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Enhancement of Cognitive Users Longevity in Cognitive Radio Network by RF Energy Harvesting

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Abstract: Cognitive Radio (CR) is an intelligent technology by which we can use the frequency spectrum of a wireless network more efficiently. Using this technology, the secondary user of a cognitive radio network can use the frequency band of primary user when it remains idle. As most of the wireless portable devices are battery operated, continuous energy supply is always critical issue. In this paper, we proposed an energy harvesting technique that can harvest more energy from RF signal than conventional energy harvesting system which leads to enhance the longevity of the cognitive user. Here we utilized a super cluster-based energy harvesting technique where we get the increased spectrum sensing time by the cognitive user in a cluster. For this, the cognitive users are able to harvest more energy from RF signal which contributes in enhancing the longevity of the cognitive user.

Keywords: Cognitive radio network, Clustering, Energy detection, Energy harvesting, Spectrum sensing.

I. INTRODUCTION

Cognitive Radio (CR) [1-2] as a revolutionary intelligent technology can maximize the utilization of the frequency resources by allowing cognitive radio users to access the spectrum bands allocated to Primary Users (PUs) when they are idle temporally. Energy supply is always a critical issue in wireless communications [3]. Powering a cognitive radio network (CRN) with Radio Frequency (RF) energy can provide a spectrum-efficient and energy efficient solution for wireless networking [4-5]. In an RF-powered cognitive radio network (RF-powered CRN), the RF energy harvesting capability allows the wireless devices (e.g., cognitive radio users) to harvest energy from RF signals and use that energy for their data transmission.

Spectrum sensing is one among the foremost vital components in energy harvest system. There exists a variety of spectrum sensing techniques, together with matched filter detection, cyclostationary detection and energy detection [6-8].When the transmitted signal is known, then the optimum method for detection of primary user detection is matched filter. Cyclostationary detection offers good performance but requires knowledge of the PU cyclic frequencies and requires a long time to complete sensing. On the opposite hand, energy detection is an pretty and appropriate methodology because of its easy implementation and low computation complexity. Conversely, its major limitation is that the received signal strength can be dangerously weakened at a particular geographic location due to multi-path fading and the shadow effect [9].

For point-to-point wireless systems powered by energy harvesting, the optimal power-allocation algorithms have been designed and shown to follow modified water-filling by Ho and Zhang [10] and Ozel et al. [11]. From a network perspective, Huang investigated the throughput of a mobile ad-hoc network (MANET) powered by energy harvesting [12]. Among other energy scavenging sources, background RF signals can be a viable new source for wireless energy harvesting [13]. In [14] and [15], simultaneous wireless power and information transfer has been investigated aiming at maximizing information rate and transferred power over single-antenna additive white Gaussian noise (AWGN) channels. Zhou et al. have proposed a new receiver design for enabling wireless information and power transmission at the same time, by judiciously integrating conventional information and energy receivers [16]. For point-to-point wireless systems, Liu et al. have studied “opportunistic” RF energy harvesting where the receiver opportunistically harvests RF energy [17].

In this paper, we proposed a super energy harvesting technique which utilizes a super cluster-based cooperative spectrum sensing technique which provides more efficient spectrum sensing. In this scheme, each SU achieves a non-fixed and longer sensing time for sensing the PU’s signal bandwidth, because both the SUs and the CHs are super-allocated to different reporting time slots. We have shown that, as sensing time is increased, the amount of harvested energy increased which leads to enhance the longevity of cognitive users in CRN. Here, we also showed the improved throughput due to increased harvested RF energy.

This remainder of this paper is organized in the following manner. Section 2 describes the working principle of the proposed model. Section 3 describes spectrum sensing. Section 4 describes energy harvesting mechanism from RF sources. Section 5 describes throughput over harvested channel. Some simulations and comparisons are given in section 6. Finally, our conclusion is in section 7.

II. WORKING PRINCIPLE OF THE PROPOSED MODEL

The working procedure of our research work i.e. super energy harvesting system is done by following processes. For energy harvesting scheme, the cognitive user need to sense the spectrum and then harvest energy from that radio signal as much as possible. Working principle of this research work is shown in following Fig.1.

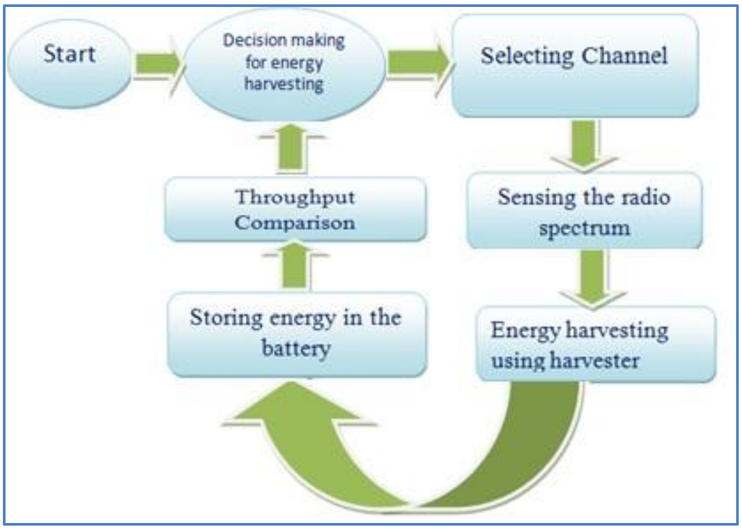

Figure.1. Working diagram of the proposed system

Cognitive user takes harvesting decision regarding its own energy state. If battery level is high, then no need to harvest energy. If battery level is low, then it needs to harvest energy. We formulate MDP formulation for channel selection. The channel choice policy utilized by the secondary user could be a mapping from the secondary user's state (i.e., the quantity of packets in the data queue and also the energy level of the energy storage) to the action (i.e., the channel to select). The secondary user does not understand the status of the channel (i.e., whether or not the channels are idle or busy). In this case, the secondary user selects a channel depending on some statistical information such as the probabilities of a channel to be idle or busy, the probability of successful packet transmission if the channel is idle, and also the probability of successful energy harvesting if the channel is busy. The secondary user performs spectrum sensing to observe the channel status after selecting the channel. If the channel status is busy the secondary user (SU) will harvest RF energy and if the channel status is idle then SU transmit a packet.

III. SPECTRUM SENSING

Spectrum sensing can be formulated as a binary hypothesis-testing problem as follows:

$$\begin{cases} H_1 : \text{PU signal is present,} \\ H_0 : \text{PU signal is absent.} \end{cases} \qquad (1)$$

Each SU implements a spectrum sensing process which is called local spectrum sensing, to detect the PU's signal. According to the status of the PU, the received signal of an SU can be formulated as follows:

$$y_j(t) = \begin{cases} \eta_j(t), & H_0 \\ h_j(t)x(t) + \eta_j(t), & H_1 \end{cases} \qquad (2)$$

where $y_j(t)$ represents the received signal at the j-th SU, $h_j(t)$ denotes the gain of the channel between the j-th SU and the PU, $x(t)$ with variance of σ_x^2 represents the signal transmitted by the PU, and $\eta_j(t)$ is a circularly symmetric complex Gaussian (CSCG) with variance of $\sigma_{\eta,j}^2$ at the j-th SU.

In addition, we make the following assumptions:

- $x(t)$ is a binary phase shift keying (BPSK) modulated signal.
- $x(t)$ and $\eta_j(t)$ are mutually independent random variables.
- the SU has complete understanding of noise and signal power.

A. Energy Detection

Energy detection is an attractive and appropriate method because of its easy implementation and low computation difficulty. It has been shown to be easy, fast and capable to find primary signals, even if previous information of the signal is unknown. It's a non coherent detection technique that detects the primary signal depending on the sensed energy. Because of its simplicity and no demand on a priori information of primary user signal, energy detection (ED) is the most popular sensing technique in cooperative sensing.

A diagram of the energy detection technique within the time domain is shown in Fig. 2. To measure the energy of the signal within the frequency band of interest, a band-pass filter is initially applied to the received signal, which is then transformed into distinct samples using an analog-to-digital (A/D) converter.

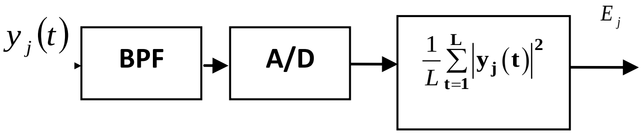

Figure 2: Block diagram of the energy detection scheme

An estimation of the received signal power is given by each SU with the following equation:

$$E_j = \frac{1}{L}\sum_{t=1}^{L}\left|y_j(t)\right|^2 \qquad (3)$$

where $y_j(t)$ is the t-th sample of a received signal at the j-th SU, and L is the total number of samples. $L = T_s F_s$, where T_s and F_s are the sensing time and signal bandwidth in hertz, respectively.

B. Conventional Cluster-based Cooperative Spectrum Sensing

A general frame structure for conventional cluster-based cooperative spectrum sensing is shown in Fig. 3. With this frame structure, all local decisions are forwarded to the CHs in the scheduled SU reporting time slots and are then forwarded to the FC in the scheduled CH reporting time slots.

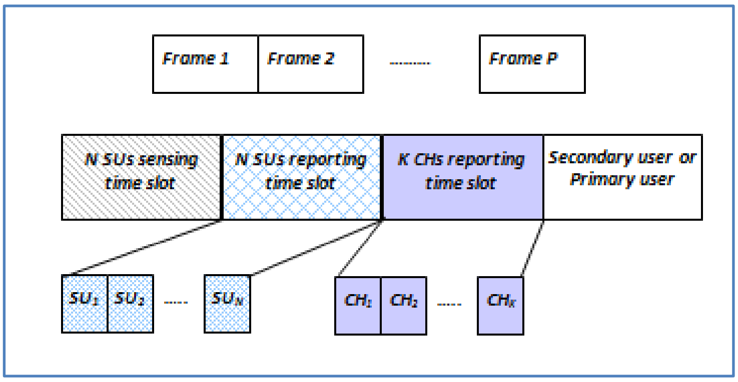

Figure 3. A conventional cluster-based cooperative spectrum sensing scheme [18]

In conventional cluster-based cooperative spectrum sensing, the N SUs in the network adopt fixed sensing time slot T_s^{con} given by

$$T_s^{con} = \frac{1}{F_s\gamma^2}\left[Q^{-1}\left(P_f^j\right) - Q^{-1}\left(P_d^j\right)\sqrt{\left(1+2\gamma\right)}\right]^2 \qquad (4)$$

to sense the PU's signal with false alarm and detection probabilities of P_f^j and P_d^j, respectively.

C. Super Cluster-based Cooperative Spectrum Sensing

In the traditional approach, sensing time slots, reporting time slots of SUs, and reporting time slots of CHs are strictly divided as shown in Fig. 3. Because of this rigid structure in the traditional approach, the reporting time slots of other SUs and CHs are not used for spectrum sensing. However, these reporting time slots can be used in sensing the spectrum by other SUs by scheduling sensing and reporting time slots effectively. To this end, a super-allocation and cluster-based cooperative spectrum sensing theme is used by increasing the sensing time interval. During this scheme, every SU will get longer sensing time slot because the other SU reporting times and also the CH reporting times are incorporated to the SU sensing time. Therefore, the sensing time slots for SUs in this method are often longer than those in the traditional approach.

Fig. 4 shows the super cluster-based cooperative spectrum sensing. Within the figure, SU_{nk} means the k-th SU in the n-th cluster in the network. To clarify the period of sensing time slot for SU_{nk}, we define the durations of the sensing and reporting time for SU_{nk} with T_s^{nk} and T_r^{nk} , gradually. During this scheme, the sensing time slot for the first SU within the first cluster, i.e. SU_{11}, is equal to the sensing time slot in the traditional scheme, i.e., $T_s^{11} = T_s^{con} = T_s$. Except for SU_{11}, other SUs can obtain longer sensing time slots by scheduling SU reporting slots followed by the reporting slot for the CH of that cluster. In this technique, secondary user (SU)s can sense the spectrum during the reporting time slots of other SUs and CHs.

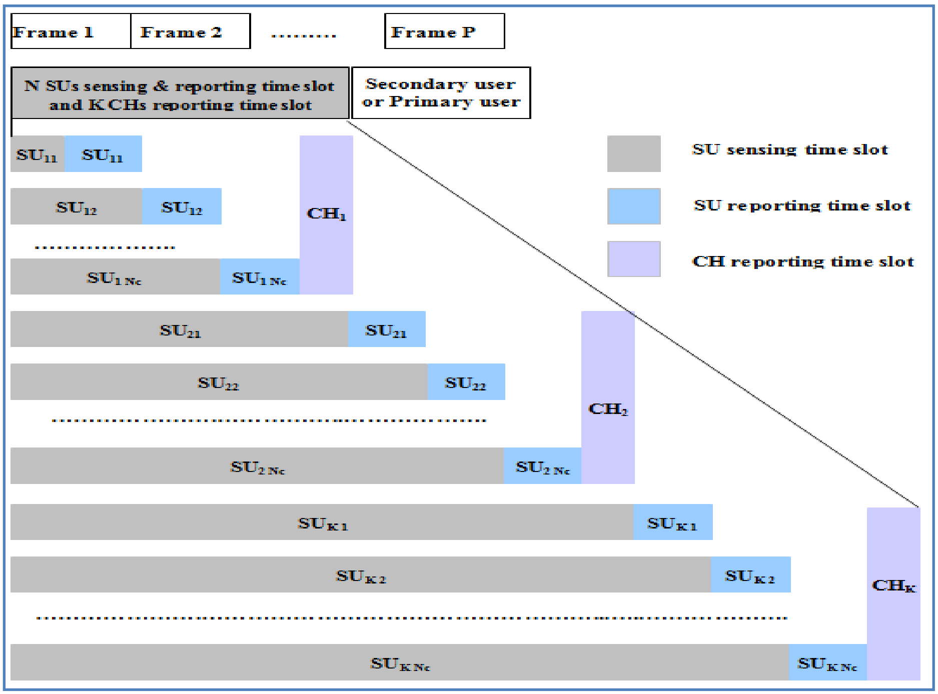

Figure 4: Super cluster-based cooperative spectrum sensing scheme [18]

IV. ENERGY HARVESTING

An energy harvester network is used to collect RF signal and convert it into electricity. Fig. 5 shows the block diagram of a typical circuit for an RF energy harvester which consists of antenna, impedance matching unit, voltage multiplier and capacitor.

- The first part of the circuit is the impedance matching unit. This is a resonator circuit which operates at a designated frequency to maximize the power transfer between the antenna and the multiplier.

- The prime elements of the voltage multiplier are the diodes of the rectifying circuit that converts RF waves (AC signal in nature) into DC signal. Generally, higher conversion proficiency can be achieved by diodes with lower built-in voltage.

- The (charging circuit) capacitor ensures a continuous delivery of power to the load. When energy harvesting is unavailable, the capacitor may also briefly function as a little energy reservoir.

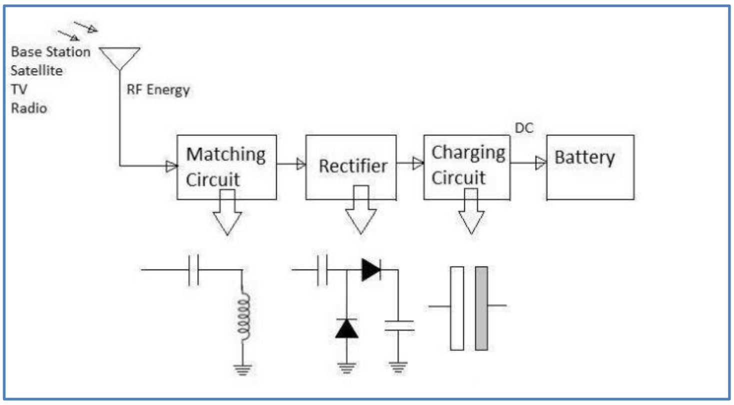

Figure 5. Circuit diagram of an RF energy harvester

V. THROUGHPUT IN A HARVESTED CHANNEL

In the current time slot k, if the probability that the SU uses the harvested channel is 1- P_f (e_s) . In such case, the expected throughput obtained in this time slot can be calculated by:

$$r(e_s) = \left[1 - P_F(e_s)\right] W_{hc} (T-\tau)\log_2(1+SNR_{hc}) \qquad (5)$$

where SNR_{hc} is the signal-to-noise ratio on the harvested channel when the transmission power of the SU on the harvested channel is P_{hc} , e_{hc} is the energy expended in transmission on the harvested channel, and W_{hc} is the bandwidth of the harvested channel.

The relation between probability of detection and probability of false alarm can be obtained by the following equations:

$$P_F(e_s) = Q\left[\sqrt{2\beta+1}.Q^{-1}\left(P_D^*\right) + \beta\sqrt{\tau.f_s}\right] \qquad (6)$$

$$P_D(e_s) = Q\left\{\frac{1}{\sqrt{2\beta+1}}.\left[Q^{-1}\left(P_F^*\right) - \beta\sqrt{\tau.f_s}\right]\right\} \qquad (7)$$

where β is the received signal-to-noise ratio (SNR) on the harvested channel measured at the cognitive receiver. P_D is the designed probability of detection of the energy detector. f_s is the frequency of sampling energy on the harvested channel, and Q(.) is the complementary distribution function of a standard Gaussian random variable.

VI. SIMULATION RESULTS FOR PERFORMANCE EVALUATION

A. Simulation Parameters:

The parameters for simulation are given in table 1.

Table 1: Parameters for simulation

Symbol	Description	Value/Metric
T	Frame time	20 ms
f_s	Sampling frequency for sampling	800 kHz
τ	Slot time	1 ms
α	Discount factor	0.9
β	SNR in energy detection	-15 dB
SNR_{hc}	SNR of the link on harvested channel	10 dB
W_{hc}	Harvested channel bandwidth	3 MHz
P_{hc}	Transmission power over harvested channel	25 mW
e_a	Available energy in the battery	10 mJ
e_u	Energy unit	1 mJ
P_a	Probability that the primary channel will be assigned	1
P_s	Sensing power	40 mW

B. Simulation Result for RF Energy Harvesting

Fig 6 shows a comparison of energy harvesting between proposed scheme and conventional scheme. Here, for first SU, the amount of harvested energy is equal to the conventional method. This figure shows only the harvested amount of energy, energy consuming is not considered here. The simulation result shown here is only for a single cluster where each cluster contains 8 SU. Here, in proposed scheme, the amount of harvested energy is increased for the successive SU in a cluster as the sensing time is increased proportionally for the successive SU, whereas in conventional method the amount of harvested energy is low and fixed, as all the SU can get less and fixed sensing time.

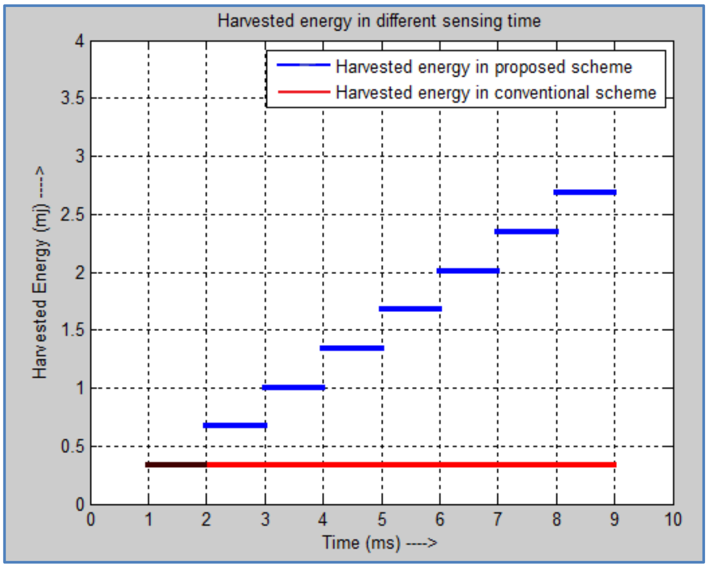

Figure 6. Increased amount of harvested energy for successive SU's due to increased sensing time in a frame

C. Simulation Result for Throughput Comparison

The throughput for SUs in harvested channel without RF energy harvesting is shown in following Fig.7.

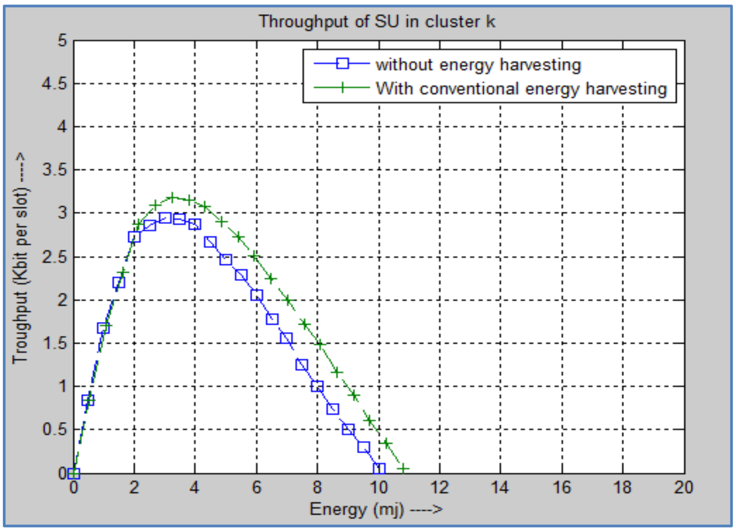

Figure 7. SU's throughput in cluster k with conventional RF energy harvesting

In Fig.8, we showed the throughput for only the second and third secondary user. In the case of rest of the SU's in cluster k, the same thing will be happened. Maximum throughput will be obtained for n'th cognitive user. This result indicates that, the optimal throughput is increased as compared with conventional scheme and as a result the longevity of the secondary user is enhanced considerably.

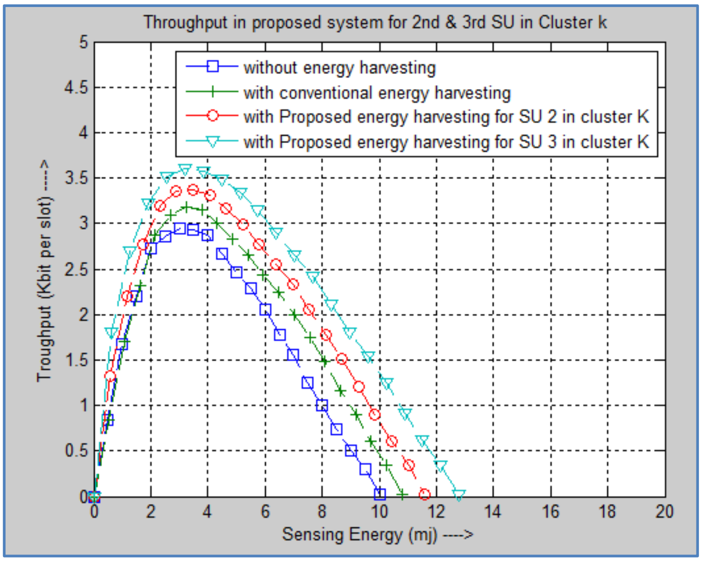

Figure. 8. Throughput of SU's with conventional scheme and throughput in proposed system for 2nd and 3rd SU in cluster k.

VII. CONCLUSION

In this paper, we have proposed a novel network architecture enabling secondary users to harvest more energy from radio frequency signal sources than conventional energy harvesting systems. As we know that, energy is proportional to the sensing time, the more sensing time we can get, the more energy we can harvest. Here, we utilized a superposition technique where spectrum sensing time is increased for successive secondary users rather than the first one considering the cluster-based cooperative spectrum sensing scheme. Using this enhanced sensing time, our energy harvester harvests increased amount of RF energy and stored it in the storage device.

At last we show that the expected throughput is increased due to more amount of energy harvested by the energy harvester. As this increased amount of energy in stored in the storage battery and can be used later by the cognitive radio user as needed, the longevity of the cognitive users in the cognitive radio network in enhanced. That is, cognitive radio user can serve extra amount of time for communication purpose due to extra amount of harvested energy.

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