Spectrum Sensing for DCF in Opportunistic Spectrum Access Environment

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Abstract

Opportunistic spectrum access was proposed to improve spectrum efficiency in which secondary users can access the unused portion of the licensed spectrum. Spectrum sensing process identifies the opportunities for secondary users to access the channel. We focus on integrating the spectrum sensing process with existing DCF. We propose spectrum sensing mechanism that can distinguish between primary and secondary signals.

1. Introduction

Opportunistic Spectrum Access (OSA) is an effective spectrum access mechanism to ease the scarcity of radio spectrum [1] [2]. Medium access control (MAC) protocol defines how the spectrum is accessed and spectrum sensing plays an important role for MAC protocols in OSA environment. MAC protocol performs coordination for secondary users (SUs) to access the channel when primary user (PU) signal is absent. It prevents SUs' access when the channel is occupied. Therefore, the performance of the secondary system depends upon the spectrum sensing process accurately identifying BUSY and IDLE states. In [3], the authors discussed about various spectrum sensing mechanisms. The most important issue for spectrum sensing in OSA is for the SUs to distinguish the signal present is whether PU and SU signal.

2. System Model

As depicted in Fig.1, we assume that there is only on PU transmitter in each licensed channel. Since the primary network has a higher priority, the PU can transmit at any time on the channel whereas the SUs can only transmit only if the channel is unoccupied. We assume that there are N SUs in the SU system. Since there is no cooperation from PU, SUs do not know when the PU will start or stop transmitting beforehand. Therefore, SUs have to rely on spectrum sensing to identify the opportunities for transmission. Moreover, since there are N SUs in the system, SUs must perform coordination governed by DCF of IEEE 802.11 standard.

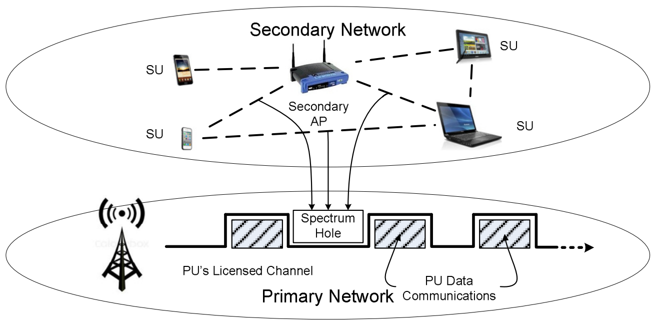

Fig.(1) System Model

From the point of view of SUs, the channel is switching between presence (ON) and absence (OFF) of PU signal which we model the duration of ON state and OFF state by two random variables, namely T_{ON} and T_{OFF}. We assume that they are independent and identically distributed (*i.i.d.*). Let $f_1(t)$ and $f_0(t)$ be the probability density functions (p.d.f's) of T_{ON} and T_{OFF}, respectively. Let P_1 and P_0 be the limiting probabilities of ON state and OFF state, respectively. They are given by:

$$P_0 = \frac{\overline{T_{OFF}}}{\overline{T_{OFF}} + \overline{T_{ON}}} = \frac{\int_0^\infty x.f_0(x)\,dx}{\int_0^\infty x.f_0(x)\,dx + \int_0^\infty y.f_1(y)\,dy}, \qquad (1)$$

$$P_1 = 1 - P_0,$$

where $\overline{T_{ON}}$ and $\overline{T_{OFF}}$ are mean sojourn times of ON state and OFF state, respectively.

3. Spectrum Sensing Mechanism

In OSA environment, a SU must be able to detect the presence of a signal on the channel and it must be able to distinguish the signal between PU and another SU. We propose a joint mechanism where energy detection (ED) and matched filter (MF) detection are performed in conjunction.

Most OSA systems and DCF employ the energy detection (ED) as the preferred spectrum sensing method because of its low complexity. Let H_0 and $\overline{H_0}$ denote the absence and presence of any signal on the channel. The received signals by a SU can be written by:

$$\begin{aligned} H_0 &: v[n] = z[n], && \text{channel is unoccupied,} \\ \overline{H_0} &: v[n] = z[n] + u[n], && \text{channel is occupied,} \end{aligned} \tag{2}$$

where $v[n]$ is the nth sample of the SU's received signal, $z[n]$ is the noise which is assumed to be Circular Symmetric Complex Gaussian (CSCG) with zero mean and variance σ^2, and $u[n]$ is the signal present. In such a case, the ED threshold for BUSY or IDLE hypothesis is:

$$V_{ED} = \frac{1}{\lambda T_s} \sum_{n=1}^{\lambda T_s} |v(n)|^2 \underset{H_0}{\overset{\overline{H_0}}{\gtrless}} \varepsilon_{ED}, \tag{3}$$

where T_s is the sensing duration, λ is the sampling rate and ε_{ED} is the threshold for ED. Furthermore, for $\overline{H_0}$ hypothesis, the sensing SU must distinguish whether the present signal is from PU or another SU.

$$\begin{aligned} H_1 &: v[n] = z[n] + u_1[n], && \text{PU signal is present,} \\ H_2 &: v[n] = z[n] + u_2[n], && \text{SU signal is present,} \end{aligned} \tag{4}$$

The MF the threshold for SU or PU hypothesis can be given as:

$$V_{MF} = \frac{\left|\mathbf{w}^H \mathbf{M}^{-1} \mathbf{v}\right|^2}{\left(\mathbf{w}^H \mathbf{M}^{-1} \mathbf{w}\right)\left(\mathbf{v}^H \mathbf{M}^{-1} \mathbf{v}\right)} \underset{H_1}{\overset{H_2}{\gtrless}} \varepsilon_{MF}, \tag{5}$$

where ε_{MF} is the threshold for MF, $\mathbf{w}$ is the known signal vector of SU and $\mathbf{M}$ is a sample covariance matrix based on the received signal vector which is estimated as:

$$\mathbf{M} = \frac{1}{\lambda T_s} \sum_{n=1}^{\lambda T_s} \mathbf{v}(n) \mathbf{v}^H(n). \tag{6}$$

Matched filter detection has higher complexity and lower error probability than that of energy detection which is negligible. However, since ED is a simple threshold mechanism, the hypothesis can have errors. Detection probability, P_D, and false-alarm probability, P_F , for ED are given by:

$$\begin{aligned} P_D(T_s) &= Q\left(\left(\frac{\varepsilon_{ED}}{\sigma^2} - \gamma - 1\right)\sqrt{\frac{\lambda T_s}{2\gamma+1}}\right), \\ P_F(T_s) &= Q\left(\sqrt{2\gamma+1}\ Q^{-1}(P_D) + \gamma\sqrt{\lambda T_s}\right), \end{aligned} \tag{7}$$

where γ is the signal-to-noise-ratio (SNR) and $Q(.)$ is the complementary function of a standard Gaussian random variable, i.e.

$$Q(x) = \left(1/\sqrt{2\pi}\right)\int_x^{\infty} \exp\left(-s^2/2\right) ds. \tag{8}$$

We can now calculate the error probability of ED as:

$$q = P_F P_0 + (1 - P_D) P_1 . \tag{9}$$

4. Proposed Sensing Protocol

DCF employs Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol with binary exponential backoff procedure [4]. Spectrum sensing process must be compatible with afore mentioned algorithms which define the behavior of secondary network. DCF employs physical carrier sensing and virtual carrier sensing which is also known as network allocation vector (NAV). We modify the existing carrier sensing process to meet the requirements of OSA environment. For efficiency, the protocol uses a discrete short sensing interval with multiple sensing rounds.

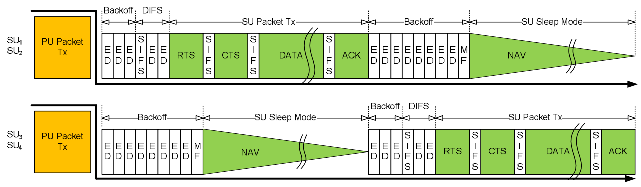

Fig.(2) Spectrum Sensing of Secondary Signal

Fig.(2) displays the spectrum sensing procedure of detecting a secondary signal. When a SU has a packet to transmit, it generates a random backoff interval which is assigned as a backoff counter value. The backoff counter of each node is decremented whenever the channel is sensed 'IDLE'. The counter will freeze when the channel is sensed 'BUSY' and it restarts again when the channel becomes vacant again. When a backoff counter of a SU reaches zero, it will start performing spectrum sensing and if the channel remains idle for DIFS, it will transmit the packet as depicted in Fig.(2). Note that all the sensing intervals of the sequence, excluding the last interval, uses ED. When a busy channel is detected, MF detection is used to identify the signal.

Fig.(3) displays the step by step procedure of spectrum sensing of a primary signal. When PU suddenly appears on the channel, the current SU transmission will be interrupted. The destination SU will not fully receive the DATA packet. Similarly, the source SU will not receive the ACK packet. Both source and destination SUs will perform spectrum sensing; two consecutive ED followed by a MF for identification, then they will wait for the end of PU transmission. Other SUs, which are currently in the sleep mode, will wake up and detect the presence of PU signal. They will switch back and forth between sleep and sense mode using the last NAV time until they detect the SU signal. When the PU signal leave the channel, the waiting source and destination SUs will immediately retransmit the failed packet. Other SUs will wait for the end of the SU transmission. This waiting time is less than the last NAV time.

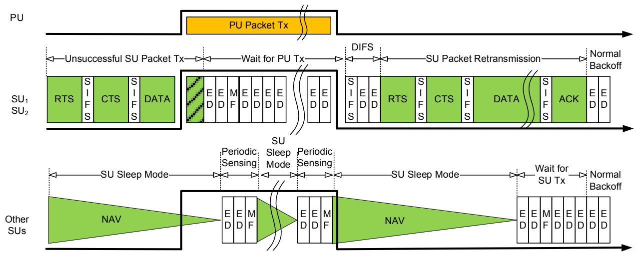

Fig.(3) Spectrum Sensing of Primary Signal

5. Effectiveness of Spectrum Sensing

From (7), we can clearly see that the error probability of spectrum sensing depends on the sensing time interval. However, to conform to the binary exponential backoff procedure of DCF, we have multiple short sensing intervals. Each sensing interval is independent of other sensing intervals because the detection only depends on the presence or absence of a signal. Since we have a discrete time process with the error probability, q, Bernoulli process can be used to model the performance of our proposed sensing protocol. If we have $(r+k)$ sensing intervals, the probability that there are k sensing errors can be expressed by the probability mass function (p.m.f) of a Pascal distribution as follows:

$$\Pr\{x=k\} = P_e = \binom{r+k-1}{r}(1-q)^r q^k, \qquad (10)$$

where r and k stands for number of correct and incorrect sensing time segments, respectively, and $r,k \in \{0,1,2,\dots\}$. If we fixed the number of correct sensing intervals, r, as a constant for the design parameter, the number of errors, k, will solely depend on q and the average number of sensing errors in a sequence of sensing segments, k_{avg}, is given by:

$$k_{avg} = \lceil r.q/(1-q) \rceil, \qquad (11)$$

where $\lceil x \rceil$ is the ceiling function of x. Fig.(4) displays number of sensing interval versus the error probability. From Fig.(4), we observe that our proposed sensing protocol has a 96% confidence for $q = 0.2$.

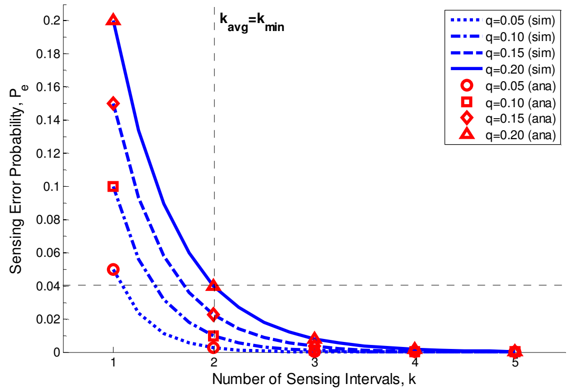

Fig.(4) Number of sensing interval versus sensing error probability.

6. Conclusions

In this paper, we propose a sensing protocol that is compatible with existing DCF. We adopted two sensing mechanism and perform them in conjunction to distinguish between primary and secondary signals. Finally, we perform simulations to verify that our proposed protocol meet the confidence level for sensing error probability.

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