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SPECTRUM SENSING USING HARD DECISION LOGIC FOR COGNITIVE RADIO NETWORKS

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ABSTRACT
Cognitive radio technology has been proposed to improve spectrum efficiency by having the cognitive radios act as secondary users to opportunistically access under-utilized frequency bands. Spectrum sensing, as a key enabling functionality in cognitive radio networks, needs to reliably detect signals from licensed primary radios to avoid harmful interference.There is two parameters associated with spectrum sensing: probability of detection and probability of false alarm. The higher the probability of detection, the better the primary users is protected. However, from the secondary users' perspective, the lower the probability of false alarm, the more the channel can be reused when it is available, thus the higher the achievable throughput for the secondary network. In this paper, we study the problem of designing the sensing duration to maximize the achievable throughput for the secondary network under the constraint that the primary users are sufficiently protected.We describe the development of an optimal number of nodes in cooperation in a cognitive radio network (CRN).

INTRODUCTION

Spectrum is a scarce resource, and licensed spectrum is intended to be used only by the spectrum owners. Cognitive radio is a new concept of reusing licensed spectrum in an unlicensed manner. The motivation for cognitive radio is various measurements of spectrum utilization that show unused resources in frequency, time and space. The introduction of cognitive radios will inevitably create increased interference and thus degrade the quality of service of the primary system. The impact on the primary system, for example in terms of increased interference, must be kept at a minimal level. To keep the impact at an acceptable level, secondary users must sense the spectrum to detect whether it is available or not. Secondary users must be able to detect very weak primary user signals. Spectrum sensing is one of the most essential components of cognitive radio. Federal Communications Commission (FCC): "Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets".(FCC) have shown that 70% of the allocated spectrum in US is not utilized. Furthermore, timescale of the spectrum occupancy varies from milliseconds to hours .This motivates the concept of spectrum reuse that allows secondary users/network to utilize the radio spectrum licensed/allocated to the primary users/network when the spectrum is temporally not being utilized. The core technology behind spectrum reuse is cognitive radio, which consists of three essential components:(1) Spectrum sensing: The secondary users are required to sense and monitor the radio spectrum environment within their operating range to detect the frequency bands that are not occupied by primary users; (2) Dynamic spectrum management: Cognitive radio networks are required to dynamically select the best available bands for communications; and (3) Adaptive communications: A cognitive radio device can configure its transmission parameters (carrier frequency, bandwidth, transmission power, etc.) to opportunistically make best use of the ever-changing available spectrum. Hence, one main aspect of cognitive radio is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access.

In December 2003, FCC issued a Notice of Proposed Rule Making that identifies cognitive radio as the candidate for implementing opportunistic spectrum sharing. The IEEE then formed the 802.22 Working Group to develop a standard for wireless regional area networks (WRAN), which is an alternative broadband access scheme operating in unused VHF/UHF TV bands. By doing so, it is required that no harmful interference is caused to the incumbent primary users, which, in the VHF/UHF bands, include TV users and the FCC part 74 wireless microphones Fig. 1 illustrates the topology of a WRAN system where the primary users are TV users and wireless microphones and the secondary users include both WRAN base station (BS) and WRAN customer premise equipment's (CPEs). The WRAN systems are designed to provide wireless broadband access to rural and suburban areas, with the average coverage radius of 33 km. The operating principle of WRAN is based on opportunistic access to temporarily unused TV spectrum. The fundamental objective for a WRAN system is to maximize the spectrum utilization of the TV channels when they are not used by the primary users. To protect the primary users, whenever the primary users become active, the WRAN system has to vacate that channel within a certain amount of time (say 2 seconds as specified by 802.22 working group). Thus spectrum sensing is of significant importance for cognitive radio systems. In 802.22 WRAN, each medium access control (MAC) frame consists of one sensing slot and one data transmission slot, thus periodic spectrum sensing is carried out. Associated with spectrum sensing are two parameters: probability of detection and probability of false alarm. The higher the detection probability, the better the primary users can be protected. However, from the secondary users' perspective, the lower the false alarm probability, the more chances the channel can be reused when it is available, thus the higher the achievable throughput for the secondary users. Thus there could exist a fundamental tradeoff between sensing capability and achievable throughput for the secondary network.

SPECTRUM SENSING

To improve the spectrum utilization efficiency, cognitive/secondary user (SU) system essentially requires dynamic spectrum access. To achieve this, cognitive user should be able to scan the primary/licensed user's frequency band as quickly as possible without interference to the licensed user communication. This requires efficient spectrum sensing technique. Hence, research into novel techniques for efficient spectrum utilization is being aggressively engaged in both academia and industry. According to the IEEE 802.22 WRAN standards for sensing TV bands, channel detection time and channel allocation time must less than or equal to 2sec, and the detection probability and false alarm probability as 90\% and 10\% respectively. Different signal processing techniques are being used for spectrum sensing. Still there is a need to develop an efficient sensing algorithm which tends to meet the cognitive radio standards.

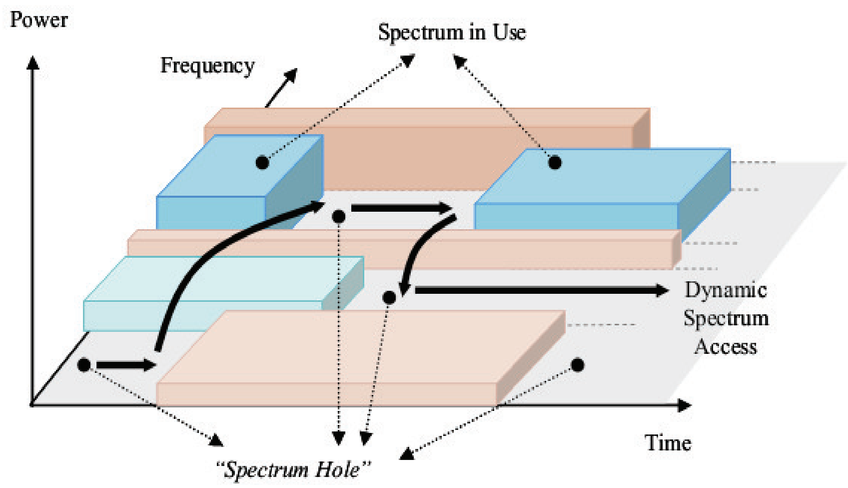

Figure 1. Spectrum hole concept

Once all available spectrum bands are characterized, appropriate operating spectrum band should be selected for the current transmission considering the Quality of Service(QoS) requirements and the spectrum characteristics. Thus, the spectrum management function must be aware of user QoS requirements. Based on the user requirements, the data rate, acceptable error rate, delay bound, the transmission mode, and the bandwidth of the transmission can be determined. Then, according to the decision rule, the set of appropriate spectrum bands can be chosen. Five spectrum decision rules which are focused on fairness and communication cost are presented. However, this method assumes that all channels have similar throughput capacity. An opportunistic frequency channel skipping protocol for the search of better quality channel is presented, where the channel decision is based on SNR. In order to evaluate the primary user activity, statistical studies on a certain frequency band based on spectrum handoff can be used for spectrum decision.

Distributed sensing using hard decision fusion logic

In this section, distributed sensing using multiple distributed CRs are considered. Figure 2 shows the cooperative sensing with selected nodes. In this figure, all CR nodes are detecting the Primary Users activity in the selected band to be scanned. However, the selection of nodes depends on the environment in which CR senses the band and belief on CR (it should not be malicious

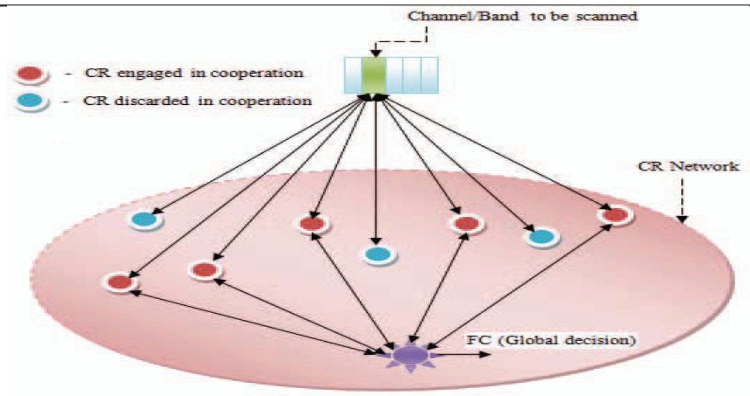

Figure 2.Coperative Sensing Model

user). Assume that there are Mnumbers of nodes are selected for cooperation to achieve the global decision. And the received signals of all nodes are independent, then, the hypothesis test takes the following form,

$$H0:(n) = wm(n), m = 0, 1, ...,M-1 \quad \text{-----------------------(1)}$$
$$H1:(n) = hm.sm(n) + wm(n),\ n = 0, 1, ...,N-1 \text{----------------(2)}$$

For each node the assumption is that the channel coefficients $h'ms$are nonzero mean, unit variance complex Gaussian random variables. The noises are independent of each other for the Mreceivers. Denote $(Pd,)$ and $(Pf,)$ are the detection and false alarm probability of mth CR user (or mth node). Then, detection probability by choosing the detection threshold $\lambda 0$is

$$P_{d,m} = Q\left[\left(\frac{\lambda_d}{\sigma_w^2} - \gamma_s |h_m|^2 - 1\right)\sqrt{\frac{N}{2\gamma_s |h_m|^2 + 1}}\right] \text{-------------------- (3)}$$

and the probability of false alarm is

$$P_{f,m} = Q\left[\left(\frac{\lambda_d}{\sigma_w^2} - 1\right)\sqrt{N}\right] \text{-------------------------- (4)}$$

Once the decision is made for each individual node, different hard decision techniques such as OR, AND, and MOST fusion rules are popularly being used for making global decision.

LOGIC-OR RULE

Logic OR rule is a simple decision rule described as follows: if one of the decisions says that there is a primary user, then the final decision declares that there is a primary user.The FC decides $H1$ when any one of the CRs in the cooperative network reports signal detection. The sum of the binary bits is at least equal to one .i.e.$\sum_{m=0}^{M-1}[ym] \geq 1$, Where ym is the binary decision of mth node. The cooperative detection probability and false alarm probability of OR fusion is,

$$\text{Qd-OR} = 1 - \prod_{m=0}^{M}(1 - Pd,m) \text{ ------------------ (5)}$$
$$\text{Qf-OR} = 1 - \prod_{m=0}^{M}(1 - Pf,m) \text{------------------ (6)}$$

LOGIC-AND RULE

Logic AND rule works as follows: if all decisions says that there is a primary user, then the final decision declares that there is a primary user.The sum of the binary bits is equal to number of nodes in the cooperation i.e.$\sum_{m=0}^{M-1}[ym] = M$.The cooperative detection probability and false alarm probability of AND fusion is,

$$\text{Qd-AND} = \prod_{m=0}^{M}(Pd,m) \text{------------------------ (7)}$$
$$\text{Qf-AND} = \prod_{m=0}^{M}(Pf,m) \text{------------------------ (8)}$$

MOST RULE

Another decision rule is based on majority of the individual decisions. If half of the decisions or more say that there is a primary user, then the final decision declares that there is a primary user. Finally, the MOST logic decides $H1$ based on the voting rule.

The sum of binary bits is more than half of the nodes in the cooperation. i.e.$\sum_{m=1}^{M}[ym] \geq M/2$.The Cooperative detection probability and false alarm probability of MOST fusion is,

$$\text{Qd-MOST}=\sum_{m=nd}^{M}\binom{M}{m}Pd,m(1-Pd,m)^{M-m} \quad \text{------------------ (9)}$$

$$\text{Qf-MOST}=\sum_{m=nd}^{M}\binom{M}{m}Pf,m(1-Pf,m)^{M-m} \quad \text{-----------------(10)}$$

The optimum number of CR users in cooperation is obtained by minimizing the total error rate. The total error rate is defined as,

eT=(1-Qd-MOST)+Qf-MOST -------------------- (11)

SIMULATED RESULTS

In order to illustrate the performance of proposed spectrum sensing algorithm, Quadrature Phase Shift Key (QPSK) signal is considered under Additive White Gaussian Noise (AWGN) and Rayleigh fading channel environment. The energy detector estimates the energy of the received signal within the desired frequency band Fusion logics AND, OR, and MOST rules of hard decision are considered for simulation. Figure 4 illustrates the Optimal sensing period for distributed spectrum sensing using different hard decision logic, with total vacant time (T)=100$msec$, γs=-15dB. From the figure, it is clear that the sensing time reduces as the number of CR users increases. It is also seen that, the MOST logic requires less sensing time compared to OR, AND fusion logics with same no of CR users in cooperation. Figure 3 shows the maximum normalized throughput of the CR Network with different number of CR users. It is seen that the throughput increases with increase of number of CR users for all hard decision fusion logic. The MOST fusion logic has maximum throughput compared to other two fusion logic. Figure 5 describes the total error rate vs. detection threshold at particular observation period for MOST fusion rule with different number of CRs in cooperation (m=0 to 10). From the figure 5, it can be seen that the optimal number of CRs required to achieve minimum error rate over all the examined range of detection thresholds is five (m=5).

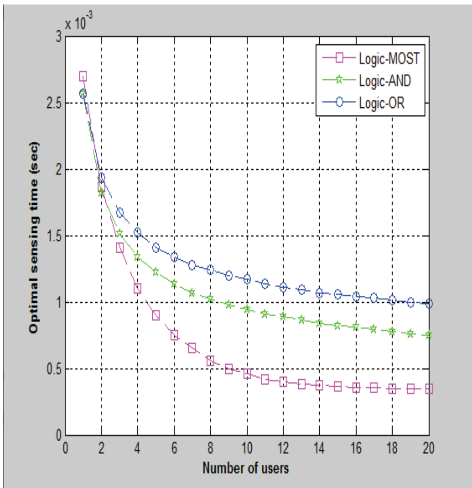

Figure. 3. Normalized achievable throughput for distributed decision fusion

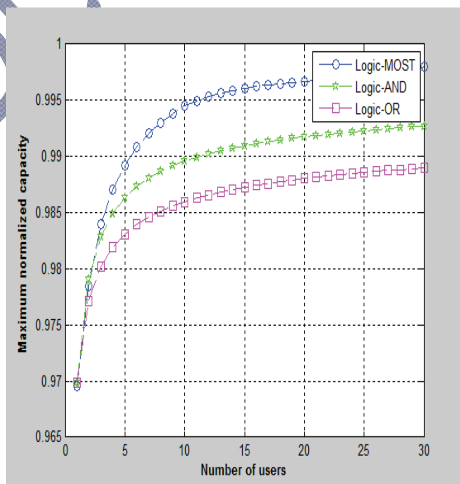

Figure. 4. Optimal sensing period for distributed spectrum sensing using hard spectrum sensing for hard decision fusion.

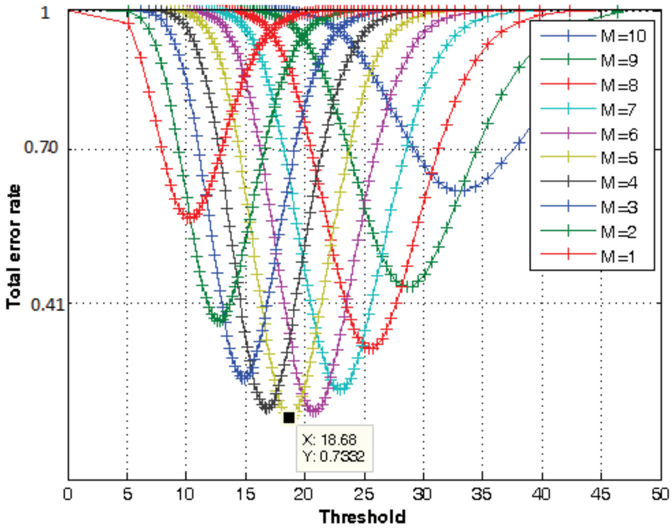

Figure 5. Total error probability Vs detection threshold for MOST fusion rule.

Figure 5. describes the total error rate vs. detection threshold at particular observation period for MOST fusion rule with different number of CRs in cooperation (m=0 to 10).From figure 5 it can be seen that from the optimal number of CRs required to achieve minimum error rate over all the examined range of detection thresholds is five (m=5).

Table 1.Achievable throughput vs. sensing period at different prior probabilities

Prior probabilities	P(H0)=0.8	P(H0)=0.75	P(H0)=0.7	P(H0)=0.6
Achievable throughput	5.289	5.007	4.706	4.126
Sensing period (milli_sec)	2.5	2.5	2.5	2.5

CONCLUSION

In this paper, energy detection method is used for sensing. This approach was extended to cooperative sensing using hard decision fusion logic. From the simulation results, we computed the optimum sensing period based on maximum Achievable throughput for CR network at desired detection and false alarm probability ($Pf\leq0.1$ and $Pd\geq0.9$). Moreover, the result discloses that the MOST fusion logic is reliable than other two logic. The optimal number of CRs required to achieve minimum error rate using MOST logic is five. The selection of best CR users in cooperation based on multiple malicious user elimination is under development to increase the throughput and reliability of cooperative sensing.

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