



Residual Energy of Energy Harvesting Cognitive Radio Networks

Anitha Bujunuru, Srinivasulu Tadisetty

Abstract: This paper analyzes cooperative spectrum sensing with energy harvesting using power splitting mode of operation simultaneously. Secondary users (SU) will harvests RF energy from primary user (PU) throughout the durations of sensing and transmission. The main aim of this paper is to analyze the residual energy of SU with power splitting ratio, number of samples, number of SUs and probability of detection. Mathematical expressions of energy consumption, harvested energy and residual energy are developed. The simulation results of residual energy with different parameters are verified and have proved that residual energy of SUs is increased with increase in power splitting ratio, number of SUs, number of samples of SU for sensing and probability of detection.

Index Terms: Cognitive radio, energy harvesting, power splitting ratio, residual energy.

I. INTRODUCTION

In wireless communication, Cognitive Radio (CR) being a perceptive and rising mechanism to utilize the unused portions of PU band successfully. The function of CR is to perceive the occupancy of PU in a given band. If the PU is off, a SU can utilize the unused bands for its communication. To obtain a collision free and rapid spectrum usage by the SUs, authentic sensing (SS) is of most required. Authentic SS is obtained by participating various SU in sensing [1], [2] and it requires higher energy consumption. In an energy constrained CR network, the nodes are powered with batteries which can either be replaced or recharged. Once the battery is exhausted, the node becomes dead and this problem can be solved with energy harvesting. In energy harvesting, the SU accumulate energy from RF and non RF signals i.e., temperature, solar and wind etc. Energy harvesting from PU signal have a remarkable importance in wireless communication. In [3], authors suggested an optimal energy utilization strategy of energy harvesting sensor node to maximize the throughput. Simultaneous Information and Power Transfer (SIPT) authorized node follows power splitting (PS) approach that divides the collected RF power for SS and EH separately.

Li et al. [4] evaluated SIPT approach in CRNs with relevant mathematical solutions for the most appropriate power

assignment and power dividing factor to accelerate the capability of secondary user.

In [5], authors investigated spectrum observing approach with perception limit to increase the overall outturn of SU with energy harvesting by taking energy causality factors and collision factors. Lu et al. [6] reviewed SIPT in cognitive radio where two energy harvested SUs are used for data transmission as relays. Yin et al. [7] reviewed frame structure that consists of non-overlapping sections of three slots that uses to sensing, harvesting and transmission. Energy depletion in CSS for data transmission from SUs to FC is done with negligible power utilization.

In [8], two non-flapping sections of sensing and reporting are discussed. The first section is used the operation of PS and in second section every SU sends its sensing data to FC with an amplifying factor (β). The continuing paper is systemized as given: In section II, a study of system model is described; computation of residual energy has stated in section III. Section IV explained simulation results and last section has given conclusion.

II. SYSTEM MODEL

System model comprises of licensed user transmitter and set of SU users. The SU system contains power splitting device, an RF energy harvester. Energy harvester gathers energy of PU signal and reserves the collected energy in buffer of infinite capacity. The SU detects the occupancy of PU in time slotted model. Each time frame (F_i) of CR consists of three slots of sensing (τ_i), reporting (τ_r), and transmission ($T_{r,i}$) times where $i = 1, 2, 3...N$ and frame structure as given in Fig. 1.

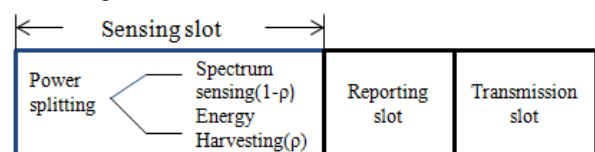


Fig.1. Frame structure

It is considered that the CR detects (may be correctly or wrongly) the occupancy of PU in ($N-1$) successive frames and transmit during N -th frame and frame structure of detection cycle as shown in Fig.2. Each frame is of length of T_f , where $T_f = \tau + \tau_r + T_{r,N}$ with equal sensing time ($\tau = \tau_1 = \tau_2 = \dots = \tau_N$) and transmission time ($T_r = T_{r,1} = T_{r,2} \dots = T_{r,N}$). The CR detects the occupancy of PU and harvests RF energy throughout the sensing time. The CR keeps the energy splitting device switched ON during τ only.

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The energy harvester and sensing circuit receives ρ and $(1 - \rho)$ portions of the power simultaneously via power splitting device. It transmits otherwise it harvests energy even during T_r if PU is actually present and goes to the next time frame.

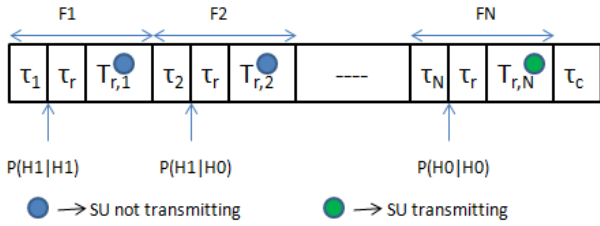


Fig.2. Frame structure for detection of cycle

The state (busy or idle) of PU is represented in [9] and the non appearance of licensed user is denoted with hypothesis H_0 and the occupancy of licensed user is denoted with H_1 hypothesis. The inert and occupied portions of the licensed user are dispensed exponentially with average values of m_0 and m_1 . The occupied and inert state probability density functions can be given in equation in (1) as [9],

$$P_0(t) = m_1^{-1} \exp\left(-\frac{t}{m_1}\right) \quad P_1(t) = m_0^{-1} \exp\left(-\frac{t}{m_0}\right) \quad (1)$$

where $P(\cdot)$ designates probability. The static probabilities, $P(H_0)$ and $P(H_1)$ is modeled as $P(H_0) = m_0/(m_0+m_1)$ and $P(H_1) = m_1/(m_0+m_1)$.

The SU utilizes its harvested energy for the purpose of sensing and data transmission. The detection cycle is starts with a minimum residual energy (ξ), i.e., the unused harvested energy, which is saved in a battery.

The received signal by each SU_i during τ can be given in equation (2)

$$S_{r_i}(n) = \varphi \sqrt{P_p} h_{pri} x_{pr}(n) + \vartheta_{r_i}(n) \quad (2)$$

The probabilities $P(H_1)$ and $P(H_0)$ indicates the probabilities of PU's at $\varphi=1$ and $\varphi=0$ that represents the existence and non-existence of PU, respectively.

The mathematical equations of EH and SS are given as equation (3) and (4) are

$$S_{r_{hi}}(n) = \varphi \sqrt{\rho} \sqrt{P_p} f_{pri} x_{pr}(n) + \sqrt{\rho} \vartheta_{r_i}(n) \quad (3)$$

(Harvesting)

$$S_{r_{si}}(n) = \varphi \sqrt{(1-\rho)} \sqrt{P_p} f_{pri} x_{pr}(n) + \sqrt{(1-\rho)} \vartheta_{r_i}(n) \quad (4)$$

..... (Sensing)

Here $v_{r_i}(n)$ designates Gaussian noise at SU_i with zero average value and variance σ_n^2 . Here $x_{pr}(n)$ represents the signal from licensed user with zero average value and unity variance. P_p denotes transmission power.

Collected signal from various SUs at FC will be evaluated using equation (5) as

$$S_c(n) = \left(\sum_{i=1}^K \sqrt{\beta_i} f_{rci} y_{r_{si}} \right) + v_c(n) \quad (5)$$

Where $n=1$ to N .

Where f_{pri} and f_{rci} are designates coefficients of fading between licensed user and SU_i and SU_i to fusion centre.

III. RESIDUAL ENERGY COMPUTATION

At the FC test statistic 'F' is calculated using equation (6) and is given as

$$F = \sum_{n=1}^N |S_c(n)|^2 \quad (6)$$

f_{pri} , f_{rci} , x_{pr} , v_{r_i} and v_c are independent to each other. Since all SUs are located at equal distance, $d_{pri} = d_p$, $d_{rci} = d_r$ with gain β .

The average measures of test statistic at H_1 and H_0 are $E(F_1) = N\mu_1$ and $E(F_0) = N\mu_0$ respectively, where

$$\mu_1 = (1 - \rho)K\beta r_1 + \sigma_c^2, \quad \mu_0 = (1 - \rho)K\beta r_0 + \sigma_c^2 \quad (7)$$

$$r_0 = d_r^{-\alpha} \sigma_c^2 \text{ and } r_1 = d_p^{-\alpha} d_r^{-\alpha} P_p + r_0 \quad (8)$$

The authorized decision limit value will be denoted by λ . Detection probability (P_d) and false alarm probability (P_f) are computed using following equation(9).

$$P_d = Q\left(\frac{\lambda - N\mu_1}{\sqrt{N\mu_1}}\right) \quad P_f = Q\left(\frac{\lambda - N\mu_0}{\sqrt{N\mu_0}}\right) \quad (9)$$

Where $Q(\cdot)$ denotes Q function.

The i th SU average power can be given by using equation (10)

$$P_{tri} = P(H_1)\beta_i(1 - \rho) \left(d_{pri}^{-\alpha} P_p + \sigma_n^2 \right) + P(H_1)\beta_i(1 - \rho)\sigma_n^2$$

$$P_{tri} = (1 - \rho)\beta_i P(H_1) \left(d_{pri}^{-\alpha} P_p + \sigma_n^2 \right) \quad (10)$$

Total K SUs will transmits N samples to FC with energy E_{tr} and it can be given as equation (11)

$$E_{tr} = \sum_{i=1}^K P_{tri} N t_{sp} \quad (11)$$

Overall dissipated energy will be indicated in equation (12) as

$$E_{diss} = E_{tr} = K P_{tri} N t_{sp} = (1 - \rho)K\beta N S \quad (12)$$

Where $S = \{ P(H_1) d_{pri}^{-\alpha} P_p + \sigma_n^2 \} t_{sp}$.

Likewise, the overall harvested energy of all SUs will be given by equation (13)

$$E_{har} = \sum_{i=1}^K [P(H_1)\rho(d_{pri}^{-\alpha} P_p + \sigma_n^2) + P(H_0)\beta_i \rho \sigma_n^2] \eta N$$

$$= \sum_{i=1}^K [\rho P(H_1) (d_{pri}^{-\alpha} P_p + \sigma_n^2) + P(H_0)\beta_i \rho \sigma_n^2] \eta N t_{sp}$$

$$E_{har} = \rho K [P(H_1) d_{pri}^{-\alpha} P_p + \sigma_n^2] \eta N t_{sp} = \eta \rho K N S \quad (13)$$

The resulted residual energy will be calculated by subtracting the overall dissipated energy from the harvested energy of entire SUs. The dissipated energy comprises energy required to drive the harvester circuit and transmission of SU information to FC. The overall residual energy will be given in equation (14)

$$E_{res} = E_{har} - E_{diss} - \epsilon$$

$$= \eta \rho K N S - (1 - \rho)K\beta N S - \epsilon$$

$$E_{res} = K N S \{ \eta \rho - (1 - \rho)\beta \} - \epsilon \quad (14)$$

IV. RESULTS AND DISCUSSIONS

The variation of residual energy with power splitting factor (ρ) as shown in Fig.3. Energy consumption is decreases and harvested energy is increases by increases power splitting ratio. There by, total average residual energy is increases.

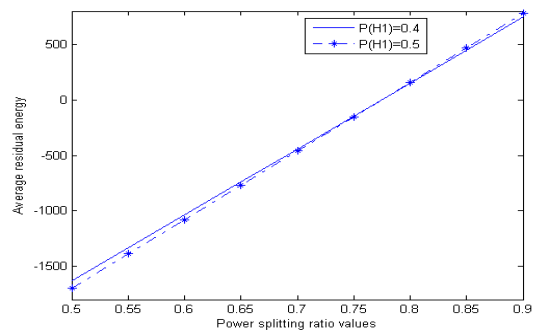


Fig.3. Power splitting ratio Vs total average residual energy

The simulation results of probability of detection with residual energy have shown in Fig.4. Increase in Pd will decrease the energy consumption there by harvested energy is increases by which increases the residual energy.

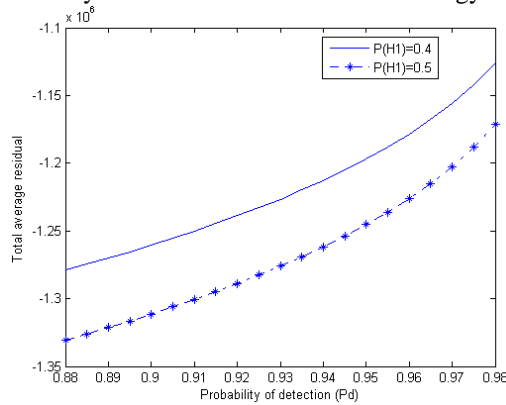


Fig.4.Pd Vs total average residual energy

Fig.5 shows the simulation results of total number of samples with residual energy. For fixed values of Pd and Pf, an increase in N value increases (1-ρ) value will decrease energy consumption and increases the harvested energy results in increase in total average residual energy. Residual energy is increases with increase in k value for fixed values of and Pf and is shown in Fig.6.

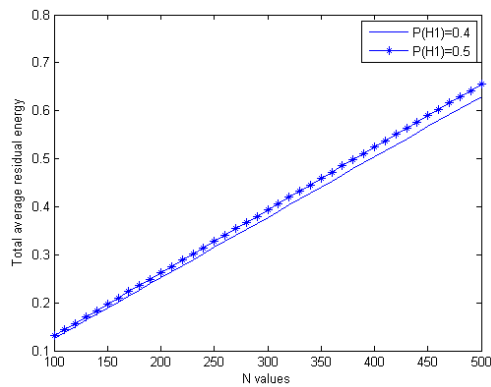


Fig.5.Total number of samples Vs total average residual energy

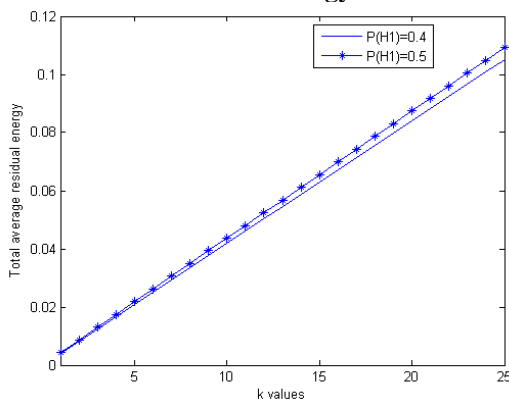


Fig.6.Number of SUs Vs total average residual energy

V. CONCLUSION

The performance of an energy harvested CR network is explored with regard to harvested energy, energy consumption and residual energy with respected to different parameters. SU harvest energy from the PU signal. Mathematical expressions

of energy consumption, harvested energy and residual energy are developed. Residual energy of SUs is increased with increase in power splitting ratio, number of SUs, number of samples and probability of detection.

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Anitha Bujunuru, working as an Associate professor in Guru Nanak Institutions Technical Campus and Research scholar from Kakatiya University Warangal. She completed her M.Tech from JNTUH, Hyderabad. She published two Text Book and research papers at International and National Journals.



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