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Hybrid protocol for wireless EH network over weibull fading channel: performance analysis

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ABSTRACT

In this paper, the hybrid TSR-PSR protocol for wireless energy harvesting (EH) relaying network over the Weibull fading channel is investigated. The system network is working in half-duplex (HD) mode. For evaluating the system performance, the closed-form and integral-form expressions of the outage probability (OP) are investigated and derived. After that, numerical results convinced that our derived analytical results are the same with the simulation results by using Monte Carlo simulation. This paper provides a novel recommendation for the wireless EH relaying network.

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1. INTRODUCTION

Due to the rapid development of the Internet of Things (IoT), 5G needs to support the massive connectivity of users and/or devices to meet the demand for low latency, low-cost devices, and diverse service types. However, energy harvesting (EH) and information transmission (IT) processes from the source (S) node to the destination (D) node in the communication network may be interrupted by fading, shadowing, and path loss. For solving this problem, the intermediate helping relay (R) node between the S node and D node is considered as an excellent solution for enhancing the system performance [1-4]. There are many types of research focused on the WCPN with helping the intermediate relay with perfect and imperfect channel state information (CSI) as investigated in [5-7]. The authors in [8] investigated the fault-tolerant schemes with the presence of imperfect CSI. Two primary protocols Half-duplex (HD) and Full-duplex (FD) are popularly used in the relaying communication network. HD mode based on the simple design and implementation is popularly used in the traditional wireless power communication networks. But the HD scheme can transmit and receive the signal at the same time in the same frequency band, and then the HD scheme has a massive spectrum efficiency loss [9-11]. In comparison with the HD scheme, the FD scheme can receive and transmit signals continuously and can achieve up to double the capacity. In addition, the FD can reduce spectral loss with the innovative in the antenna technology [12-14]. Based on these problems, the hybrid TSR-PSR protocol can be considered as a novel solution for improving the system performance of the wireless EH relaying network.

In this paper, we propose and investigate the hybrid TSR-PSR protocol for wireless energy harvesting (EH) relaying network over the Weibull fading channel in half-duplex (HD) mode. To evaluate the performance of the proposed system, the closed-form and integral-form expression of the outage probability (OP) is analyzed and derived. Numerical results confirm that our obtained analytical results match well with the Monte Carlo simulations in connection with all possible system parameters. This paper provides a novel recommendation for the wireless EH relaying network. The main contributions of this research can be focused on as the followings:

a. We propose and investigate the hybrid TSR-PSR protocol for wireless EH relaying network over the Weibull fading channel in HD mode.
b. We derive the closed-form and integral-form expressions of the OP.
c. The influence of all main system parameters on the outage probability is investigated and discussed.
d. All results are verified by the Monte Carlo simulation.

2. SYSTEM MODEL AND SYSTEM PERFORMANCE ANALYSIS

The EH relaying network is illustrated in Figure 1. The energy harvesting (EH) and information transmission (IT) of the model system are presented in Figure 2. In Figure 2, we denote T is the block time of the EH and IT processes [13-15].

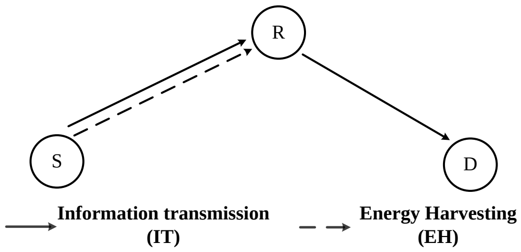

Figure 1. System model

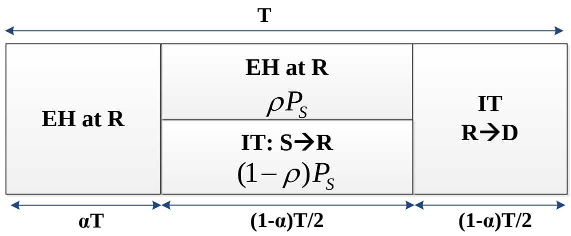

Figure 2. EH and IT processes

2.1. Energy harvesting phase

The received signal at the relay R in the first interval time slot αT can be formulated as

$$y_r^1 = \sqrt{P_s} h x_s + n_r \quad (1)$$

Where P_s is the transmitting power of source S, h is channel gain and n_r denoted the additive white Gaussian noise (AWGN) which has zero-mean and variance N_0

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

Based on (1), the harvested energy in the first timeslot can be given by

$$E_1 = \eta \alpha T P_s |h|^2 \quad (2)$$

Where $0 < \eta \le 1$ is the energy conversion efficiency.

The received signal at R in the second time slot can be expressed as

$$y_r^2 = \sqrt{\rho P_s} h x_s + n_r \tag{3}$$

Therefore, the harvested energy in this time slot also can be given by

$$E_2 = \eta\rho\left(\frac{1-\alpha}{2}\right)TP_s|h|^2 \tag{4}$$

From (2) and (4), the total average transmitted power at the relay R can be obtained as

$$P_r = \frac{E_r}{(1-\alpha)T/2} = \frac{E_1+E_2}{(1-\alpha)T/2} = \kappa\eta P_s|h|^2 \tag{5}$$

Where $\kappa = \frac{2\alpha+(1-\alpha)\rho}{1-\alpha}$

2.2. Information transmission phase

In the second interval time slot, the received signal at the relay R can be expressed as

$$y_r = \sqrt{(1-\rho)P_s} h x_s + n_r \tag{6}$$

In this model, we will consider the Amplify and Forward (AF) protocol. Hence the received signal and transmitted signal at the relay R have a relationship with the following which denoted amplifying factor

$$\chi = \frac{x_r}{y_r} = \frac{1}{\sqrt{(1-\rho)P_s|h|^2 + N_0}} \tag{7}$$

Where x_r is the transmitting signal at R

In the third time slot, the received signal at the destination D can be given as

$$y_d = gx_r + n_d \tag{8}$$

Where g is channel gain of R-D link and n_d is AWGN at the destination which has zero-mean and variance N_0 Substituting (6), (7) into (8), we have:

$$\begin{aligned} y_d &= gx_r + n_d = g\chi y_r + n_d = g\chi\left\{\sqrt{(1-\rho)P_s} h x_s + n_r\right\} + n_d \\ &= \underbrace{g\chi\sqrt{(1-\rho)P_s} h x_s}_{signal} + \underbrace{g\chi n_r + n_d}_{noise} \end{aligned} \tag{9}$$

The overall signal to noise ratio (SNR) from S to D can be obtained from (9)

$$\gamma_{SRD} = \frac{\mathrm{E}\left\{|signal|^2\right\}}{\mathrm{E}\left\{|noise|^2\right\}} = \frac{(1-\rho)P_s|h|^2|g|^2\chi^2}{|g|^2\chi^2 N_0 + N_0} \approx \frac{\kappa\eta(1-\rho)\Delta XY}{\kappa\eta Y + (1-\rho)} \tag{8}$$

Where $X = |h|^2, Y = |g|^2, \Delta = \frac{P_s}{N_0}$

Remark

The cumulative density function (CDF) and probability density function (PDF) of random variable (RV) X, Y can be calculated by [14], respectively.

$$F_i(x) = 1 - \exp\left[-\left(\frac{x}{a}\right)^b\right] \tag{11}$$

Where $i \in (X, Y)$, a and b are the Weibull parameter. From (11), PDF of X, Y can be obtained as

$$f_i(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} \exp\left[-\left(\frac{x}{a}\right)^b\right] \tag{12}$$

2.3. Outage probability (OP) analysis

The OP of the system can be defined as

$$OP = \Pr\left(\gamma_{SRD} < \gamma_{th}\right) \tag{13}$$

Where $\gamma_{th} = 2^{2R} - 1$ is the threshold of system and R: source rate

Substituting (10) into (13), we have

$$\begin{aligned} OP &= \Pr\left(\frac{\kappa\eta(1-\rho)\Delta XY}{\kappa\eta Y + (1-\rho)} < \gamma_{th}\right) = \Pr\left[X < \frac{\gamma_{th}}{(1-\rho)\Delta} + \frac{\gamma_{th}}{\kappa\eta\Delta Y}\right] \\ &= \int_0^\infty F_X\left[\frac{\gamma_{th}}{(1-\rho)\Delta} + \frac{\gamma_{th}}{\kappa\eta\Delta Y} \mid Y = y\right] f_Y(y)dy \end{aligned} \tag{14}$$

Combine with (11), (12), (14) can be rewritten as

$$OP = 1 - \frac{b}{a^b}\int_0^\infty y^{b-1} \times \exp\left[-\frac{1}{a^b}\left(\frac{\gamma_{th}}{(1-\rho)\Delta} + \frac{\gamma_{th}}{\kappa\eta\Delta y}\right)^b\right] \times \exp\left[-\left(\frac{y}{a}\right)^b\right]dx \tag{15}$$

Special case

When b=1 Weibull fading will correspond to the Rayleigh fading channel

The (15) can be reformulated as

$$OP = 1 - \frac{1}{a}\exp\left[-\frac{\gamma_{th}}{a(1-\rho)\Delta}\right]\int_0^\infty \exp\left(-\frac{\gamma_{th}}{\kappa\eta\Delta y}\right)\exp\left(-\frac{y}{a}\right)dx \tag{16}$$

Apply eq [3.324,1] of table of integral [16], The (16) can be rewritten as

$$OP = 1 - 2\exp\left[-\frac{\gamma_{th}}{a(1-\rho)\Delta}\right] \times \sqrt{\frac{\gamma_{th}}{a\kappa\eta\Delta}} K_1\left(2\sqrt{\frac{\gamma_{th}}{a\kappa\eta\Delta}}\right) \tag{17}$$

Where $K_v(\bullet)$ is the modified Bessel function of the second kind and v^{th} order.

3. RESULTS AND AND DISCUSSION

For validation, the correctness of the derived system performance expressions, as well as investigation of the effect of various parameters on the system performance, a set of Monte Carlo simulations are conducted in this section [17-25]. The system OP versus α and ρ is plotted in Figure 3 with basic system parameters as b=0.5, Δ=10 dB. In this analysis, the α and ρ vary from 0 to 1 continuously. From the research results, the system OP increases significantly with rising the α and ρ to 1. All the simulation and analytical curves matched well with each other.

Furthermore, Figure 4 shows the connection between the system OP and TS factor α with R=0.5 bps, ρ=0.5 and η=0.8. As shown in Figure 4, we can see that the system OP has a decrease when the TS factor α varies from 0 to 1 in connection with the fact that more power is used for harvesting energy at R than power is used for information transmission between D,R and S. Again all simulation and analytical results agree well with each other.

Moreover, the function of the OP on the energy conversion efficiency η is illustrated in Figure 5. Here we set the main system parameters as R=0.5 bps, Δ=5 dB, and b=0.5. Similar to the above cases, the OP of the model system increase crucially while the energy conversion efficiency varies from 0 to 1. It can be observed that the more efficient energy conversion of the system the less outage probability. In addition, the analytical curve is the same as the simulation curve as shown in Figure 5. Finally, the OP versus the source rate R is shown in Figure 6 with α=0.5, η=0.8 and γ_0= 5, 10 dB. From the results, the OP increases significantly when the source rate increases from 0 to 7. We can see that the simulation and the analytical result are the same with all values of the source rate R.

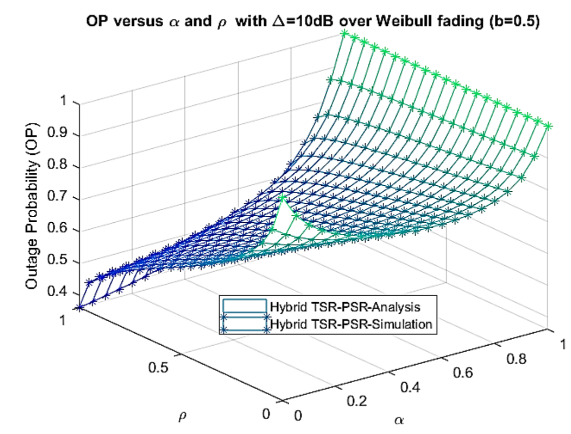

Figure 3. OP versus α and ρ

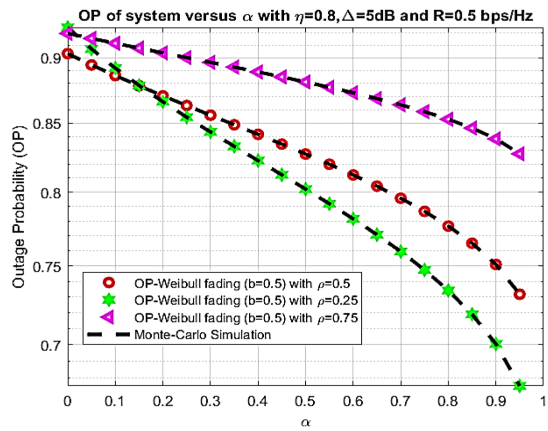

Figure 4. OP versus α

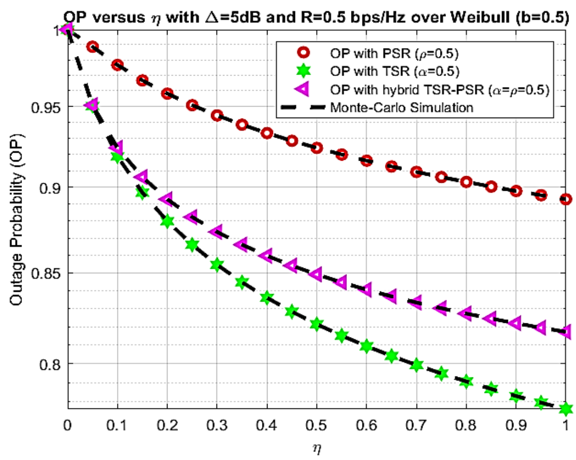

Figure 5. OP versus η

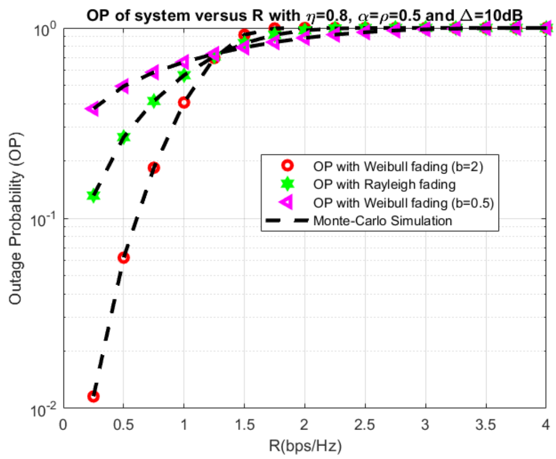

Figure 6. OP versus R

4. CONCLUSION

In this paper, the hybrid TSR-PSR protocol for wireless EH relaying network over the Weibull fading channel in HD mode is investigated. To evaluate the performance of the proposed system, the closed-form and integral-form expression of the OP is analyzed and derived. Numerical results confirm that our derived analytical results match well with the Monte Carlo simulations in connection with all possible system parameters. This paper provides a recommendation for the wireless EH relaying network

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