D-S Theory based Cooperative Spectrum Sensing in Cognitive Radio Networks with Energy Harvesting

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Keywords: Computer Engineering and Information Technology;

Abstract

In this paper, we propose a Dempter-Shafer (D-S) theory based cooperative spectrum sensing in Cognitive Radio Networks (CRNs) combined with energy harvesting. Each Cognitive User (CU) is provided with an energy harvester that can harvest energy from the licensed spectrum that is otherwise allocated to Primary Users (PU) under a null hypothesis. Simulation results show that the energy harvesting CU performs better than the traditional CU.

1. Introduction

Cognitive Radio (CR) is a new promising technology that improves licensed spectrum usage by allowing CUs to access the unused spectrum [1]. CUs are opportunistic and only active when all PUs are inactive. CUs instantly vacate the allocated spectrum band when a PU appears. Energy detection is an attractive method because it does not require any prior knowledge of the primary signal. However, a single CU may not distinguish the primary signal because of multipath fading due to the hidden terminal problem. To mitigates this problem a cooperative spectrum sensing technique is used.

J. Paradisoet. al [2] has recently proposed energy harvesting from environmental energy sources such as solar, radio frequency or temperature gradients, etc. In CRN, the sensing time greatly affects the sensing performance of energy detection, which is reflected by the measurement of basic probability assignment (BPA) [3]. In CRN with energy harvesting, each CU harvests the energy from the licensed PU spectrum when the PU is present. Later, CU's harvested energy is consumed by spectrum sensing, data processing, and data transmission.

In this research the main contributions are:

- We consider D-S theory based cooperative spectrum sensing.
- We consider an energy harvester adopted CU that can harvest the primary signal energy from the PU transmitter when the PU is detected on the licensed spectrum.
- Finally, simulation results show that the energy harvesting CU performs better compared to the traditional CU [3].

2. System Model

The received signal at the j-th CU can be formulated as follows

$$y_j(l) = \theta h_j(l) x(l) + n_j(l) \quad (1)$$

where $\theta = 1$ denotes the presence of the PU under the alternative hypothesis while $\theta = 0$ denotes the absence of the PU under the null hypothesis, $x(l)$ is the primary signal transmitted from the licensed PU, $h_j(l)$ is the channel gain between the j-th CU and the PU, $n_j(l)$ is the additive white Gaussian noise, and $y_j(l)$ is the received sensing result at the j-th CU.

2.1. Energy Detection Technique

In energy detection technique, the power of the received signal samples is measured at the j-th CU which individually averaged and squared to estimate its own energy as follows

$$E_{y_j} = \frac{1}{L}\sum_{l=1}^{L} y_j(l) \quad (2)$$

where L is the total number of samples that is defined as $L = 2T_s W$, T_s is the sensing time in second and W is the signal bandwidth.

Based on the Central Limit Theorem, when the number of sensing samples L is relatively large, the received signal energy can be approximated as a Gaussian random variable under both hypotheses

$$E_y \cong \begin{cases} N(\mu_0 = L, \sigma_0^2 = 2L), & H_0 \\ N(\mu_1 = L(1+\gamma), \sigma_1^2 = 2L(1+2\gamma)), & H_1 \end{cases} \quad (3)$$

where γ is the SNR of the sensing channel between the PU and the CU that is defined as $\gamma = h^2 p_s / \sigma^2$.

2.2. D-S theory Based Spectrum Sensing

After a sensing time, each CU will estimate its self-assessed decision credibility which is equivalent to BPA for hypotheses. We measure a BPA function as a form of the cumulative density function as follows

$$m_{0j} = \int_{E_y}^{+\infty} \frac{1}{\sqrt{8\pi T_s W}} e^{\left(-\frac{(x-2T_s W)}{4T_s W}\right)} dx \quad (4)$$

$$m_{1j} = \int_{-\infty}^{E_y} \frac{1}{\sqrt{8\pi T_s W(1+2\gamma)}} e^{\left(-\frac{(x-2T_s W(1+\gamma))}{4T_s W(1+2\gamma)}\right)} dx \quad (5)$$

All the BPA of the j-th CU for both hypotheses will be combined to make a global decision using D-S theory as follows

$$m_0 = m_{01} \oplus m_{02} \oplus, \ldots, \oplus m_{0N} = \frac{\sum_{D_1 \cap D_2 \cap \ldots \cap D_N = H_0} \prod_{j=1}^{N} m_{0j}}{1 - \sum_{D_1 \cap D_2 \cap \ldots \cap D_N = \varphi} \prod_{j=1}^{N} m_{0j}} \quad (6)$$

And

$$m_1 = m_{11} \oplus m_{12} \oplus, \ldots, \oplus m_{1N} = \frac{\sum_{D_1 \cap D_2 \cap \ldots \cap D_N = H_1} \prod_{j=1}^{N} m_{1j}}{1 - \sum_{D_1 \cap D_2 \cap \ldots \cap D_N = \varphi} \prod_{j=1}^{N} m_{1j}} \quad (7)$$

where D is the frame of discernment which is defined as $\{H_0, H_1, \varphi\}$, here φ denotes either hypotheses is true.

After getting the final combination result, m_0 and m_1 the global decision is made upon at the fusion centreas follows

$$\begin{cases} P_d : & if\ m_1 > m_0 \\ P_f : & if\ m_0 > m_1 \end{cases} \quad (8)$$

2.3. Energy Harvesting

An energy harvesting consisting two phases: During the *first phase*, each CU harvests the primary signal energy from the license PU transmitter, and the signal energy is converted into electrical power and stored in a battery. During the s*econd phase*, when the CU detects the absence of the PU, the CUs begin to transmit data to each other, and the stored electrical power is used to supply the transmission. The total harvested energy, E_j^H at the j-th CU is given as follows

$$E_j^H = \theta\left(T_s\left(T - T_s - T_r\right)P_d\right)p_s h^2 \quad (9)$$

The total energy consumption, E_j^C at the j-th CU is given as follows

$$E_j^C = p_{ss}T_s + p_a\left(T - T_s - T_r\right)\left(1 - \theta\right) + p_c T \quad (10)$$

where p_{ss} is the spectrum sensing power, p_a is the transmission power at the absence of the PU, p_c is the circuit consumed power, T_r is the reporting time and P_d is the probability of detection based on D-S theory.

In the proposed approach, the total residual energy, E_R^P in the CRN is given as follows

$$E_R^P = E_0 + \sum_{j=1}^{N}\left(E_{Hj} - E_{Cj}\right) \quad (11)$$

In the traditional CU approach, the total residual energy, E_R^{Trad} in the CRN is given as follows

$$E_R^{Trad}{}_R = E_0 + \sum_{j=1}^{N} E_{Cj} \quad (12)$$

where E_0 is the initial energy stored in the battery before communication.

3. Simulation Results

To evaluate the performance of the proposed energy harvesting CU, numerical evaluations were carried out using the Monte Carlo method under the following conditions [4]: $L = 250$, $W = 6MHz$, $N = 5$, $p_s = 100$ mW, $p_a = 20$ mW, $p_{ss} = 1$ mW, $p_c = 5$ mW, $T_s = 25$ ms, $T_r = 5ms$, $T = 100$ ms, $\sigma^2 = 1$ mW, $E_0 = 2.5 \times 10^3 mW$.

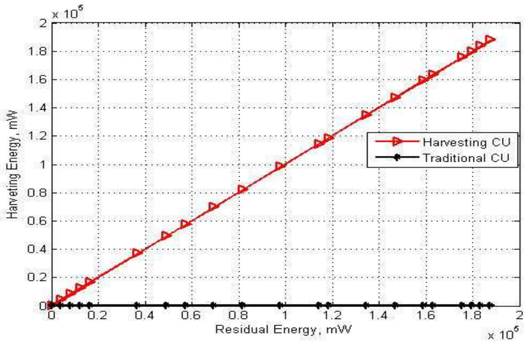

Fig. 1: Energy harvesting CU approach vs traditional CU approach [3]

Fig. 1 shows the energy harvesting versus the residual energy with probability of detection. It is clear that the residual energy, E_R^P in the proposed approach improves with the increasing the energy harvesting, E_j^H based on the Eq. (11) compared to the traditional CU approach based on the Eq. (12).

4. Conclusion

Results show that the proposed energy harvesting CU performs better than the traditional CU approach.

5. Acknowledgements

This work was supported by Hardiman Scholarship Postgraduate Research Foundation of National University of Ireland Galway (NUIG), Galway, Ireland.

6. References

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