TELKOMNIKA, Vol.17, No.6, December 2019, pp.2764~2771
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i6.12973

Hybrid decode-amplify and forward protocol of FD EH relaying network: outage probability analysis

Van-Duc Phan[1], Duy-Hung Ha*[2], Minh Tran[3], Tran Thanh Trang[4], Thanh-Long Nguyen[5]
[1]Center of Excellence for Automation and Precision Mechanical Engineering,
Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam
[2]Wireless Communications Research Group, Faculty of Electrical and Electronics Engineering,
Ton Duc Thang 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
[4]National Key Laboratory of Digital Control and System Engineering, Ho Chi Minh City, Vietnam
[5]Center for Information Technology, Ho Chi Minh City University of Food Industry,
Ho Chi Minh City, Vietnam
*Corresponding author, e-mail: haduyhung@tdtu.edu.vn

Abstract

Nowadays, many research papers focus on the WPCN problem and how to improve its efficiency. In this research, we propose and investigate Hybrid Decode-Amplify and Forward Protocol (HDAF) of the Full-Duplex (FD) Energy Harvesting (EH) Relaying Network with the Time Switching (TS) protocol. In the beginning stage, we present the HDAF mode, which can be work like a Decode-and-Amplify (DF) or Amplify-and-Forward (AF) modes based on the best of its performance in the FD EH relaying network. Furthermore, the closed-form expression of the outage probability (OT) is analyzed and derived in connection with the primary system parameters. Besides, the comparison of the system performance in the AF, DF, and HDAF is proposed and investigated. Finally, all the results are convinced by the Monte Carlo simulation for all cases.

Keywords: *energy harvesting (EH), full-duplex (FD), hybrid decode-amplify and forward protocol (HDAF), outage probability (OT)*

1. Introduction

Remotely powering wireless communication device is an innate tendency in modern wireless networks, especially when a user or communication device has limited access to battery power or the resources necessary to regularly replace the batteries. Recently, wireless-powered communication has gained considerable interest because of its capability to deal with the energy scarcity in energy-constrained wireless networks. The energy-constrained communication systems have a limited operational lifetime, and to maintain network connectivity, periodical battery replacement or recharging is performed, which is nevertheless costly, inconvenient, and sometimes impossible. As such, energy harvesting, which scavenges energy from external natural resources such as solar, wind or vibration, has gained a great deal of interest, since it provides a cost-effective solution to prolong the lifetime of wireless communications systems. However, the amount of energy harvested from natural resources is random and highly depends on some uncontrollable factors such as the weather conditions, which makes reliable communication difficult. An attractive solution that overcomes the above limitation is to harvest energy from human-made radio frequency (RF) electromagnetic radiation (also known as wireless power transfer) [1-6]. In the last decade, many research papers focused on WPCN and how to improve its efficiency. This concept of a tradeoff between EH and information transmission in WPCN was proposed and investigated in [7] and extended in [8]. Moreover, the concept of partial network-level cooperation for EH networks was presented in detail in [9], and in [10] wireless EH and information transfer in cognitive relay networks was intensely analyzed. In WPCN, the two traditional time switching (TSP) and power splitting (PSP) protocols have been intensively studied in the literature, and many from these studies have compared the system performance of the two protocols under different scenarios [11-15].

Received April 21, 2019; Revised July 2, 2019; Accepted July 18, 2019

In this research, we propose and investigate hybrid decode-amplify and forward protocol (HDAF) of the full-duplex (FD) energy harvesting (EH) relaying network with the time switching (TS) protocol. In the beginning stage, we present the HDAF mode, which can be work like a decode-and-amplify (DF) or amplify-and-forward (AF) modes based on the best of its performance in the FD EH relaying network. Furthermore, the closed-form expression of the outage probability (OT) is analyzed and derived in connection with the primary system parameters. In addition, the comparison of the system performance in the AF, DF, and HDAF is proposed and investigated. Finally, all the results are convinced by the Monte Carlo simulation for all cases. The main contribution of this paper can be drawn as the follows:

– The HDAF of the FD EH relaying network is proposed and investigated.
– The closed-form expression of the system OP is derived and investigated in connection with the primary system parameters.
– The comparison of the system performance in the AF, DF, and HDAF is proposed and investigated.
– The Monte Carlo simulation convinces all the results.

The remaining part of this research can be drawn like the below sections. We propose the system model network in sections 2, and the outage probability analysis is provided in section 3. Section 4 gives the research results and discussions, and some conclusions are written in the last section.

2. System Model

In this section, Figure 1 presents the HDAF of the FD EH relaying network in the TS Protocol. In this model system, the information is transferred from the source (S) to the destination (D), through an energy-constrained intermediate relay (R). The energy harvesting (EH) and information transferring (IT) phases of the system model are drawn in Figure 2. In this scheme, T is the block time of the proposed system. In the first interval time (αT), where α is the TS factor α ∈ (0, 1), the R harvests energy from the S. Here; we consider the interference noise at the relay node which the factor f. In the remaining interval time (1-α) T, the information is transferred from the S to R and D, as shown in Figure 2. All the fading channels from S to R and R to D are proposed as the Raleigh fading channels [16-20].

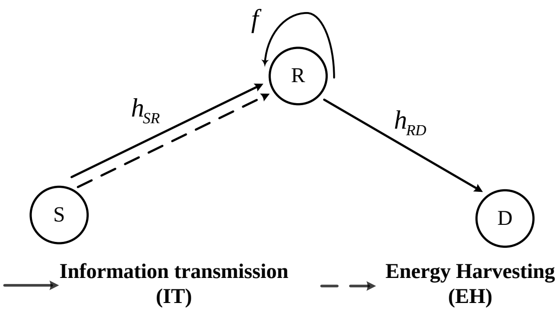

Figure 1. System model

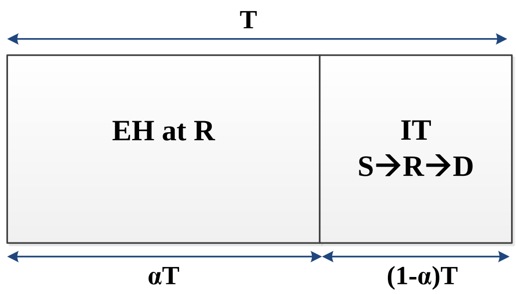

Figure 2. The EH and IT phases

3. System Performance Analysis

The received signal at the relay can be expressed as

$$y_r = h_{SR}x_s + fx_r + n_r \tag{1}$$

where h_{SR} is the channel coefficient, x_s is the energy symbol with $\mathrm{E}\left\{|x_s|^2\right\} = P_s$, x_r is the loopback interference due to full-duplex relaying and satisfies $\mathrm{E}\left\{|x_r|^2\right\} = P_r$ where $\mathrm{E}\{\bullet\}$

denotes the expectation operation, n_r is the zero-mean additive white Gaussian noise (AWGN) with variance N_0, f is the loopback interference.

Moreover, the energy harvesting in the relay can be computed as

$$P_r = \frac{E_h}{(1-\alpha)T} = \frac{\eta\alpha P_s |h_{SR}|^2}{1-\alpha} = kP_s |h_{SR}|^2 \quad (2)$$

where we denote $k = \frac{\eta\alpha}{1-\alpha}$. The received signal at the destination can be given as

$$y_d = h_{RD} x_r + n_d \quad (3)$$

where h_{RD} is the channel coefficient and n_d is the zero-mean AWGN with variance N_0. In this paper, we consider the hybrid Decode-Amplify and forward (HDAF) protocol. In the AF protocol, the relay amplifies the input signal by a factor β which is given by

$$\beta = \frac{x_r}{y_r} = \sqrt{\frac{P_r}{|h_{SR}|^2 P_s + |f|^2 P_r + N_0}} \quad (4)$$

substituting (4) into (3). Finally, we have

$$y_d = h_{RD} \beta y_r + n_d \quad (5)$$

Moreover, then substituting (1) into (5), the received signal at the destination can be rewritten as

$$y_d = h_{RD}\beta y_r + n_d = h_{RD}\beta(h_{SR}x_s + f x_r + n_r) + n_d = \underbrace{h_{RD}\beta h_{SR}x_s}_{signal} \; \underbrace{h_{RD}\beta f x_r + h_{RD}\beta n_r + n_d}_{noise} \quad (6)$$

after doing some algebra, the end to end signal to interference noise (SINR) can be obtained as in [21]

$$SINR_{AF} = \frac{\mathrm{E}\left\{|signal|^2\right\}}{\mathrm{E}\left\{|noise|^2\right\}} = \frac{\dfrac{P_s |h_{SR}|^2 |h_{RD}|^2}{|f|^2}}{\dfrac{N_0 P_s |h_{SR}|^2}{P_r |f|^2} + P_r |h_{RD}|^2 + N_0} \quad (7)$$

substituting (2) into (7), the end to end SINR at the destination can be reformulated as

$$SINR_{AF} = \frac{k\Psi |h_{SR}|^2 |h_{RD}|^2}{k^2\Psi |h_{SR}|^2 |h_{RD}|^2 |f|^2 + k|f|^2 + 1} \quad (8)$$

where we denote $\Psi = \frac{P_s}{N_0}$.

3.1. DF

In the DF protocol, from (1) the SINR at the relay can be given as

$$SINR_R = \frac{P_s|h_{SR}|^2}{P_r|f|^2+N_0} = \frac{P_s|h_{SR}|^2}{kP_s|h_{SR}|^2|f|^2+N_0} \approx \frac{1}{k|f|^2} \quad (9)$$

from (3) the SINR at the destination can be expressed as

$$SINR_D = \frac{P_r|h_{RD}|^2}{N_0} = \frac{kP_s|h_{SR}|^2|h_{RD}|^2}{N_0} = k\Psi|h_{SR}|^2|h_{RD}|^2 \quad (10)$$

3.2. Outage Probability (OP)

In HDAF protocol, the OP can be defined as follows

$$OP_{HDAF} = \Pr(SINR_R > \gamma)OP_{DF} + \Pr(SINR_R \le \gamma)OP_{AF} \quad (11)$$

where OP_{DF} and OP_{AF} are the outage probabilities in case of DF and AF modes, respectively, and $\gamma = 2^{2R}-1$ is the threshold of the system and R is the source rate.

The first term in (11) defines that the signal at the relay is successfully decoded and operates in DF mode. The terns $\Pr(SINR_R > \gamma)$ and $\Pr(SINR_R \le \gamma)$ are respectively given as

$$\begin{aligned}\Pr(SINR_R > \gamma) &= \Pr\left(\frac{1}{k|f|^2} \le \gamma\right) = \Pr\left(\frac{1}{k\gamma_2} \le \gamma\right) = \Pr\left(\gamma_2 \ge \frac{1}{k\gamma}\right) = 1-\Pr\left(\gamma_2 < \frac{1}{k\gamma}\right) \\ &= 1-F_{\gamma_2}\left(\frac{1}{k\gamma}\right) = \exp\left(-\frac{\lambda_f}{k\gamma}\right)\end{aligned} \quad (12)$$

where we denote $\gamma_2 = |f|^2$ and λ_f is the mean of the random variable (RV) $|f|^2$.

Similar to the above case, we have

$$\Pr(SINR_R \le \gamma) = 1-\Pr(SINR_R > \gamma) = 1-\exp\left(-\frac{\lambda_f}{k\gamma}\right) \quad (13)$$

the probability of operating in DF mode is given by

$$OP_{DF} = \Pr(SINR_D \le \gamma \mid SINR_R > \gamma) \quad (14)$$

using the law of conditional probability, (14) can be reformulated as

$$OP_{DF} = \frac{\Pr(SINR_D \le \gamma, SINR_R > \gamma)}{\Pr(SINR_R > \gamma)} \quad (15)$$

Since, from (9) and (10), $SINR_R$ and $SINR_D$ are independent of each other, (15) can be obtained as

$$\begin{aligned}OP_{DF} &= \frac{\Pr(SINR_D \le \gamma)\Pr(SINR_R > \gamma)}{\Pr(SINR_R > \gamma)} = \Pr(SINR_D \le \gamma) \\ &= \Pr\left(k\Upsilon|h_{SR}|^2|h_{RD}|^2 \le \gamma\right) = \Pr\left(|h_{SR}|^2|h_{RD}|^2 \le \frac{\gamma}{k\Psi}\right) \\ &= \Pr\left(\gamma_1 \le \frac{\gamma}{k\Psi}\right)\end{aligned} \quad (16)$$

where we denote $\gamma_1 = |h_{SR}|^2 |h_{RD}|^2$.

3.3. Remark

The cumulative density function (CDF) of γ_1 can be derived as

$$\begin{aligned} F_{\gamma_1}(x) &= \Pr(\gamma_1 \le x) = \Pr\left(|h_{SR}|^2 |h_{RD}|^2 \le x\right) \\ &= \Pr\left(|h_{SR}|^2 \le \frac{x}{|h_{RD}|^2}\right) = \int_0^\infty F_{|h_{SR}|^2}\left(\frac{x}{|h_{RD}|^2} \,|\, |h_{RD}|^2 = y\right) f_{|h_{RD}|^2}(y)dy \\ &= 1 - \lambda_{rd} \int_0^\infty e^{-\frac{x\lambda_{sr}}{y}} e^{-y\lambda_{rd}} dy \end{aligned} \tag{17}$$

where λ_{sr} and λ_{rd} are the mean of RV $|h_{SR}|^2$ and $|h_{RD}|^2$, respectively. Apply equation (3.324,1) of the table of integral [21], (17) can be reformulated as

$$F_{\gamma_1}(x) = 1 - 2\sqrt{x\lambda_{sr}\lambda_{rd}} \times K_1\left(2\sqrt{x\lambda_{sr}\lambda_{rd}}\right) \tag{18}$$

where $K_v(\bullet)$ is the modified Bessel function of the second kind and v[th] order. Applying (18) and replace $x = \frac{\gamma}{k\Psi}$, equation (16) can be obtained as

$$OP_{DF} = 1 - 2\sqrt{\frac{\gamma\lambda_{sr}\lambda_{rd}}{k\Psi}} \times K_1\left(2\sqrt{\frac{\gamma\lambda_{sr}\lambda_{rd}}{k\Psi}}\right) \tag{19}$$

Next, we will find the probability to operate in AF mode. The OP of AF mode can be given as

$$\begin{aligned} OP_{AF} &= \Pr\left(SINR_{AF} \le \gamma \,|\, SINR_R \le \gamma\right) = \frac{\Pr\left(SINR_{AF} \le \gamma, SINR_R \le \gamma\right)}{\Pr\left(SINR_R \le \gamma\right)} \\ &= \frac{P}{\Pr\left(SINR_R \le \gamma\right)} \end{aligned} \tag{20}$$

where $P = \Pr\left(SINR_{AF} \le \gamma, SINR_R \le \gamma\right)$. From (8) and (9), we have

$$\begin{aligned} P &= \Pr\left(\frac{k\Psi |h_{SR}|^2 |h_{RD}|^2}{k^2\Psi |h_{SR}|^2 |h_{RD}|^2 |f|^2 + k|f|^2 + 1} \le \gamma, \frac{1}{k|f|^2} \le \gamma\right) \\ &= \Pr\left(\frac{k\Psi\gamma_1}{k^2\Psi\gamma_1\gamma_2 + k\gamma_2 + 1} \le \gamma, \gamma_2 \ge \frac{1}{k\gamma}\right) \\ &= \Pr\left[k\Psi\gamma_1\left(1 - k\gamma\gamma_2\right) \le k\gamma\gamma_2 + \gamma, \gamma_2 \ge \frac{1}{k\gamma}\right] = 1 \end{aligned} \tag{21}$$

substituting (13), (19) and (21) into (11), the OP of HDAF protocol can be claimed as

$$OP_{HDAF} = 1 - 2\sqrt{\frac{\gamma\lambda_{sr}\lambda_{rd}}{k\Psi}} \times K_1\left(2\sqrt{\frac{\gamma\lambda_{sr}\lambda_{rd}}{k\Psi}}\right) + \frac{1}{1 - \exp\left(-\frac{\lambda_f}{k\gamma}\right)} \tag{22}$$

4. Numerical Results and Discussion

In this section, we investigate the influence of the primary system parameters such as α, ψ, η, and RFro on the OP of the proposed model system and the comparison of the AF, DF, and HDAF modes on the system performance [22-25]. In Figure 3, the effect of η on the system OP is plotted. In this case, we consider three cases of AF, DF, and HADF modes and set the main system parameters as α = 0.8, ψ = 1 dB, and R = 0.5 bps/Hz. In this figure, we can see that the OP of AF and DF modes have a slight decrease the increases with rising α, but the OP of the HDAF mode has a tendency decrease with rising α. It can be observed that the HDAF mode has a better system performance in comparison with the both AF and DF modes. Furthermore, the influence of ψ on the system OP is illustrated in Figure 4 for the AF, DF, and HDAF modes. Here we set η = 0.8, α = 0.5, and R = 0.5 bps/Hz for this model system. Again, the system OP of all three modes significant decrease when ψ rises from 0 to 50 dB and the system OP in HDAF mode is better than other cases. In Figures 3 and 4, all simulation results using Monte Carlo simulation is the same with the analytical results.

Moreover, the influence of R and α on the system OP is dawn in Figures 5 and 6, respectively. In these Figures., we investigate all AF, DF, and HDAF cases with the main parameters are set as α = 0.8, η = 0.8, ψ = 1 dB, and R = 0.5 bps/Hz. From the results, we can see that the system OP in HDAF mode is a lot of better than in AF and DF modes. Then, the system OP increases with rising R from 0 to 7 and decreases with rising α from 0 to 1, respectively. All the analytical results agree with the simulation results using Monte Carlo simulation.

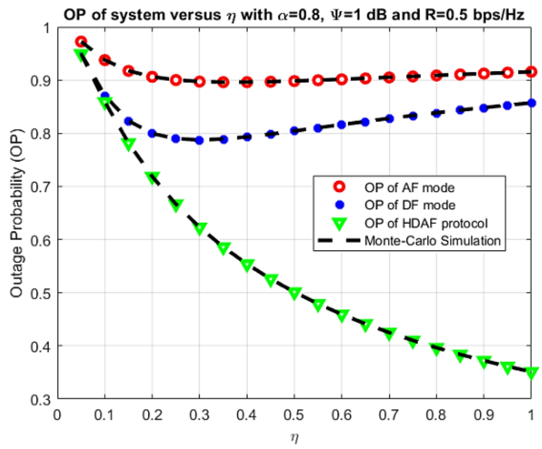

Figure 3. OP versus η

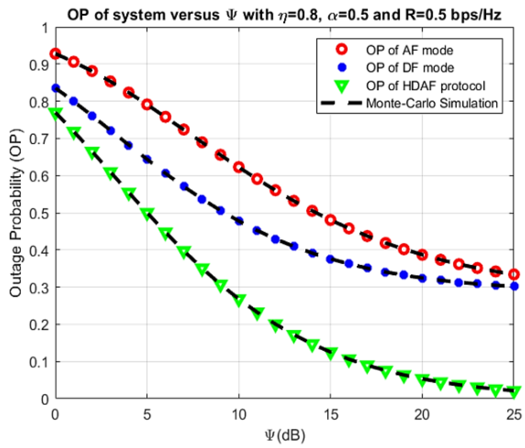

Figure 4. OP versus ψ

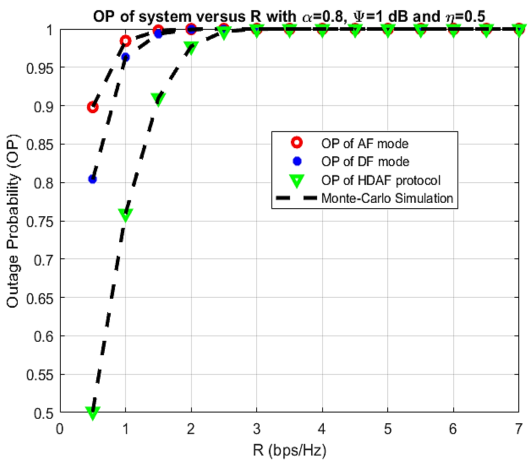

Figure 5. OP versus R

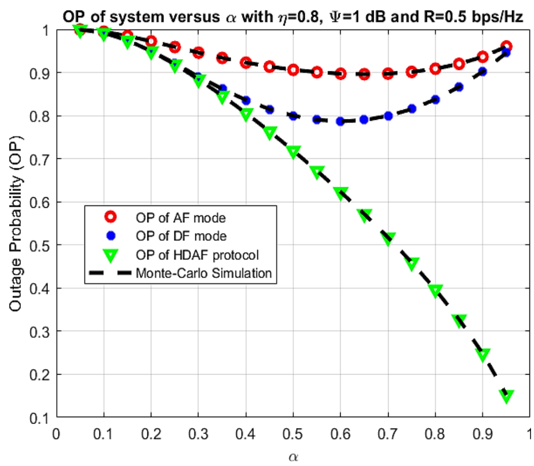

Figure 6. OP versus α

4. Conclusion

In this research, we propose and investigate hybrid Decode-Amplify And Forward Protocol (HDAF) of the Full-Duplex (FD) Energy Harvesting (EH) Relaying Network with the Time Switching (TS) protocol. In the beginning stage, we present the HDAF mode, which can be work like a Decode-and-Amplify (DF) or Amplify-and-Forward (AF) modes based on the best of its performance in the FD EH relaying network. Furthermore, the closed-form expression of the outage probability (OT) is analyzed and derived in connection with the primary system parameters. Also, the comparison of the system performance in the AF, DF, and HDAF is proposed and investigated. Finally, all the results are convinced by the Monte Carlo simulation for all cases. The results can provide the novel recommendation for the wireless relaying communication network shortly.

Acknowledgments

This research was supported by National Key Laboratory of Digital Control and System Engineering (DCSELAB), HCMUT, VNU-HCM, Vietnam.

References

[1] Chen He, Chao Zhai, Yonghui Li, and Branka Vucetic. Cooperative Strategies for Wireless-Powered Communications: An Overview. *IEEE Wireless Communications*. 08 2018; 25(4): 112-19.
[2] Yu H, Lee H, Jeon H. What is 5G? Emerging 5G Mobile Services and Network Requirements. *Sustainability*. 2017; 9: 1848.
[3] Sharma V, Karmakar P. *A Novel Method of Opportunistic Wireless Energy Harvesting in Cognitive Radio Networks*. 2015 7th International Conference on Computational Intelligence, Communication Systems and Networks. 2015.
[4] Boccardi, Federico, Robert Heath, Angel Lozano, Thomas Marzetta, Petar Popovski. Five Disruptive Technology Directions for 5G. *IEEE Communications Magazine.* 2014; 52(2): 74-80.
[5] Dai, Linglong, Bichai Wang, Yifei Yuan, Shuangfeng Han, Chih-Lin I, Zhaocheng Wang. Non-orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends. *IEEE Communications Magazine*. 09 2015; 53(9): 74-81.
[6] Saito, Yuya, Yoshihisa Kishiyama, Anass Benjebbour, Takehiro Nakamura, Anxin Li, Kenichi Higuchi. *Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access*. 2013 IEEE 77th Vehicular Technology Conference (VTC Spring). 2013.
[7] Varshney, Lav R. *Transporting Information and Energy Simultaneously*. 2008 IEEE International Symposium on Information Theory. 2008.
[8] Zhou, Xun, Rui Zhang, Chin Keong Ho. *Wireless Information and Power Transfer: Architecture Design and Rate-energy Tradeoff*. 2012 IEEE Global Communications Conference (GLOBECOM). 2012.
[9] Kashef Mohamed, Anthony Ephremides. Optimal Partial Relaying for Energy-Harvesting Wireless Networks. *IEEE/ACM Transactions on Networking*. 2016; 24(1): 113-22.
[10] Wang Zihao, Zhiyong Chen, Yao Yao, Bin Xia, Hui Liu. *Wireless Energy Harvesting and Information Transfer in Cognitive Two-way Relay Networks*. 2014 IEEE Global Communications Conference. 2014.
[11] Ju Minchul, Kyu Min Kang, Kyu Sung Hwang, Cheol Jeong. Maximum Transmission Rate of PSR/TSR Protocols in Wireless Energy Harvesting DF-Based Relay Networks. *IEEE Journal on Selected Areas in Communications.* 2015; 33(12): 2701-717.
[12] Nguyen TN, Do DT, Tran PT, Voznak M. Time Switching for Wireless Communications with Full-Duplex Relaying in Imperfect CSI Condition. *KSII Transactions on Internet and Information Systems*. 2016; 10(9).
[13] Gu Yanju, Sonia Aissa. RF-Based Energy Harvesting in Decode-and-Forward Relaying Systems: Ergodic and Outage Capacities. *IEEE Transactions on Wireless Communications*. 2015; 14(11): 425-434.
[14] Zhou Zheng, Mugen Peng, Zhongyuan Zhao, Yong Li. Joint Power Splitting and Antenna Selection in Energy Harvesting Relay Channels. *IEEE Signal Processing Letters*. 2015; 22(7): 823-827.
[15] Liu L, Zhang R, Chua K. Wireless Information and Power Transfer: A Dynamic Power Splitting Approach. *IEEE Transactions on Communications.* 2013; 61(9): 3990-4001.
[16] Tan N. Nguyen, THQ Minh, Phuong T Tran, Miroslav Voznak. Adaptive Energy Harvesting Relaying Protocol for Two-Way Half Duplex System Network over Rician Fading Channel. *Wireless Communications and Mobile Computing*. 2018.

[17] Tin, Phu Tran, Tran Hoang Quang Minh, Tan N Nguyen, Miroslav Voznak. System Performance Analysis of Half-Duplex Relay Network over Rician Fading Channel. *TELKOMNIKA (Telecommunication, Computing, Electronics and Control).* 2018; 16(1): 189.-199.
[18] Rashid, Tarique, Sunil Kumar, Akshay Verma, Prateek Raj Gautam, Arvind Kumar. Pm-EEMRP: Postural Movement Based Energy Efficient Multi-Hop Routing Protocol for Intra Wireless Body Sensor Network (Intra-WBSN). *TELKOMNIKA Telecommunication, Computing, Electronics and Control*. 2018; 16(1): 166-173.
[19] AF Morabito. Power Synthesis of Mask-Constrained Shaped Beams Through Maximally-Sparse Planar Arrays. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2016; 14(4): 1217-1219.
[20] C Zhong, H Suraweera, G Zheng, I Krikidis, Z Zhang. Wireless information and power transfer with full duplex relaying. *IEEE Trans. Commun*. 2014; 62(10): 3447–3461.
[21] Table of Integrals, Series, and Products. 2015. doi:10.1016/c2010-0-64839-5
[22] 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.* 2018; 18: 1781.
[23] Tan N Nguyen, THQ Minh, Phuong T Tran, Miroslav Voznak, TT Duy, Thanh-Long Nguyen, Phu Tran Tin. 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*. 2019; 1: 178-187.
[24] Nguyen TN, Minh THQ, Nguyen TL, Ha DH, Voznak, M. Performance Analysis of User Selection Protocol in Cooperative Networks with Power Splitting Protocol Based Energy Harvesting Over Nakagami-m/Rayleigh Channel. *Electronics.* 2019; 8: 448.
[25] Nguyen TN, Minh THQ, Nguyen TL, Ha DH, Voznak M. Multi-Source Power Splitting Energy Harvesting Relaying Network in Half-Duplex System Over Block Rayleigh Fading Channel: System Performance Analysis. *Electronics*. 2019; 8: 67.