Impact of Imperfect Spectrum Sensing on Hybrid Backscatter Assisted Cognitive Wireless Powered Radio Networks

Young Ki Choi, Su Min Kim, and Junsu Kim
Department of Electronics Engineering, Korea Polytechnic University, Siheung, Korea.
(E-mail: junsukim@kpu.ac.kr)

***Abstract*—In this paper, we propose a proper sensing period when the detection probability of determining the state of the primary user (PU) changes in a hybrid harvest-then-transmit (HTT) system according to the sensing period. The proposed system uses cooperative spectrum sensing based on energy detection using "n-out-of-K" voting rule to the existing hybrid HTT system. The performance of the proposed hybrid HTT system is evaluated numerically. The numerical results show that there exists the optimal sensing period and our proposed hybrid HTT system can achieve the ideal throughput even for imperfect sensing situations.**

***Index Terms*—Hybrid HTT, energy detection, threshold, Sensing Time**

I. Introduction

The number of IoT users have been increased as the use of IoT devices increase in many fields. As a result, there are two problem of battery efficiency and limited frequency. The following methods have been studied to solve these problems.

As a solution to the battery problem, a harvest-then-transmit (HTT) method based on full-duplex for transferring data to information receiver (IR) using harvested energy from hybrid-access-point (HAP), which consists of IR and power beacon (PB), was stuided in [1]. A backscatter communication (BackCom) method for reflecting signals from primary transmitter (PT) and PB as an incident signal rather than using analog-to-digital conversion to generate signals was studied in [2]–[4]. As a solution to the problem of spectrum allocation, cognitive radio (CR) method in which secondary communication users, cognitive users (CUs), shares a primary channel and information transmission method varies according to the state of a primary user (PU) was studied in [5]. The method with IoT equipments as secondary users was studied in [6]. To determine the state of the PU in cognitive wireless powered communication networks (CWPCN) the cooperative spectrum sensing based on energy detection using "n-out-of-K" voting rule was studied in [7].

A hybrid HTT system was studied as a way to solve the problem of battery and frequency allocation at the same time. If the state of PU is busy, CUs are in an ambient backscatter (AB) mode or HTT mode using PT as an incident signal. Conversely, if the state of PU is idle, CUs are in bistatic scatter (BS) mode or HTT mode using PB as an incident signal in [8].

The hybrid HTT system assumes perfect detection in cooperative spectrum sensing but in real radio systems, the detection probability varies with sensing period which affects information transmission stability and system throughput. In this paper, we propose a proper sensing period when the detection probability for determining the state of the PU changes in the hybrid HTT system according to the sensing period. The proposed system employes cooperative spectrum sensing based on energy detection using "n-out-of-K" voting rule. The performance of the proposed hybrid HTT system is evaluated numerically. The numerical results show that the throughput of our proposed hybrid HTT system flexibily varies, differently from an existing hybrid system where the throughput is decreased constantly.

The rest of the paper is organized as follows. In Section II, system model proposed. In Section III, a proper sensing period is proposed. In Section IV simulation result are prensented. Finally, In Section V conducive remarks are drown.

II. System Model

Fig. 1 shows the system model considered in this paper. The hybrid HTT system consists of primary and secondary communications. The primary communication includes primary transmitter (PT) and primary receiver (PR), and the secondary communication includes K CUs (e.g., low-power IoT devices), PB, and IR. We assume that all terminals are equipped with a single antenna. PT and PB serve as signal transmitters for energy transfer to CUs or incident signal generators in BackCom mode for CUs. The CUs powered by the PT or the PB because CUs do not have any embedded energy. The CUs operate in BackCom mode or HTT mode using signals from the PT or the PB, but not simultaneously.

In the system model, h_i^i, h_h^i, and g_h^i denote the channel power gains between the PT and the CUs, between the PB and the CUs, and between the IR and the CUs, respectively. We assume that the distance between each of CUs is shorter than the distance between the PT and the CUs. Therefore, we can say that the pathloss of the signal is almost identical and the same SNR γ and threshold λ are applied. we assume independent and identically distributed (i.i.d) rayleigh fadings.

Fig. 2 shows the operation protocol considered in this paper. The protocol is considered applied differently depending on

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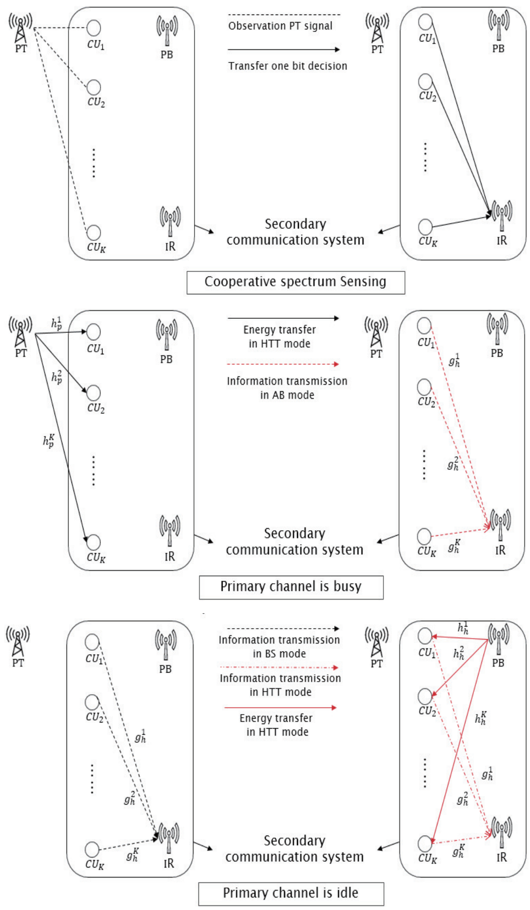

Fig. 1. Hybrid HTT with cooperative spectrum sensing system model.

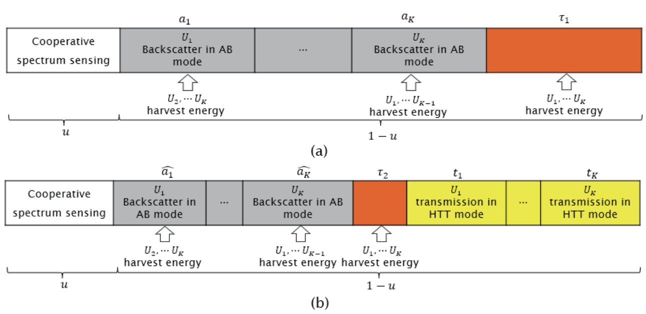

Fig. 2. Proposed hybrid HTT protocal.

the state of the PU. First, CUs observe the PT signal and make the decisions on the state of PU, then transfer them to IR. At the IR, all decisions from the CUs are fused and the state of the PU is determined based on them. Then, CUs perform HTT mode or BackCom mode depending on the state of the PU. If the PU is determined to be in the busy state, the protocol (a) in Fig. 2 is used. The CUs can either only harvest energy from PT as HTT mode or reflect PT signal for transmitting inforamtion to the IR as AB mode. Conversely, if the PU is determined to be in the idle state, the protocol (b) in Fig. 2 is used. the CUs can either transmit information to the IR by using harvested energy from PB and PT as HTT mode or reflect the PB signal as BS mode. We assume that CUs employ time division multiple access, so that if CU_1 work as BackCom mode to transfer information, the other CUs can work HTT mode to harvest energy from the PT or the PB. Additionally we also assume that total time duration of the protocal is 1. u is cooperative spectrum sensing time duration, and 1-u is information transmission time duration. Denote a_k and $\hat{a}_k$ be the time allocated that CUs can work as BackCom mode when the PU state is busy and idle, respectively. τ_1 and τ_2 is time allocated that all CUs can harvest energy when the state of the PU is busy or idle. t_k is the time allocated that CUs can transmit information when state of the PU is idle in [8].

A. Cooperative spectrum sensing

In cooperative spectrum sensing, CUs observe the signal from the PT and make one bit decision D_i (1 standing for the presence of the PU, 0 for the absence of the PU) and send it to the IR. The IR fuses the decisions received from CUs to determine the state of the PU by applying the following "n-out-of-K" voting rule in [7],

$$Y = \sum_{i=1}^{K} D_i \begin{cases} \geq n, & \mathrm{H}_1, \\ < n, & \mathrm{H}_0, \end{cases}$$

where H_1 indicates that the signal of PU exist and H_0 dose not exist. In cooperative spectrum sensing, the false alarm and missed detection can be expressed as follow.

$$Q_m = 1 - Prob\{H_0 \mid H_1\} = \sum_{l=n}^{K} \binom{K}{l} P_d^l (1-P_d)^{K-l},$$

$$Q_f = Prob\{H_1 \mid H_0\} = \sum_{l=n}^{K} \binom{K}{l} P_f^l (1-P_f)^{K-l},$$

where $P_{f,i}$ and $P_{d,i}$ follow the equations in [7].

B. When primary user is busy

If the status of the PU is determined to be busy, the CUs perform AB mode or HTT mode. In HTT mode, CUs only do harvest energy from PT. On the other hand, in AB mode CUs backscatter the signal of PT for information transmission. The backscatter bits of CUs in AB mode R_a^i is given by

$$\begin{aligned} R_a^i &= B_a^i a_i \\ &= R_s(\frac{N-u}{N})\frac{B_a^i}{K} \\ &= R_s(\frac{N-u}{N})\frac{R_s(\frac{N-u}{N})}{K} \\ &= \frac{(R_s(\frac{N-u}{N}))^2}{K}, \end{aligned}$$

where B_a^i is the achievable backscatter rate of CUs in AB mode. N, u and K are the total time slot, the sensing time slot and user.

If an error occurs in cooperative spectrum sensing, the IR determines that the state of PU as idle, and CUs exploit PB instead of PT to perform information transmission. However, the PB can not be used while PU is busy, so the information transmission can not be performed. As a result, the transmission bits that can be achieved with the PU being busy are as follows

$$R_{busy} = \begin{cases} \sum_{i=1}^{K} R_a^i, & Q_m \text{ is not occur,} \\ 0, & Q_m \text{ is occur.} \end{cases}$$

C. When primary user is idle

If the status of the PU is determined to be idle, the CUs perform BS mode and HTT mode. In BS mode, CUs backscatter the signal from the PB for information transmission. The backscatter bits of CUs in BS mode R_b^i is given by

$$R_b^i = B_b^i \hat{a}^i,$$

where B_b^i is the achievable backscatter rate of CUs in BS mode.

In HTT mode, CUs perform information transmission by using harvested energy from the PT and the PB. The information transmission bits of CUs in HTT mode is given by

$$R_h^i = t_i W log_2(1 + \frac{\gamma_p^i \tau_1 + \gamma_h^i \tau_2}{\sigma^2}),$$

where γ_p^i and γ^i are SNR, when CUs perform information transmission to the IR using harvested energy from the PT and the PB, respectively. W and σ^2 denoted the bandwidth and the noise power at the IR, respectively.

If an error occurs in cooperative spectrum sensing, the IR determines that the state of PU as busy, and CUs exploit the PT instead of the PB to perform information transmission. However, the PT can not be used while PU is idle, so the information transmission can not be performed. As a result, the transmission bits that can be achieved with the PU being idle are as follows

$$R_{idle} = \begin{cases} \sum_{i=1}^{K} (R_h^i + R_b^i), & Q_f \text{ is not occur,} \\ 0, & Q_f \text{ is occur.} \end{cases}$$

III. Optimal sensing time

In this section, since total detection probability to determine the state of PU is varying according to sensing period, a suitable cooperative spectrum sensing period is proposed.

Using P_d affected by SNR γ_i and threshold λ_i, the sensing period of energy detection can be obtained as follows as in [9],

$$u = P_d^{-1}(\hat{P}_d | \gamma_i, \lambda_i).$$

The cooperative spectrum sensing is based on energy detection. With P_d, the detection probability in the cooperative spectrum sensing is also affected by SNR γ_i, and threshold λ_i and can be expressed as $P_{succ} = 1 - (Q_f + Q_m)$. Using this

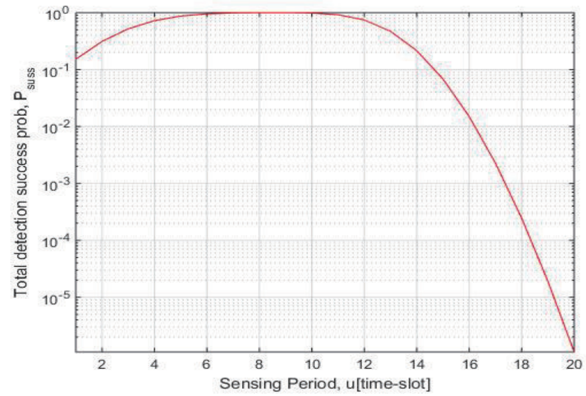

Fig. 3. Total detection probability in cooperative spectrum sensing.

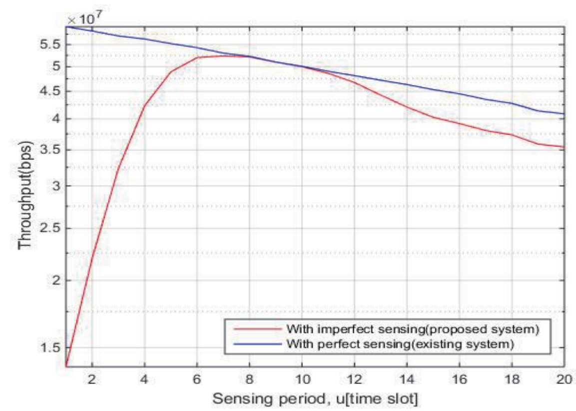

Fig. 4. Throughput for existing hybrid HTT vs. propose hybrid HTT.

P_{suss}, the sensing period of the cooperative spectrum sensing can be obtained as follows

$$u = P_{suss}^{-1}(\hat{P}_{suss} | \gamma_i, \lambda_i),$$

where $\hat{P}_{suss}$ denotes the required P_{suss}.

Fig. 3 shows the total detection probability according to the sensing period obtained above. When the sensing period is between 8 and 10 points, the total detection probability is almost to be 1 which means perfect. However, as the sensing period increases over 10 time slots than the 8 to 10 points, the total detection probability decreases steeply. This is because Q_m decreases as the sensing period increases, while Q_f increases.

IV. Numerical result

Fig. 4 shows the throughput of the proposed hybrid HTT system, which is varying according to the sensing period proposed in this paper, compared with an existing system assuming perfect detection. At 8 to 10 time slots in sensing period, we can see that the throughput of the system proposed in this paper is similar to the throughput of the existing system, and in the rest of the points, the throughput proposed in this paper is worse than the throughput of the existing system. When the sensing period is shorter than 8 to 10 points, the total detection probability is higher than that between 8 and 10 points, while Q_f increases in the cooperative spectrum sensing. It is difficult to determine the state of the PU in these points, which make it difficult to transmit information. In overall, the decrease in throughput is due to the decrease in information transmission time as the sensing period increases. As a result, it is appropriate to set the points between 8 and 10 of sensing period that is similar to those of the existing hybrid system which assuming the detection probability to be perfect.

V. CONCLUSION

In this paper, we applied practical cooperative spectrum sensing to the existing hybrid HTT system assuming perfect sensing since total detection probability varies according to sensing period in real radio systems. The numerical results show that if the sensing period is short, throughput decreases because the total detection probabilities are small, and if the sensing period increases, the throughput also decreases due to the increasing Q_f in the cooperative spectrum sensing. Finally, there exists the optimal sensing period that provides the throughput of ideal hybrid HTT system assuming perfect sensing.

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