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WIRELESS ENERGY HARVESTING RELAYING NETWORKS UNDER IMPERFECT CSI: THROUGHPUT ANALYSIS

MẠNG CHUYỂN TIẾP THU THẬP NĂNG LƯỢNG KHÔNG DÂY TRONG ĐIỀU KIỆN ƯỚC LƯỢNG KÊNH KHÔNG HOÀN HẢO: PHÂN TÍCH THÔNG LƯỢNG

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ABSTRACT

The purpose of this research aims to investigate an amplify-and-forward-based (AF) energy harvesting (EH) system with imperfect channel state information (CSI), where two-end-nodes and one relay are operated in half-duplex mode. Power splitting-based relaying (PSR) protocol is used to transmit information from source to destination by the energy harvesting enabled relay. The authors propose that the initial power contained in the battery is used to run the relay. After that, to transmit signal the relay has to harvest energy from the attained RF signals. The exact integral and approximate closed-form expressions for the outage probability and throughput of this system have been derived. The validity of analytical results is verified by Monte Carlo simulations.

Keywords*: Energy harvesting; imperfect channel state information (CSI); PSR protocol; half-duplex; amplify-and-forward-based.*

TÓM TẮT

Trong bài báo này, tác giả nghiên cứu một hệ thống thu thập năng lượng (EH) dựa trên khuếch đại và chuyển tiếp (AF) trong điều kiện ước lượng kênh không hoàn hảo, nơi mà 2 nút đầu cuối và một nút chuyển tiếp được hoạt động ở chế độ bán song công. Giao thức PSR được sử dụng để truyền thông tin và năng lượng từ nguồn đến đích bằng nút chuyển tiếp. Cụ thể, để truyền tín hiệu đến đích, nút chuyển tiếp phải thu thập năng lượng từ tín hiệu RF thu được và dùng chính năng lượng đó để xử lý thông tin chuyển tiếp. Bài báo đưa ra công thức tích phân chính xác và biểu thức gần đúng của xác suất dừng, thông lượng của hệ thống này. Giá trị của kết quả phân tích được kiểm chứng bởi mô phỏng Monte Carlo.

Từ khóa: *Thu thập năng lượng; ước lượng kênh không hoàn hảo; giao thức PSR; bán song công; khuếch đại và chuyển tiếp.*

1. INTRODUCTION

In conventional sensor networks and cellular networks, wireless devices are normally powered by replaceable or rechargeable batteries, which have the limited life-time. Replacing or recharging the batteries periodically leads to several disadvantages such as inconveniences in the operation of a sensor network with thousands of distributed sensor nodes, danger to the technicians when the devices are located in toxic environments, and even impossibility in the case of the medical sensors implanted inside human bodies. In such situations, energy harvesting (EH) is a potential solution to provide a perpetual power supply and also is an attractive approach to prolong the wireless networks' lifetime [1,2]. Typical sources for energy harvesting are solar, vibration and wind. Recently, electromagnetic (EM) power in the radio signals has been proposed as a new viable source for EH, supported by the advantage that the wireless signals can carry both energy as well as information [3]. This is an attractive direction for many researchers.

On the other hand, there are a number of applications of relay stations (RS) to improve the performances of wireless networks. The application of relays was first standardized in IEEE 802.16j [4]. For example, the RS have also been considered in the LTE-advanced systems to reach target throughput and coverage requirements. Moreover, relaying strategy is a promising technique to deal with fading channel and path-loss in wireless networks. The extensive studies in the literature showed that the transmission/reception cooperation between nodes of a network provides significant benefits including bandwidth and energy efficiencies and reliability. In the studies presented in [4–6], RS operate in a half-duplex (HD) mode due to the non-trivial implementation problems related to transmitting and receiving in the same frequency band and during the same time slot. Since a half-duplex relay can forward a message from source to destination over two time slots, it makes an inefficient use of the radio channel resource.

However, most of previous works assume that CSI is well known at receiver. This assumption is not true in real practice and hence in this work, an AF-based EH system using PSR protocol [7] with constraint of imperfect CSI [8,9] is proposed.

The main contributions of this paper are summarized as follows:

- We use a protocol termed "power switching based relaying" for the EH-based system as depicted in Fig. 1, where the relay node receives wireless energy from source node.
- The closed-form of system's performance, in terms of outage probability, throughput is derived.

In the remainder of this study, the paper is arranged as follows. Section 2 presents the depiction of suggested EH relaying system. Then Section 3 will analysis outage probability and throughput of proposed system. Next, in Section 4 some numerical examples are picked and analyzed. We will also give conclusions in this section.

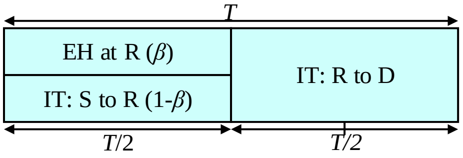

Fig.1 *Power switching based relaying protocol.*

2. SYSTEM MODEL

2.1. Channel model

We consider system performance under impacts of Imperfect Channel State Information (CSI) estimation model. In particular, all the channels are assumed to be block fading, i.e., the channel remains constant over a block but changes independently from one block to another. It is assumed that the channel from S to R and R to D has the channel coefficient $h(t)$ and $g(t)$, respectively. They are zero-mean and variance.We model the channel h, g as the sum of the channel estimate h, g and the channel estimation error Δ_h and Δ_g respectively, as in [8].

$$h(t) = h(t) + \Delta_h(t), \qquad (1)$$
$$g(t) = g(t) + \Delta_g(t).$$

2.2 Relay model

We make the following assumptions regarding relay node:

- The relay node has no other embedded energy supply and thus needs to first harvestenergy from source node for information processing. In practice, harvested power canbe stored in batteries and then are supplied asa source of transmitting power in order toforward the source information to the destination node.
- The receiver structure at relay node isdesigned for energy havesting.

2.3 Energy harvesting model

Fig.2 shows that we examine an AF-based energy harvesting system that contains two-end-nodes and one relay respectively designated by S, D, and R. In usual relaying network, with half-duplex transmission, source-nodes S transfers their signal to relay nodes in the first-time slot, then the signal will be amplified and forwarded to destination node in the second time slot by the relay.

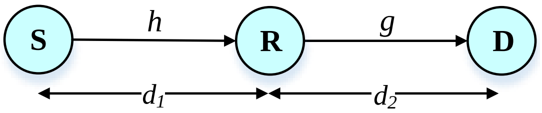

Fig.2 *System model.*

Furthermore, we examine a one-way linear relaying network which the normalized distances are denoted by d_1, $d_2 = d_1, r + d_r$. We implement single antenna for the source and destination while the AF relay has single receive antenna and single transmit antenna. We propose that the initial power contained in the battery is used to run to initial the relay. After that, to transmit signal the relay has to harvest energy from attained RF signals. The transferring channel from the source to relay and then to destination are respectively assigned as h and g. The factors of complicated channel of A and B points are denoted by $h_{AB} \sim CN\left(0, d_{AB}^{-\alpha}\right)$ with α is path loss exponent. Information is transmitted mutually from s_1 point to s_2 point by the relay in the TWR protocol. Due to implementing request-to-send/clear-to-send (RTS/CTS) based channel guess program, relaying system can be supported by estimating CSI.

2.4 Signal model

The signal received at the input of the energy harvesting receiver is expressed as:

$$y_r(t) = \sqrt{\frac{p_s}{d_1^m}}\left(h + \Delta h\right) s_s(t) + n_a^r \qquad (2)$$

In the PSR protocol, received signal is divided into two paths: $\sqrt{\beta} y_r(t)$ is sent to the energy harvesting receiver and the information receiver got the remaining signal strength, $\sqrt{1-\beta} y_r(t)$. At the input of the energy harvesting receiver, the signal is:

$$\sqrt{\beta} y_r(t) = \frac{1}{\sqrt{d_1^m}} \sqrt{\beta p_s} hs(t) + \sqrt{\beta} n_a^{[r]}(t) \text{ [9].}$$

Hence, the energy harvested in PSR protocol is given by:

$$E_h^{PSR} = \frac{\eta \beta T}{2} \frac{p_s\left(\left|h\right|^2 + \sigma_h^2\right)}{d_1^m} \qquad (3)$$

where $0 \le \eta \le 1$ denotes the energy harvesting efficiency at the energy receiver and it depends on the rectifier and the energy harvesting circuitry.

Next, the energy of end-to-end signal is deployed in case of implementing non-oscillating relay. In that condition, all coming signal and noise samples are separated individually, and the power of transmitting relay is illustrated by:

$$p_r = \frac{E_h^{PSR}}{T/2} = \frac{\eta\beta p_s\left(|h|^2 + \sigma_h^2\right)}{d_1^m} \tag{4}$$

Therefore, the received signal at the input of the information receiver in the PSR protocol is expressed as:

$$y_r(t) = \sqrt{\frac{(1-\beta)p_s}{d_1^m}}(h + \Delta h)s_s(t) + \sqrt{1-\beta}\,n_a^r \tag{5}$$

By utilizing attained energy, the relay uses a relay gain S to magnify the obtained signal. So the received signal at the relay is computed by:

$$s_r(t) = y_r(t)S \tag{6}$$

where S is amplifying parameter, and given by (7).

$$\begin{aligned} S &= \sqrt{\frac{p_r d_1^m}{(1-\beta)p_s\left(|h|^2 + \sigma_h^2\right) + d_1^m \sigma_{n^{[R]}}^2}} \\ &\approx \sqrt{\frac{\eta\beta}{(1-\beta)}} \end{aligned} \tag{7}$$

In (7), the approximation value can be derived for high transmission power case. The sampled attained signal at the end-node $y_d(t)$ can be calculated as:

$$y_d(t) = \sqrt{\frac{1}{d_2^m}}\left(g + \Delta_g\right)s_r(t) + n^{[D]}(t) \tag{8}$$

where $n^{[D]}(k) = n_a^d(k) + n_c^d(k)$, where the range from relay to end-node is denoted by d_2 ; $n^{[D]} = n_a^d + n_c^d$ is AWGN which the average is zero and the variance is $\sigma_{n^{[D]}}^2 \triangleq \sigma_{n_a^{[D]}}^2 + \sigma_{n_c^{[D]}}^2$.

Subtituting (5), (6) and (7) into (8), the end-to-end signal can be restored as (9).

$$\begin{aligned} y_d(t) \approx{} & \sqrt{\frac{\eta\beta p_s}{d_1^m d_2^m}}hgs_s(t) + \sqrt{\frac{\eta\beta p_s}{d_1^m d_2^m}} \\ & \times\left\{g\Delta_h s_s(t) + h\Delta_g s_s(t) + \Delta_h\Delta_g s_s(t)\right\} \\ & + \sqrt{\frac{\eta\beta}{(1-\beta)d_2^m}}n^{[R]}\left\{\Delta_g + g\right\} + n^{[D]}(t) \end{aligned} \tag{9}$$

The SNR is show in (10) at the top of next page.

3. OUTAGE PROBABILITY AND THROUGHPUT

3.1 Outage probability

Hence, the outage probability of system is defined as:

$$P_{out} = \Pr\left(SNR < \gamma_0\right) \tag{11}$$

Subtituting (10) into (11) and putting:

$$a = \sigma_{\Delta g}^2$$

$$b = \left(\sigma_{\Delta h}^2 + \frac{d_1^m}{(1-\beta)P_S}\sigma_{n^{[R]}}^2\right)$$

$$c = \sigma_{\Delta g}^2\sigma_{\Delta h}^2 + \frac{d_1^m}{(1-\beta)P_S}\sigma_{\Delta g}^2\sigma_{n^{[R]}}^2 + \frac{\left((1-\beta)d_1^m d_2^m \sigma_{n^{[D]}}^2\right)}{2\eta\beta P_S}$$

$$Y = |g|^2$$

$$X = |h|^2$$

The outage probability is determined as:

$$\begin{aligned} P_{out} &= \Pr\left\{\frac{XY}{Xa + Yb + c} < \gamma_{th}\right\} \\ &= 1 - \frac{1}{\Omega_h}e^{\frac{\gamma_{th}b}{\Omega_g}}\int_{\gamma_{th}a}^{\infty} e^{-\left(\frac{y}{\Omega_h} + \frac{\gamma_{th}(c+\gamma_{th}ab)}{(y-\gamma_{th}a)\Omega_g}\right)}dy \end{aligned} \tag{12}$$

Finally, apply (eq. 8.407.1) given in [10] we obtained proposition 1 as (13).

3.2 Throughput

The delay-limited transmission of throughput is shown as:

$$\tau = \frac{1}{2} R(1 - P_{out}) \qquad (14)$$

4. NUMERICAL RESULTS AND DISCUSSION

This section includes the comparison of trial test results and analytical outcomes of outage probability and throughput. To be simple, it is proposed that the connection channels of base station and practical energy station are independent with each other andsimilarly Rayleigh fading. It is supposed that energy transmission at S, R, D are the same. The unit of SNR is dB. The length between S and R, R and D are equal to each other. The authors set the source transmission rate as R = 3 bps/Hz, energy harvesting efficiency η = 1, source transmission P_s = 1 Joules/sec, path loss exponent m = 2.7 and the outage SINR threshold is given by $\gamma_0 = 2^R - 1$; then make use of the notation δ_h and δ_g in figure to denote the variances of the channel estimation errors from S to R and R to D, respectively.

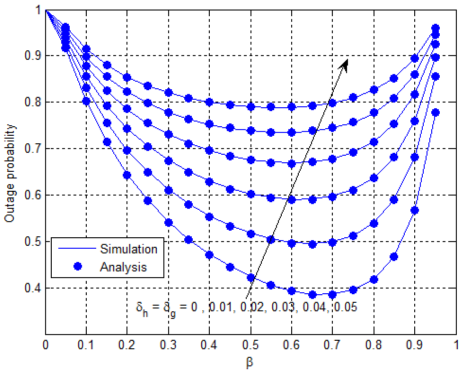

Fig.4 *Outage probability of proposed system in different β.*

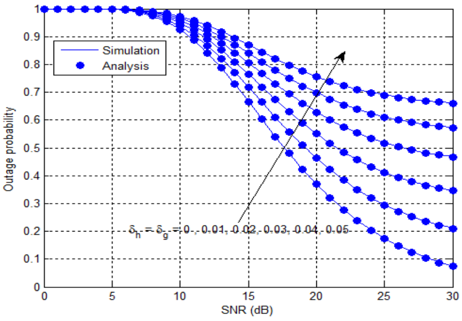

Fig.5 *Outage probability of proposed system in different SNR.*

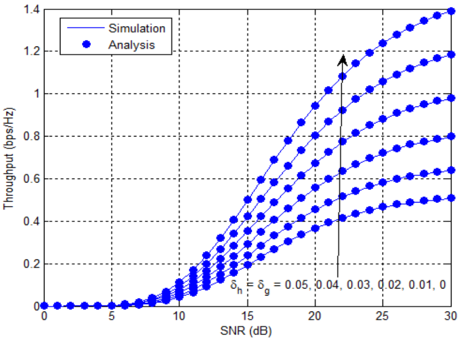

Fig.6 *Through put of proposed system in different SNR*

$$SNR = \frac{|g|^2 |h|^2}{|g|^2 \left(\sigma_{\Delta h}^2 + \frac{d_1^m}{(1-\beta) p_s} \sigma_{n^{[R]}}^2 \right) + |h|^2 \sigma_{\Delta g}^2 + \sigma_{\Delta g}^2 \sigma_{\Delta h}^2 + \frac{d_1^m}{(1-\beta) p_s} \sigma_{n^{[R]}}^2 \sigma_{\Delta g}^2 + \frac{(1-\beta) d_1^m d_2^m \sigma_{n^{[D]}}^2}{\eta \beta p_s}} \qquad (10)$$

$$P_{out} = 1 - \frac{1}{\Omega_h} e^{\frac{-b\gamma_{th}}{\Omega_g} - \frac{\gamma_{th} a}{\Omega_h}} \sqrt{\frac{4\gamma_{th} \Omega_h (c + \gamma_{th} ab)}{\Omega_g}} K_1 \left(\sqrt{\frac{4\gamma_{th} (c + \gamma_{th} ab)}{\Omega_g \Omega_h}} \right) \qquad (13)$$

Fig.5 shows the outage probability at noise = 0.01; β = 0.03; $\delta_h = \delta_g$ = 0, 0.01, 0.02, 0.03, 0.04, 0.05; 0 ≤ SNR ≤ 30. The system performance will be enhanced when SNR is increased at source node. In this experiment, the impact of imperfect CSI noise on outage probability and throughput can also be seen in Fig.5 and Fig.6, respectively. It is noted that Fig. 6 shows the throughput at noise = 0.01; $\beta = 0.03$; $\delta_h = \delta_g = 0.05, 0.04, 0.03, 0.02, 0.01, 0$; $0 \leq SNR \leq 30$.

5. CONCLUSION

In this paper, the impact of imperfect channel estimates on the overall performance of a two-hop relay system that employs a two-phase AF network over Rayleigh fading has been investigated. Specifically, considering the imperfect estimation and SNR variation of the fading channels, the authors formulate the outage probability and the throughput is evaluated for the best performance at high SNR scenario in terms of imperfect channel state information (CSI). With such a practical CSI modeling, exact approximation expression for the overall outage probability with proper power splitting fraction in energy harvesting to obtain optimal throughput have been derived.

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