International Journal of Electrical and Computer Engineering (IJECE)
Vol. 10, No. 2, April 2020, pp. 1255~1262
ISSN: 2088-8708, DOI: 10.11591/ijece.v10i2.pp1255-1262

Hybrid TSR-PSR in nonlinear EH half duplex network: system performance analysis

Phu Tran Tin[1], Duy-Hung Ha[2], Tran Thanh Trang[3]
[1]Faculty of Electronics Technology, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam
[2]Wireless Communications Research Group, Faculty of Electrical and Electronics Engineering,
Ton Duc Thang University, Ho Chi Minh City, Vietnam
[3]National Key Laboratory of Digital Control and System Engineering, Ho Chi Minh City, Vietnam

Article Info

Article history:

Received May 10, 2019
Revised Oct 9, 2019
Accepted Oct 15, 2019

Keywords:

Energy harvesting (EH)
Half-duplex (HD)
Monte Carlo simulation
Relaying network
Success probability (SP)

ABSTRACT

Nowadays, harvesting energy (EH) from green environmental sources and converting this energy into the electrical energy used in purpose to supply the communication network devices is considered the main research direction. In this research, we investigate the hybrid TSR-PSR Nonlinear Energy Harvesting (EH) Half-duplex (HD) Relaying network in terms of the Success Probability (SP). For this purpose, we derive the integral-form of the system SP. In addition, we use the Monte Carlo simulation for verifying the correctness of the analytical expression. We can see in the research results that all the simulation and analytical values are the same in connection with all primary system parameters.

Corresponding Author:

Duy-Hung Ha,
Wireless Communications Research Group,
Faculty of Electrical and Electronics Engineering,
Ton Duc Thang University,
Ho Chi Minh City, Vietnam.
Email: haduyhung@tdtu.edu.vn

1. INTRODUCTION

Nowadays, harvesting energy (EH) from green environmental sources and converting this energy into the electrical energy used in purpose to supply the communication network devices is considered the main research direction. Furthermore, this solution can provide not only the environmentally friendly energy supplies, but also the self-maintained, long-lived, and autonomous communication systems. In the series of the leading environmental green energy sources, such as solar, wind, geothermal, and mechanical, the radio frequency (RF) signals can be considered as the prospective energy source in the future. [1-9]. Wireless nodes can harvest RF energy either in the time domain before data reception, or in the power domain by dividing the received RF signals for the EH and information decoding (ID) [9-12]. In a cooperative network, authors in [13-16] developed two new relaying protocols based on the receiver structures adopted at R, termed time switching-based relaying (TSR) and power splitting-based relaying (PSR). From [14-16], the TSR and PSR protocols have some drawbacks; for instance, TSR has to lose some information while it switches to the harvesting mode and PSR has a low coverage area. In another way, PSR requires a complicated hardware structure to make sure that a proper portion of energy from the source signal is extracted for energy harvesting. In contrast, TSR can simplify the hardware at the expense of the throughput or achievable rate of the system. Based on the fact that both TSR and PSR protocols have their drawbacks, the prospective idea is to combine these two protocols to get the best out of them. This is a solution that can obtain in this paper by using an adaptive relaying protocol [17-18].

In this research, we investigate the hybrid TDR-PSR Nonlinear Energy Harvesting (EH) Half-duplex (HD) Relaying network in terms of the Success Probability (SP). For this purpose, we derive the integral form of the SP in connection with all primary system parameters. Also, we use the Monte Carlo simulation for verifying the correctness of the analytical expression. We can focus on the main contributions as the follows
a. The hybrid TDR-PSR Nonlinear EH HD Relaying network is proposed and investigated.
b. The integral-form expressions of the system SP are derived.
c. The correctness of the analytical expressions are verified by the Monte Carlo simulation.

2. SYSTEM MODEL

In this paper, the hybrid TDR-PSR Nonlinear EH HD Relaying network is illustrated in Figure 1. In this model, the information is transferred from the source (S) to the multi-destination (D_i), through relay node (R). The energy harvesting (EH) and information transmission (IT) of the system model are proposed in Figure 2. As shown in Figure 2, T is the block time. In the first interval time (αT), the relay node R harvests energy ρP_s and receives the information $(1-\rho)P_s$ from the source signal, where α is the time switching factor $\alpha \in (0, 1)$ and ρ is the power splitting factor $\rho \in (0, 1)$. In the remaining interval time (1-α) T, the relay node R transfers information to the destination node D [12-16].

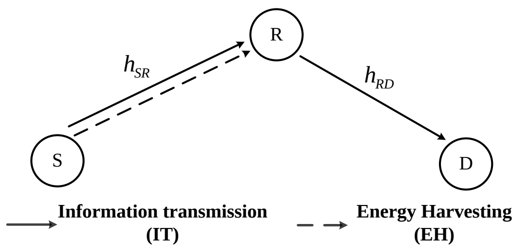

Figure 1. System model

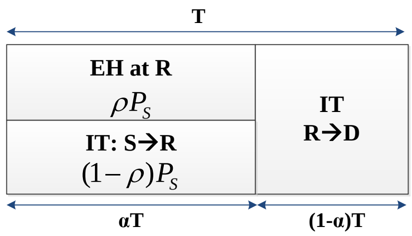

Figure 2. The EH and ITphases

2.1. Energy harvesting (EH) phase

In this phase, the received signal at the relay R can be given as

$$y_r = \sqrt{\rho P_s} h_{SR} x_s + n_r \tag{1}$$

Where x_s is the energy symbol and must be satisfied $\mathrm{E}\left\{|x_s|^2\right\} = 1$ which $\mathrm{E}\{\bullet\}$ is the expectation operator.

P_s is the transmit power of the source.
n_r is the additive white Gaussian noise (AWGN) at the relay node with variance N_0.
h_{SR} is channel gain between S-R link and belongs to Rayleigh channel.

In this paper, the nonlinear transformation model proposed in reference [19] is used. The transmission power at the relay can be given as

$$P_r = \begin{cases} \kappa P_s |h_{SR}|^2, & P_s |h_{SR}|^2 \le P_{th} \\ \kappa P_{th}, & P_s |h_{SR}|^2 > P_{th} \end{cases} \tag{2}$$

Where we denote $\kappa = \frac{\eta\rho\alpha}{1-\alpha}$, P_{th} is the saturation threshold of the rechargeable power of the hardware circuit.

2.2. Information transmission (IT) phase

The received signal at the relay R in the first time slot can be calculated as

$$y_r = \sqrt{(1-\rho)P_s} h_{SR} x_s + n_r \tag{3}$$

In the second time slot, after receiving the signal from the source R, the relay amplifíes with β factor as following

$$\beta = \frac{x_r}{y_r} = \sqrt{\frac{1}{(1-\rho)P_s |h_{SR}|^2 + N_0}} \tag{4}$$

The received signal at the destination D can be formulated as

$$y_d = \sqrt{P_r} h_{RD} x_r + n_d \tag{5}$$

Where x_r is the transmission signal at relay and must be satisfied $\mathrm{E}\left\{|x_r|^2\right\} = 1$, n_d is the additive white Gaussian noise (AWGN) at the relay node with variance N_0, h_{RD} is channel gain between R-D link and also belongs to Rayleigh channel.

Substituting (4) into (5) and then combine with (3), (5) can be rewritten as

$$\begin{aligned} y_d &= \sqrt{P_r} h_{RD} \beta y_r + n_d = \sqrt{P_r} h_{RD} \beta \left[\sqrt{(1-\rho)P_s} h_{SR} x_s + n_r \right] + n_d \\ &= \underbrace{\sqrt{(1-\rho)P_s} h_{SR} x_s \sqrt{P_r} h_{RD} \beta}_{signal} + \underbrace{\sqrt{P_r} h_{RD} \beta n_r + n_d}_{noise} \end{aligned} \tag{6}$$

The end to end signal to noise ratio can be computed as

$$\begin{aligned} \gamma_{e2e} &= \frac{(1-\rho)P_r P_s |h_{SR}|^2 |h_{RD}|^2 \beta^2}{P_r |h_{RD}|^2 \beta^2 N_0 + N_0} = \frac{(1-\rho)P_r P_s |h_{SR}|^2 |h_{RD}|^2}{P_r |h_{RD}|^2 N_0 + N_0 \left[(1-\rho)P_s |h_{SR}|^2 + N_0 \right]} \\ &\approx \frac{(1-\rho)P_s |h_{SR}|^2 |h_{RD}|^2}{|h_{RD}|^2 N_0 + \frac{(1-\rho)P_s |h_{SR}|^2 N_0}{P_r}} \end{aligned} \tag{7}$$

3. THE SYSTEM PERFORMANCE

The successful probability (SP) can be defined as

$$SP = \Pr\left(\gamma_{e2e} > \gamma_{th}\right) = \Pr\left(\frac{(1-\rho)P_s |h_{SR}|^2 |h_{RD}|^2}{|h_{RD}|^2 N_0 + \frac{(1-\rho)P_s |h_{SR}|^2 N_0}{P_r}} > \gamma_{th} \right) \tag{8}$$

Where γ_{th} is the threshold of the system.

Substituting (2) into (8), (8) can be obtained as

$$\begin{aligned} SP &= \Pr\left(\frac{(1-\rho)P_s|h_{SR}|^2|h_{RD}|^2}{|h_{RD}|^2 N_0 + \frac{(1-\rho)N_0}{\kappa}} > \gamma_{th}, P_s|h_{SR}|^2 \le P_{th} \right) \\ &+ \Pr\left(\frac{(1-\rho)P_s|h_{SR}|^2|h_{RD}|^2}{|h_{RD}|^2 N_0 + \frac{(1-\rho)P_s|h_{SR}|^2 N_0}{\kappa P_{th}}} > \gamma_{th}, P_s|h_{SR}|^2 > P_{th} \right) \\ &= P_1 + P_2 \end{aligned} \tag{9}$$

Where we denote

$$P_1 = \Pr\left(\frac{(1-\rho)P_s|h_{SR}|^2|h_{RD}|^2}{|h_{RD}|^2 N_0 + \frac{(1-\rho)N_0}{\kappa}} > \gamma_{th}, P_s|h_{SR}|^2 \le P_{th} \right) \tag{10}$$

We denote

$$X = |h_{SR}|^2, Y = |h_{RD}|^2 \text{ and } \Psi = \frac{P_s}{N_0}, \chi = \frac{P_{th}}{P_s}.$$

The (10) can be rewritten as

$$P_1 = \Pr\left(\frac{(1-\rho)\Psi XY}{Y + \frac{(1-\rho)}{\kappa}} > \gamma_{th}, X \le \chi \right) = \int_0^{\chi} \underbrace{\Pr\left[\frac{(1-\rho)\Psi xY}{Y + \frac{(1-\rho)}{\kappa}} > \gamma_{th} \right]}_{\Phi(x)} f_X(x)dx \tag{11}$$

Here, considering that

$$\begin{aligned} \Phi(x) &= \Pr\left[\frac{(1-\rho)\Psi xY}{Y + \frac{(1-\rho)}{\kappa}} > \gamma_{th} \right] = \Pr\left[Y\left\{(1-\rho)\Psi x - \gamma_{th}\right\} > \frac{(1-\rho)\gamma_{th}}{\kappa} \right] \\ &= \begin{cases} \Pr\left[Y > \frac{(1-\rho)\gamma_{th}}{\kappa\left\{(1-\rho)\Psi x - \gamma_{th}\right\}} \right], & x \ge \frac{\gamma_{th}}{(1-\rho)\Psi} \\ 0, & x < \frac{\gamma_{th}}{(1-\rho)\Psi} \end{cases} \\ &= \begin{cases} \exp\left[-\frac{(1-\rho)\lambda_{rd}\gamma_{th}}{\kappa\left\{(1-\rho)\Psi x - \gamma_{th}\right\}} \right], & x \ge \frac{\gamma_{th}}{(1-\rho)\Psi} \\ 0, & x < \frac{\gamma_{th}}{(1-\rho)\Psi} \end{cases} \end{aligned} \tag{12}$$

Where λ_{rd} is the mean value of the random variable (RV) $|h_{RD}|^2$.

We assume that $\frac{\gamma_{th}}{(1-\rho)\Psi} \le \chi$ and then substituting (12) into (11), we have

$$P_1 = \lambda_{sr} \int_{\frac{\gamma_{th}}{(1-\rho)\Psi}}^{\chi} \exp\left[-\frac{(1-\rho)\lambda_{rd}\gamma_{th}}{\kappa\left\{(1-\rho)\Psi x - \gamma_{th}\right\}}\right] \times \exp\left(-\lambda_{sr} x\right) dx \tag{13}$$

Now, we will find P_2 from (9) as the following

$$P_2 = \Pr\left(\frac{(1-\rho)\Psi XY}{Y + \frac{(1-\rho)X}{\kappa\chi}} > \gamma_{th}, X > \chi\right) = \int_{\chi}^{\infty} \underbrace{\Pr\left[\frac{(1-\rho)\Psi xY}{Y + \frac{(1-\rho)x}{\kappa\chi}} > \gamma_{th}\right]}_{\Theta(x)} f_X(x) dx \tag{14}$$

Where

$$\Theta(x) = \Pr\left[\frac{(1-\rho)\Psi xY}{Y + \frac{(1-\rho)x}{\kappa\chi}} > \gamma_{th}\right] = \Pr\left\{Y\left[(1-\rho)\Psi x - \gamma_{th}\right] > \frac{(1-\rho)x\gamma_{th}}{\kappa\chi}\right\}$$
$$= \begin{cases} \Pr\left\{Y > \frac{(1-\rho)x\gamma_{th}}{\kappa\chi\left[(1-\rho)\Psi x - \gamma_{th}\right]}\right\}, & x \ge \frac{\gamma_{th}}{(1-\rho)\Psi} \\ 0, & x < \frac{\gamma_{th}}{(1-\rho)\Psi} \end{cases} \tag{15}$$
$$= \begin{cases} \exp\left\{-\frac{(1-\rho)\lambda_{rd} x\gamma_{th}}{\kappa\chi\left[(1-\rho)\Psi x - \gamma_{th}\right]}\right\}, & x \ge \frac{\gamma_{th}}{(1-\rho)\Psi} \\ 0, & x < \frac{\gamma_{th}}{(1-\rho)\Psi} \end{cases}$$

Substituting (15) into (14), P_2 can be claimed as

$$P_2 = \lambda_{sr} \int_{\chi}^{\infty} \exp\left\{-\frac{(1-\rho)\lambda_{rd} x\gamma_{th}}{\kappa\chi\left[(1-\rho)\Psi x - \gamma_{th}\right]}\right\} \times \exp(-\lambda_{sr} x) dx \tag{16}$$

Finally, we can obtain the SP as following

$$SP = \lambda_{sr} \int_{\frac{\gamma_{th}}{(1-\rho)\Psi}}^{\chi} \exp\left[-\frac{(1-\rho)\lambda_{rd}\gamma_{th}}{\kappa\left\{(1-\rho)\Psi x - \gamma_{th}\right\}}\right] \times \exp\left(-\lambda_{sr} x\right) dx + \lambda_{sr} \int_{\chi}^{\infty} \exp\left\{-\frac{(1-\rho)\lambda_{rd} x\gamma_{th}}{\kappa\chi\left[(1-\rho)\Psi x - \gamma_{th}\right]}\right\} \times \exp(-\lambda_{sr} x) dx \tag{17}$$

4. NUMERICAL RESULTS AND DISCUSSION

In this section, the Monte Carlo simulation is used for validating the analytical expression in the above section [20-25]. Figure 3 shows the SC versus time switching factor α with the main system parameters as η=0.4, 0.85; $\psi = P_{th} = 5$ dB; ρ=0.5 and $\gamma_{th}=0.25$. From Figure 3 we can state that the SP of the system network has a massive increase while time switching factor α varies from 0 to 0.9, and the simulation and analytical values are the same. Moreover, the effect of energy efficiency η on the system SP. Here, we set α=0.5; ρ=0.5 and $\gamma_{th}=0.25$. Similarity as Figure 4, the system SP increases significantly with the rising of energy efficiency η, and the analytical results agree with the simulation values.

Furthermore, the influence of P_{th} and ψ on the system SP are drawn in Figures 5 and 6, respectively. From the results, we can see that the system SP increases considerably with the rising of P_{th} and ψ. In addition, the system SP versus the power splitting factor ρ is presented in Figure 7. From Figure 7, we can see that the system SP has a considerable increase in the first interval of ρ and the has a decease. The optimal value of the system SP can be obtained with the values of ρ from 0.5 to 0.6. In all Figures 5-7, the simulation values match well with the analytical values for verifying the correctness of the analytical expressions.

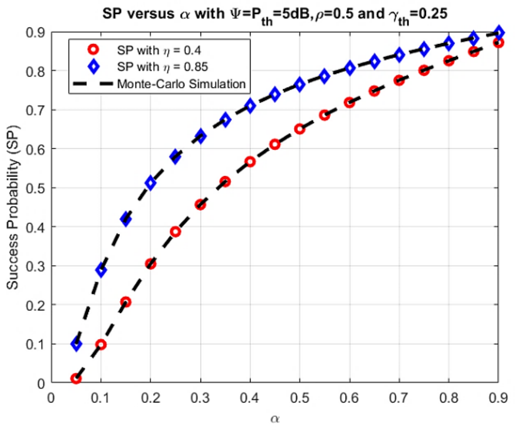

Figure 3. SP versus α

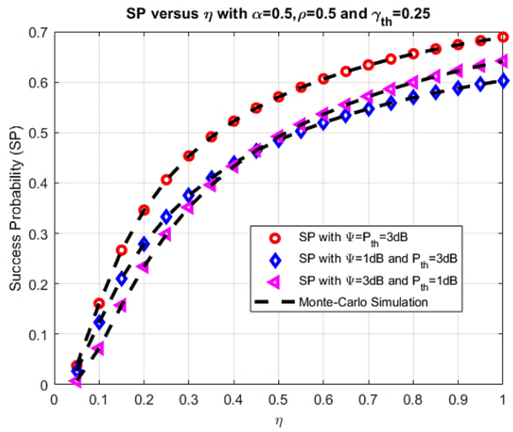

Figure 4. SP versus η

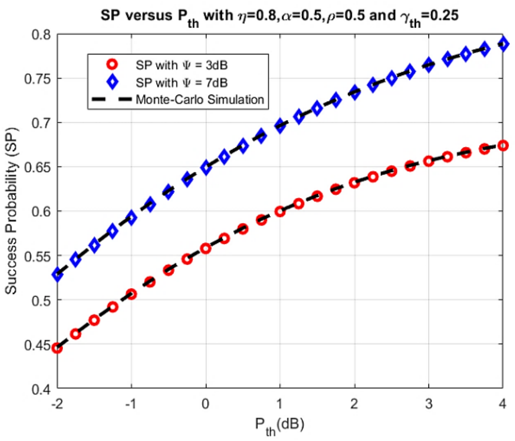

Figure 5. SP versus P_{th}

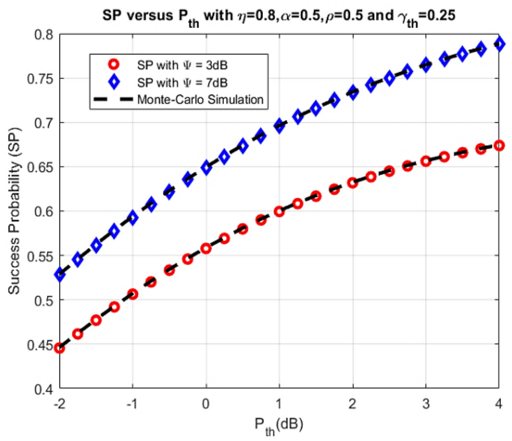

Figure 6. SP versus ψ

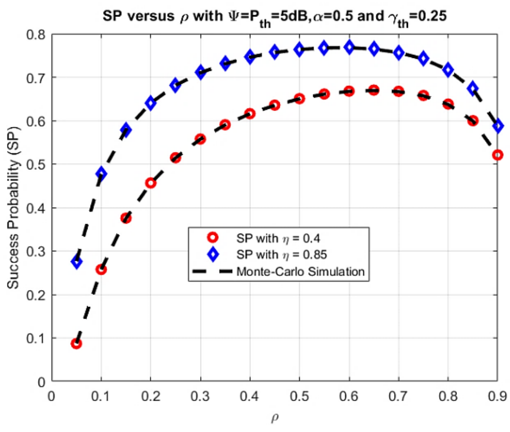

Figure 7. SP versus ρ

5. CONCLUSION

In this research, we investigate the hybrid TDR-PSR Nonlinear Energy EH HD Relaying network in terms of the SP. Firstly, we derive the integral form of the SP in connection with all primary system parameters. In addition, we use the Monte Carlo simulation for verifying the correctness of the analytical expression. From the research results, we can state that all the simulation and analytical values are the same in connection with all primary system parameters.

ACKNOWLEDGMENTS

This research was supported by National Key Laboratory of Digital Control and System Engineering (DCSELAB), HCMUT, VNU-HCM, Vietnam.

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