ENERGY EFFICIENT PERIODIC SPECTRUM SENSING AND TRANSMISSION TRADEOFF IN CR NETWORKS

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Abstract

The cognitive radio system with the primary user and a single secondary user (SU) accesses multiple channels via periodic spectrum sensing. In this sensing scheme average energy cost of SU that includes channel switching, spectrum sensing and data transmission. The sensing reliability throughput is increased and delay of the secondary transmission is reduced. In this proposed scheme, when the channel is busy, the user is handed off to another channel which improves energy efficiency and reduces time consumption. A new algorithm is proposed to reduce the cost of energy consumption. The increasing throughput and also reduced delay are validated by the numerical results.

Keywords: Periodic spectrum sensing, trade-off, Cognitive Radio, sensing/Transmission trade off, Spectrum Handoff

1. Introduction

Cognitive radio involuntarily detects accessible channels in wireless spectrum and consequently changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band in one location. It allows incumbent wireless providers to spectacularly enhance the capacity of their network and diminish the interference. The issue of spectrum underutilization in wireless can be solved in a better way than others by using Cognitive radio technology.

Spectrum sensing is the key enabling technology for cognitive radio networks. The main objective of spectrum sensing is to provide more spectrum access opportunities to cognitive radio users without interfering with the operations of the licensed network. The periodic spectrum sensing involves balancing the tradeoffs among spectrum utilization, interference to Primary Users and sensing overhead by selecting an appropriate sensing period. The sensing time and sensing period are the two key sensing parameters for periodic spectrum sensing scheme.

A novel generalized detector is proposed in [2], this detector by examining the target sub band by exploiting the noise information of white sub band. A combination of sleeping and censoring as a energy saving mechanism, in spectrum sensing is focused on [1] to maximize the channel utilization while limiting the interference to primary users. A periodic spectrum sensing opportunistic spectrum accesses to remove the partial availability by sensing the channel periodically. The SU only transmits data or wait without transmitting, on the channel that is sensed in the same frame.

In wideband cognitive radio networks, spectrum handoff is performed when multiple narrow band channels are available for sharing. When the current channel is sensed as busy, the spectrum handoff will result in high energy consumption and hence it is not always preferred, particularly in wireless cognitive sensed networks [5] where energy is critical. Instead the SU is chosen to stop transmission and wait on the current channel for a period of time with the increased delay and reduced average throughput. In this proposed system, energy consumption of the SU is considered.

The optimal spectrum access strategy is designed to maximize the throughput of the SU without considering the energy constraint [6].Based on the literature [7],[8],[9],it is known that the existing systems use either the sensing/Transmission trade off while neglecting spectrum hand off or the wait/switch trade off while ignoring sensing errors.

In the proposed scheme is designed to maximize the throughput and reduce the delay of the secondary user in addition to reducing the power constraint. In the proposed system the periodic spectrum sensing/transmission trade off is used to reduce the power. The optimal sensing and spectrum handoff occurs based on the availability of the channel on the particular time interval i.e., either to switch to another channel or to retain the same channel. The total energy cost of the SU includes the energy due to spectrum sensing, hand off and data transmission with the increase in reliability, average throughput and delay.

Section I deals with the introduction of the model. Section II deals with the system model and Section III explains the system approach considering the spectrum access mechanism. Section IV describes and solves the optimization problem. Performance analysis is given in section V and section VI gives the brief conclusion.

2. SYSTEM MODEL

Consider a cognitive radio, which has M channels shared between a primary link and a secondary link as shown in fig 1. One of the M channels is allocated to the SU at any given instant of time. The secondary transmission is processed through periodic spectrum sensing and each frame consists of a sensing in which each frame consists of a sensing slot of duration τ_s and transmission slot of duration T.

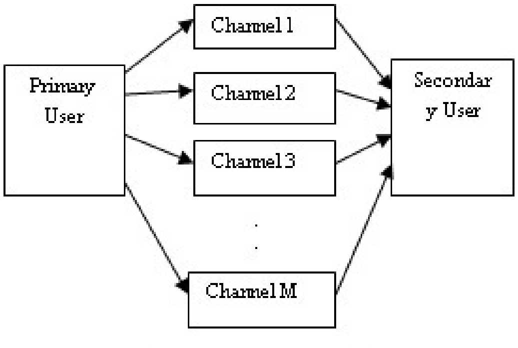

Fig.1 System Model

The primary transmission is continuous and it follows an on-off traffic model [10], where the probability of the transmission being on (off) is the same for each channel. In the sensing slot, the wide band sensing is performed by the SU to obtain the availability status of all channels. The channels are sensed simultaneously by energy detection.

Let SNR be the average received signal to noise ratio of the PU's signal on each channel and it is assumed when transmitting one packet of data [11]. P_d and P_f are detection probability and false alarm probability respectively. Then

$$P_d = Q\left(\frac{1}{\sqrt{2\gamma+1}}\left(Q^{-1}(P_F) - \left(\sqrt{T_s f_s}\gamma\right)\right)\right) \quad (1)$$

$$P_f = Q\left(\frac{1}{\sqrt{2\gamma+1}}\left(Q^{-1}(P_D)\left(\sqrt{T_s f_s}\gamma\right)\right)\right) \quad (2)$$

Where $P_D \, and \, P_F$ are the target detection probability and false alarm probability respectively, they are considered as the same for all channels.

A minimum sensing time exists for a fixed sampling frequency f_s to satisfy the target detection probability and false alarm probability.

The minimum sensing time is $\tau_S{}^{min}$ [2] and it is given by

$$\tau_S^{min} = \frac{1}{\gamma^2 f_s}\left(Q^{-1}(P_F)Q^{-1}(P_F)\left(\sqrt{2\gamma+1}\right)\right) \quad (3)$$

The energy consumption is determined by using the length of sensing time used during the energy detection. Thus the energy cost of the SU is minimized by using $\tau_S{}^{min}$ as the sensing duration. $\tau_S{}^{min}$ is not the finest in terms of reducing the total energy cost. When the sensing time is increased, it will result in more perfect sensing results, reduced probability of switching to a channel and thereby reduces the energy consumption and increases the throughput and delay constraints of the secondary transmission. Hence optimal τ_S will exist as far as when the SU is considered. When the information about the availability of all channels is obtained through sensing, the SU will decide whether it switches to another vacant channels or retains on the current channel.

3. PROBLEM FORMULATION

We consider a cognitive radio system with a primary user and a secondary user with M channels shared between these users. The secondary transmission is done through periodic spectrum sensing. In this periodic spectrum sensing optimization can be achieved, when the spectrum tradeoff is considered jointly with periodic spectrum sensing.

The optimization can be achieved by reducing the delay, improving the throughput, reducing the false alarm probability and also by increasing the detection probability. The problem can be formulated as

$\tau_s^{min}, P_s; J(\tau_s P_s);\ P_d(\tau_s)\ \geq\ P_{dt};$
$P_f(\tau_s) \leq P_{ft}; R(\tau_s P_s) \geq \dot{R}; D(\tau_s P_s) \leq D$ (4)

Where J is the total average energy consumption required to complete the transmission of one packet of data. R is the average throughput and D is the average delay. Ř and Ď are the thresholds for the average throughput and delay of the secondary transmission respectively. By deriving the expression for $, R\ and\ D$, the optimization can be achieved.

Let us launch the probabilities for hypothesis testing in the spectrum sensing. $H_i\ and\ H_i'$ are the events of hypothesis testing. Consider 0 and 1 are the channel idle and channel busy respectively, that is assumed to be known for the primary system [10].

$P_{ci} = (1 - P_f)(1 - \rho),$
$P_{fi} = (1 - P_d)\rho,$
$P_{cb} = P_d.\rho,$
$P_{fb} = P_f(1 - \rho)$

the functions of sensing slot durationτ_S.

4. Proposed Algorithm

The secondary user accesses the primary user spectrum when the primary user is not using the system. When the secondary user starts to sense the channel and if the currently sensed channel is idle then it starts transmission. The secondary user periodically senses the spectrum. If the current channel is idle then it starts its transmission with the probability of P_1 (event1) or otherwise it senses all other channels with the probability of $(1 - P_1)$. If all the channels are sensed busy with the probability of (P_b), then the least time taken by the transmission of the channel i.e., V_t the SU handoff to another channel (event3) which has lesser V_t with the probability of $(1 - P_S)$ is calculated. When any of the channel is in idle state, the SU switches to that channel resumes data transmission for T with the probability $(1 - P_b)$ (event 4) or otherwise. If the busy time of all the channel is greater than T, SU waits on the current channel and power off for T with the probability of P_S (event 2). The above proposed algorithm is to minimize the energy consumption and also to reduce the delay.

4.1 Average Energy Consumption.

The energy consumption in cognitive radio is the total energy consumed by secondary user is to sense, transmit switching and also waits for the current channel. The average time required for the secondary user to complete the transmission of one packet of data with time duration of S is given by $T_S = \frac{S}{P_t}$

P_t is the probability of transmission.

$$N(\tau_S, P_S) = \left[\frac{S}{P_t}.T\right] \quad (5)$$

If the current channel is idle then it starts its transmission with the probability of P_1 event 1.

$$E_1 = P_{ci} + P_{fi} = (1 - P_f)(1 - \rho) + (1 - P_d)\rho, \quad (6)$$

When the current channel is sensed busy, the secondary user periodically senses all other channels sensed as busy with the probability of P_b.

$$P_b = (P_{ci} + P_{cb})^{M-1}$$
$$= [P_d(\rho) + (1 - P_f)(1 - \rho)]^{M-1} \quad (7)$$

Calculate V_t, if V_t is greater than the transmission time, the SU waits on the current channel with the probability of P_b i.e., event 2. $E_2 = (1 - P_1\ P_b P_S)$. The SU chooses the idle channel to continue its transmission with the probability of P_b i.e., event 3. $E_3 = (1 - P_1)P_b(1 - P_S)$ and $E_4 = (1 - P_b)$.

The total probability is given by

$$P_t = (1 - \rho)(1 - P_f) + \rho(1 - P_d) + (1 - P_1)P_b(1 - P_S)(1 - P_1)(1 - P_b) \quad (8)$$

The probability of all other channels is busy, based on the value of least time taken by the transmission (V_t) of the channels, the probability of waiting at the same channel and power off for T. The total energy cost for the energy consumption due to spectrum sensing, spectrum hand-off and data transmission.

$$J(\tau_S, P_S) = N\tau_S E_S + N(E_3 + E_4)J_{SW} + SE_t \quad (9)$$

For the secondary system, consider that sensing power P_S, transmission power P_t and J_{SW} are known, the average energy cost can be obtained by deriving the average energy cost which is low due to switching.

4.2 Average throughput

The throughput of the secondary user based on the probability of false alarm and probability of detection. Each frame consists of sensing slot of duration τ_S and total transmission slot T.

The secondary user accesses the spectrum periodically, when the primary user is not present i.e., the channel is idle, the secondary user starts its transmission. The primary transmission can arrive at any time during the transmission slot T, causing the interference among the primary and secondary transmission. When the interference occurs the secondary transmission rate is approximately zero.

Consider the SU data rate

$$C_0 = log_2(1 + SNR) \quad (10)$$

Where SNR is the received SNR at the secondary user. The channel is idle and the PU being off in a given channel β_0 and is known based on the traffic model of a given system [10]

Let t be the average time duration for the primary transmission to occur in an idle channel for a transmission slot T and

$$t = T - \beta_0(1 - e^{T/\beta_0}) \quad (11)$$

The number of bits transmitted in one transmission slot T is denoted by

$$\mathrm{B_T} = \left(1 - \left(\frac{\mathrm{t}}{\mathrm{T}}\right) \mathrm{C_0}.\mathrm{T}\right) \quad (12)$$

$$R(\tau_S, P_S) = \frac{P_{ci}B_T + \left(P_3(1-P_e)\right) + P_4(1-P_n).B_T}{\tau_S + T} \quad (13)$$

4.3 Average Delay

In the secondary transmission, the delay is caused by spectrum sensing and SU is waiting on the current channel without transmission and $N\tau_S$ is the delay due to the spectrum sensing. When all the channels are sensed as busy, the probability that the SU waits on the current channel is given by

$$P_{WT}(\tau_S, P_S) = E_2 = (1 - P_1).P_b.P_S \quad (14)$$

Where P_{WT}power of SU is waits on the current channel. The average delay is to complete the transmission of one packet of data is given by

$$D(\tau_S, P_S) = N\tau_S + NTP_{WT} \quad (15)$$

From the above equations, it is known that for a given τ_S, R is monotonically diminishing with $P_{S,}$, because the less data can be delivered when the SU's waiting time more on the current channel. For given τ_S, $J(P_S)$ is continuously decreasing with P_S when

$$J_{SW} \geq E_S(\tau_S/P_1(\tau_S)) \quad (16)$$

The optimal is given by

$P_S^{opt}(\tau_S)$ = min $\alpha(\tau_S), \beta(\tau_S)$ are obtained by substituting $R(\tau_S, P_S) = \check{\mathrm{R}}$ and

$D(\tau_S, P_S) = \check{\mathrm{D}}$ respectively.

$$R(\tau_S, P_S) = \frac{P_{ci}B_T + \left(P_3(1 - P_e)\right) + P_4(1 - P_n).B_T}{\tau_S + T}$$

$$\alpha(\tau_S) = 1 - \frac{(\tau_S+T)-1P_{ci}.B_T+P_4(1-P_n).B_T}{(1-P_e)(1-P_1).P_b.B_T} \quad (17)$$

from equation (15)

$$D(\tau_S, P_S) = N\tau_S + NT(1 - P_1).P_b.P_S$$

$$\beta(\tau_S) = \frac{D-N\tau_S}{(1-\eta)(1-P_1).P_b} \quad (18)$$

5. Performance Analysis

In this section, performance of the proposed scheme evaluated. The optimality of the proposed periodic spectrum sensing and access mechanisms and comparison of the secondary transmission in terms of throughput and delay is carried out. We assume three channels between the primary and secondary user. The duration of a packet of data is $S = 5sec$ the duration of each transmission slot $T = 1sec$ and the power required for spectrum sensing and transmission $P_S = 40mw$ and $P_t = 69.5mw$.

The results of all these figures are obtained by letting the received SNR of the PU's signal that is, $\gamma = -10db$, the probability of channel being busy $\rho = 0.45$ and the probability of target detection and false alarm probability $P_d = 0.7$ and $P_f = 0.3$ respectively. The throughput and delay thresholds are defined as $R = \mu R_0$ and $D = \lambda S$ where $\mu(0,1)$ and $\lambda(0,1)$ and $R_0 = (1 - \rho)C_0$ are the average throughput and delay constraints which can be active in the optimization procedure.

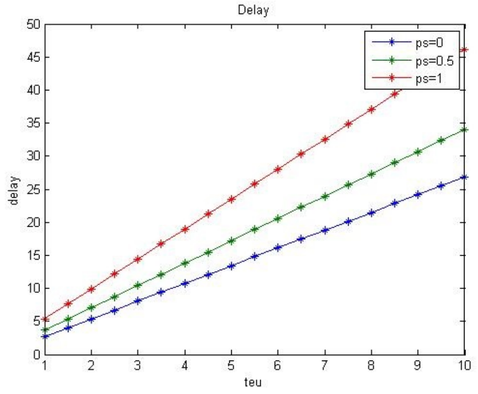

Fig 2. Delay with throughput coefficient for different P_S

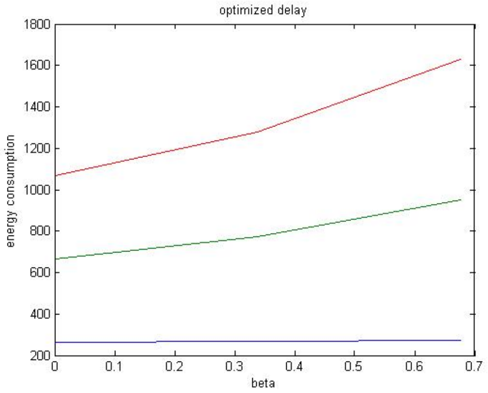

Fig. 3 energy consumption with delay for different P_S

From fig. 2,3 and 4 depicts that the throughput of the proposed scheme is increased and the delay of the system is reduced for different sensing powerP_S.

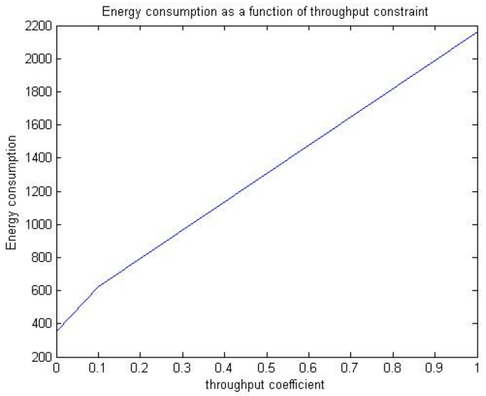

Fig 4. Energy consumption with throughput coefficient

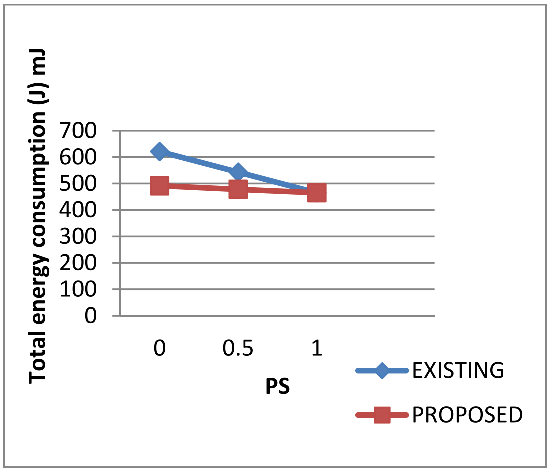

Fig 5 Total energy consumption when Jsw = 40 mJ

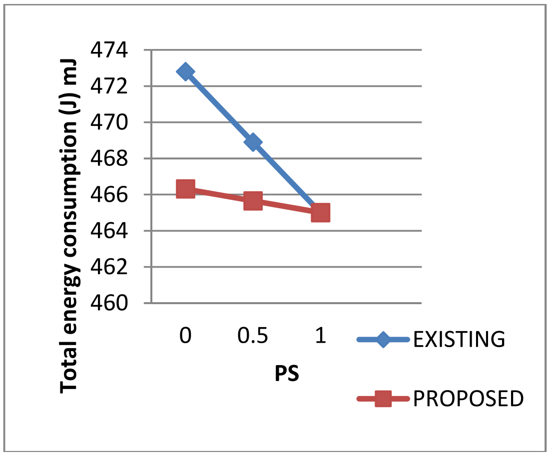

Fig 6 Total energy consumption when Jsw = 2 mJ

From fig 5 and 6 depicts that the energy consumption is reduced for two different energy cost. Therefore the energy consumption and delay time is reduced at the same time throughput is increased.

6. Conclusion

The proposed optimized system results in lesser energy consumption with the better channel switching probability. It is achieved by calculating the least time taken by the transmission i.e., V_t of all channels. Based on the V_t, the secondary user will decide whether to wait on the same channel with power off or switch over to another channel which is $V_t < T$. So, the sensing time spectrum handoff to false channel is reduced, thereby increases throughput and also reduces the energy consumption and delay incur in the system, which results in better energy efficiency.

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