

Design of Energy Harvesting Protocol for Relay Mobile Node in WLAN

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Abstract— In this paper, we propose the balanced time power switching based relaying (TPSR) protocol for energy harvesting enabled mobile node in WLAN called energy harvesting cooperative networks (EHCN). Specifically, we develop outage and throughput performance characterizations in term of energy harvesting efficient factor in the proposed scheme. It is shown that the optimal throughput of the EHCN is critically dependent on the threshold signal-to-noise (SNR) value. The tightness of our proposed protocol is determined through Monte Carlo simulation results. Finally, our results provide useful guidelines for design of the energy harvesting enabled WLAN.

Keywords—energy harvesting cooperative networks, amplify-and-forward, time power switching based relaying, throughput, WLAN.

I. INTRODUCTION

In recent decades, human were looking for energy sources such as solar, wind, hydropower and other sources from ambient environment to alternate fossil fuel. Surprisingly, radio frequency (RF) signal could be a power source that we can harvest enough energy for certain devices as a promising solution. The key of energy harvesting technique is that the RF signals can transmit information and energy simultaneously [6-9]. In the near future, mobile devices in the EHCN will have the ability of wireless communication and energy harvesting so as to maintain communication function without the need of using external energy source. This revolution will be reach due to the development of the wireless power transmission.

Recently, the authors in [6] were proposed two protocols of an amplify-and-forward (AF) relaying system for energy harvesting and information processing. These two protocol are: i) time switching-based relaying (TSR) protocol where the receiver switches between information processing and energy harvesting; ii) power splitting-based relaying (PSR) protocol where the receiver splits the receiver signal in two parts for information processing and energy harvesting.

In addition, two other protocols were used in [8] and they are time switching cooperative multiuser transmission (TSCMT) protocol and the power splitting cooperative multiuser transmission (PSCMT) protocol. There are explicit expressions for each protocol after theoretically analyzing the outage probability of the system. The results illustrated that

PSCMT protocol is outperform than the TSCMT protocol which mean that PSCMT protocol has lower system outage probability.

In [7] secondary users (SUs) in the cognitive radio can be obtained expected achievable throughput when optimal data-fusion and decision-fusion strategies converge to a single-slot spectrum sensing. Another research [9] shows that RF energy of transmission from primary transmitters (PTs) can be harvested by secondary transmitters (STs). There are two zones: guard zone and harvesting zone that associate with PT and ST respectively. Similarity, the transmitters of primary user (PU) and secondary user (SU) operate in time-slotted mode. The SU can harvest energy exclusively from ambient RF using save-then-transmit protocol.

Moreover, the authors in [10] proposed an optimization formulation to obtain the channel access policy for the SU to maximize its throughput. On the other hand, they also apply an online learning algorithm to observe the environment and adapt the channel access action. After evaluate the efficiency and converge of the learning algorithm, the numerical results show that the learning algorithm can achieve the performance close to that obtained from the optimization in term of throughput. Based on the analytical result, distributed wireless power chargers can be deployed to power coexisting wireless transmitters in a sensor network.

Our contribution's summarization is described on the rest of this paper as follows. The overall system model of energy harvesting enabled mobile node in the EHCN introduced on section II. In section III, the protocols and analytically expression of the achievable throughput are proposed. The numerical result of the optimal throughput with different values of the fixed bit rates are illustrated on Section IV. The conclusions of this paper are showed on the last section – section V.

II. SYSTEM MODEL

In Fig. 1, we consider a simple EHCN used for harvesting energy and transmit information following AF scheme. There are three devices: AP node is S, energy constrained relay mobile node R and destination mobile node D.

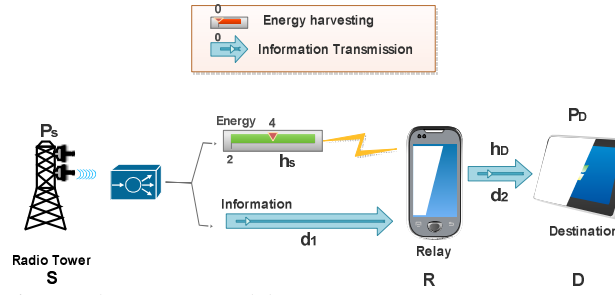


Fig. 1: The System Model

Each device is equipped one single antenna and work in half-duplex mode. The relay node R forwards the information sent from AP which denoted as S to forwarding signal to the destination mobile node D. Because we assume that between S and D has no immediate link, the information must be transmitted through R before reach the destination D.

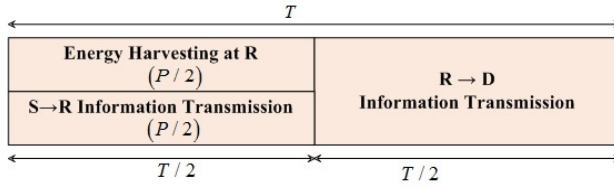


Fig. 2: The balanced TPSR protocol for energy harvesting and information processing at the relay mobile node.

We consider new model as the *balanced time power switching based relying* (TPSR) protocol respecting the energy harvesting protocol. Fig. 2 shows the protocol for considered network. In our TPSR protocol, we denote parameter T which designated for the block time in which the information is transmitted from the AP to the destination mobile node. In the first haft of T which is $\frac{T}{2}$ the energy is processed and the information is transmitted between the AP and the relay mobile node. In the power splitting context, the total power of transmitted signal is depicted by P. In addition, due to the simplicity on implementation, the amplify-and-forward (AF) relaying protocol at relay nodes is utilized by WiFi systems follow the EHCN technology.

Another assumption is that the relay mobile node only has limited energy supply. Hence, the energy from the AP needs to be harvested before processing information on relay node R. In reality, the collected energy can be used to charge batteries then act as power source for forwarding information form AP to destination node. EHCN's channel model is considered as flat Rayleigh fading.

In the next section, the application of TPSR protocol for the EHCN where the energy harvested from the source node (AP) powers is feeded for relay mobile node. In addition, through variety cases of time and power fractions in the proposed TPSR protocol, the closed-form expression of the achievable throughput is extracted.

III. THE BALANCED TPSR IN ENERGY HARVESTING ENABLED WLAN

A. The balanced TPSR protocol

As we have discussed on the previous section, WLAN can enable energy harvesting ability and relay mobile node can scavenge the energy from RF signals emitted by the AP to support the transmission data between the relay and destination node. The energy will be harvested from the AP's RF signals then accumulated on battery of the relay node in the first hop. In the second hop, the backup energy in the battery will be used to perform information transmission. The TPSR protocol will be analyzed to get the better perception of the performance.

In TPSR protocol, we separate the power of received signal y_R to two parts: energy harvesting receiver $\frac{1}{2}P$ and information receiver $\frac{1}{2}P$ in the proposed TPSR protocol. At the input of energy harvesting receiver, the signal received y_{RE} is represented as

$$y_{RE} = \sqrt{\frac{1}{2}P_S} g_S x_S + \sqrt{\frac{1}{2}} n_R, \quad (1)$$

where P_S is the transmitted power of the AP; g_S denotes as channel coefficient between the AP and relay mobile node while x_S denotes as transmitted signal from AP; $n_R \sim CN(0, \sigma_R^2)$ denotes as the total additive white Gaussian noise (AWGN) introduced at the relay mobile node by the receiving antenna and signal band conversion.

A rectifier, energy processing module in relay mobile node, equipped with a Schottky diode and a low-pass filter (LPF) convert incoming signal in (1) to a direct current signal i_{DC} . The direct current is used to charge the battery and to transmit the information. The direct current signal is used to charge the battery and to supply information transmission [14]. Hence, the energy harvested in the TPSR protocol is given by

$$E_h = \kappa E\{i_{DC}\} \frac{1}{2} T = \kappa P_S |g_S|^2 \frac{1}{4} T, \quad (2)$$

where $E\{\cdot\}$ denotes expectation operation, $0 < \kappa \leq 1$ depicts the energy harvesting efficiency at the energy receiver and it depends on the rectifier and the energy harvesting circuitry.

In the second stage, the power collected form AP support the information processing after amplified at the relay node. Unlikely the harvesting energy receiver, the information receiver in the TPSR protocol receives the signal as

$$y_R = \sqrt{\frac{1}{2}P_S} g_S x_S + \sqrt{\frac{1}{2}} n_R, \quad (3)$$

Applying AF relaying protocol, the received messages are amplified by the relay using a factor G defined as

$$G^{-1} = \sqrt{\frac{1}{2} P_s |g_s|^2 + \sigma_r^2}. \quad (4)$$

The source signal is amplified and forwarded to destination node by relay node after processing at relay mobile node. The power is used to forward signal is P_r , it relied on the capacity of energy that collected during the harvesting period. The received signal at the destination mobile node y_D can be expressed as

$$y_D = \sqrt{P_r g_D} G y_R + n_D, \quad (5)$$

where $n_D \sim CN(0, \sigma_D^2)$ is the additive white Gaussian noise (AWGN) introduced at the destination mobile node. Then, y_D can be rewritten as (6) by alternating y_R and G from (3), (4) into (5)

$$y_D = \frac{\sqrt{\frac{1}{2} P_r P_s g_s g_D x_s}}{\sqrt{\frac{1}{2} P_s |g_s|^2 + \sigma_r^2}} + \frac{\sqrt{P_r g_D n_R}}{\sqrt{\frac{1}{2} P_s |g_s|^2 + \sigma_r^2}} + n_D. \quad (6)$$

On the other hand, the relay mobile node transmits the amplified signal using the harvested energy E_h as a source of power for transmitting signal in $\frac{1}{2}T$ time, and hence the transmitted power from the relay mobile node P_r is calculated by

$$P_r = \frac{E_h}{\frac{1}{2}T} = \frac{1}{2} \kappa P_s |g_s|^2. \quad (7)$$

The below expression is the calculation of received signal at the destination mobile node y_D . It come up by alternating the P_r from (7) into (6)

$$y_D = \underbrace{\frac{\sqrt{\kappa P_s |g_s|^2 \frac{1}{4} P_s g_s g_D x_s}}{\sqrt{\frac{1}{2} P_s |g_s|^2 + \sigma_r^2}}}_{\text{Signal part}} + \underbrace{\frac{\sqrt{\kappa P_s |g_s|^2 \frac{1}{2} g_D n_R}}{\sqrt{\frac{1}{2} P_s |g_s|^2 + \sigma_r^2}} + n_D}_{\text{Noise part}} \quad (8)$$

Finally, the end-to-end SNR at the destination can be expressed by

$$\begin{aligned} SNR_D &= \frac{\frac{1}{8} \kappa P_s |g_s|^2 |g_D|^2}{\frac{1}{4} \kappa |g_D|^2 \sigma_r^2 + \frac{1}{4} \sigma_D^2 + \frac{\frac{1}{2} \sigma_r^2 \sigma_D^2}{P_s |g_s|^2}} \\ &= \frac{\kappa P_s |g_s|^2 |g_D|^2}{2 \kappa |g_D|^2 \sigma_r^2 + 2 \sigma_D^2 + \frac{\sigma_r^2 \sigma_D^2}{4 P_s |g_s|^2}} \end{aligned} \quad (9)$$

B. Throughput Analysis

In this work, we consider the delay-limited transmission mode where the achievable throughput τ is determined by evaluating the outage probability P_{out} of the system with a fixed source transmission rate Z (bps/Hz). We have $Z \triangleq (1/2) \log_2(1 + SNR_0)$ and denote SNR_0 as the threshold signal-to-noise ratio for exact data detection at the destination. Moreover, in order to analyze the outage probability of the balanced TPSR protocol at the destination mobile node, we first obtain the instantaneous mutual information between the relay and the destination mobile node is given by

$$I_{RD} \triangleq (1/2) \log_2(1 + SNR_D), \quad (10)$$

The signal-to-noise ratio at the destination mobile node is SNR_D . The outage probability of the system as the probability that the instantaneous mutual information I_{RD} is lower than fixed source transmission rate Z . The outage probability can be illustrated as

$$P_{out} = Pr(I_{RD} < Z) = Pr(SNR_D < \lambda), \quad (11)$$

where $Pr(\cdot)$ is probability operation and the value λ can be calculated by $\lambda = 2^{2Z} - 1$. Specifically, we derive the closed-form SNR_D as the following expression at high SNR. Therefore, the approximate outage probability P_{out} can be determined by

$$\begin{aligned} P_{out} &\approx Pr\left(\frac{1}{2} \frac{\kappa P_s |g_s|^2 |g_D|^2}{\kappa |g_D|^2 \sigma_r^2 + \sigma_D^2} < \lambda\right) \\ &= Pr\left(|g_D|^2 < \frac{\sigma_D^2 \lambda}{\frac{1}{2} \kappa P_s |g_s|^2 - \kappa \sigma_r^2 \lambda}\right). \end{aligned} \quad (12)$$

Relying on the (12), Lemma 1 is conducted

Lemma 1: Here are some equation for simplifying $A \triangleq \frac{1}{4} \kappa \sigma_r^2 SNR_0$, $B \triangleq \frac{1}{4} \sigma_D^2 SNR_0$ and $C \triangleq \frac{1}{8} \kappa P_s$. At high SNR, the approximate calculation the outage probability of

the destination mobile node for the balanced TPSR protocol in the energy harvesting networks is given by [6]

$$P_{out} = Pr\left(|g_D|^2 < \frac{B}{C|g_S|^2 - A}\right) \approx 1 - \exp\left(-\frac{A}{C\Omega_S}\right), \quad (13)$$

where the mean of the exponential random variables of $|g_S|^2$ and $|g_D|^2$, are Ω_S and Ω_D .

The achievable throughput τ of the balanced TPSR protocol at the destination is demonstrated by

$$\tau = (1 - P_{out}) \frac{1}{2} Z = (1 - P_{out}) \frac{1}{2} Z. \quad (14)$$

IV. NUMERICAL RESULTS

In order to illustrate the solution to the optimization throughput problems of the AF energy harvesting enabled relaying network in the proposed TPSR protocol we come up with the numerical results. There are some parameters will be evaluated. The optimal value of throughput τ , optimal value of bit rate in the balanced TPSR scheme. In particular, we setup common parameters as follow: the fixed transmission rate of the source changes $Z = 2$ (bps/Hz) to $Z = 6$ (bps/Hz), source transmission power $P_S = 2$ (Watt), $d_1 = d_2 = 1$. In all simulations Ω_S and Ω_D are denoted as the mean values of the exponential random variables $|g_S|^2$ and $|g_D|^2$, respectively, and set to 1.

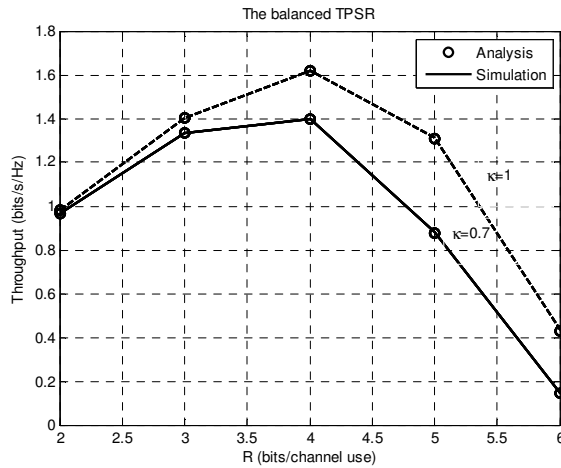


Fig. 3. Simulation based and analytical throughput τ at the destination with respect to bit rate and energy harvesting efficiency

The simulation results depend on the expressions of the outage probability which is evaluated by averaging these calculations over 10^5 random realizations of the Rayleigh

fading channels of g_S and g_D . As illustration in Fig. 3, the maximized throughput can be obtained as $Z = 4$ (bps/Hz). In addition, it is true that energy harvesting efficiency has impact on the maximal throughput. Intuitively, the gap performance can be seen clearly, especially in the case Z greater than 4 (bps/Hz).

V. CONCLUSIONS

This paper proposes the balanced TPSR protocol applied appropriate wireless energy harvesting and information transmission in the next generation communications (i.e. WLAN). In addition, the outage performance of the AF relaying scheme has been derived, where the relay mobile nodes harvest energy from the AP through the received RF signal and then use harvested energy to amplify information and forward the source signal to the destination mobile node. More importantly, the optimal bit rate in the proposed TPSR protocol are chosen in order to maximize the throughput of the system were also numerically investigated.

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