Jammer against eavesdropper in half-duplex energy harvesting cooperative relaying networks: secrecy outage probability analysis

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ABSTRACT
In this paper, we have investigated the Half-Duplex (HD) Energy Harvesting (EH) Cooperative Relaying Networks with one source node, one destination node, one intermediate relay and in the presence of the Jammer Against Eavesdropper. We have analyzed the system performance in terms of the integral form expression of secrecy outage probability. In addition, we have investigated the effect of source rate, time switching factor, energy coefficient, and the ratio Ps/N0 on the system performance. Finally, all the mathematical, analytical expressions are verified by Monte Carlo simulation, and the analytical results match well with the simulation ones to convince the correctness of the analytical expression.

Keywords:
Energy harvesting (EH)  
Half-Duplex (HD)  
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1. INTRODUCTION
Nowadays, harvesting energy (EH) from green environmental solar, wind, geothermal, and mechanical, the radio frequency (RF) signals can be considered as the prospective energy source in the future. RF signals can be proposed as the role of information transmission or harvesting energy in the communication network [1-8]. In a traditional network, the security problem to protect the wireless communication network is based on cryptographic technologies. Nowadays, the physical layer security (PLS) with the new technology is considered as an extensive research direction to protect the modern communication network. PLS technology is considered as a novel way to protect the confidential communication from a source node to its destination in the wireless cooperative communication network as studied in [9, 10]. In various system network such as cooperative relaying, jamming, multiuser scheduling, multiple-input-multiple-output (MIMO) with using PLS is considered in [11-15].

In this paper, we have proposed and investigated the Jammer Against Eavesdropper In Half-Duplex (HD) Energy Harvesting (EH) Cooperative Relaying Networks with one source node, one destination node, one intermediate relay, and in the presence of the Jammer Against Eavesdropper. We have analyzed the
system performance in terms of the integral form expression of secrecy outage probability. In addition, we have investigated the effect of source rate, time switching factor, energy coefficient, and the ratio $P_s/N_0$ on the system performance. Finally, all the mathematical, analytical expressions are verified by Monte Carlo simulation, and the analytical results match well with the simulation ones to convince the correctness of the analytical expression. The main contribution of this research can be formulated as the following:

a. The integral form of expression of secrecy outage probability is derived.
b. The effect of source rate, time switching factor, energy coefficient, and the ratio $P_s/N_0$ on the system performance is demonstrated.
c. The Monte Carlo simulation is conducted to verify the correctness of the analytical expressions.

2. SYSTEM MODEL

We consider a communication scenario with the help of a friendly jammer ($J$), as illustrated in Figure 1. The EH and IT processing are proposed in Figure 2. In this scheme, $T$ is the block time in which the source fully transmits the information data to the destination. In the first interval time ($\alpha T$), the $R$ and $J$ harvest energy from the $S$ signal, where $\alpha$ is the time switching factor $\alpha \in (0, 1)$ In the two remaining intervals time $(1-\alpha)T/2$, the $S$ and $R$ node transfer information to the $D$ node [5-7, 16-24].

![System model diagram](image)

Figure 1. System model

2.1. Energy harvesting phase

In the first phase, the source will supply the energy for both jammer and relay nodes. Hence, the harvested energy at the jammer and relay can be given as, respectively

$$E_J = \eta P_s \alpha T \left|h_{SJ}\right|^2$$

$$E_R = \eta P_s \alpha T \left|h_{SR}\right|^2$$

The average transmitted power at the jammer and relay nodes can be obtained from (1) and (2), respectively

$$P_J = \frac{E_J}{(1-\alpha)T/2} = \frac{\eta P_s \alpha T \left|h_{SJ}\right|^2}{(1-\alpha)T/2} = k P_s \left|h_{SJ}\right|^2$$

$$P_R = k P_s \left|h_{SR}\right|^2$$

Where $k = \frac{2\eta}{1-\alpha}$

2.2. Information transmission phase

In the second phase, the received signal at the relay can be rewritten as

$$y_r = h_{SR} x_s + n_r$$

Where $h_{SR}$ is the channel gain of S-R link, $x_s$ is the transmitted signal from source and $n_r$ is additive white Gaussian noise (AWGN) with variance $N_0$ and $E[|x_s|^2] = P_s$ which $E[\bullet]$ is expectation operator.

In the third phase, the received signal at the destination can be given by

$$y_d = h_{RD} x_r + n_d$$

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Where $h_{RD}$ is the channel gain of R-D link, $x_r$ is the transmitted signal from relay and $n_d$ is (AWGN) with variance $N_0$ and $E\{|x_r|^2\} = P_R$

Here, we consider amplify and forward (AF) mode at the relay. Hence, the amplify factor can be given as

$$\delta = \frac{x_r}{y_r} = \frac{P_R}{P_R|h_{SR}|^2+N_0} \quad (7)$$

Substituting (7) into (6), we have:

$$y_d = h_{RD}\delta y_r = h_{RD}\delta [h_{SR}x_s + n_r] + n_d = \frac{h_{SR}h_{RD}\delta x_s + h_{RD}\delta n_r + n_d}{\text{signal}} \quad (8)$$

From (8), the end to end signal to noise ratio (SNR) of S-R-D link can be calculated as

$$\gamma_{SRD} = \frac{E[|\text{signal}|^2]}{E[|\text{noise}|^2]} = \frac{|h_{SR}|^2|h_{RD}|^2\delta^2 P_s}{|h_{RD}|^2\delta^2 N_0+N_0} = \frac{|h_{SR}|^2|h_{RD}|^2 P_s}{|h_{RD}|^2 N_0 N_0 P_R} \quad (9)$$

After doing some algebra and using the fact that $N_0<<P_R$, (9) can be rewritten as

$$\gamma_{SRD} = \frac{|h_{SR}|^2|h_{RD}|^2 P_s}{P_R|h_{RD}|^2+N_0 P_R P_s|h_{SR}|^2} \quad (10)$$

Substituting (3) and (4) into (10), the end to end SNR can be reformulated as

$$\gamma_{SRD} = \frac{\kappa \Phi|h_{SR}|^2|h_{RD}|^2}{\kappa|h_{RD}|^2+\kappa \Phi X} = \frac{\kappa \Phi |Y|^2}{\kappa \Phi Y + 1} \quad (11)$$

Where $\Phi = \frac{P_s}{N_0}$, $X = |h_{SR}|^2$, $Y = |h_{RD}|^2$

3. **OUTAGE PROBABILITY (OP)**

The received signal at the eavesdropper can be given by

$$y_E = h_{SE}x_s + h_{JE}x_j + n_E \quad (12)$$

Where $h_{SE}$ is the channel gain of S-E link and $n_E$ is AWGN with variance $N_0$ and $E\{|x_s|^2\} = P_J$

To protect information from being eavesdropped by E, the friendly jammer J performs jamming. Hence, the SNR at the eavesdropper can be expressed as

$$\gamma_E = \frac{|h_{SE}|^2 P_S}{|P_J|h_{JE}|^2+N_0} \quad (13)$$

Substituting (3) and (4) into (13), we have:

$$\gamma_E = \frac{\Phi|h_{SR}|^2}{\kappa|h_{SR}|^2+\kappa \Phi |Y|} = \frac{\Phi Z}{\kappa \Phi Y + 1} \quad (14)$$

Where $Z = |h_{SE}|^2$, $V = |h_{SJ}|^2$, $|h_{JE}|^2$

Next, the channel capacity of S-R-D and of eavesdropper can be obtained as, respectively

$$R_{SRD} = \frac{(1-a^2)}{2} \log_2(1 + \gamma_{SRD}) \quad (15)$$

$$R_E = \frac{(1-a^2)}{2} \log_2(1 + \gamma_E) \quad (16)$$

**Lemma 1.** The cumulative distribution function of $V$ can be computed as
\[ F_V(a) = \int_{0}^{\infty} F_{|h_{sj}|^2} \left( \frac{a}{|h_{je}|^2} \right) f_{|h_{je}|^2}(x) dx \]  

(17)

Utilizing the result in [25], the CDF of X and Y can be shown as the below (18)

\[ F_V(a) = 1 - 2\sqrt{\lambda_{sj} \lambda_{je}} a K_1(2\sqrt{\lambda_{sj} \lambda_{je}} a) \]  

(18)

where \( K_v(\bullet) \) is the modified Bessel function of the second kind and \( v \)th order and \( \lambda_{sj}, \lambda_{je} \) are mean of random variables (RVs) \( |h_{sj}|^2, |h_{je}|^2 \), respectively.

From (18), the probability density function (PDF) of V can be calculated as, after applying the following formula

\[ \frac{\partial K_n(z)}{\partial z} = -K_{n-1}(z) - \frac{n}{z} K_n(z) \]

(19)

3.1. Secrecy Outage probability (SOP)

The Secrecy capacity of the system can be defined as

\[ R = \max(0, R_{SRD} - R_E) = \left[ \log_2 \left( \frac{1 + y_{SRD}}{1 + y_E} \right) \right]^+ \]  

(20)

Where \([x]^+ = \max(0, x)\)

The SOP can be formulated by

\[ SOP = Pr(R < R_s) = Pr \left( \frac{1 + y_{SRD}}{1 + y_E} < \rho \right) = Pr(\gamma_{SRD} < \rho + \rho y_E - 1) \]

\[ = \int_{0}^{\infty} F_{\gamma_{SRD}}(\rho + \rho y_E - 1) f_{\gamma_E}(x) dx \]  

(21)

Where \( \rho = 2R_s \) and \( R_s \) is source rate.

In order to calculate the probability in (21), we have to find \( F_{\gamma_{SRD}}(a) \) and \( f_{\gamma_E}(b) \).

At first, we have:

\[ F_{\gamma_{SRD}}(a) = Pr(\gamma_{SRD} < a) \]  

(22)

Substituting (11) into (22), (22) can be rewritten as

\[ F_{\gamma_{SRD}}(a) = Pr \left( \frac{k\Phi \gamma Y}{kY + 1} < a \right) = Pr \left( X < \frac{a}{\Phi} + \frac{a}{k\Phi Y} \right) \]

\[ = \int_{0}^{\infty} F_X \left( \frac{a}{\Phi} + \frac{a}{k\Phi Y} \right) f_Y(y) dy \]

\[ = \int_{0}^{\infty} \left( 1 - \exp \left( -\lambda_{SR} \left( \frac{a}{\Phi} + \frac{a}{k\Phi Y} \right) \right) \right) f_Y(y) dy \]

\[ = 1 - \lambda_{RD} \exp \left( -\frac{\lambda_{SR} a}{\Phi} \right) \int_{0}^{\infty} \exp \left( -\frac{\lambda_{SR} a}{k\Phi Y} \right) \times \exp(-\lambda_{RD} y) \ dy \]  

(23)

Where \( \lambda_{SR}, \lambda_{RD} \) are the mean of RVs \( |h_{sr}|^2, |h_{rd}|^2 \), respectively.

Apply equation [3.324,1] of the table of integral, we can obtain as followings

\[ F_{\gamma_{SRD}}(a) = 1 - 2 \exp \left( -\frac{\lambda_{SR} a}{\Phi} \right) \sqrt{\frac{\lambda_{SR} \lambda_{RD} a}{k\Phi}} \times K_1 \left( \sqrt{\frac{\lambda_{SR} \lambda_{RD} a}{k\Phi}} \right) \]  

(24)

Next, combine with (14), the CDF of \( \gamma_E \) can be given by

\[ F_{\gamma_E}(x) = Pr(\gamma_E < x) = Pr \left( \frac{\Phi Z}{k\Phi V + 1} < x \right) = Pr \left( Z < \frac{x}{\Phi} + kxV \right) \]

\[ = \int_{0}^{\infty} F_Z \left( \frac{z}{\Phi} + kxV \right) f_Z(y) dy \]  

(25)

Applying the result from (19), equation (25) can be computed
\[ F_{\gamma E}(x) = 2 \sqrt{\lambda_{SJ} \lambda_{JE}} \int_0^\infty \{ 1 - \exp \left[ -\lambda_{SE} \left( \frac{x}{\Phi} + kxy \right) \right] \} \times K_0 \left( 2 \sqrt{\lambda_{SJ} \lambda_{JE} y} \right) dy \]

\[ = 1 - 2 \sqrt{\lambda_{SJ} \lambda_{JE}} \exp \left( - \frac{\lambda_{SE} x}{\Phi} \right) \int_0^\infty \exp(-kx\lambda_{SE}y) \times K_0 \left( 2 \sqrt{\lambda_{SJ} \lambda_{JE} y} \right) dy \]  

(26)

Where \( \lambda_{SE} \) is the mean of \( RV|h_{SE}|^2 \)

Applying Taylor series as follows

\[ \exp(-kx\lambda_{SE}y) = \sum_{n=0}^{\infty} \frac{(-kx\lambda_{SE}y)^n}{n!} = \sum_{n=0}^{\infty} \frac{(-1)^n(kx\lambda_{SE})^n}{n!} y^n \]  

(27)

Substituting (27) into (26), we have:

\[ F_{\gamma E}(x) = 1 - 2 \sqrt{\lambda_{SJ} \lambda_{JE}} \exp \left( - \frac{\lambda_{SE} x}{\Phi} \right) \sum_{n=0}^{\infty} \frac{(-1)^n(kx\lambda_{SE})^n}{n!} y^n \times K_0 \left( 2 \sqrt{\lambda_{SJ} \lambda_{JE} y} \right) dy \]  

(28)

By changing variable \( t = \sqrt{y} \) and then applying equation \([6.561,16]\) of table of integral, equation (28) can be reformulated as

\[ F_{\gamma E}(x) = 1 - \sum_{n=0}^{\infty} \frac{(-1)^n(kx\lambda_{SE})^n}{n!(\lambda_{SJ} \lambda_{JE})^{n+1/2}} \times \exp \left( - \frac{\lambda_{SE} x}{\Phi} \right) \times \left( \Gamma(n + 1) \right)^2 \]  

(29)

From (30), the PDF of \( \gamma_E \) can be obtained as

\[ f_{\gamma E}(x) = \frac{\partial F_{\gamma E}(x)}{dx} = \sum_{n=0}^{\infty} \frac{(-1)^n(kx)^n(\lambda_{SE})^{n+1}}{n!(\lambda_{SJ} \lambda_{JE})^{n+1/2}} \times \exp \left( - \frac{\lambda_{SE} x}{\Phi} \right) \times \left( \Gamma(n + 1) \right)^2 \]  

(30)

Applying results from (23) and (30) for (21), finally the SOP can be claimed by

\[ SOP = \int_0^\infty \left\{ 1 - 2 \exp \left( - \frac{\lambda_{SR}(p+\rho-1)}{\Phi} \right) \sqrt{\frac{\lambda_{SR}\lambda_{RD}[p+\rho-1]}{k\Phi}} \times K_1 \left( 2 \sqrt{\frac{\lambda_{SR}\lambda_{RD}[p+\rho-1]}{k\Phi}} \right) \right\} f_{\gamma E}(x) dx \]  

(31)

4. NUMERICAL RESULTS AND DISCUSSION

In this section, the effect of source rate, time switching factor, energy coefficient, and the ratio \( P_s/N_0 \) on the system performance is investigated. The SOP versus the source rate \( R_S \) is plotted in Figure 3 with the main system parameters as \( \Phi = 5 \) Db, \( \eta = 0.8 \) and \( \alpha = 0.25, 0.5, 0.85 \). As shown in Figure 3, the SOP significantly increases while the source rate increases from 0 to 6 bps/Hz. Figure 4 presents the influence of \( \Phi \) on the system SOP. In Figure 4, we set \( \eta = 0.8, \alpha = 0.5 \) and \( R_S = 0.5, 1.0, 1.5 \) bps/Hz, respectively. From the results, we can see that the system SOP crucially falls down with the rising of \( \Phi \) from 0 to 30 dB. In Figure 3 and Figure 4, the simulation results match well with the analytical ones for verifying the correctness of the system performance analysis.

The effect of the energy efficiency coefficient on the system SOP is illustrated in Figure 5, in which we set \( \alpha = 0.5, R_S = 0.5 \) bps/Hz, \( \Phi = 1, 5, 10 \) dB, respectively. Here, we can state that the system SOP has fallen down when \( \eta \) varies from 0 to 1. Furthermore, the system SOP versus time switching factor \( \alpha \) is drawn in Figure 6. We set \( \Phi = 5 \) dB, \( R_S = 0.5 \) bps/Hz, and \( \eta = 0.25, 0.5, 1 \), respectively. The same as the above case, the system SOP decreases massively with the rising of \( \alpha \) from 0 to 1. As shown in Figure 5 and Figure 6, the analytical and the simulation results are the same to convince the analytical system performance analysis.
5. CONCLUSION
In this paper, we have investigated the HD EH Cooperative Relaying Networks in the presence of the Jammer Against Eavesdropper. We have analyzed the system performance in terms of the integral form expression of secrecy outage probability. In addition, we have investigated the effect of source rate, time switching factor, energy coefficient, and the ratio $P_s/N_0$ on the system performance. Finally, all the mathematical, analytical expressions are verified by Monte Carlo simulation, and the analytical results match well with the simulation ones to convince the correctness of the analytical expression.

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