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Throughput Maximization in Cooperative Spectrum Sensing

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Abstract—*The rapid boom in the popularity of wireless digital communication technologies and devices has led to shortage of spectral resources. The static allocation for specific applications results in inefficient utilization of spectral resource. Hence various attempts were made to increase the utilization efficiency and efforts results in form of a technology called as cognitive radios. It can resolve issues of spectrum scarcity and can fulfill growing demand by permitting a cognitive user to exploit band when it is not accessed by licensee. Their one of very essential mechanism is spectrum sensing. It is a process of observing activities of licensee in a radio resource to transmit without any interference. To do so, various sensing techniques are used. Issues related to non cooperating sensing like channel impairment are resolved by cooperative spectrum sensing. It improves detection probability. A cognitive network said to be efficient if detection has maximum throughput with minimum error probability. In this paper, we study about cognitive radios, energy detection, cooperative sensing and maximum throughput for optimal number of working sensors.*

1. INTRODUCTION

The last decade has witnessed the rapid boom in the demand of wireless digital communication technologies and devices (laptops, tablets and smart phones). On the one side, the wireless networks are allotted on the basis of static assignment scheme where government authorities like Federal Communication Commission (FCC) in United States and Telecom Regulation Authority of India (TRAI) in India provide the radio spectrum to a service provider of a large geographical region for long time. But a report of FCC shows that most of the licensed spectral resources like telemetry data, TV broadcasting are inefficiently utilized and resulting in scarcity of this limited and precious resource [1]. On the other side, increased diversity (voice, video and multimedia) and high Quality-of-Service (QoS) application necessities resulting in overcrowding in licensed spectral resources or even some licensed exempt resource like ISM (Industrial, Scientific Medical) band. Deploy a new or boosting the existing services one of very severe task. In order to resolve the issue of spectrum scarcity and to increase the spectral efficiency, Cognitive Radio (CR) is considered as a promising technique [2, 3]. The term was first coined by J. Mitola.

CRs are radio platform that are used for the enhancing the spectrum utilization efficiency by allowing a Secondary (unlicensed) User (SU) to exploit a spectrum band when it is not used by a Primary (licensed) User (PU) [4]. PUs is given superiority over SUs or the rights on the usage of a particular slice of the spectrum. The bands of frequency that are not exploited by the PUs are called white spaces (spectrum holes) [5]. CRs are smart radios which are aware of its operating environment, communication parameters (bandwidth, carrier frequency, transmission power) and adaptively change these to optimize the spectrum usage.

Among much functionality, one of important function performed by CRs is spectrum sensing [6]. It is procedure of continuously scanning a spectral resource to utilize it opportunistically. For this SUs must follow two etiquettes [7] : (1) they are allowed to occupy only vacant spectral resources; (2) the SU must withdraw from spectral resource immediately if any PU starts transmission to protect it from collision. The sensing is only dependent upon SUs. This method of spectrum sensing is also included in IEEE 802.22 standard [8]. There are three types of sensing schemes. First which require both primary signal and noise power information like Matched Filter (MF) and Cyclostationary Detection (CSD). Second which require only noise power information like Energy Detection (ED) .Third which requires no information on noise power or primary signal [9]. In this paper, we consider ED for spectrum sensing because of much lower complexity and ease of implementation than other schemes [10, 11].

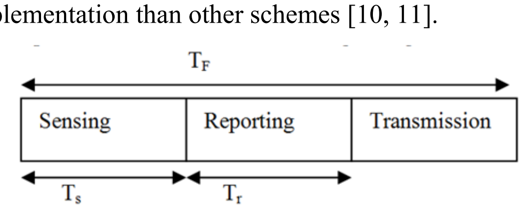

Fig. 1: Frame arrangement of periodic sensing.

Due to extreme channel fading, channel impairments multipath shadowing or fading, spectrum sensing quality easily suffers which result in hidden terminal issue. A non-cooperative spectrum sensing algorithm may not work well so

Cooperative Spectrum Sensing (CSS) algorithms by utilizing multi-user diversity resolves this issue [12-14] .The detection include sensing, reporting and transmission slot [15] as shown in Fig. 1.The longer duration of sensing (Ts) improves system performance but decays transmission time. Reporting duration (Tr) also increase with number of cooperating users which in turn reduce the period of transmission. Hence both need to be controlled to maximize the throughput [16-18].

Further article is distributed as follows. The section 2 consists of background information. The problem formation is done in section 3. The section 4 consists of numerical results. Conclusion is provided in section 5. References are in section 6.

2. BACKGROUND

Energy Detector

The task of identifying unused radio resources is referred as spectrum sensing. Out of several methods of performing sensing, ED is often used. It requires only noise power information unlike MF and CSD which require information of both signal and noise power. To conclude about system occupancy, it measures the energy of received waveform and compares it with system threshold λ. The sensing follows binary hypothesis [19]. Let $y_i(k)$ is the received signal at i^{th} CR user and $w_i(k)$ is noise with $\mathcal{N}(0, \sigma_w^2)$, x(k) is signal transmitted by PU with $\mathcal{N}(0, \sigma_s^2)$and h(k) is impulse response of channel between ith CR user and PU. The Signal to Noise Ratio (SNR) of CR user is $\gamma = |h_i|^2\sigma_s^2 / \sigma_w^2$

$y_i(k) = w_i(k)$ $\quad H_0$: PU is absent

$= w_i(k) + h_i x(k)$ $\quad H_1$: PU is present

If received signal energy V≥ λ, then SU consider that the channel is occupied (H_1) else channel is vacant (H_0). It contains a pre-filter (band pass) followed by an Analog to Digital Converter (ADC) and then their output is squared and summed to obtain following decision measure.

$$V = \frac{1}{2T_sF_s}\sum_{k=1}^{2T_sF_s}|x[k]|^2 \quad (1)$$

The evaluation of energy detector is done by P_d (probability of detection) and P_f (probability of false alarm). Let $2f_s$ is sampling frequency. When $2T_sf_s$ (number of samples N) is large enough then decision measure follows Chi square distribution. The values for Circular Symmetric Complex Gaussian (CSCG) noise are given below [16].

$$P_d = Q\left(\frac{\lambda}{(1+\gamma)\sigma_w^2\sqrt{2T_sF_s}} - \sqrt{2T_sF_s}\right) \quad (2)$$

$$P_f = Q\left(\frac{\lambda}{\sigma_w^2\sqrt{2T_sF_s}} - \sqrt{2T_sF_s}\right) \quad (3)$$

High P_d (better protection to PU) and low value of P_f (increment in channel reuse) are desirable. Here Q(.) is Q function and given as

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{\frac{-z^2}{2}}dz \quad (4)$$

3. COOPERATING SPECTRUM SENSING

Issues related to single CR detection are overcome by cooperative detection algorithms. CSS has 3 steps: sensing, reporting and decision as in Fig. 2. It mitigates hidden terminal, channel impairments problem by taking advantage of spatial diversity provided by multiple working sensors. Each CR user carries out sensing using ED in the sensing step to make a local decision. All local decisions are reported to Fusion Center (FC) via a band manager. The FC applies various rules to make a final global decision regarding absence or presence of PU.

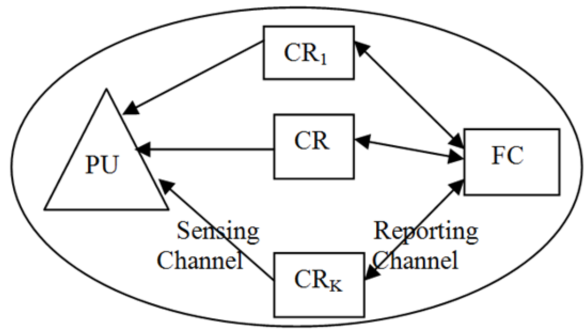

Fig. 2: CSS in a sensor network.

Various decision rules are used to obtain a collaborative decision. There are two types of fusion rules: Hard and Soft combination. The actual information without any processing is given to FC in soft fusion. Hence more accurate result but scheme exploits more bandwidth. Commonly used approaches are Equal Gain Combining, Maximum Ratio Combining and Optimal Soft Combination Scheme. The Equal Gain Combining scheme is utilized with high SNR of received signal and an equal weightage is provided to all the incoming energies. The Maximum Ratio Combining scheme combines the received signal energies by providing them different weightage based on the signal strength. Neymann Pearson based approach is used which optimizes the detection performance in Optimal Soft Combination scheme.

The n out of K rules is implemented by FC to combine local decisions in hard fusion rule. Final decision is counted as H_1 whenever at least n out of K local decisions indicate H_1. By taking P_d and P_f as detection and false alarm probability of individual user, then Q_d (global detection probability) and Q_f (global false alarm probability) is given by

$$Q_d = \sum_{i=n}^{K}\binom{K}{i}{P_d}^i(1-P_d)^{K-i} \quad (5)$$

$$Q_f = \sum_{i=n}^{K}\binom{K}{i}{P_f}^i(1-P_f)^{K-i} \quad (6)$$

Total working sensors are K and value of n tells which OR, AND or majority rule is implemented. The n out of K rule acts like OR and AND rule by setting n=1 and n = K respectively.

$$Q_{d,OR} = 1 - (1 - P_d)^K \quad (7)$$

$$Q_{f,OR} = 1 - (1 - P_f)^K \quad (8)$$

$$Q_{d,AND} = (P_d)^K \quad (9)$$

$$Q_{f,AND} = (P_f)^K \quad (10)$$

When n is greater than K/2 then it act like majority rule. This rule is given as

$$Q_{d,majority} = \sum_{\lfloor i=K/2 \rfloor}^{K} \binom{K}{i} P_d{}^i (1 - P_d)^{K-i} \quad (11)$$

$$Q_{f,majority} = \sum_{\lfloor i=K/2 \rfloor}^{K} \binom{K}{i} P_f{}^i (1 - P_f)^{K-i} \quad (12)$$

4. THROUGHPUT

A cognitive user can send the information only when the PU is not active. Hence, the CRs can transmit data when the decision goes in favors of false alarm or missed detection. Hence there are two possibilities for activation of CRs [19, 20].

Case 1: Absence of PU and no false alarm triggering by CRs. The throughput attained by CRN is $\frac{(T_F - T_s - KT_r)}{T_F} C_{H0}$

Case 2: Presence of PU but no detection by CRs. The throughput attained by CRN is $\frac{(T_F - T_s - KT_r)}{T_F} C_{H1}$

The normalized throughput of cognitive users are provided by

$$th_o(K, T_s, T_F) = \frac{T_F - T_s - KT_r}{T_F} P(H_0)[1 - P_f(K, T_s, T_F)]C_{H0} \quad (13)$$

$$th_1(K, T_s, T_F) = \frac{T_F - T_s - KT_r}{T_F} P(H_1)[1 - P_d(K, T_s, T_F)]C_{H1} \quad (14)$$

Here $P(H_0)$ and $P(H_1)$ are probabilities whether PU is absent and present respectively. Ts is duration of sensing, Tr is duration of reporting and T_F is duration of total frame. K is number of optimal users. Let γ_s and γ_p is SNR of secondary and primary system respectively.

$$C_{Ho} = \log_2(1 + \gamma_s) \quad (15)$$

$$C_{H1} = \log_2\left(1 + \frac{\gamma_s}{1+\gamma_p}\right) \quad (16)$$

The average value of throughput of cognitive network is

$$th(K, T_s, T_F) = th_o(K, T_s, T_F) + th_1(K, T_s, T_F) \quad (17)$$

The high value of sensing duration protects the systems by providing less false alarm rate but it reduces transmission duration also. So the highest throughput (optimum) will be attained when number of users and sensing duration are optimized.

$$th_{opt}(K_{opt}, T_s, T_F) = th_0(K_{opt}, T_{s(opt)}, T_F) + th_1(K_{opt}, T_{s(opt)}, T_F) \quad (18)$$

5. NUMERICAL RESULTS

Receiver Operating Characteristic (ROC) for different hard fusion rules of CSS is provided in Fig. 3. Average throughput increase with increasing number of working users when reporting delay is 0 as in Fig. 4. But throughput first increase and then decrease with increasing working users when reporting delay is nonzero in AND rule. For OR rule average throughput is plotted against number of cooperating users as in Fig. 5. Average throughput decrease with increase in number of users for Tr = 0 ms. The decay is steady as Tr is increasing after 5 users. Average throughput variation with number of working users for different fusion rules is shown in Fig. 6. Here majority rule gives the optimum performance.

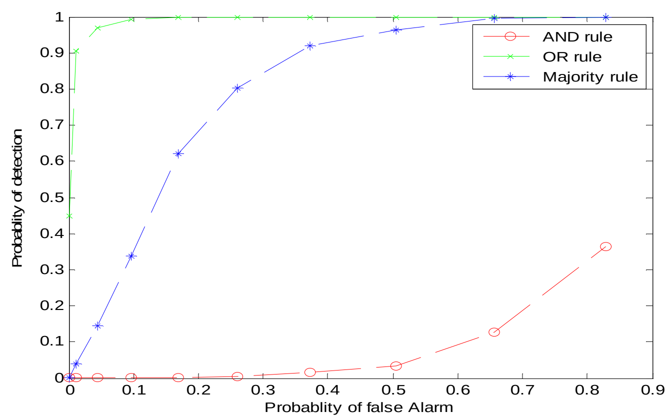

Fig. 3: ROC of CSS

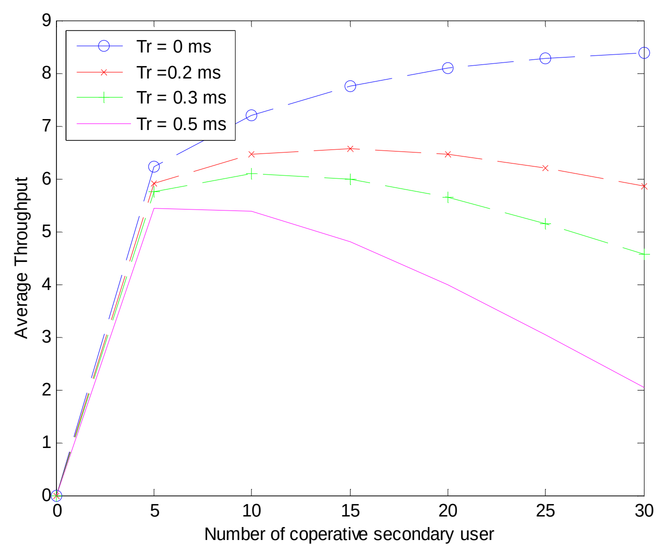

Fig. 4: Average Throughput vs number of cooperative secondary users for different T_r for AND rule.

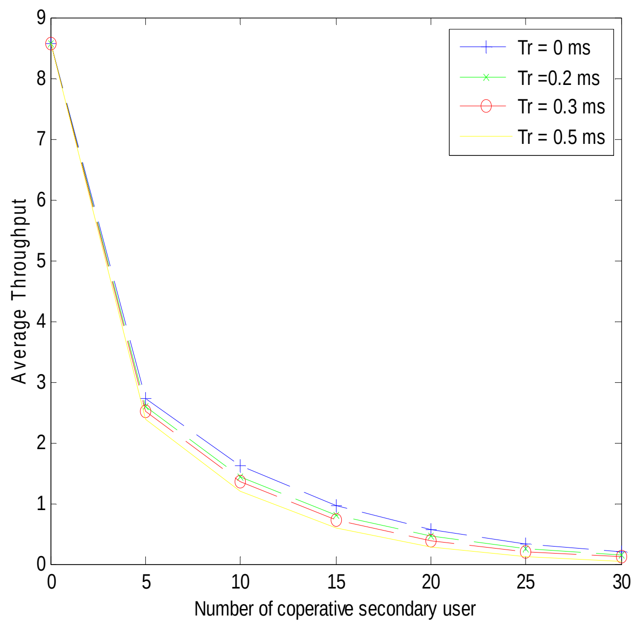

Fig. 5: Average Throughput vs number of cooperative secondary users for OR rule.

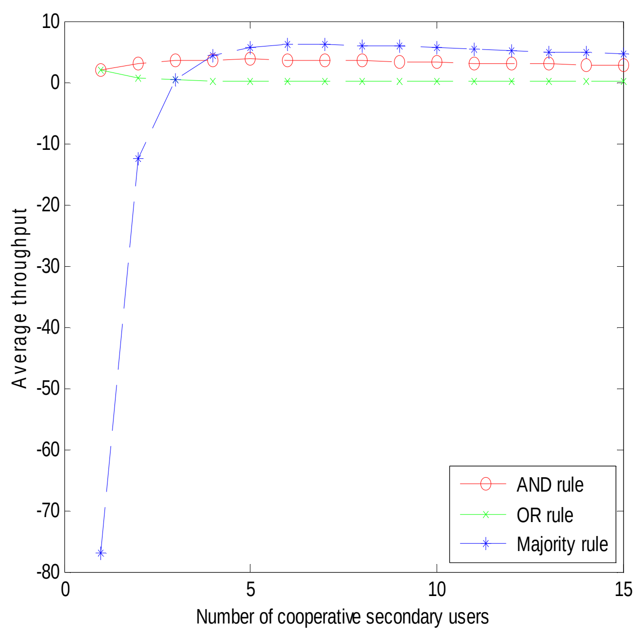

Fig. 6: Average Throughput vs number of cooperative secondary users for different fusion rule.

6. CONCLUSIONS

In this paper, we studied CSS in energy detection based CRs. We have investigated throughput problem in CSS and considered the influence of sensing and reporting duration. With numerical results it can be shown that average throughput is achieved through optimization. It can also be seen maximum throughput is achieved when only certain number of working sensors are chosen.

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