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Article · February 2021

DOI: 10.12928/telkomnika.v19i1.15265

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TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 19, No. 1, February 2021, pp. 206~212
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v19i1.15265

Lower and upper bound form for outage probability analysis in two-way of half-duplex relaying network under impact of direct link

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Article Info

Article history:

Received Jan 10, 2020
Revised Aug 2, 2020
Accepted Aug 29, 2020

Keywords:

Energy harvesting
Half-duplex
Outage probability
Two-way

ABSTRACT

In this paper, the system performance of the two-way of half-duplex (HD) relaying network under the impact of the direct link is studied. The model system has two sources (S) and one destination (D) communicate by direct link and via relay (R). For system performance analysis, we derived the lower and upper bound for outage probability (OP). Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

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1. INTRODUCTION

Nowadays, wireless powered communication network (WPCN) is the best solution for overcoming the limitation in energy harvesting in the wireless-powered communication with the considerable demand energy in energy-constrained wireless networks. Based on the fact that human-made radio frequency (RF) can carry both energy and information, WPCN is considered as the leading solution for at our time [1-6]. In this time, many researched focus on the efficiency of the WPCN and its solution. Authors in [7] studied the outage probability between some points based on the tradeoff fundamental and [8] proposed and designed the practical receiver for energy and information transmission and its advantages for the communication network. Furthermore, authors in [9] presented and demonstrated the practical energy harvesting communication network, and [10] 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 these protocols are proposed and investigated in [11-15].

In this paper, the system performance of the two-way of half-duplex (HD) relaying network under the impact of the direct link is studied. The model system has two sources (S) and one destination (D) communicate by direct link and via relay (R). For system performance analysis, we derived the lower and upper bound for outage probability (OP). Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

2. SYSTEM MODEL

In this section, Figure 1 proposed the system model. The energy harvesting (EH) and information transferring (IT) phases are drawn in Figure 2 [16-20]. The energy harvesting and information transmission is formulated as the followings.

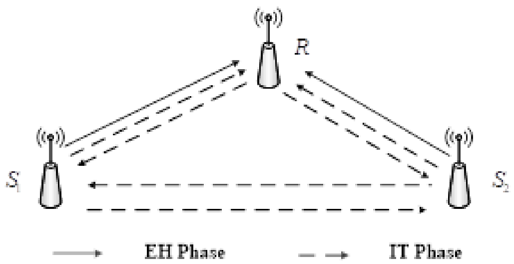

Figure 1. System model

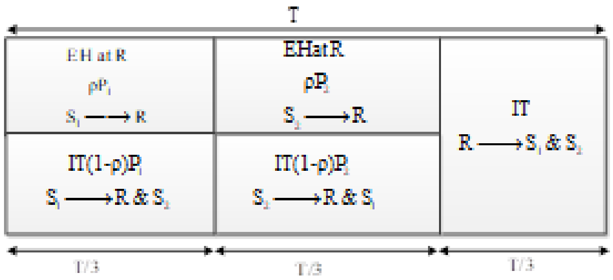

Figure 2. The EH and IT phases

2.1. Energy harvesting process

The received signal at R and S_2 are;

$$\begin{aligned} y_{1,R}^{I} &= h_{1,R}x_1 + n_r^{I}, \\ y_{1,2}^{I} &= h_{1,2}x_1 + n_2^{I} \end{aligned} \tag{1}$$

The harvested energy at R is;

$$E_h^{I} = \eta\rho(T/3)P_1|h_{1,R}|^2 \tag{2}$$

where $0 < \eta \le 1$ is energy conversion efficiency and $0 < \rho < 1$ is the power splitting factor. The received signals at R and S_1 are;

$$\begin{aligned} y_{2,R}^{II} &= h_{2,R}x_2 + n_r^{II}, \\ y_{2,1}^{II} &= h_{2,1}x_2 + n_1^{II} \end{aligned} \tag{3}$$

where $E\{|x_2|^2\} = P_2$. The total harvested energy at R is;

$$E_h = \eta\rho(T/3)\left(P_1|h_{1,R}|^2 + P_2|h_{2,R}|^2\right) \tag{4}$$

From (4), we have;

$$E_h = \eta\rho(T/3)\left(P_1|h_{1,R}|^2 + P_2|h_{2,R}|^2\right) = \eta\rho(T/3)P\left(|h_{1,R}|^2 + |h_{2,R}|^2\right) \tag{5}$$

where $P_1 = P_2 = P$ The average transmit power at R is;

$$P_R = \frac{E_h}{T/3} = \eta\rho P\left(|h_{1,R}|^2 + |h_{2,R}|^2\right) \tag{6}$$

2.2. Information transmission phase

The received signal at R and S_2 can be calculated as;

$$y_{1,R}^{I} = \sqrt{1-\rho} h_{1,R} x_1 + n_r^I, \qquad y_{1,2}^{I} = h_{1,2} x_1 + n_2^I \tag{7}$$

The received signal at R and S_1 are;

$$y_{2,R}^{II} = \sqrt{1-\rho} h_{2,R} x_2 + n_r^{II}, \qquad y_{2,1}^{II} = h_{2,1} x_2 + n_1^{II} \tag{8}$$

The received signal at S_1 and S_2 can be formulated as;

$$y_1^{III} = h_{R,1} x_R + n_1^{III}, \qquad y_2^{III} = h_{R,2} x_R + n_2^{III} \tag{9}$$

where $\mathrm{E}\left\{|x_R|^2\right\} = P_R$. In AF protocol, the amplifying coefficient χ can be formulated as;

$$\chi = \frac{x_R}{y_R} = \sqrt{\frac{P_R}{(1-\rho)\left[P_1|h_{1,R}|^2 + P_2|h_{2,R}|^2\right] + N_0}} = \sqrt{\frac{P_R}{(1-\rho)P\left[|h_{1,R}|^2 + |h_{2,R}|^2\right] + N_0}} \tag{10}$$

From (9), the received signal at S_1 can be rewritten as;

$$y_1^{III} = h_{R,1}\chi y_R + n_1^{III} = h_{R,1}\chi\left(y_{1,R}^{I} + y_{2,R}^{II}\right) + n_1^{III} \tag{11}$$

Replace (7), (8) into (11), finally we have;

$$\begin{aligned} y_1^{III} &= h_{R,1}\chi\left(y_{1,R}^{I} + y_{2,R}^{II}\right) + n_1^{III} \\ &= h_{R,1}\chi\left[\sqrt{1-\rho} h_{1,R} x_1 + \sqrt{1-\rho} h_{2,R} x_2 + n_r^I + n_r^{II}\right] + n_1^{III} \\ &= \underbrace{\chi h_{R,1} h_{1,R}\sqrt{1-\rho} x_1 + h_{R,1}\chi\sqrt{1-\rho} h_{2,R} x_2}_{signal} + \underbrace{h_{R,1}\chi n_r + n_1^{III}}_{noise} \end{aligned} \tag{12}$$

Therefore, as shown in (12) can be rewritten as;

$$y_1^{III} = \underbrace{h_{R,1}\chi\sqrt{1-\rho} h_{2,R} x_2}_{signal} + \underbrace{h_{R,1}\chi n_r + n_1^{III}}_{noise} \tag{13}$$

From (13), the signal to noise ratio (SNR) of S_2-R-S_1 link can be formulated as;

$$\gamma_{2,1}^{AF} = \frac{E\left[|signal|^2\right]}{E\left[|noise|^2\right]} = \frac{|h_{R,1}|^2|h_{2,R}|^2 P_2\chi^2(1-\rho)}{|h_{R,1}|^2\chi^2 N_0 + N_0} = \frac{|h_{R,1}|^2|h_{2,R}|^2 P(1-\rho)}{|h_{R,1}|^2 N_0 + \frac{N_0}{\chi^2}} \tag{14}$$

From (10) and (14), we have;

$$\gamma_{2,1}^{AF} \simeq \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1 + (1-\rho)} \tag{15}$$

where $\Psi = \frac{P_2}{N_0} = \frac{P}{N_0}, \varphi_1 = |h_{R,1}|^2, \varphi_2 = |h_{2,R}|^2$. From (8) the received signal at D is

$$\gamma_{2,1}^{direct} = \frac{P_2|h_{2,1}|^2}{N_0} = \Psi\varphi_3 \tag{16}$$

where $\varphi_3 = |h_{2,1}|^2$. Finally, the overall SNR at S_1 is;

$$\gamma_{MRC}^{AF} = \gamma_{2,1}^{AF} + \gamma_{2,1}^{direct} = \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1+(1-\rho)} + \Psi\varphi_3 = X + Y \quad (17)$$

where $X = \frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1+(1-\rho)}$ and $Y = \Psi\varphi_3$

3. OUTAGE PROBABILITY (OP) ANALYSIS

3.1. Exact analysis

The OP of the system at the source S_1 can be difined as;

$$OP = Pr(\gamma_{MRC}^{AF} < \gamma_{th}) = Pr(X + Y < \gamma_{th}) = \int_0^{\gamma_{th}} F_X(\gamma_{th} - y) f_Y(y) dy \quad (18)$$

where γ_{th} is the predetermined threshold of the system. To find the probability in (18), we have to calculate the cumulative distribution function (CDF) of X. So, the CDF of X can be found as;

$$\begin{aligned}
F_X(x) &= Pr(X < x) = Pr\left(\frac{\varphi_1\varphi_2\Psi\eta\rho(1-\rho)}{\eta\rho\varphi_1 + (1-\rho)} < x\right) \\
&= Pr\left[\varphi_2 < \frac{x(\eta\rho\varphi_1+(1-\rho))}{\varphi_1\Psi\eta\rho(1-\rho)}\right] = Pr\left[\varphi_2 < \frac{x}{\Psi(1-\rho)} + \frac{x}{\varphi_1\Psi\eta\rho}\right] \\
&= \int_0^{\infty} F_{\varphi_2}\left[\left(\frac{x}{\Psi(1-\rho)} + \frac{x}{\varphi\Psi\eta\rho}\right) | \varphi_1 = \varphi\right] \times f_{\varphi_1}(\varphi) d\varphi \\
&= 1 - \lambda_1\, exp\left[-\frac{x\lambda_2}{\Psi(1-\rho)}\right] \int_0^{\infty\int\left(-\frac{x\lambda_2}{\varphi\Psi\eta\rho} - \lambda_1\varphi\right)} exp
\end{aligned} \quad (19)$$

where λ_1, λ_2 are the mean of random variables (RVs) φ_1, φ_2, respectively. Applying as shown in (3.324,1) of [ref: table of…], in (19) can be reformulated by;

$$F_X(x) = 1 - 2\, exp\left[-\frac{x\lambda_2}{\Psi(1-\rho)}\right] \times \sqrt{\frac{x\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(2\sqrt{\frac{x\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \quad (20)$$

Substituting (20) into (18), we can obtain;

$$OP = 1 - exp\left(-\frac{\gamma_{th}\lambda_3}{\Psi}\right) - \frac{2\lambda_3}{\Psi}\int_0^{\gamma_{th}} \begin{array}{l} exp\left[-\frac{(\gamma_{th}-y)\lambda_2}{\Psi(1-\rho)} - \frac{y\lambda_3}{\Psi}\right] \\ \times \sqrt{\frac{(\gamma_{th}-y)\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(2\sqrt{\frac{(\gamma_{th}-y)\lambda_1\lambda_2}{\Psi\eta\rho}}\right) dy \end{array} \quad (21)$$

where λ_3 is the mean of RV φ_3

3.2. Lower and upper bound analysis

We will perform the OP of the system in terms of lower and upper bound form. From (17), we can compute as (22).

$$2\, min(X, Y) \le X + Y \le 2\, max(X, Y) \quad (22)$$

Therefore, the OP of the system in lower bound form can be given by;

$$OP_{LB} = Pr\left[min(X, Y) < \frac{\gamma_{th}}{2}\right] = 1 - \underbrace{Pr\left(X \ge \frac{\gamma_{th}}{2}\right)}_{P_1} \underbrace{Pr\left(Y \ge \frac{\gamma_{th}}{2}\right)}_{P_2} \quad (23)$$

From (20), P_1 can be calculated as (24).

$$P_1 = 1 - Pr\left(X < \frac{\gamma_{th}}{2}\right) = exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \tag{24}$$

Next, P_2 can be found as;

$$\begin{aligned} P_2 &= 1 - Pr\left(Y < \frac{\gamma_{th}}{2}\right) = 1 - Pr\left(\Psi\varphi_3 < \frac{\gamma_{th}}{2}\right) \\ &= 1 - Pr\left(\varphi_3 < \frac{\gamma_{th}}{2\Psi}\right) = exp\left(-\frac{\lambda_3\gamma_{th}}{2\Psi}\right) \end{aligned} \tag{25}$$

From (24), (25) and (23), we have;

$$OP_{LB} = 1 - exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)} - \frac{\lambda_3\gamma_{th}}{2\Psi}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right) \tag{26}$$

Similar as above, the upper bound OP of system can be computed as;

$$\begin{aligned} OP_{UB} &= Pr\left[max(X,Y) < \frac{\gamma_{th}}{2}\right] = Pr\left(X < \frac{\gamma_{th}}{2}\right) Pr\left(Y < \frac{\gamma_{th}}{2}\right) \\ &= \left\{1 - exp\left[-\frac{\gamma_{th}\lambda_2}{2\Psi(1-\rho)}\right] \times \sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}} \times K_1\left(\sqrt{\frac{2\gamma_{th}\lambda_1\lambda_2}{\Psi\eta\rho}}\right)\right\} \times \left\{1 - exp\left(-\frac{\lambda_3\gamma_{th}}{2\Psi}\right)\right\} \end{aligned} \tag{27}$$

4. NUMERICAL RESULTS AND DISCUSSION

The system performance of the model system is investigated as in [21-27]. The OP as a function of the energy coefficient η is drawn in Figure 3 with the main system parameters as $\gamma_{th} = 1, \psi = 5\ dB$, and $\rho = 0.5$. In this figure, we considered the exact, upper, and lower bound analysis of the system OP. The results show that the system OP decrease with the increasing of the energy coefficient. In the same way, the system Op versus γ_{th} is illustrated in Figure 4, and we set $\eta = 1$, $\psi = 10\ dB$, and $\rho = 0.5$. The system OP has a significant rise while γ_{th} varies from 0 to 6 as shown in Figure 4 for all cases with lower and upper bound. From Figures 3 and 4, the simulation and the analytical values agree well. Moreover, the system OP versus ψ and ρ are presented in Figures 5 and 6, respectively. We set $\gamma_{th} = 1$, $\eta = 1$, and $\rho - 0.85$ for Figure 4, $\psi = 5\ dB$ for Figure 5, respectively. From Figure 5, it can be stated that the system OP falls while ψ rises from -5 dB to 15 dB. The system OP has a slight fall with ρ varies from 0 to 0.5 and then has a rise with the remaining values of ρ. The maximum value of the system OP can be obtained with $\rho = 0.5$, as shown in Figure 6. Once again, the simulation results have an agreement with the mathematical, analytical results, as in Figures 5 and 6.

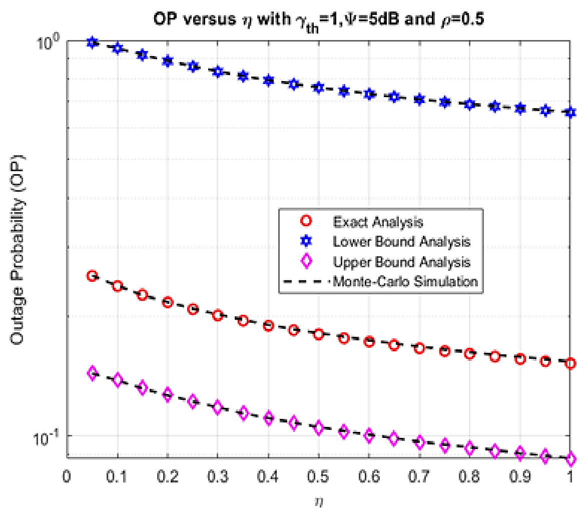

Figure 3. OP versus η

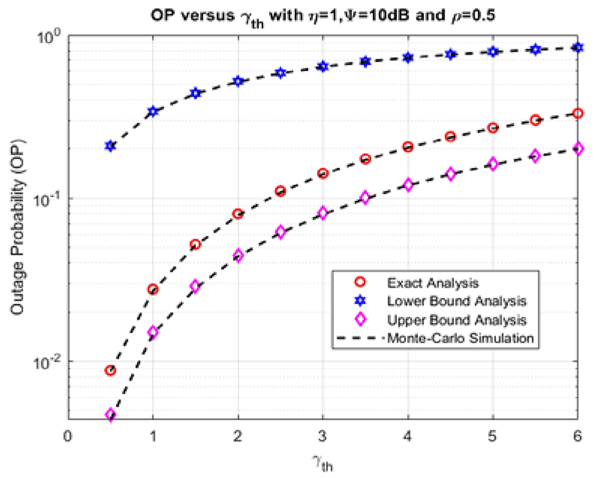

Figure 4. OP versus γ_{th}

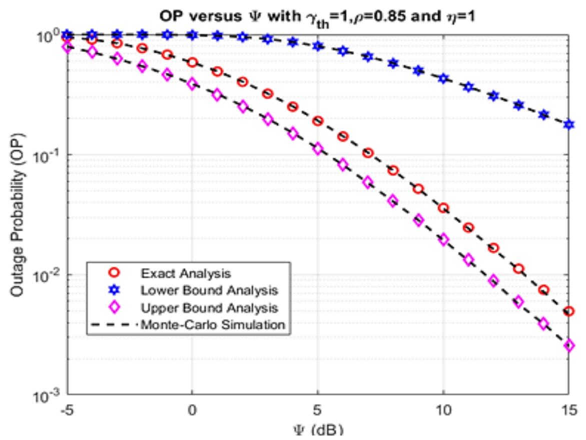

Figure 5. OP versus ψ

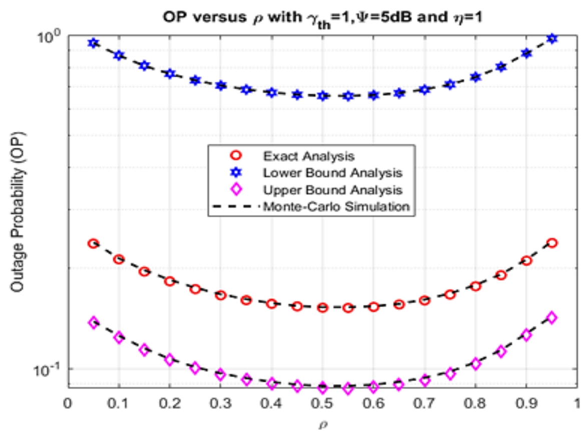

Figure 6. OP versus ρ

5. CONCLUSION

In this paper, the system performance of the two-way of HD relaying network under the impact of the direct link is studied. The model system has two S and one D communicate by direct link and via R. For system performance analysis, we derived the lower and upper bound for OP. Furthermore, the analytical expressions of the system performance are verified by using the Monte Carlo simulation in the effect of main parameters. As shown in the results, we can the simulation and analytical results have a good agreement.

REFERENCES

[1] Suzhi Bi, *et al*., "Wireless powered communication: Opportunities and challenges," *IEEE Communication Magazine,* vol. 53, no. 4, pp. 117-125, April 2015.

[2] Niyato D., Kim D. I., Maso M., Han Z., "Wireless powered communication networks: research directions and technological approaches," *IEEE Wireless Communications,* vol. 24, no. 6, pp. 88-97, July 2017.

[3] Heejung Y., *et al*., "What is 5G? emerging 5G mobile services and network requirements," *Sustainability,* vol. 9, no. 10*,* pp. 1-22, October 2017.

[4] Xun Zhou, *et al*., "Wireless information and power transfer: architecture design and rate-energy tradeoff," *IEEE Transactions on Communications,* vol. 61, no. 11, pp. 4754-4767, November 2013.

[5] Nguyen N. T., *et al*., "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.

[6] Nguyen N. T*., et al*., "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, pp. 1-14, April 2019.

[7] Nguyen T., Quang Minh T., Tran P., Vozňák M., "Energy harvesting over rician fading channel: a performance analysis for half-duplex bidirectional sensor networks under hardware impairments," *Sensors,* vol. 18, no. 6, June 2018.

[8] Nguyen Tan N., *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. 178-87, March 2019.

[9] Liu, Ruoheng, Ivana Maric, Predrag Spasojevic, Roy D. Yates, "Discrete memoryless interference and broadcast channels with confidential messages: secrecy rate regions," *IEEE Transactions on Information Theory,* vol. 54, no. 6, pp. 2493-507, June 2008.

[10] P. K. Gopala, L. Lai and H. El Gamal, "On the secrecy capacity of fading channels," *IEEE Transactions on Information Theor*y, vol. 54, no. 10, pp. 4687-4698, October 2008.

[11] Sun Li Qinghe Du, "A review of physical layer security techniques for internet of things: challenges and solutions," *Entropy,* vol. 20, no. 10, pp. 1-21, September 2018.

[12] Kuhestani Ali, Abbas Mohammadi, and Mohammadali 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, February 2018.

[13] Hu 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, February 2018.

[14] Tin Phu Tran, *et al*., "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. 1-16, February 2019.

[15] Zhao R., Yuan Y., Fan L., He Y. C., "Secrecy performance analysis of cognitive decode-and-forward relay networks in nakagami-m fading channels," *IEEE Transactions on Communications,* vol. 65, no. 2, pp. 549-563, February 2017.

[16] Tin Phu, *et al*., "Secrecy performance of TAS/SC-based multi-hop harvest-to-transmit cognitive WSNs under joint constraint of interference and hardware imperfection," *Sensors,* vol. 19, no. 5, pp. 1-20, March 2019.

[17] Tran Dinh Hiew, *et al.,* "Performance enhancement for multi-hop harvest-to-transmit WSNs with path-selection methods in presence of eavesdroppers and hardware noises," *IEEE Sensors Journal*, vol 18, no. 12, pp. 5173-5186, April 2018.

[18] Van-Duc Phan, *et al*.,"Outage probability analysis of dual energy harvesting relay network over rayleigh fading channel using SC and MRC technique," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 16, no. 2, pp. 803-811, November 2019.

[19] Tan N. Nguyen, *et al*., "Outage probability analysis of EH relay-assisted non-orthogonal multiple access (NOMA) systems over block Rayleigh fading channel," *International Journal of Electrical and Computer Engineering,* vol .9, no. 5, pp. 3607-3614, October 2019.

[20] Caijun Zhong, *et al*., "Wireless information and power transfer with full duplex relaying," *IEEE Transactions on Communications*, vol. 2, no. 10, pp. 3447-3461, October 2014.

[21] Nguyen Tan N., Phuong T. Tran, Miroslav Vozňák, "Power splitting-based energy-harvesting protocol for wireless-powered communication networks with a bidirectional relay," *International Journal of Communication Systems,* vol. 31, no. 13, June 2018.

[22] Bhatnagar M. R., "On the capacity of decode-and-forward relaying over rician fading channels," *IEEE Communications Letters,* vol. 17, no. 6, pp. 1100-1103, June 2013.

[23] Daniel Zwillinger, "Table of Integrals, Series, and Products," *Academic Press,* Springer: NY, USA, 2015.

[24] Nasir A. A., Zhou X., Durrani S., Kennedy R. A., "Relaying protocols for wireless energy harvesting and information processing," *IEEE Transactions on Wireless Communications,* vol. 12, no. 7, pp. 3622-3636, July 2013.

[25] Phu Tran Tin, *et al*., "Exploiting direct link in two-way half-duplex sensor network over block rayleigh fading channel: upper bound ergodic capacity and exact SER analysis," *Sensors*, vol. 20, no. 4, 2020.

[26] Phu Tran Tin, *et al*., "Energy harvesting half-duplex af power splitting protocol relay network over rician channel in case of maximizing capacity," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 4, pp.1615-1624, August 2019.

[27] Phu Tran Tin, *et al*., "Exploiting direct link in two-way half-duplex sensor network over block rayleigh fading channel: upper bound ergodic capacity and exact SER analysis," *Sensors*, vol. 20, no. 4, 2020.