TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 19, No. 4, August 2021, pp. 1162~1168
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v19i4.17683

Lower and upper bound form of outage probability in one-way AF full-duplex relaying network under impact of direct link

Phu Tran Tin[1], Van-Duc Phan[2], Le Anh Vu[3]
[1]Faculty of Electronics Technology, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam
[2]Faculty of Automobile Technology, Van Lang University, Ho Chi Minh City, Vietnam
[3]Optoelectronics Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Article Info

Article history:

Received Aug 18, 2020
Revised Dec 9, 2020
Accepted Dec 23, 2020

Keywords:

Energy harvesting
Monte Carlo simulation
Outage probability
Relaying network

ABSTRACT

This paper proposed and investigated the one-way amplify-and-forward (AF) full-duplex relaying network under impact of direct link. For the system performance analysis, the exact and lower and upper bound form of the system outage probability (OP) are investigated and derived. In this system model, authors assume that the E uses the maximal ratio combining (MRC) technique. Finally, we can see that the analytical and the simulation values overlap to verify the analytical section using the Monte Carlo simulation. Also, we investigate the influence of the system primary parameters on the proposed system OP.

Corresponding Author:

Van-Duc Phan
Faculty of Automobile Technology
Van Lang University
Ho Chi Minh City, Vietnam
Email: duc.pv@vlu.edu.vn

1. INTRODUCTION

Radio frequency (RF) signals can carry both information and energy can be considered as the main electrical sources in communication network, called wireless powered networks (WPNs) [1]-[10]. In [11], authors studied the outage probability between some points based on the tradeoff fundamental, and [12] proposed and designed the practical receiver for energy and information transmission and its advantages for the communication network. Furthermore, the authors in [13] presented and demonstrated the practical energy harvesting communication network, and [14] proposed and investigated the continuous energy and power transmission in the cognitive relaying communication network. Moreover, the time switching and the power splitting protocols design for the communication network and the comparison between them are proposed and investigated in [15]-[18].

This paper proposed and investigated the one-way amplify-and-forward (AF) full-duplex relaying network under impact of direct link. For the system performance analysis, the exact and lower and upper bound form of the system outage probability (OP) are investigated and derived. In this system model, authors assume that the E uses the maximal ratio combining (MRC) technique. Finally, we can see that the analytical and the simulation values overlap to verify the analytical section using the Monte Carlo simulation. Also, we investigate the influence of the system primary parameters on the proposed system OP.

2. SISTEM MODEL

In Figure 1, we illustrated the system model of the peoposed system and the energy harvesting (EH) and information processing (IT) phases are illustrated in Figure 2 as in [19]-[25]. In this model, all of the channels are Rayleigh fading. Then the CDF of the channel gains $|h_{\mathrm{SR}}|^2$, $|h_{\mathrm{RD}}|^2$ and $|h_{\mathrm{SD}}|^2$ can be formulated as (1).

$$F_{|h_{SR}|^2}(x) = 1 - exp(-\lambda_{\mathrm{SR}} x),$$

$$F_{|h_{RD}|^2}(x) = 1 - exp(-\lambda_{\mathrm{RD}} x),$$

$$F_{|h_{SD}|^2}(x) = 1 - exp(-\lambda_{\mathrm{SD}} x) \tag{1}$$

Here, we assume (2)

$$\lambda_{\mathrm{SR}} = (d_{\mathrm{SR}})^{\chi}, \lambda_{\mathrm{RD}} = (d_{\mathrm{RD}})^{\chi}, \lambda_{\mathrm{SD}} = (d_{\mathrm{SD}})^{\chi} \tag{2}$$

then we have (3).

$$F_{|f|^2}(x) = 1 - exp(-\lambda_{RR} x) \tag{3}$$

Finally, the PDFs of $|h_{SR}|^2$, $|h_{RD}|^2$ and $|f|^2$ can be given as the follows

$$f_{|h_{SR}|^2}(x) = \lambda_{\mathrm{SR}}\, exp(-\lambda_{\mathrm{SR}} x),$$

$$f_{|h_{RD}|^2}(x) = \lambda_{\mathrm{RD}}\, exp(-\lambda_{\mathrm{RD}} x),$$

$$f_{|h_{SD}|^2}(x) = \lambda_{\mathrm{SD}}\, exp(-\lambda_{\mathrm{SD}} x),$$

$$f_{|f|^2}(x) = \lambda_{RR}\, exp(-\lambda_{RR} x) \tag{4}$$

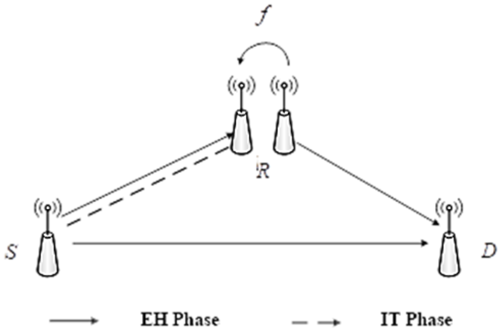

Figure 1. System model

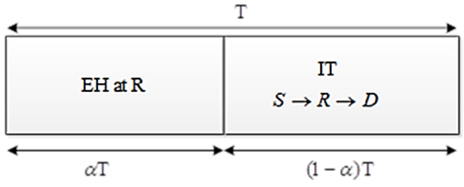

Figure 2. The time switching protocol

2.1. Energy harvesting and Information transmission

The received signal at the relay can be expressed as

$$y_R = h_{SR} x_s + f x_R + n_R \tag{5}$$

The average transmitted power at the relay can be computed as the following

$$P_R = \frac{E_h}{(1-\alpha)T} = \frac{\eta\alpha}{1-\alpha} P_s |h_{SR}|^2 = \kappa P_s |h_{SR}|^2 \tag{6}$$

where $\kappa = \dfrac{\eta\alpha}{1-\alpha}$. The received signal at the destination can be given by

$$y_D = h_{RD} x_R + n_D \tag{7}$$

where n_D is the AWGN with variance N₀. The amplification factor are formulated as the (8).

$$\beta = \frac{x_R}{y_R} = \sqrt{\frac{P_R}{|h_{SR}|^2 P_S + |f|^2 P_R + N_0}} \tag{8}$$

From (7) and combining with (5), we can obtain:

$$y_D = h_{RD}\beta y_R + n_D = h_{RD}\beta[h_{SR}x_s + f x_R + n_R] + n_D$$

$$= \underbrace{h_{RD}h_{SR}x_s\beta}_{signal} + \underbrace{h_{RD}\beta f x_R}_{\text{interference}} + \underbrace{h_{RD}\beta n_R + n_D}_{noise}$$

After doing some algebra, the end-to-end signal to interference noise (SINR) can be obtained as (9),

$$SINR_{AF} = \frac{E\{|signal|^2\}}{E\{|\text{inteference}|^2\} + E\{|noise|^2\}} = \frac{\frac{P_s|h_{SR}|^2|h_{RD}|^2}{|f|^2}}{\frac{N_0 P_s|h_{SR}|^2}{P_R|f|^2} + P_R|h_{RD}|^2 + N_0}$$

$$= \frac{\kappa\Phi|h_{SR}|^2|h_{RD}|^2}{\kappa^2\Phi|h_{SR}|^2|h_{RD}|^2|f|^2 + \kappa|f|^2 + 1} \tag{9}$$

where $\Phi = \frac{P_s}{N_0}$. Next, the destination will also receive the information directly from the source. Therefore, the SINR in this phase can be obtained by (10).

$$\gamma_{direct} = \Phi|h_{SD}|^2 \tag{10}$$

Finally, using the MRC technique at the receiver, the overall SINR of the system can be claimed as (11),

$$\gamma_{MRC}^{AF} = SINR_{AF} + \gamma_{direct} = \frac{\kappa\Phi|h_{SR}|^2|h_{RD}|^2}{\kappa^2\Phi|h_{SR}|^2|h_{RD}|^2|f|^2 + \kappa|f|^2 + 1} + \Phi|h_{SD}|^2 = X + Y \tag{11}$$

where $X = \frac{\kappa\Phi|h_{SR}|^2|h_{RD}|^2}{\kappa^2\Phi|h_{SR}|^2|h_{RD}|^2|f|^2 + \kappa|f|^2 + 1}$ and $Y = \Phi|h_{SD}|^2$.

3. SYSTEM PERFORMANCE ANALYSIS

3.1. Exact analysis

The System OP at the source destination can be defined as (12),

$$OP = Pr(\gamma_{MRC}^{AF} < \gamma_{th}) = Pr(X + Y < \gamma_{th}) = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y) f_Y(y)\,dy \tag{12}$$

where γ_{th} is the predetermined threshold of the system. To find the probability in (12), we have to calculate the cumulative distribution function (CDF) of X and the probability density function (PDF) of Y. So, the CDF of X can be found as (13).

$$F_X(x) = Pr(X < x) = Pr\left(\frac{\kappa\Phi|h_{SR}|^2|h_{RD}|^2}{\kappa^2\Phi|h_{SR}|^2|h_{RD}|^2|f|^2 + \kappa|f|^2 + 1} < x\right) \tag{13}$$

By denoting $T = |h_{SR}|^2|h_{RD}|^2$ and $Z = |f|^2$, the (13) can be reformulated by (14).

$$F_X(x) = Pr\left(\frac{\kappa\Phi T}{\kappa^2\Phi T Z + \kappa Z + 1} < x\right)$$

$$= Pr[\kappa\Phi T < x(\kappa^2\Phi T Z + \kappa Z + 1)]$$

$$= Pr[T(\kappa\Phi - \kappa^2\Phi Z x) < x(\kappa Z + 1)]$$

$$= \begin{cases} Pr\left[T < \frac{x(\kappa Z+1)}{\kappa\Phi - \kappa^2\Phi Z x}\right] if Z < \frac{1}{\kappa x} \\ 1 if Z \geq \frac{1}{\kappa x} \end{cases}$$

$$= \int_0^{\frac{1}{\kappa x}} F_T\left(\frac{x(\kappa Z+1)}{\kappa\Phi-\kappa^2\Phi Z x}|Z = z\right) f_Z(z)dz + \int_{\frac{1}{\kappa x}}^{\infty} f_Z(z)dz \tag{14}$$

From (10), the CDF of random variables (RVs) T can be computed by (15).

$$F_T(t) = Pr(T < t) = Pr(|h_{SR}|^2|h_{RD}|^2 < t)$$

$$= \int_0^{\infty} F_{|h_{SR}|^2}\left(\frac{t}{|h_{RD}|^2}||h_{RD}|^2 = y\right) f_{|h_{RD}|^2}(y)dy$$

$$= 1 - \lambda_{RD}\int_0^{\infty} exp\left(-\lambda_{RD}y - \frac{\lambda_{SR}t}{y}\right)dy \tag{15}$$

Applying equation (3.324,1) of [23] as shown in (15) can be reformulated by (16),

$$F_T(t) = 1 - 2 \times \sqrt{\lambda_{SR}\lambda_{RD}t} \times K_1\left(2\sqrt{\lambda_{SR}\lambda_{RD}t}\right) \tag{16}$$

where $K_v(\bullet)$ is the modified Bessel function of the second kind and vth order. Applying (16) for (14), $F_X(x)$ can be obtained by (17).

$$F_X(x) = 1 - 2\lambda_{RR} \times \int_0^{\frac{1}{\kappa x}} exp(-\lambda_{RR}z) \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}x(\kappa z+1)}{\kappa\Phi-\kappa^2\Phi z x}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}x(\kappa z+1)}{\kappa\Phi-\kappa^2\Phi z x}}\right)dz \tag{17}$$

Next, the CDF of Y can be found as (18).

$$F_Y(y) = Pr(Y < y) = Pr(\Phi|h_{SD}|^2 < y) = Pr\left(|h_{SD}|^2 < \frac{y}{\Phi}\right)$$

$$= 1 - exp\left(-\frac{\lambda_{SD}y}{\Phi}\right) \tag{18}$$

From (18), the PDF of Y can be obtained by (19).

$$f_Y(y) = \frac{\partial F_Y(y)}{\partial y} = \frac{\lambda_{SD}}{\Phi}exp\left(-\frac{\lambda_{SD}y}{\Phi}\right) \tag{19}$$

Substituting (17) and (19) into (12), finally, the OP in exact form can be claimed as (20),

$$OP = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y)f_Y(y)dy$$

$$= 1 - exp\left(-\frac{\lambda_{SD}\gamma_{th}}{\Phi}\right) - \frac{2\lambda_{RR}\times\lambda_{SD}}{\Phi}\int_0^{\gamma_{th}}\int_0^{\frac{1}{\kappa(\gamma_{th}-y)}} exp\left(-\lambda_{RR}z - \frac{\lambda_{SD}y}{\Phi}\right) \times \Upsilon(y,z) \times K_1[2\Upsilon(y,z)]\, dydz \tag{20}$$

where $\Upsilon(y,z) = \sqrt{\frac{\lambda_{SR}\lambda_{RD}(\gamma_{th}-y)(\kappa z+1)}{\kappa\Phi-\kappa^2\Phi z(\gamma_{th}-y)}}$.

3.2. Lower and upper bound analysis

From (11), we can compute as (21).

$$2\,min(X,Y) \leq X + Y \leq 2\,max(X,Y) \tag{21}$$

Therefore, the OP of the system in lower bound form can be given by (22).

$$OP_{LB} = Pr\left[min(X,Y) < \frac{\gamma_{th}}{2}\right] = 1 - \underbrace{Pr\left(X \geq \frac{\gamma_{th}}{2}\right)}_{P_1}\underbrace{Pr\left(Y \geq \frac{\gamma_{th}}{2}\right)}_{P_2} \tag{22}$$

From (17), P_1 can be calculated as (23).

$$P_1 = 1 - Pr\left(X < \frac{\gamma_{th}}{2}\right) = 2\lambda_{RR} \times$$

$$\int_0^{\frac{2}{\kappa\gamma_{th}}} exp(-\lambda_{RR} z) \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}}\right) dz \quad (23)$$

Next, P_2 can be found as (24).

$$P_2 = 1 - Pr\left(Y < \frac{\gamma_{th}}{2}\right) = exp\left(-\frac{\lambda_{SD}\gamma_{th}}{2\Phi}\right) \quad (24)$$

Substituting (23) and (24) into (22), we have:

$$OP_{LB} = 1 - 2\lambda_{RR} \times exp\left(-\frac{\lambda_{SD}\gamma_{th}}{2\Phi}\right)$$

$$\times \int_0^{\frac{2}{\kappa\gamma_{th}}} exp(-\lambda_{RR} z) \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}}\right) dz \quad (25)$$

Similar to the above, the upper bound OP of the system can be computed as (26).

$$OP_{UB} = Pr\left[max(X, Y) < \frac{\gamma_{th}}{2}\right] = Pr\left(X < \frac{\gamma_{th}}{2}\right) Pr\left(Y < \frac{\gamma_{th}}{2}\right)$$

$$= \left\{1 - 2\lambda_{RR} \times \int_0^{\frac{2}{\kappa\gamma_{th}}} exp(-\lambda_{RR} z) \times \sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}} \times K_1\left(2\sqrt{\frac{\lambda_{SR}\lambda_{RD}\gamma_{th}(\kappa z+1)}{2\kappa\Phi - \kappa^2\Phi z\gamma_{th}}}\right) dz\right\}$$

$$\times \left\{1 - exp\left(-\frac{\lambda_{SD}\gamma_{th}}{2\Phi}\right)\right\} \quad (26)$$

4. NUMERICAL RESULTS AND DISCUSSION

The system OP versus α is shown in Figure 3 with η=1, γth =1, and Φ =7 dB. The results show that the OP of the model system has a massive decrease with the rising of α from 0 to 0.45 and the has a considerable increase when α rises to 1 in three cases with exact, lower and upper bound analysis. The maximal value of the system OP can be obtained with α=0.45. Furthermore, the OP is considered as the function of γ_{th}, as shown in Figure 4. Here we set η=0.8, α=0.25, and Φ =5 dB. Here, γ_{th} increases from 0 to 6, as shown in Figure 4. As shown in Figure 4, the system OP increases significantly when β rises in three cases with exact, lower, and upper bound analysis. From Figures 4 and 5, the analytical and the simulation curves overlap each others as shown in the analytical section.

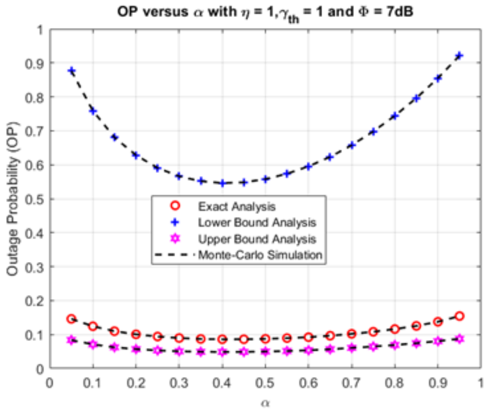

Figure 3. OP versus α

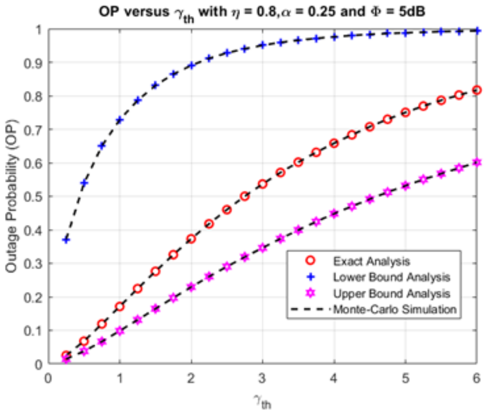

Figure 4. OP versus γ_{th}

Furthermore, the system OP versus η and Φ are investigated in Figures 5 and 6, respectively. In Figure 5, the main system parameters are set as $\alpha=0.75$, $\gamma_{th}=1$ and $\Phi=5$ dB, and in Figure 6, we set $\alpha=0.5$, $\gamma_{th}=1$, and $\eta=1$ respectively. From Figures 5 and 6, it can be observed that the system OP has a slight increase with rising η from 0 to 1 and has a massive decrease when Φ varies from -5 to 15 dB, respectively. Also, the simulation and analytical values agree to justify the analytical section.

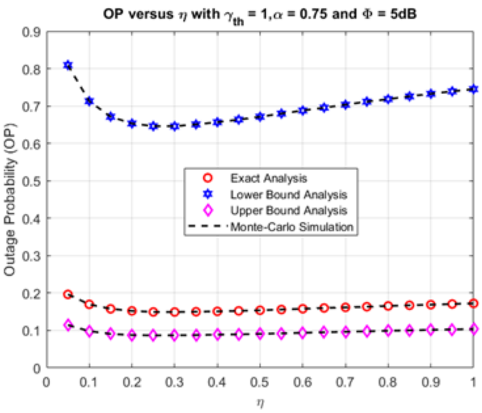

Figure 5. OP versus η

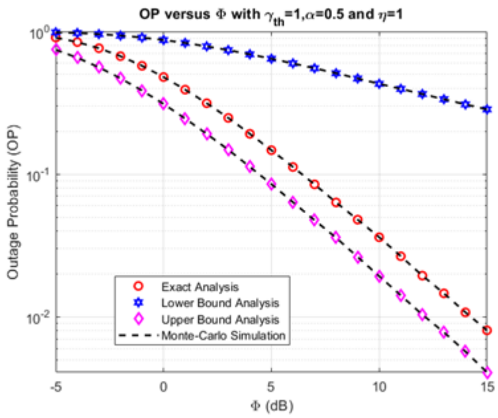

Figure 6. OP versus Φ

5. CONCLUSION

This paper proposed and investigated the one-way AF full-duplex relaying network under impact of direct link. For the system performance analysis, the exact and lower and upper bound form of the system outage probability (OP) are investigated and derived. In this system model, authors assume that the E uses the MRC (maximal ratio combining) technique. Finally, we can see that the analytical and the simulation values overlap to verify the analytical section using the Monte Carlo Simulation. Also, we investigate the influence of the system primary parameters on the proposed system OP.

ACKNOWLEDGEMENTS

This research was supported by the Industrial University of Ho Chi Minh City (IUH), Vietnam, under grant No. 72/HD-DHCN.

REFERENCES

[1] S. Bi, C. K. Ho, and R. Zhang, “Wireless powered communication: Opportunities and challenges,” *IEEE Commun. Mag.*, vol. 53, no. 4, pp. 117-125, Apr. 2015, doi:10.1109/mcom.2015.7081084.

[2] D. Niyato, D. I. Kim, M. Maso, and Z. Han, “Wireless Powered Communication Networks: Research Directions and Technological Approaches,” *IEEE Wirel. Commun.*, vol. 24, no. 6, pp. 88-97, December 2017, doi: 10.1109/mwc.2017.1600116.

[3] H. Yu, H. Lee, and H. Jeon, “What is 5G? Emerging 5G Mobile Services and Network Requirements,” *Sustainability* vol. 9, no. 10, 2017, doi:10.3390/su9101848.

[4] X. Zhou, R. Zhang, and C. K. Ho, “Wireless Information and Power Transfer: Architecture Design and Rate-Energy Tradeoff,” *IEEE Trans. Commun.*, vol. 61, no. 11, pp. 4754-4767, Nov. 2013, doi:10.1109/tcomm.2013.13.120855.

[5] T. N. Nguyen, M. Tran, D-H Ha, T. T. Trang, and M. Voznak, “Multi-source in DF Cooperative Networks with the PSR Protocol Based Full-duplex Energy Harvesting over a Rayleigh Fading Channel: Performance Analysis,” *Proceedings of the Estonian Academy of Sciences*, vol. 68, no. 3, pp. 264-275, May 2019, doi: 10.3176/proc.2019.3.03.

[6] T. N. Nguyen, M. Tran, T.-L. Nguyen, D.-H. Ha, and M. Voznak, “Performance Analysis of a User Selection Protocol in Cooperative Networks with Power Splitting Protocol-Based Energy Harvesting Over Nakagami-m/Rayleigh Channels,” *Electronics*, vol. 8, no. 4, pp. 448, Apr. 2019, doi: 10.3390/electronics8040448.

[7] T. Nguyen, T. Q. Minh, P. Tran, M. Vozňák, “Energy Harvesting over Rician Fading Channel: A Performance Analysis for Half-Duplex Bidirectional Sensor Networks under Hardware Impairments,” *Sensors*, vol. 18, no. 6, 2018, pp. 1781, doi: 10.3390/s18061781.

[8] T. N. Nguyen *et al.*, “Performance Enhancement for Energy Harvesting Based Two-way Relay Protocols in Wireless Ad-hoc Networks with Partial and Full Relay Selection Methods,” *Ad Hoc Networks*, vol. 84, pp. 178-187, Mar. 2019, doi: 10.1016/j.adhoc.2018.10.005.

[9] T. Dinh and N. Ha, “Power beaconassisted energy harvesting wireless physical layer cooperative relaying networks: performance analysis,” *Symmetry*, vol. 12, no. 1, pp. 106, Jan 2020, doi: 10.3390/sym12010106.

[10] P. K. Gopala, L. Lai and H. El Gamal, “On the Secrecy Capacity of Fading Channels,” *IEEE Transactions on Information Theory*, vol. 54, no. 10, pp. 4687-4698, Oct. 2008. doi: 10.1109/TIT.2008.928990.

[11] S. Li and Q. Du, “A Review of Physical Layer Security Techniques for Internet of Things: Challenges and Solutions,” *Entropy*, vol. 20, no. 10, pp. 730, doi:10.3390/e20100730.

[12] K. Ali, A. Mohammadi, and Mohammadi, “Joint Relay Selection and Power Allocation in Large-Scale MIMO Systems with Untrusted Relays and Passive Eavesdroppers,” *IEEE Transactions on Information Forensics and Security*, vol. 13, no. 2, pp. 341-355, Feb. 2018, doi:10.1109/tifs.2017.2750102.

[13] H. Lin *et al*., “Cooperative Jamming for Physical Layer Security Enhancement in Internet of Things.” *IEEE Internet of Things Journal*, vol. 5, no. 1, pp. 219-228, Jan. 2018, doi:10.1109/jiot.2017.2778185.

[14] P. T. Tin, D. T. Hung, T. Nguyen, T. Duy, and M. Voznak, “Secrecy Performance Enhancement for Underlay Cognitive Radio Networks Employing Cooperative Multi-Hop Transmission with and without Presence of Hardware Impairments,” *Entropy*, vol. 21, no. 2, pp. 217, Feb. 2019, doi:10.3390/e21020217.

[15] R. Zhao, Y. Yuan, L. Fan, and Y.-C. He, “Secrecy Performance Analysis of Cognitive Decode-and-Forward Relay Networks in Nakagami-m Fading Channels.,” *IEEE Trans. Commun*, vol. 65, no. 2, pp. 549-563, February 2017, doi: 10.1109/TCOMM.2016.2618793.

[16] P. T. Tin, M. Tran, T. N. Nguyen, and T.-L. Nguyen, “System performance analysis of hybrid time power switching protocol of EH bidirectional relaying network in amplify-and-forward mode,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 1, pp. 118-126, April 2019, doi: 10.11591/ijeecs.v14.i1.pp118-126.

[17] P. T. Tin, M. Tran, T. N. Nguyen, and T.-L. Nguyen, “A new look at energy harvesting half-duplex DF power splitting protocol relay network over rician channel in case of maximizing capacity,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 13, no. 1, pp. 249-257, January 2019, doi: 11591/ijeecs.v13.i1.pp249-257.

[18] T. N. Nguyen, M. Tran, T.-L. Nguyen, D.-H. Ha, and M. Voznak, “Performance Analysis of a User Selection Protocol in Cooperative Networks with Power Splitting Protocol-Based Energy Harvesting Over Nakagami-m/Rayleigh Channels,” *Electronics*, vol. 8, no. 4, pp. 448, Apr. 2019, doi: 10.3390/electronics8040448.

[19] T. Nguyen, T. Q. Minh, P. Tran, and M. Vozňák, “Energy Harvesting over Rician Fading Channel: A Performance Analysis for Half-Duplex Bidirectional Sensor Networks under Hardware Impairments,” *Sensors*, vol. 18, no. 6, pp. 1-22, 2018, doi: 10.3390/s18061781.

[20] V.-D. Phan, P. T. Tin, M. Tran, T. T. Trang, “User selection protocols in FD PSP EH cooperative network over rayleigh fading channel: outage and intercept probability,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 4, Dec. 2019, doi: 10.11591/ijpeds.v10.i4.pp2130-2137.

[21] H. Ju and R. Zhang, “Throughput Maximization in Wireless Powered Communication Networks,” *IEEE Trans. Wirel. Commun.,* vol. 13, no. 1, pp. 418-428, Jan. 2014, doi: 10.1109/TWC.2013.112513.130760.

[22] M. R. Bhatnagar, “On the Capacity of Decode-and-Forward Relaying over Rician Fading Channels,” *IEEE Commun. Lett*., vol. 17, no. 6, pp. 1100-1103, Jun. 2013. doi:10.1109/lcomm.2013.050313.122813.

[23] D. Zwillinger, “Table of Integrals, Series, and Products,” *Springer: NY, USA*, 2015. doi:10.1016/c2010-0-64839-5.

[24] A. A. Nasir, X. Zhou, S. Durrani and R. A. Kennedy, "Relaying Protocols for Wireless Energy Harvesting and Information Processing," in *IEEE Transactions on Wireless Communications*, vol. 12, no. 7, pp. 3622-3636, July 2013, doi: 10.1109/TWC.2013.062413.122042.

[25] N. Tan, T. H. Q. Nguyen, P. Minh, T. Tran, and M. Voznak, “Adaptive Energy Harvesting Relaying Protocol for Two-Way Half Duplex System Network over Rician Fading Channels,” *Wirel. Commun. Mob. Comput*., vol. 2018, April 2018, doi: 10.1155/2018/7693016.