, $r=0.01$ and $K$ value varies from 1 to 6.

Figure 2 is drawn between network utility function versus detection threshold ($\lambda$) for different values of CRs.
As 'K' value increases, 'λ' value increases and also network utilization increases. If the number of CRs increases in proposed CSS network, improves the co-operation among CR users increases hence network utility function increases. Network utility is minimum with OR-logic (K=1) and maximum with majority logic (K=4). Above performance is evaluated using conventional energy detection scheme. As the co-operation among the CR users are increases, detection probability also increases.

Figure 2. Detection threshold versus network utility function over AWGN fading channel for various values of CRs (K).

Figure 3 shows the graph between network utility function versus detection threshold for various values of error rates. Above fig. shows the comparison between perfect and imperfect reporting channel. As error value (r) value increases in R-channel, network utility decreases and network utility is maximum with perfect R-channel (r=0).

Figure 3. Detection threshold versus network utility function over AWGN fading channel for various values of error rate in R-channel (r).

Figure 4. Detection threshold versus network utility function over AWGN fading channel for various values of CRs (K).

Figure 5. Detection threshold versus network utility function over AWGN fading channel for various values of error rate in R-channel (r).
Figure 4 is drawn between $(Q_x + Q_y)$ Vs ‘λ’ for various values of ‘K’. As ‘K’ value increases, total error values decreases because of the cooperation of CRs. Total error value is maximum with single CR user and it decreases with increasing the number of CRs in the network.

The effect of error rate (r) in R-channel on total error probability for various values of detection thresholds are shown in Figure 5. Comparison curves are provided using the simulations between perfect and imperfect R-channel also shown in Figure 5. Total error rate value is minimum with perfect reporting channel and it increases as error rate increases in reporting channel.

4. Conclusions

In this paper, we have analyzed the performance of network utility function using cooperative spectrum sensing network. The performance is evaluated over imperfect reporting channels with an energy detector scheme. The BSC with imperfect nature having an error probability rate (r) in R-channel is considered to show the effect of error rate on network parameters. This paper also deals with optimization of CSS network parameters by maximizing network utility factor and minimizing the total error probability rate over AWGN channel. Comparison between perfect and imperfect R-channel using simulation results are provided. This type of work is used in the application to achieve the optimized performance of CSS network.

5. 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, Feb. 2005.
2. Simon Haykin. Cognitive Radio: Brain-Empowered Wireless Communications, IEEE Journal on Selected Areas in Communications. 2005; 23(2):201–20.
3. Ganesan G, Li YG. Cooperative Spectrum Sensing in Cognitive Radio Networks. In: Proceedings IEEE Symp. New Frontiers Dynamic Spectrum Access Networks (DySPAN’05), Baltimore, USA; 2005 Nov. p. 137–43.
4. Zhang W , Mallik RK, Letaief KB. Optimization of Cooperative Spectrum Sensing with Energy Detection in Cognitive Radio Networks, IEEE Trans. Wireless Commun. 2009; 8(12):5761−66.
5. Suwen Wu, Ming Zhao, Jinkang Zhu. Optimal Number of Secondary Users through Maximizing Utility in Cooperative Spectrum Sensing, IEEE Vehicular Technology Conference Fall, Sep 2009, p. 5.
6. Bommena Pruthviraj Kumar, Deepa Das, Susmita Das. Cooperative Spectrum Sensing Optimization through Maximizing the Network Utility and Minimizing the Error Probability. IEEE Global Conference on Communication Technologies (GCCT’15), Tamilnadu; 23rd - 24th Apr 2015.
7. Ajay Singh, Bhatnagar MR, Mallik RK. Optimization of Cooperative Spectrum Sensing with an Improved Energy Detector over Imperfect Reporting Channels. In: Proceedings of IEEE Vehicular Technology Conference, USA; September 2011. p. 1-5.