

## INVESTIGATION ON HARVESTED ENERGY-ASSISTED RELAY SELECTION MODES IN WIRELESS POWERED FULL-DUPLEX RELAYING NETWORKS

### ĐÁNH GIÁ CHẾ ĐỘ TRUYỀN LỰA CHỌN NÚT CHUYỂN TIẾP THU THẬP NĂNG LƯỢNG VÔ TUYẾN TRONG MẠNG VÔ TUYẾN CHUYỂN TIẾP SONG CÔNG

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#### ABSTRACT

*In this paper, the authors investigate relay selection for decode-and-forward (DF) Full-duplex (FD) based wireless energy harvesting relaying networks. Considering time-switching based relaying (TSR) protocol, this investigation is concerned with the performance of maximum harvested energy relay selection (MHE-RS) scheme. In particular, this work analyzes the system performance in terms of outage probability (OP) and throughput over Rayleigh fading channels. As important achievement, the integral-form for exact expression and closed-form for approximate expression are derived. Finally, these analytical expressions are validated by the Monte-Carlo simulation.*

**Keywords:** Decode and forward; energy harvesting; time switching based relaying; relay selection.

#### TÓM TẮT

*Trong bài báo này, chúng tôi đánh giá mạng vô tuyến chuyển tiếp lựa chọn nút chuyển tiếp song công (FD) áp dụng kỹ thuật giải mã và chuyển tiếp (DF) có khả năng thu thập năng lượng vô tuyến. Xem xét giao thức chuyển tiếp dựa trên chuyển đổi thời gian, bài báo này đề cập giao thức lựa chọn nút chuyển tiếp thu thập năng lượng cực đại MHE-RS. Cụ thể, bài báo phân tích chất lượng hệ thống liên quan xác suất dừng và thông lượng cho mạng vô tuyến dùng các kênh truyền fading Rayleigh. Kết quả quan trọng là biểu thức chính xác dạng tích phân và biểu thức tính gần đúng đã được chứng minh. Cuối cùng, các biểu thức phân tích này được kiểm chứng qua mô phỏng Monte-Carlo.*

**Từ khóa:** giải mã và chuyển tiếp; thu thập năng lượng; chuyển tiếp dựa trên thay đổi thời gian thu năng lượng; lựa chọn nút chuyển tiếp.

#### 1. INTRODUCTION

The wireless communication network has a limited lifetime and battery replacement or charging is a way to keep continuing operation in such network. This takes a lot of time, inconvenient, risky or sometime unfeasible. In recent years, there are many works related to energy harvesting from the natural environment, such as sun, solar, wind, vibration and so on [1]. In fact,

this technique can provides new power supply schemes for wireless communication network and solve problem of energy assumption efficient in sensor node. Normally, the data transmission mode operates in one-way in wireless network. The performances of relay networks will be improved by full duplex transfer [2,3]. In addition, the RF signal can carry both energy and information which leads to deploy simultaneous wireless information and power

transfer (SWIPT) [5,6]. In hardware implementation, the circuit design aims to combine information processing and power transfer at the same time on a unit. Furthermore, SWIPT using relays has been known as great idea to expand coverage and prolong lifetime of wireless network that also a way to improving quality of service.

In this paper, we are concerned with relay selection system and using DF protocol. In this system, the transmitted signal transfers to relays from source, after that the relays which assists system compare and choose a best relay to forward to destination.

The contributions of this paper are list as follow

i) Proposing a relay selection protocol, which can select an appropriate relay to assist the transmission between a given source-destination pair considering a dual-hop DF relaying network with multiple wireless energy harvesting relays.

ii) Deriving the analytical expression for outage probability and throughput, also obtaining the closed-form expression of their approximation in high SNR case. Based on the analytical expressions, the optimal throughput and energy harvesting time are discussed in detail.

The rest of this paper is organised as follows. In Section 2, the system model and proposed relay selection protocols are presented. In Section 3, we formulate the expressions for outage probability and throughput of system. In Section 4, numerical results verify derived analytical expressions. Finally, Section 5 concludes the paper.

## 2. SYSTEM MODEL

### 2.1. Relay selection network topology

In this model, we investigate a one-way FD EH relay selection network with DF protocol as illustrated in Fig. 1. The system consists of one source node and one destination node, denoted by  $S$  and  $D$ , respectively and  $N$  relays, denoted by  $R_i, i=1, \dots, N$ .

In this scenario, it is assumed that source node and destination node are equipped with one antenna and relay node is equipped with two antennas. The self-interference is caused by the FD mode. The residual self-interference channels at relay node  $R_i$  is denoted by  $f_i$ .

It is assumed that the direct link between sources does not exist due to the shadowing effect.

*Relay model:* To perform capability of harvested energy, in this FD relaying, the relay only has limited power supply, and relies on external charging through harvesting energy from the source transmission [6,7].

### 2.2. Relay Selection Protocol

Relay selection (RS) is an effective method to enhance the performance of multi-relay communication system with a low complexity, in which only one relay is selected among all the relay candidates [5]. In this paper, we proposes RS scheme for one-way FD EH relaying network, namely, maximum harvested energy relay selection (MHE-RS). In particular, the relay with the largest harvested energy is chosen to assistance transmit information to destination node. The index of the selected relay is given by

$$b = \arg \max_{i=1, \dots, N} (E_i) \quad (1)$$

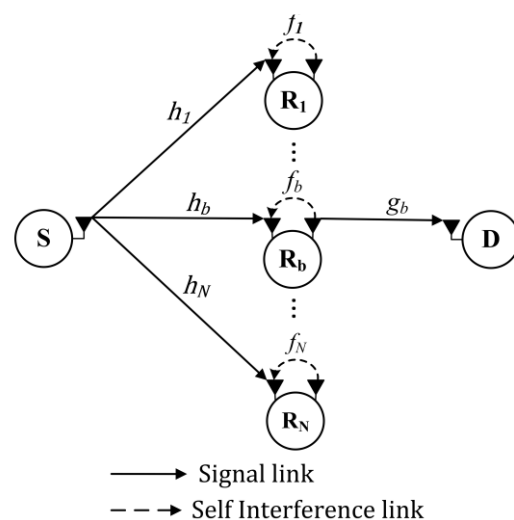


Fig.1. System model

### 2.3. Analysing system performance

In energy harvesting phase, source  $S$  transmits power to assistance node  $R$  via RF signal. Therefore, the received signal at  $R$  is described as

$$y_i = \frac{\sqrt{P_s}}{\sqrt{d_{1i}^m}} \times h_i \times x_s(t) + n_{r_i}(t) \quad (2)$$

in which  $i=1, \dots, N$  is the number of relay node.

Hence, we can calculate the total harvested energy during the EH stage as following [3]

$$E_i = \eta \frac{P_s}{d_{1i}^m} |h_i|^2 \alpha T \quad (3)$$

where  $0 \leq \eta \leq 1$  is the portion signal power splitting to scavenge energy.

As in [3, 4], we assume that the energy harvested during the energy harvesting phase is stored in a super-capacitor and then fully consumed by the relay to forward the source signal to the destination. Hence, the relay transmit power can be computed as .

$$p_{r_i} = \frac{E_i}{(1-\alpha)T} = \mu \frac{P_s}{d_{1i}^m} |h_i|^2 \quad (4)$$

Here, we denoted the value  $\mu = \eta \alpha / (1-\alpha)$

In the information processing stage, the sources,  $S$ , transmits its respective symbol  $x_s(t)$  to  $R_i$ . Simultaneously,  $R_i$  broadcasts another symbol  $x_{r_i}(t)$  to the destination  $D$ . Therefore, the received signal at  $R_i$  is

$$y_{r_i}(t) = \frac{\sqrt{P_s}}{\sqrt{d_{1i}^m}} \times h_i \times x_s(t) + \sqrt{p_r} \times f_i \times x_{r_i}(t) + n_{r_i}(t) \quad (5)$$

In DF relaying protocol, the transmitted symbol at  $R_i$  is denoted by  $x_{r_i}(t)$ , and is the code translation of the prior received signal at relay, given as

$$x_{r_i}(t) = \overline{x_s}(t) \quad (6)$$

At destination node, the received signal at  $D$ ,  $y_d(t)$ , is expressed as

$$y_d(t) = \frac{\sqrt{p_{r_i}}}{\sqrt{d_{2i}^m}} g_i x_{r_i}(t) + n_d(t) \quad (7)$$

where  $n_d(t)$  is the AWGN at  $D$  with zero-mean and variance of  $N_0$ .

According to (5) and applying some steps in manipulation, the instantaneous received SINR of  $S \rightarrow R$  hop is written as

$$\gamma_{s,r}^i = \frac{\gamma_s |h_i|^2}{\mu \gamma_s |h_i|^2 |f_{r_i}|^2 + 1} \quad (8)$$

Similarly, based on (7) the instantaneous received SNR of  $R \rightarrow D$  hop is expressed as

$$\gamma_{r,d}^i = \mu \gamma_s |h_i|^2 |g_i|^2 \quad (9)$$

where  $\gamma_s = p_s / N_0$

To look insights system performance, we evaluate the special case. In high SNR, i.e.  $\gamma_s \rightarrow \infty$ , the expressions in (8) and (9) can be re-expressed respectively as below

$$\gamma_{s,r}^{\gamma_s \rightarrow \infty, i} = \frac{1}{\mu |f_i|^2} \quad (10)$$

$$\text{And } \gamma_{r,d}^{\gamma_s \rightarrow \infty, i} = \mu \gamma_s |h_i|^2 |g_i|^2 \quad (11)$$

Based on DF relaying protocol, the end-to-end SINR of the system is determined as

$$\gamma_{e2e}^i = \min(\gamma_{s,r}^i, \gamma_{r,d}^i) \quad (12)$$

## 3. PERFORMANCE ANALYSIS

In this section, we will study the performance of the considered schemes in terms of outage probability and throughput over Rayleigh fading channels.

Through this paper, we denote “ $OP$ ” stands for outage probability and “ $\tau$ ” for throughput of the system, PDF is probability density function and CDF is cumulative distribution function.

### 3.1. Outage Probability Analysis

The outage probability of the system is defined as the probability that the system SINR is below a threshold SNR,  $\gamma_0$ . In

two-hop DF relaying protocol, the mistake of one of the two hops leads to the outage event of the transmission. Thus, the system's outage probability can be mathematically formulated as

$$OP = \Pr\{\gamma_{e2e}^b < \gamma_0\} \quad (13)$$

Substituting (12) into (13), the outage can be re-written as

$$\begin{aligned} OP &= \Pr\{\min(\gamma_{s,r}^b, \gamma_{r,d}^b) < \gamma_0\} \\ &= \Pr\{\gamma_{r,d}^b < \gamma_0\} + \Pr\{\gamma_{r,d}^b > \gamma_0, \gamma_{s,r}^b < \gamma_0\} \\ &= OP_1 + OP_2 \end{aligned} \quad (14)$$

Interestingly, by substituting (3) into (1), the best selected relay index is expressed as

$$b = \arg \max_{i=1, \dots, N} (|h_i|^2) \quad (15)$$

**Proposition 1:** The outage probability of MHE-RS scheme is

$$\begin{aligned} OP_{MHE-RS} &= \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \frac{k}{\Omega_h} \left\{ 1 - S\left(\frac{\gamma_0}{\mu\gamma_s\Omega_g}, \frac{k}{\Omega_h}\right) \right. \\ &\left. + \exp\left(-\frac{1}{\mu\gamma_0\Omega_f}\right) S\left(\frac{\gamma_0}{\mu\gamma_s\Omega_g} - \frac{1}{\mu\gamma_s\Omega_f}, \frac{k}{\Omega_h}\right) \right\} \end{aligned} \quad (16)$$

Where  $S(u, v) = \int_{\gamma_0/\gamma_s}^{\infty} \exp(-u/x - vx) dx$ ,

**Proof:** see in appendix A.

**Proposition 2:** In high SNR the outage probability of MHE RS scheme is given as

$$\begin{aligned} OP_{MHE-RS}^{\gamma_s \rightarrow \infty} &= 1 - 2 \left\{ 1 - \exp\left(\frac{-1}{\mu\Omega_f\gamma_0}\right) \right\} \\ &\sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \sqrt{\frac{k\gamma_0}{\mu\gamma_s\Omega_g\Omega_h}} K_1 \left( 2 \sqrt{\frac{k\gamma_0}{\mu\gamma_s\Omega_g\Omega_h}} \right) \end{aligned} \quad (17)$$

**Proof:** In high SNR, with independence of  $\gamma_{s,r}^{\gamma_s \rightarrow \infty}$  and  $\gamma_{r,d}^{\gamma_s \rightarrow \infty}$  the outage expression in (13) can be derived as

$$\begin{aligned} OP^{\gamma_s \rightarrow \infty} &= 1 - \left( 1 - \underbrace{\Pr\{\gamma_{s,r}^{\gamma_s \rightarrow \infty, b} < \gamma_0\}}_{OP_1^{\gamma_s \rightarrow \infty}} \right) \\ &\times \left( 1 - \underbrace{\Pr\{\gamma_{r,d}^{\gamma_s \rightarrow \infty, b} < \gamma_0\}}_{OP_2^{\gamma_s \rightarrow \infty}} \right) \end{aligned} \quad (18)$$

The first element in (18) is

$$\begin{aligned} OP_1^{\gamma_s \rightarrow \infty} &= \Pr\left\{|f_i|^2 > \frac{1}{\mu\gamma_0}\right\} = 1 - F_{|f_i|^2}\left(\frac{1}{\mu\gamma_0}\right) \\ &= \exp\left(-\frac{1}{\mu\Omega_f\gamma_0}\right) \end{aligned} \quad (19)$$

and  $OP_2$  can be expressed as below

$$\begin{aligned} OP_2^{\gamma_s \rightarrow \infty} &= 1 - 2 \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \\ &\sqrt{\frac{k\gamma_0}{\mu\gamma_s\Omega_g\Omega_h}} K_1 \left( 2 \sqrt{\frac{k\gamma_0}{\mu\gamma_s\Omega_g\Omega_h}} \right) \end{aligned} \quad (20)$$

Finally, substituting (19) and (20) into (18) to results in the proposition 2 is derived.

### 3.2. Throughput Analysis

In delay- constrained transmission mode, the source transmits information at a fixed rate and outage probability plays a pivotal role in the throughput. Given that source S transmit information with fixed rates  $R_c$  bits/sec/Hz, respectively, then we derive the throughput as below

More specifically, the throughput of the relay selection and full duplex energy harvesting relaying system is calculated as

$$\tau_{MHE-RS} = (1 - \alpha) \times (1 - OP_{MHE-RS}) \times R_c \quad (21)$$

Especially, in high SNR, the desired throughput is expressed as

$$\tau_{MHE-RS}^{\gamma_s \rightarrow \infty} = (1 - \alpha) (1 - OP_{MHE-RS}^{\gamma_s \rightarrow \infty}) R_c \quad (22)$$

The optimal time switching could be calculated by solving the optimization problem as below

$$\alpha_{MHE-RS}^{opt} = \arg \max_{0 < \alpha < 1} \{\tau_{MHE-RS}(\alpha)\} \quad (23)$$

It is worth noting that finding optimal coefficient is hard problem. Fortunately, these optimal time switching fractions can be found in simulation section.

### 4. NUMERICAL RESULTS AND DISCUSSION

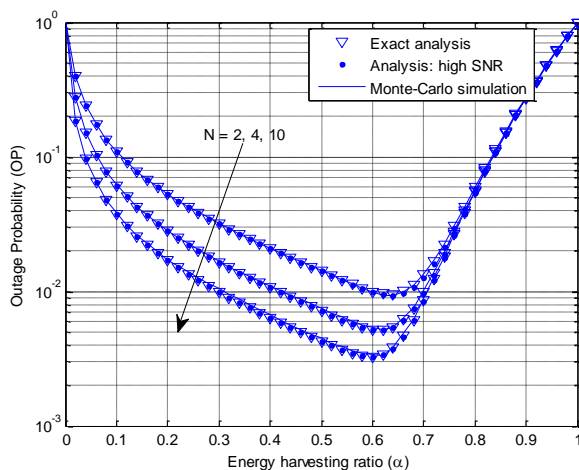
In this section, we present numerical results in order to illustrate the solution to the

throughput optimization issues of the energy harvesting enabled relaying scheme in the proposed RS protocols. Through numerical method, the optimal throughput in terms of energy harvesting time ratio in the TSR scheme is evaluated. In these simulations, we setup the transmission power  $\gamma_s = 25$  (dB), the distance corresponds each hop is normalized as  $d_1 = d_2 = 1$ , path loss factor  $m = 3$ , the energy harvesting efficiency  $\eta = 0.9$ , the fixed transmission rate of the source  $R_c = 2$  (bps), hence  $\gamma_0 = 2^2 - 1 = 3$ . In all simulations,  $\Omega_h$  and  $\Omega_g$  are denoted as the mean values of the exponential random variables  $|h_i|^2$  and  $|g_i|^2$ , respectively, are set to  $\Omega_h = d_1^{-m}$  and  $\Omega_g = d_2^{-m}$ .

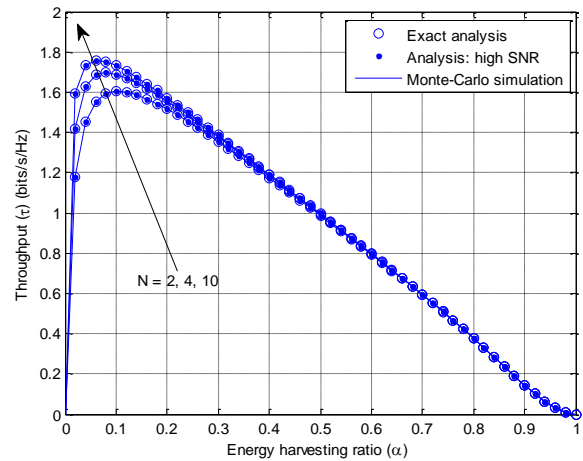
#### 4.1. Impact of energy harvesting time ratio

The outage probability depends on the energy harvesting time ratio as illustration in Fig. 3. As can be seen clearly that when the time use to energy harvesting  $\alpha = 0.4$  to  $\alpha = 0.7$ , it results in outage probability come to zero.

In parallel, the throughput depends on the energy harvesting time ratio. When the outage probability is considered in high rate that means the quantity of throughput is reduced.



**Fig2.** Outage probability versus energy harvesting time ratio. With number of assistant relay  $N = 2, 4, 10$ , mean of self interference channel  $\lambda_f = -15$  (dB)



**Fig 3.** Throughput versus energy harvesting time ratio.

#### 4.2. Performance of the system versus the number of the relay

For evaluation of impacts of the number of the relay on the system performance, the throughput is proved that depend on the number of the relay. The more number of the relay, the outage probability will be improved as in Fig. 4, while the higher number of relay leads to higher throughput as in Fig. 5. It is confirmed that the outage performance and the throughput of both exact analysis and analysis with high SNR are the same.

## 5. CONCLUSION

In this paper, the authors have proposed a relay selection protocol for FD-DF relaying network with SWIPT, where one of candidate constrained relay node is selected to forward the source signal to the destination. In order to determine the achievable throughput, analytical expressions for the outage probability and the optimal value of energy harvesting time in TSR protocol can be found by simulation. The simulation results show that, the more relays support, the more throughput can be obtained. Besides, the quality of relaying system also depends on proposed relay selection scheme.

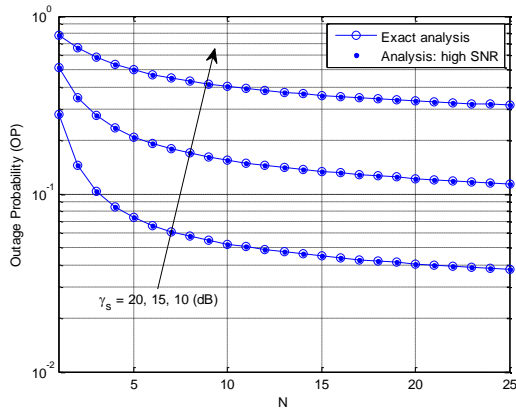


Fig 4. Outage probability of the system versus the number of the relay  $\alpha = 0.2$ ,  $\lambda_f = -15$  (dB)

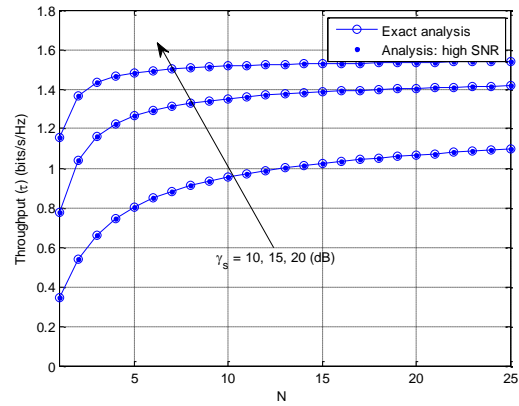


Fig 5. Throughput of the system versus the number of the relay  $\alpha = 0.2$ ,  $\lambda_f = -15$  (dB)

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### APPENDIX A

Based on relay selection scheme in (15), CDF of  $|h_b|^2$  channel is given as

$$f_{|h_b|^2}(x) = \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \frac{k}{\Omega_h} \exp\left(\frac{-kx}{\Omega_h}\right) \quad (24)$$

where the value of first term in (14) is determined as

$$OP_1 = \Pr\left\{\mu\gamma_s |h_b|^2 |g_b|^2 < \gamma_0\right\} = \int_0^{\infty} F_{|g_b|^2}\left(\frac{\gamma_0}{\mu\gamma_s x}\right) f_{|h_b|^2}(x) dx \quad (25)$$

Substituting the PDF of  $|h_b|^2$  in (24) and CDF of  $|g_b|^2$  into (25). The OP is re-expressed as

$$OP_1 = 1 - \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \frac{k}{\Omega_h} \int_0^{\infty} \exp\left(\frac{-\gamma_0}{\mu\gamma_s\Omega_g x} - \frac{kx}{\Omega_h}\right) dx \quad (26)$$

$$OP_2 = \Pr\left\{|g_b|^2 > \frac{\gamma_0}{\mu\gamma_s|h_b|^2}, |f_i|^2 > \frac{1}{\mu\gamma_0} - \frac{1}{\mu\gamma_s|h_b|^2}\right\} \quad (27)$$

$$= \int_0^{\gamma_0/\gamma_s} \left(1 - F_{|g_b|^2}\left(\frac{\gamma_0}{\mu\gamma_s\Omega_g x}\right)\right) f_{|h_b|^2}(x) dx + \int_{\gamma_0/\gamma_s}^{\infty} \left(1 - F_{|g_i|^2}\left(\frac{\gamma_0}{\mu\gamma_s\Omega_g x}\right)\right) \times \left(1 - F_{|f_i|^2}\left(\frac{1}{\mu\gamma_0} - \frac{1}{\mu\gamma_s x}\right)\right) \times f_{|h_b|^2}(x) dx$$

Finally, the second term in (14) is determined as

$$OP_2 = \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \frac{k}{\Omega_h} \int_0^{\gamma_0/\gamma_s} \exp\left(\frac{-kx}{\Omega_h} - \frac{\gamma_0}{\mu\gamma_s\Omega_g x}\right) dx + \exp\left(-\frac{1}{\mu\gamma_0\Omega_f}\right) \quad (28)$$

$$\times \sum_{k=1}^N \binom{N}{k} (-1)^{k-1} \frac{k}{\Omega_h} \times \int_{\gamma_0/\gamma_s}^{\infty} \exp\left(\frac{1}{x\mu\gamma_s\Omega_f} - \frac{\gamma_0}{x\mu\gamma_s\Omega_g} - \frac{kx}{\Omega_h}\right) dx$$

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