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Physical security layer with friendly jammer in half-duplex relaying networks over rayleigh fading channel: Intercept probability analysis

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ABSTRACT

In this research, thephysical security layer with a friendly jammerin half-duplex (HD) relaying networksover the Rayleigh fading channel is proposed and investigated. Firstly, we proposed the system model and the time switching,power splitting protocolsfor the system model. Then we conductedthe mathematical analysisfor deriving theexact analysis and asymptotic analysisintegral forms for intercept probability (IP). Finally, the analytical formulationis verified by the Monte Carlo Simulation with all main system parameters. From the results, we can show that the simulation and analytical values are the same values.

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1. INTRODUCTION

Nowadays, harvesting energy (EH) from green environmental sources such as sun, wind, etc and converting this energy into the electrical energy for the communication network devices is the hot reseach direction in both civil and industial purposes. In the series of the leading environmental green energy sources, 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 sensor nodes [1-8]. In the past, we used the traditional network security protocol, which is working based on cryptographic technologies for security protecting wireless networks. For extensive research efforts, the physical-layer security (PLS), which is opareting normal wihthout key negotiation and distribution, is proposed and investigated in the modern communication network. Furthermore, PLS technology has a huge advantage for protecting the confidential communication between a source node to its destination as studied [9-10]. The PLS in the wireless networks with cooperative relaying, jamming, multiuser scheduling, multiple-input-multiple-output (MIMO) ..etc have been proposed and investigated in [11-15].

In this research, the physical security layer with a friendly jammer in half-duplex (HD) relaying networks over the Rayleigh fading channel is proposed and investigated. In the first stage, we proposed the system model and the time switching, power splitting protocols for the system model. Then we conducted the mathematical analysis for deriving the exact analysis and asymptotic analysis integral forms for intercept probability (IP). Finally, the analytical formulation is verified by the Monte Carlo Simulation with all main system parameters. The research results show that the analytical and simulation are the same values.

2. SYSTEM MODEL

The system model, in which a source node (S) communicates with a destination node (D) via the intermediate Relay node (R) in the presence of a passive eavesdropper (E) with the help of a friendly jammer (J), is illustrated in Figure 1. The energy harvesting (EH) and information processing (IT) processes of the system model are drwan 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 (αT), the R and J harvest energy from the S signal, where α is the time switching factor α ∈ (0, 1) In the two remaining intervals time (1-α)T/2, the S and R node transfer information to the D node [5-7, 16-24].

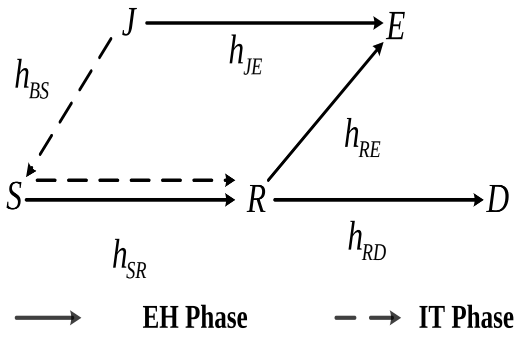

Figure 1. System model

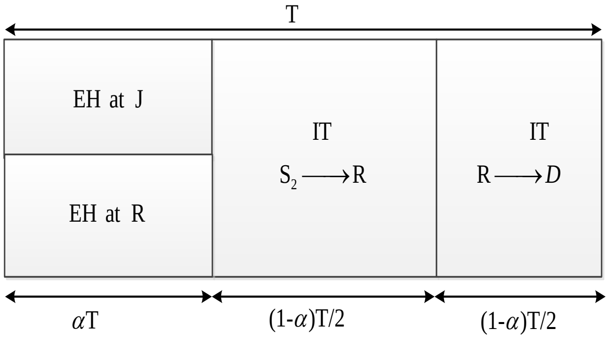

Figure 2. The EH and IT phases

2.1. Energy harvesting (EH) 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:

$$E_J = \eta P_S \alpha T \left| h_{SJ} \right|^2 \tag{1}$$

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

where $0 < \eta \le 1$ is energy conversion efficiency, P_S is the average transmitted power at the source, and h_{SJ}, h_{SR} are the channel gain of S-J link, S-R link, respectively.

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

$$P_J = \frac{E_J}{(1-\alpha)T/2} = \frac{\eta P_S \alpha T \left| h_{SJ} \right|^2}{(1-\alpha)T/2} = \kappa P_S \left| h_{SJ} \right|^2 \tag{3}$$

$$P_R = \kappa P_S \left| h_{SR} \right|^2 \tag{4}$$

where $\kappa = \dfrac{2\eta\alpha}{1-\alpha}$

2.2. Information transmission phase

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

$$y_r = h_{SR} x_s + n_r \tag{5}$$

whereh_{SR} is the channel gain of S-R link, x_s is the transmitted signal from the S and n_r is additive white Gaussian noise (AWGN) with variance N_0.

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

$$y_d = h_{RD} x_r + n_d \tag{6}$$

whereh_{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.

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

$$\zeta = \frac{x_r}{y_r} = \sqrt{\frac{P_R}{P_s \left|h_{SR}\right|^2 + N_0}} \tag{7}$$

The received signal at the E can be given by:

$$\begin{aligned} y_E &= h_{RE} x_r + h_{JE} x_J + n_E = h_{RE} \beta y_r + h_{JE} x_J + n_E \\ &= h_{RE} \beta \left[h_{SR} x_s + n_r \right] + h_{JE} x_J + n_E \\ &= \underbrace{h_{RE} \beta h_{SR} x_s}_{signal} + \underbrace{h_{RE} \beta n_r + h_{JE} x_J + n_E}_{noise} \end{aligned} \tag{8}$$

whereh_{RE} is the channel gain of R-E link and n_E is AWGN with variance N_0.

3. INTERCEPT PROBABILITY (IP)

The SNR at the eavesdropper can be expressed as:

$$\gamma_E = \frac{\mathrm{E}\left\{\left|signal\right|^2\right\}}{\mathrm{E}\left\{\left|noise\right|^2\right\}} = \frac{\left|h_{SR}\right|^2 \left|h_{RE}\right|^2 \beta^2 P_s}{\left|h_{RE}\right|^2 \beta^2 N_0 + \left|h_{JE}\right|^2 P_J + N_0} \tag{9}$$

Substituting (3) into (9), we have:

$$\gamma_E = \frac{\left|h_{SR}\right|^2 \left|h_{RE}\right|^2 \psi}{\left|h_{RE}\right|^2 + \dfrac{\kappa\psi \left|h_{SJ}\right|^2 \left|h_{JE}\right|^2 + 1}{\beta^2}} \tag{10}$$

where $\psi = \dfrac{P_s}{N_0}$

After doing some algebra, the (10) can be reformulated as:

$$\begin{aligned} \gamma_E &= \frac{\left|h_{SR}\right|^4 \left|h_{RE}\right|^2 \kappa\psi}{\kappa \left|h_{SR}\right|^2 \left|h_{RE}\right|^2 + \kappa\psi \left|h_{SR}\right|^2 \left|h_{SJ}\right|^2 \left|h_{JE}\right|^2 + \kappa \left|h_{SJ}\right|^2 \left|h_{JE}\right|^2 + 1} \\ &= \frac{\kappa\psi X^2 Y}{\kappa XY + \kappa\psi XZ + \kappa Z + 1} \end{aligned} \tag{11}$$

where $X = |h_{SR}|^2, Y = |h_{RE}|^2, Z = |h_{SJ}|^2 |h_{JE}|^2$

*Lemma1.*Please note that all channels are the Rayleigh fading channels, so the probability density function (PDF) of $|h_i|^2$ can be given by:

$$f_{|h_i|^2}(x) = \lambda_i e^{-\lambda_i x} \tag{12}$$

where $i \in (SR, RE)$. Moreover, the cumulative distribution function (CDF) of $|h_i|^2$ also can be obtained by:

$$F_{|h_i|^2}(x) = 1 - e^{-\lambda_i x} \tag{16}$$

where λ_i is the mean value of the exponential random variable $|h_i|^2$.

*Lemma2.*The CDF of Z can be computed as respectively:

$$F_Z(a) = \int_0^\infty F_{|h_{SJ}|^2}\left(\frac{a}{|h_{JE}|^2} \,|\, |h_{JE}|^2 = x\right) f_{|h_{JE}|^2}(x)dx \tag{13}$$

Utilizing the result in [25], the CDF of Z can be shown as the below equation, respectively:

$$F_Z(a) = 1 - 2\sqrt{\lambda_{SJ}\lambda_{JE} a} K_1\left(2\sqrt{\lambda_{SJ}\lambda_{JE} a}\right) \tag{15}$$

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 the random variable (RV) $|h_{SJ}|^2, |h_{JE}|^2$, respectively.

From (15), the PDF of Z can be calculated as, after applying the formula,

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

$$f_Z(a) = \frac{\partial F_Z(a)}{\partial a} = 2\sqrt{\lambda_{SJ}\lambda_{JE}} K_0\left(2\sqrt{\lambda_{SJ}\lambda_{JE} a}\right) \tag{16}$$

3.1. Exact analysis

The IP can be defined by:

$$IP = \Pr\left(\gamma_E \ge \gamma_{th}\right) \tag{17}$$

Substituting (11) into (17); finally, we have:

$$\begin{aligned} IP &= \Pr\left(\frac{\kappa\psi X^2 Y}{\kappa XY + \kappa\psi XZ + \kappa Z + 1} \ge \gamma_{th}\right) \\ &= \Pr\left\{Z\left(\kappa\psi\gamma_{th} X + \kappa\gamma_{th}\right) \le XY\left(\kappa\psi X - \kappa\gamma_{th}\right) - \gamma_{th}\right\} \\ &= \begin{cases} \Pr\left\{Z \le \dfrac{XY\left(\kappa\psi X - \gamma_{th}\right) - \gamma_{th}}{\left(\kappa\psi\gamma_{th} X + \kappa\gamma_{th}\right)}, X \ge \dfrac{\gamma_{th}}{\psi} \text{ and } XY \ge \dfrac{\gamma_{th}}{\left(\kappa\psi X - \kappa\gamma_{th}\right)}\right\} \\ 0 \qquad , X < \dfrac{\gamma_{th}}{\psi} \text{ or } XY < \dfrac{\gamma_{th}}{\left(\kappa\psi X - \kappa\gamma_{th}\right)} \end{cases} \end{aligned} \tag{18}$$

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

The (20) can be rewritten by:

$$IP = \Pr\begin{cases} X \geq \dfrac{\gamma_{th}}{\psi} \\ Y \geq \dfrac{\gamma_{th}}{X\left(\kappa\psi X - \kappa\gamma_{th}\right)} \\ Z \leq \dfrac{XY\left(\kappa\psi X - \kappa\gamma_{th}\right) - \gamma_{th}}{\left(\kappa\psi\gamma_{th} X + \kappa\gamma_{th}\right)} \end{cases} \tag{19}$$

$$= \int_{\frac{\gamma_{th}}{\psi}}^{\infty} f_X(x)dx \int_{\frac{\gamma_{th}}{x\left(\kappa\psi x - \kappa\gamma_{th}\right)}}^{\infty} f_Y(y)dy \int_{0}^{g(x,y)} f_Z(z)dz$$

where $g(x,y) = \dfrac{xy\left(\kappa\psi x - \kappa\gamma_{th}\right) - \gamma_{th}}{\left(\kappa\psi\gamma_{th} x + \kappa\gamma_{th}\right)}$

Applying (16) and (19) can be reformulated as:

$$IP = 2\lambda_{SR}\lambda_{RE}\sqrt{\lambda_{SJ}\lambda_{JE}} \int_{\frac{\gamma_{th}}{\kappa\psi}}^{\infty} \exp\left(-\lambda_{SR} x\right)dx \int_{\frac{\gamma_{th}}{x\left(\kappa\psi x - \gamma_{th}\right)}}^{\infty} \exp\left(-\lambda_{RE} y\right)dy \int_{0}^{g(x,y)} K_0\left(2\sqrt{\lambda_{SJ}\lambda_{JE} z}\right)dz \tag{20}$$

3.2. Asymptotic analysis

Atthe high SNRregime, the (11)can be approximatedas $\gamma_E^{\infty} \approx \dfrac{XY}{Z}$

The IP can be computed as:

$$IP^{\infty} = \Pr\left(\gamma_E^{\infty} \geq \gamma_{th}\right) = \Pr\left\{\frac{XY}{Z} \geq \gamma_{th}\right\} = \Pr\left\{Z \leq \frac{W}{\gamma_{th}}\right\} = \int_{0}^{\frac{w}{\gamma_{th}}} F_Z\left(\frac{W}{\gamma_{th}} \mid W = w\right) f_W(w)dw \tag{21}$$

where $W = XY$.

Similar in Lemma2,the CDF and PDF ofW can be obtained as, respectively:

$$F_W(b) = 1 - 2\sqrt{\lambda_{SR}\lambda_{RE} b}\, K_1\left(2\sqrt{\lambda_{SR}\lambda_{RE} b}\right) \tag{22}$$

$$f_W(b) = 2\sqrt{\lambda_{SR}\lambda_{RE}}\, K_0\left(2\sqrt{\lambda_{SR}\lambda_{RE} b}\right) \tag{23}$$

Substituting (15) and(23) into (21), we have:

$$IP^{\infty} = 2\sqrt{\lambda_{SR}\lambda_{RE}} \int_{0}^{\infty} \left\{1 - 2\sqrt{\frac{\lambda_{SJ}\lambda_{JE} w}{\gamma_{th}}} K_1\left(2\sqrt{\frac{\lambda_{SJ}\lambda_{JE} w}{\gamma_{th}}}\right)\right\} K_0\left(2\sqrt{\lambda_{SR}\lambda_{RE} w}\right)dw \tag{24}$$

4. NUMERICAL RESULTS AND DISCUSSION

The influence of ψ on the system IP is plotted in Figure 3 with the main system parameters is set up as η=0.8, α=0.5, R= 0.5, 1.0, 1.5 bps/Hz respectively. From the results, we can state that the asymptotic IP is convergence to the exact IP at the end of the ψ values, and the analytical values are the same as the simulation values. The higher R, the worst IP values.

The influence of ψ on the system IP is presented in Figure4 with the main system parameters is set up as ψ=15 dB, α=0.25, 0.5, 0.85, R= 0.5bps/Hz respectively. And the IP versus η and Ris illustrated in Figures 5 and 6.Here we set up the primary system parameters asψ=15 dB,R= 0.5bps/Hz, α=0.25, 0.5, 0.85, η=0.25, 0.5, 1 respectively. From the results, we can state that the analytical values are the same as the simulation values. The better values of the IP is getting with the lower values of η,α, but with the higher values of R. All the research results are convinced by analytical expressions.

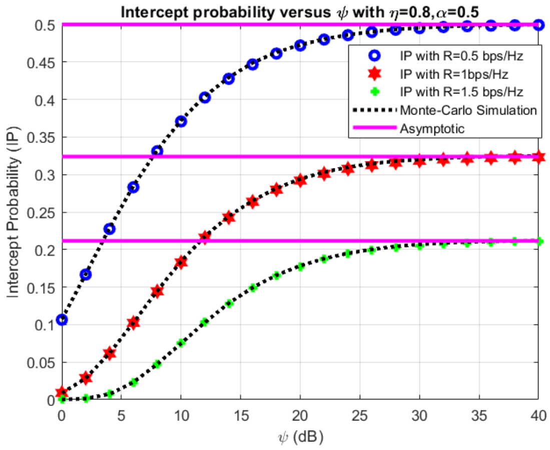

Figure 3. IP versus ψ

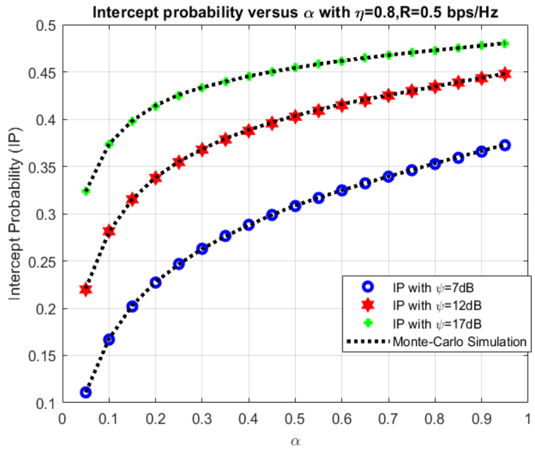

Figure 4. IP versus α

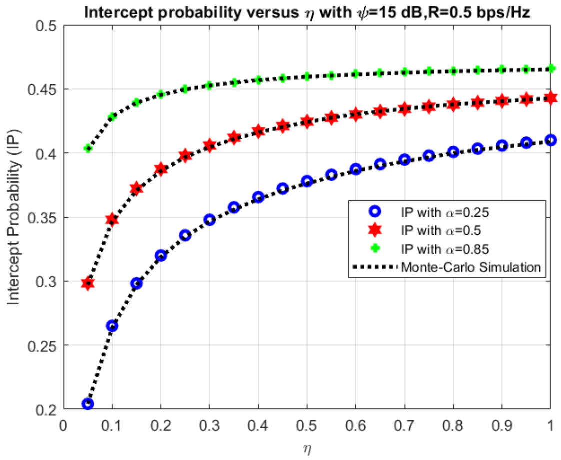

Figure 5. IP versus η.

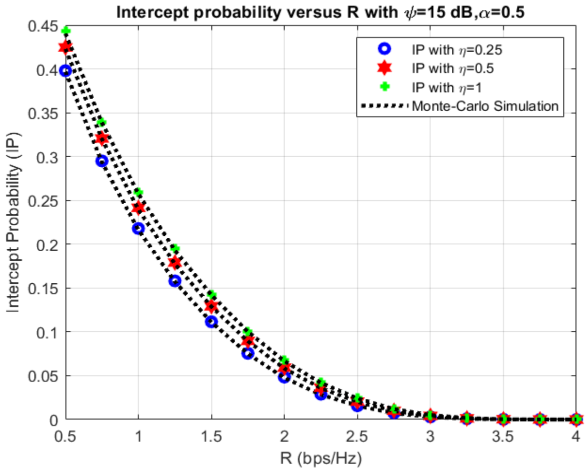

Figure 6. IP versus R

5. CONCLUSION

In thisresearch, the physical security layer with a friendly jammer in half-duplex (HD) relaying networks over the Rayleigh fading channel is proposed and investigated. In the first stage, we proposed the system model and the time switching, power splitting protocols for the system model. Then we conducted the mathematical analysis for deriving the exact analysis and asymptotic analysis integral forms for Intercept probability (IP). Finally, the analytical formulation is verified by the Monte Carlo Simulation with all main system parameters. The research results show that the analytical and simulation are the same values.

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