Optimal Paring of Spectrum Sensing Duration and Threshold for Energy-Harvesting CRNS

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ABSTRACT

Energy harvesting cognitive radio system where the secondary transmitter harvests energy either at transmitter or receiver end and it detects vacant channels from the used one and share it among the other users. This system operates under energy causality constraint it means average consumed energy should not exceed average harvest energy and collision constraint means the interference should not be occurred between the shared channels for protection of primary system. In this paper, we suggest a method to optimal pairing of sensing duration and energy detectors threshold to increase average throughput of the system by the use of energy harvesting system. To satisfy collision constraint, sensing duration must be kept smaller. Proposed algorithm use in this paper is Matched filter detection.

The matched filter also referred to as coherent detector, is a sensing technique. It is very accurate since it maximizes the received signal-to-noise ratio (SNR). Matched filter correlates the signal with time shifted version and compares between the final output of matched filter and predetermined threshold will determine the PU presence.

Keywords: Cognitive radio networks, spectrum sensing, energy-harvesting, sensing duration, matched filter.

1. INTRODUCTION

Energy harvesting cognitive radio system collects energy from environmental sources. The devices that require a sustainable energy supply system to replace fixed power supply [1]. Energy-harvesting wireless network has been based on the simple point-to-point connection refers to a communications connection between two nodes or endpoints [2]–[3]. Since the harvested energy arrival at the sender's battery is unlimited. To improve performance [4] consumed energy must optimized carefully based on the current battery state and data's memory area. To know the status and capacity of additive white Gaussian noise (AWGN) channels is must for energy-harvesting point-to-point communication. To achieve higher throughput and lower delay on fading channels, transmission policies for energy-harvesting senders were developed considering the causal or non causal information concerning channel state and energy arrival. The objective of Cognitive radio network system is to improve spectral efficiency by sharing the licensed spectrum [5]. In order to deal with the problem of interference on the shared spectrum, spectrum sensing techniques for opportunistic spectrum access have been developed as a way to provide sufficient protection to other devices [6]. To improve spectrum sensing performance, optimization of sensing duration and threshold has also been researched to determine how to make the most successfully use of the licensed spectrum [7]. Moreover, the issue surrounding sensing configuration has been studied in various environments, such as asynchronous communication mechanism that allows single reader and writer processes to access a shared memory in such a way that interference between concurrent reads and writes is avoided. Asynchronous less communication is used when data is more important than avoiding latency [8]–[10]. We have to consider both the collision constraint and energy causality constraint in their design, to achieving both energy efficiency and spectral efficiency for energy-harvesting systems. The collision constraint and energy causality constraint means the interference should not be occurred between the shared channels for protecting licensed network and average consumed energy should not exceed average harvest energy for environmental sources [11].

Accurate sensing configuration design is needed when these two constraints have to be considered in their design. The sensing duration and threshold are important sensing parameters which strongly affect system performance. For this reason,. Park et al. analyzed the effect of the energy causality constraint with respect to the sensing threshold from the long-term perspective [12]. They derived the optimal sensing threshold from the tradeoff between the probability of detecting idle spectrum and probability of being in active mode. To detect whether the signal is present or absent on the channel can be expedited if we pass the signal through a band pass filter and then matched filter that will accentuate the useful signal and cause to stop the noise signal. A matched filter will peak out the signal component at some instant of time and cause to stop the noise amplitude at the same time. If signal is present on the channel, a large peak will occur at that instant whereas the signal is absent, no such peak will appear. This arrangement will make it possible to decide whether the signal is present or not in the channel. Coherent detection can achieve a shorter sensing time for a certain probability of false alarm or probability of detection. But it needs the prior knowledge of licensed user's features such as (i) bandwidth, (ii) modulating type and order, (iii) operating frequency and pulse shaping, which would be possible only if the licensed user intends leveraging cooperation and also it requires accurate synchronization with primary system.

To achieve coherency with primary user signal by performing timing, carrier synchronization and channel equalization and power is consumed to demodulate the signal. Detecting above features and implementing matched filter detection is possible when primary users are recognizable in pilots, preambles, synchronization words or spreading codes that can be used for Matched filter detection. A matched filter detection technique is the optimal linear filter used to maximize the signal to noise ratio (SNR) in the presence of additive white Gaussian noise. Cooperation among Cognitive users is established to estimate the Primary user's presence or absence is used to take the overall resolution about the licensed users.

The goal of this paper is to design the sensing duration and threshold together with an eye toward maximizing the average throughput of the energy-harvesting CRN for a given amount of harvested energy. For this, both the sensing duration and the sensing threshold need to be optimized with respect to each other. Optimal sensing duration and sensing threshold directly from the enhance effectiveness problem is a difficult proposition, since they are twist two things together not only with the sensing performance but also with the energy causality constraint. Hence, it is necessary to reduce interdependence the effect of the sensing duration on the performance from the effect of the sensing threshold. Our assigned work is to analyze the effect of sensing duration and sensing threshold on the system performance.

The results of the analysis are then used to derive the optimal sensing duration from a long-term evaluation. Furthermore, we have a look to find how an appropriate sensing threshold that meets the necessary of the optimal sensing duration derived previously. The sensing duration and sensing threshold pairing gives measured assessment into how to collectively design the sensing configuration in an energy-harvesting CRN using Matched filter detection.

The remainder of the paper is organized as follows. Section 2 presents the system model and summarizes the main assumptions in this paper. Section 3 formulates the throughput maximization problems cooperative spectrum sensing, respectively. Section 4 develops algorithms to solve the formulated problems for energy harvesting CRNs, respectively. Numerical results are presented in Section 5 to validate the theoretical results. Finally, Section 6 concludes the paper.

2. SYSTEM MODEL

This section introduces the concept of the energy-harvesting CRN. We will start by demonstrating the CRN model, which is comprised of a licensed network and an energy-harvesting secondary network. The exploiting opportunity spectrum access with mode decision process and corresponding energy utilization [13] and its energy model for the unlicensed network are then presented.

CRN-MODEL

We are considering here, the primary network is licensed to utilize the spectrum, while the secondary network doesn't. The primary transmitter sends data to the primary receiver as soon as data traffic onset. The data traffic of the primary network follows a standardized random process. For each and every slot, the spectrum state changes randomly. Figure 1 shows the Energy-harvesting CRN model where the secondary transmitter executes exploiting opportunity spectrum access. The solid lines represent the necessary links of the primary and secondary network, respectively, and the dotted lines represent unwanted links which produce collision and interference, respectively.

If the primary network is not utilizing the spectrum, we can call it as an idle spectrum, whereas it utilizing the spectrum i.e., primary network is sending its data is called busy spectrum denoted by $H0$ and $H1$ respectively. The probability of a spectrum state being idle, denoted as $\Pr[H0]$, and that of a spectrum state being busy, denoted as $\Pr[H1]$, are given by $\pi0$ and $\pi1$, respectively, where $\pi0 + \pi1 = 1$. The secondary transmitter implement spectrum sensing during the sensing duration $\tau \in [0, T]$ at the starting of each and every time slot. We define the normalized sensing duration as τ/T which imply the relative sensing duration compared to the slot duration. Depending on the sensing result, the secondary transmitter finds whether or not to send data to the secondary receiver. We assume that the secondary transmitter always has data to transmit [14]. When the secondary transmitter correctly senses that the spectrum is idle under the hypothesis $H0$, it can transmit data successfully without any interference. However, when it accesses the spectrum under the hypothesis $H1$ due to a false sensing result, two kinds of interference additionally appear as shown in Figure 1: interference from the primary transmitter to the secondary signal and interference from the secondary transmitter to the primary signal.

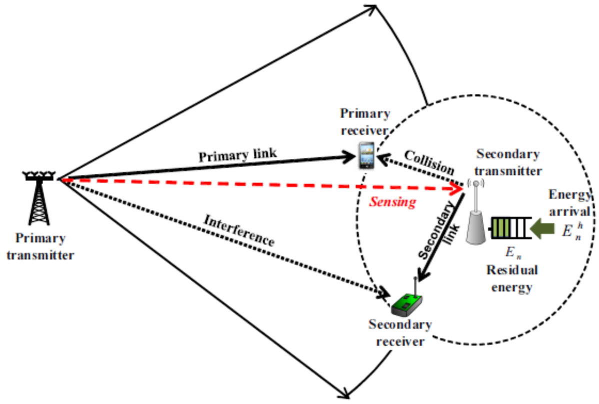

Fig.1: Energy-harvesting CRN model

We specifically identify the probability that the secondary interference collides with the primary signal as a collision probability, which is restricted by regulations governing CRNs. We consider that the channel for all the links, including the desired data link of the secondary network and the interference link from the primary transmitter to the secondary receiver, is modeled as an Additive White Gaussian Noise channel [15].

Consider the secondary receiver is capable of decoding the received signal in the presence of primary interference by using capacity achieving AWGN channel coding. Additive White Gaussian Noise is a basic noise model used in information theory to mimic the effect of many random processes. If no interference exists, the throughput of the secondary network is denoted as $C0 = \log(1 + \gamma s)$, where γs indicates the received signal to noise ratio (SNR) of the secondary transmitter's signal measured at the secondary receiver [16]. Otherwise, if interference from the primary transmitter does exist, its throughput is denoted $(1 + \gamma p)$, where γp indicates the received SNR of the primary transmitter's signal measured at the secondary network.

Since the secondary receiver operates in geographical proximity to the secondary transmitter compared to the primary transmitter, we assume that the received SNR high as much of secondary transmitter. Matched filter detection also known as coherent detection can achieve sensing duration small. To satisfy collision constraint, shorter sensing time is very important. For a certain probability of false alarm or probability of detection, it requires the accurate synchronization and prior knowledge of primary user's i.e., licensed users features.

Energy Model for Opportunistic Spectrum Access

Spectrum sensing consumes time duration and *energy* and introduces false alarm and miss detections. Let us denote $Eh\ n \in \mathrm{R+}$ as the energy arrival process at each and every slot *n* which follows an independent and scattered random process with mean $\mathrm{E}[Eh\ n] = eh$. The starting energy is stored in an energy storage area of the secondary transmitter's battery. The battery capacity is assumed to be infinite 1 to avoid excess energy. The performance analysis tractable of energy harvesting system shown in Figure 2. The leakage from the energy storage area is assumed to be negligible and there is no energy supply in addition to the energy-harvesting. The energy-harvesting secondary transmitter consumes energy for spectrum sensing and data transmission. Energy recharging/harvesting unit sends energy to location system and then moved to sensor and ADC [17]. Analog digital converter converts analog signal to digital in terms of 0's and 1's respectively.

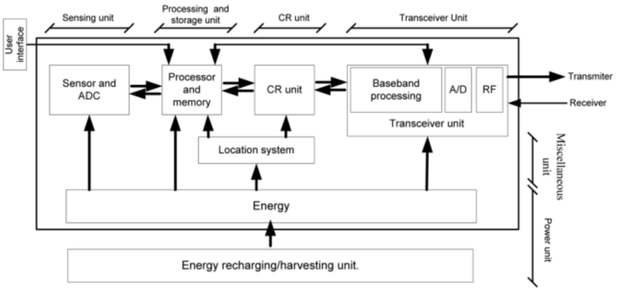

Fig. 2: Energy Harvesting System

2.1 Spectrum Access within Energy Causality Constraint

The sensing duration is a significant system parameter describing how long and how often the secondary network accesses the spectrum shown in Figure 3.

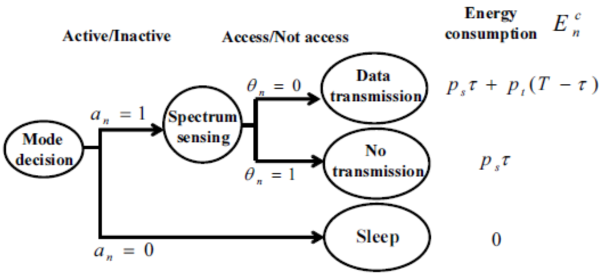

Fig. 3: Exploiting opportunity of spectrum access with mode decision process and the corresponding energy consumption

Opportunistic Spectrum Access with Spectrum Sensing

To overcome tradeoff between probability of idle spectrum and probability of being an active mode, the secondary transmitter carries out spectrum sensing with energy detection when it switches to active mode.

Active Probability by Energy Causality Constraint

The sensing duration is directly connected with the decision of whether or not to switch the active mode. Within a single slot it is hard to understand the relationship between the sensing duration and the mode decision. Here mode decision is affected by the result getting from prior decisions. In order to understand this complex relationship, we consider the probability that the system is in the active mode or the active probability from a long-term outlook.

Sensing Duration by Energy Causality Constraint

The average energy consumption varies with the sensing duration and threshold while the average harvested energy should not exceed the average consumed energy [3]. It shows that demonstration of the behavior of the average energy consumption corresponding to the sensing duration when the sensing-to-transmission power ratio is two. The sensing range of an event with respect to a specific sensor coincides with a sensing range the sensor has and depends on the sensitivity of the sensor. The event duration is, however, usually longer than the *sensing duration* of the sensor. As the high sensing time, we can achieve two chances. One is accessing the idle spectrum and another one is the achieving increased sensing energy. More energy is then consumed for spectrum sensing and data transmission. However, if the sensing time is too high means the transmission time leads to short, and then the quantity of energy consumption for data transmission is reduced. When $\tau/T = 1$, only the sensing energy psT is consumed. Based on the behavior of average energy consumption and according to the sensing duration we can examine how frequently the secondary transmitter is able to be in active mode by an operating policy. For a given average harvested energy $\mathrm{E}[Eh\ n]$, the operating region of secondary transmitter can be divided by three regions depending on the sensing duration as follows.

(i) Energy-surplus region (ii) Energy-deficit region and (iii) Energy-equilibrium region. In the energy-surplus region, the consumed energy is lesser than the harvested energy and its active probability is 1. In other words, even if the secondary transmitter tries to carry out spectrum access in every slot, it does not know-how an energy shortage occurs. In the energy deficit region, unlicensed transmitter suffers from an energy shortage for the majority of the time slots if it carries out spectrum access at each and every slot.

Collision Probability with respect to Sensing Duration.

The active probability in this region is restricted by $\lambda(\tau, \varepsilon, eh)$. In the energy-equilibrium region, the average energy consumption is the same amount as the average harvested energy when the active probability is 1. This gives that the secondary transmitter can remain in active mode making the best use of all the harvested energy for the majority of time slots. The probability that the secondary transmitter accesses the idle spectrum and is available to sending data without delay is the spectrum access capabilities of the energy-harvesting CRN are limited by the average consumed energy should not exceed average harvested energy (energy causality constraint), which creates two conflicting effects: an advantage takes place from availability probability.

The average energy causality constraint restricts the operation of the unlicensed i.e., secondary transmitter [4, 5]. To evaluate its performance, we have to define the performance metrics while considering the active probability and compare them with the condition for an energy-unconstrained CRN.

3. COOPERATIVE SPECTRUM SENSING

The primary users destructive channel effects are called cooperative spectrum sensing. To perform its own local spectrum sensing measurements independently, every cognitive radio user makes decision on whether the primary user is present or not [9]. To enhance the SNR a matched filter is often used at the receiver front end. Matched filter coefficients are basically given by the complex conjugated reversed signal samples in terms of discrete signals. If the amplitude and phase of the received signal are known coherent receivers are used results in a perfect match between the matched filter coefficients and the signals. The impulse response of a filter producing maximum output signal- to-noise ratio is the mirror image of message signal. With a noncoherent receiver the detection after the matched filter is generally based on the power or magnitude of the signal since we need both real and imaginary parts to define the signal entirely. Implementation of cooperative spectrum sensing implies that all of the cognitive radio users forward their decisions to common receiver. Here the common receiver fuses the cognitive radio users decisions and makes a final decision to infer the absence or presence of primary user.

3.1 System Model for Cooperative Spectrum Sensing

Depends on the presence or absence of primary user, we face a problem of existence based spectrum sensing is to differentiate between two hypothesizes: that the possibly faded primary user signal is present or it is absent at a sufficiently high power level and low power level. The detector can detect the weakest signal present consistently and constantly over the channel. The spectrum sensing problem can be formulated based upon the appearance or nonappearance of primary user in the concerned band or sub band based on binary hypothesis testing model [13] as

H0 Licensed User Absent
H1 Licensed User Present (1)

Any detection scheme can be written as a possibly random function F: RN → {0, 1}, where F maps the N dimensional received vector y = (y[1], y[2],y[3], • • • , y[N]) onto the set {0, 1}. If the received signal only has noise means the decision shows ‘0’, whereas it has both the noise and signal means it decision shows ‘1’. Considering a single fusion centre with N number of cognitive user scattered across a given cognitive radio network. The received signal at each cognitive user based on the appearance or non-appearance of licensed user is given by

$$y_i(t) = H_0: n_i(t)$$
$$y_i(t) = H_1: h_i(t)x_i(t) + n_i(t) \qquad (2)$$

Where the received signal at the ith cognitive user is represented by $y_i(t)$ and gain of the channel between the licensed user and the ith cognitive user represented by hi(t). The signal transferred by the licensed used is represented by $x_i(t)$ and the additive white Gaussian noise (AWGN) at the ith cognitive user represented by ni(t). In order to above considerations we assume that the channels corresponding to different unlicensed user are assumed to be independent and identically distributed, and the cognitive user and licensed user share a common spectrum of concerned band or sub band. Cooperative spectrum sensing shown in Figure 4.

In wireless communication networks, uncertainties in received signal strength arises due to channel fading or shadowing which may wrongly interpret that the primary system is located out of the secondary user’s interference range as the primary signal may be experiencing a deep fade or being heavily shadowed by obstacles. Figure 5 gives the comparison analysis of long observation period versus short observation period. Any uncertainty in the received power of the primary signal translates into a higher detection sensitivity requirement.

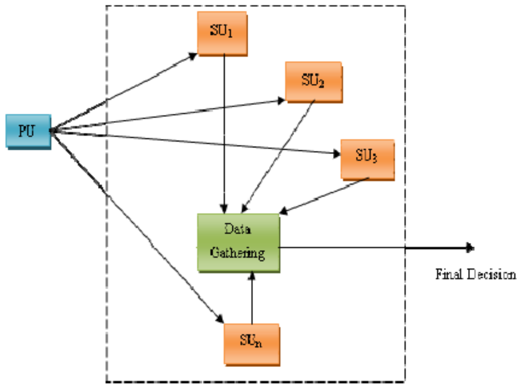

Fig. 4: Spectrum in cooperative environment

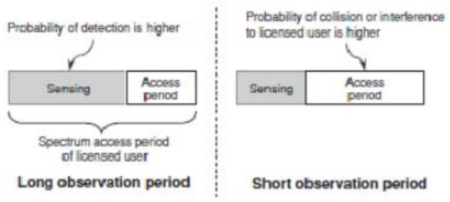

Fig. 5: Observation period of sensing in cooperative environment

Topology discovery: It performs establishing Common control channel (CCC) and finding neighbors.

Cooperative optimization: Determines the number of cooperative users (N) and spectrums to be sensed (M).

Cooperative sensing: When nodes rely only on their own spectrum sensing results, they may not be able to detect the primary user due to shadowing. To increase sensing accuracy sensing duty may be distributed among nodes. Achieving sensing in a distributed manner is called cooperative sensing. It also known as common receiver fuses the cognitive radio decisions and makes a final decision to infer the absence or presence of the licensed user. Figure 6 shows block diagram of matched filter. For a given sequence of sensing, the CU estimates the SNR of its received signal in the AWGN channel. The SNR observed from the CUs are then communicated to the overall fusion centre through the control channel for final decision. Finally, the fusion centre coordinates with the observations of all the CUs and their observed SNR to make a final decision about the presence or absence of the PU signal.

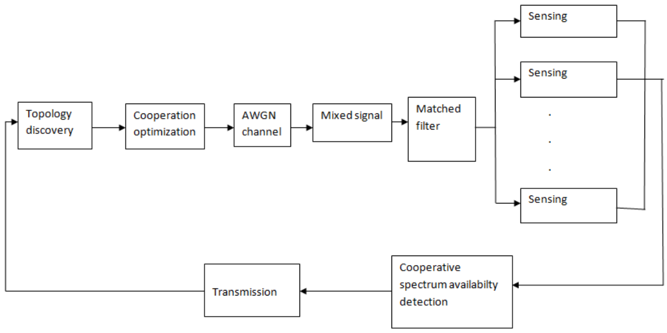

Fig. 6: Block diagram of spectrum sensing

4. EXPERIMENTAL RESULTS

Figure 7 presents the simulation result when the sensing duration and threshold are optimized together according to the average harvested energy. This indicates tradeoff between the active probability and collision probability also needs to be considered when optimizing the sensing duration and sensing threshold in conjuction with each other.

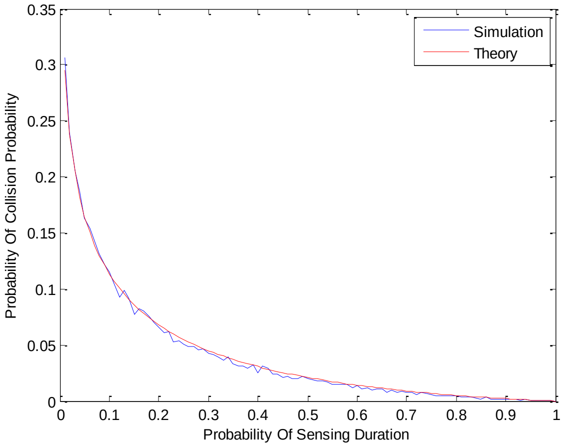

Fig. 7: Active probability of sensing duration and collision probability

The optimal solution pairing is the energy-equilibrium pairing, which satisfies the equality of collision constraint and maintains the energy equilibrium. This means that the system makes the most of the spectrum access within the permissible range of collision probability by maximizing the active probability for a given average harvested energy. Figure 8 represents the graph of Average energy harvested in active mode, according to normalized sensing duration for the various sensing thresholds.

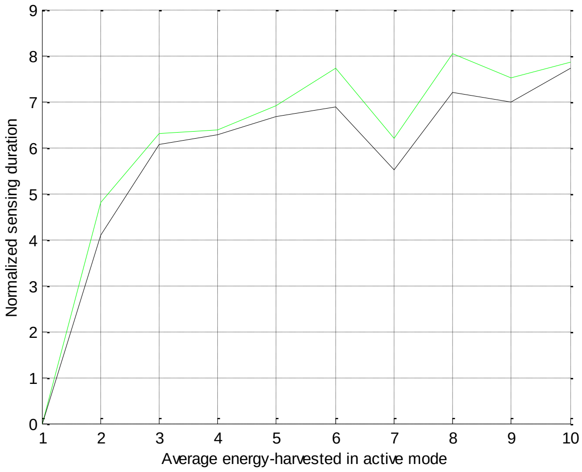

Fig. 8: Average energy harvested in active mode, according to normalized sensing duration for the various sensing thresholds

Figure 9 shows optimal pair of sensing duration and threshold. The graph presents the simulation result when the sensing duration and threshold are optimized together according to the average harvested energy. Figure 10 illustrates the optimal sensing duration corresponding to the average harvested energy for a fixed sensing threshold. We set the normalized sensing threshold to

$$\varepsilon/\sigma 2w = 0.023.$$

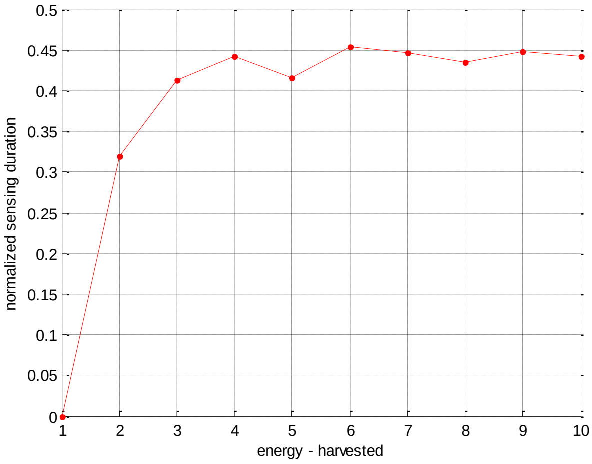

Fig. 9: Simulation plot of harvested energy vs normalized sensing duration

Note that the solid line indicates the optimal sensing duration which varies with the average harvested energy. We can see that the optimal sensing duration behavior changes with the average harvested energy in three distinctive cases.

- When the average harvested energy is larger than 12.1*mJ*, the optimal sensing duration is $\tau m(\varepsilon, eh)$, which comes from the sensing-throughput tradeoff. In this case, the optimal sensing duration does not vary with the average harvested energy and the the system can achieve as great a maximum average throughput as an energy unconstrained CRN.
- When the average harvested energy is less than 12.1*mJ*, the optimal sensing duration is determined from among $\tau e(\varepsilon, eh)$ and $\tau c(\varepsilon, eh)$ based on the tradeoff between the constraints.

The variation in sensing duration affects the tradeoff between the active probability and collision probability. When the average harvested energy decreases, the optimal sensing duration, $\tau e(\varepsilon, eh)$, is decreased in order to maintain the energy-equilibrium, but the collision probability increases at the same time.

As the sensing duration continues to drop until the collision probability reaches the target collision probability, the optimal sensing duration becomes $\tau c(\varepsilon, eh)$ in order to maintain the collision constraint. Consequently, the optimal sensing duration is determined based on which of the constraints, energy-equilibrium or collision constraint, must be maintained.

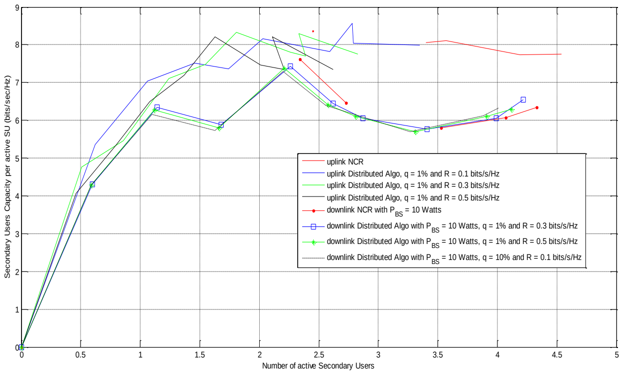

Fig. 10: Simulation of uplink and downlink distribution with active secondary user vs capacity per active SU

Figure 11 also shows that if the sensing duration is not optimized according to the average harvested energy, the system does not achieve the maximum average throughput. Note that the cases of '_' and 'O' indicate that the normalized sensing duration is fixed at 0.122 and 0.06, respectively, for all average harvested energy amounts. In the case where the sensing duration is fixed to 0.122, the system cannot achieve the maximum average throughput when the average harvested energy is less than 12.1*mJ*. In the case where the sensing duration is fixed to 0.06, the system can achieve the maximum average throughput only when the average harvested energy is 11*mJ*. Consequently, the sensing duration needs to be redesigned corresponding to the average harvested energy in order to achieve the maximum average throughput.

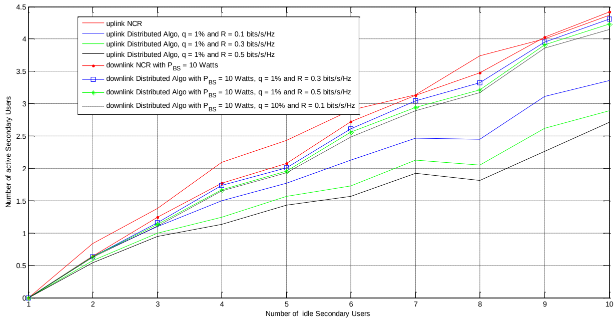

Fig. 11: No. of secondary user idle versus active secondary users

The sensing power and transmission power are set to 0.02W and -0.32W, respectively [15]. The received SNR measured at the secondary network is -3dB, which represents the minimum SNR that obliges the secondary transmitter to detect the primary signal [13]. The slot length, the probability of being idle, the secondary SNR, and the target collision probability are 0.1s, 0.34W, 8dB, and 0.1, respectively. The system parameters are shown in Table I.

Table 1: Value of Parameters in Numerical Result

Parameter	Notation	Value
Sensing power	*ps*	0.02W
Transmission power	*pt*	-0.32W
Slot length	*T*	0.1s
Prob. of being idle state	π0	0.34W
Primary SNR	*γp*	-3dB
Secondary SNR	*γs*	8dB
Normalized sensing threshold	*ε*/*σ*2*ω*	0.023
Target collision probability	*Pc*	0.1

Figure 12 shows the graph for total error rate versus threshold for different number of g out of G CRs that controls the fusion rule. While doing optimal pairing of spectrum sensing duration and threshold using matched filter detection, we have receive more error. So we need to know the status of primary user. We observe there are noticeable differences in the performance. With the system confguration shown in Table I, respect to the sensing duration for a given sensing threshold. At eh=6.5mJ, the system performances are not affected by the active probability no matter what sensing duration the system operates with. We then observe that the optimal sensing duration is τm(ε,eh). At eh=5.7mJ, the system performance is particularly degraded when the sensing duration is set to τm(ε,eh).

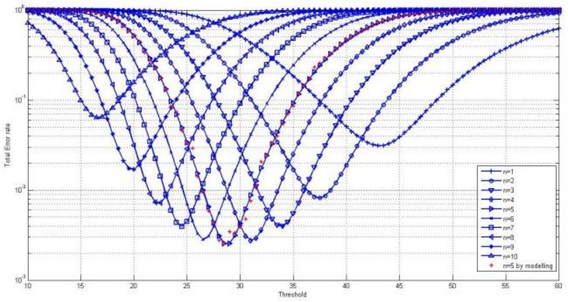

Fig. 12: Total error probability for g out of G = 10 cognitive radios versus local threshold with SNR = 10db and L = 10 sensed samples used at each Cognitive radio

To get the maximized average throughput, system varies with the sensing threshold on is τm(ε,eh). At eh=5.7mJ, the system performance is particularly degraded when the sensing duration is set to τm(ε,eh). To avoid degradation arising from the active probability, the system needs are design to the energy-equilibrium duration, τe(ε,eh). At eh=3.5mJ, the system doesnot satisfy the collision constraint when the sensing duration is set to τe(ε,eh). The sensing duration is therefore redesigned to τc(ε,eh). Based on the optimal sensing duration derived by (15), we can maximize the average throughput. However, the maximized average throughput varies with the sensing threshold. Achieving the maximum average throughput necessitates considering the effect of the sensing threshold.

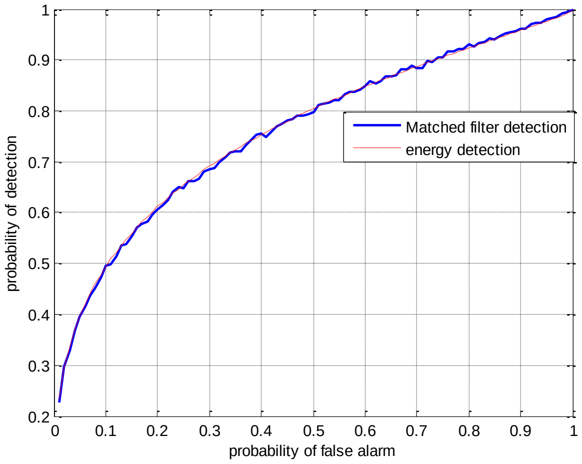

Fig. 13: Simulation to plot probability of detection (Pd) vs. probability of false alarm (Pf)

Figure 13 shows signal estimation theory, a receiver operating characteristic (ROC) curve is a graphical plot which demonstrates the performance of a binary classifier system as with threshold variation. In order to increase the performance of spectrum sensing, we allow various SU to cooperate by sharing their information and to reduce the communication overheads, users share their decision statistics based on the binary hypothesis testing. It is created by plotting the probability of detection vs. Probability of False alarm, at various threshold values. In general, if both of the probability distributions for detection and false alarm are known, the ROC curve can be generated by plotting the CDF of the detection probability in the y-axis versus the CDF of the false alarm probability in x-axis. The sensing performance of the proposed scheme, in terms of its ROC curve is evaluated using simulations. It is assumed that the PU signal is likely-equally Binary Phase Shift Keying (BPSK) signal [16] with prior probabilities Pr {H0} = Pr {H1} = 0.5 and the noises at CUs are AWGN with zero mean and unit variance.

6. CONCLUSION

In this paper the secondary network in an energy-harvesting CRN must reduce the sensing duration until the energy-equilibrium or collision constraint is satisfied. Based on analysis of the optimal solution, we investigated the relationship between the optimal sensing duration and the corresponding sensing threshold in order to maximize the average throughput thus giving insight into how to coordinate them. This work represents a key milestone in jointly optimizing the sensing parameters of energy-harvesting CRNs. The results provided in this paper provide a meaningful message about how to design the system configuration of an energy-dominant system which is more sensitive to energy consumption than to channel conditions. In order to sense the spectrum holes consistently and resourcefully, in this paper we propose a matched filter based cooperative spectrum sensing in CR networks. Advantage of this scheme is it can work with very low SNR with the knowledge of the licensed users signal, i.e., bandwidth, type of modulation, and order of modulation etc., the prior probability of the licensed user's activity, and SNRs of the PU signal at cognitive radio terminals. Simulation results based on receiver operating characteristics curve show that the sensing performance of the proposed scheme. The only limitation of the proposed scheme is we should have the prior knowledge about the PU signal before sensing the channel. The choice of matched filter detection technique proposed here to estimate the channel in the lower SNR regime. Consequently, finding lower bound of min τ (Threshold) and upper bound of max τ is still an open issue. Future work is in progress in this direction is to achieve maximize the throughput for the Gaussian Relay Channel with respect to CRNs.

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