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Nandita Deka, Rupaban Subadar

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Energy harvesting based performance analysis in Nakagami-m fading channels

Nandita Deka* and Rupaban Subadar

Department of ECE,
North Eastern Hill University,
Shillong, Meghalaya, India
Email: nandeka89@gmail.com
Email: rupaban.subadar@gmail.com
*Corresponding author

Abstract: Energy harvesting (EH) is an emerging technology to harvest energy from the transmitter's radio frequency (RF) signals to the receiver. In this paper, a novel closed-form expression for the outage probability (OP) and average bit error rate (ABER) based on energy harvesting are derived over Nakagami-m fading channel. Moreover, we assume the power splitting (PS) harvesting technique in our proposed system. The power splitting receiver separates the received signal into information transmission and energy harvesting receiver with a power splitter factor. Numerical results are also presented to analyse the impact of various system parameters, such as the power splitter factor and shaping parameter of the considered fading channel.

Keywords: Nakagami-m fading; RF signals; energy harvesting; PS factor; outage probability; ABER; average bit error rate.

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Biographical notes: Nandita Deka received her BE in ECE from Assam Engineering College, Guwahati, India in 2012, and M. Tech degree in VLSI Design from North Eastern Hill University, Shillong, India in 2015. She is currently pursuing PhD from the Department of ECE, North Eastern Hill University, Shillong, India.

Rupaban Subadar received his MTech in Electronics Design from Tezpur Central University, Tezpur, India in 2001, and PhD from Indian Institute of Technology, Guwahati, India in 2011. He is currently an Associate Professor in the Department of Electronics and Communication Engineering, North Eastern Hill University, Shillong, India. His research interest includes wireless communication. He has many publications in reputed journals of IEEE, Elsevier etc.

1 Introduction

RF signals propagating through wireless channels become a sophisticated phenomenon and prone to various effects, including multipath fading due to reflections, refractions, and scattering. The main goal of a wireless receiver is to minimise the impact of fading and provide a better quality of service. In wireless channels, accurate modelling helps the design engineer to reduce this effect. Some of the models are offered to describe the statistical behaviour of multipath fading (Simon and Alouini, 2005). Practically, Nakagami-m fading is a primary fading distribution that describes Rayleigh, Rician fading model. However, the Nakagami distribution gives more flexibility and accurate experimental data for many physical propagation channels than other distributions (Al-Hussaini and Al-Bassiouni, 1985).

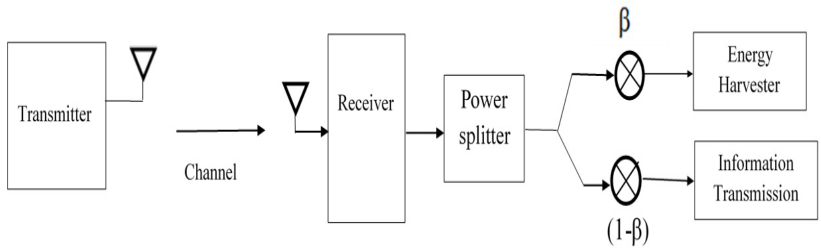
Energy harvesting is a prominent technology that can extend the lifetime of sensor networks by taking advantage of the energy emitted by RF signals (Mishra et al., 2015). Although the conventional method of extracting energy from a sensor network can provide a limited battery life, the ability to transmit both information and power simultaneously has been studied in Varshney (2008). Since RF signals can convey both information and energy simultaneously, a new and exciting research study has been explored, namely simultaneous wireless information and power transfer (SWIPT) (Grover and Sahai, 2010; Song et al., 2014; Varshney, 2008; Zhou et al., 2013). The concept of SWIPT is preferred and has rapidly become an important research area in both industry and academic fields. Its advantages include reducing the complexity of wireless networks and providing better performance. Two main protocols are presented in this study: power splitting (PS) and time switching (TS) (Nasir et al., 2013). In Chen et al. (2009), the author studied that the channels suffer from interferences and considered amplify-and-forward relaying networks that show EH for TS becomes more sensitive to EH for PS under the same channel condition. The analysis of wireless communication systems for various performance requirements such as outage probability, throughput, and average error probability using TS fraction has been explored (Van et al., 2016; Zhong et al., 2015). In Liu et al. (2014), the author assumes a harvest-then-transmit method where the outputs of the wireless power are combined with the information sent by the sources. The author designed a receiver to minimise the circuit complexity, interference, and power consumption for information decoding and enhance the power amplifier efficiency (Choi et al., 2020). In Ashraf et al. (2021), the paper gives an overall review of SWIPT that enables the transmission of information and energy simultaneously, providing energy and spectral efficiency considering 5G and beyond 5G wireless networks. However, as per our knowledge, SWIPT systems over Nakagami-m fading channels using power splitters schemes are not reported in other literature. This motivates us to carry out the current research work.

In this context, we have presented the closed-form expression for OP and ABER over Nakagami-m fading channels with a power splitter at the receiver side. Further, the impact of the fading parameters, power splitter factor on the system performance has been studied. The remaining parts of the paper are organised as follows: In Section 2, the System model is presented for analysis purposes. In Section 3, performance of the proposed system has been derived. Section 4 presents the numerical results of the OP and ABER for different variables of the fading parameter and the power splitter ratio. Our work is concluded in Section 5.

2 System model

Here, we consider the Nakagami-m fading channel. The channel is assumed to be slow and frequency non-selective. Figure 1 shows the proposed model that has been considered for evaluation of the system performance.

Figure 1 The system model



As shown in Figure 1, the model consists of one transmitter and one receiver considering Nakagami-m fading channels. The receiver uses power splitter protocol to collect the signal and breaks into two parts: one part for energy harvester with power splitter factor β and the other part for information receiver with $(1-\beta)$.

Assuming the signal envelope r_l to be Nakagami-m fading distribution whose probability density function (PDF) is given as (Aalo, 1995)

$$p_r(r_l) = \frac{2m^m r_l^{2m-1}}{\Psi_l^{\,m}\Gamma(m)} \exp(-\frac{mr_l^2}{\Psi_l}), \qquad r_l \geq 0 \tag{1}$$

where $\Psi_l = E[a_l^2]$ is the mean signal power, $m \in (1/2, \infty)$.

The PDF of SNR in Nakagami-m fading channel (Chen et al., 2009) is given by

$$f_\gamma(\gamma) = \frac{m^m \gamma^{m-1}}{\bar{\gamma}^m \Gamma(m)} e^{-\frac{m\gamma}{\bar{\gamma}}}, \quad \gamma \geq 0, \ \ m \geq \frac{1}{2} \tag{2}$$

Further, the received signal is inserted into a power splitter, where the received signals split into the information and energy harvester separately. Applying random variable transformation, $f_s(s) = \frac{1}{\beta} f_\gamma\left(\frac{s}{\beta}\right)$ we can obtain the PDF by inserting equation (2) in $f_s(s)$ as

$$f_s(s) = \frac{m^m s^{m-1}}{\bar{\gamma}^m \Gamma(m) \beta^m} e^{-\frac{ms}{\bar{\gamma}\beta}} \tag{3}$$

where $\Gamma(\cdot)$ is the Gamma function and $\bar{\gamma}$ is the average received SNR per bit.

3 Performance evaluation

3.1 Outage probability

The outage probability (P_o) is defined as the probability that the instantaneous SNR falls below a certain threshold, γ_{th} (Aalo, 1995; Simon and Alouini, 2005) is given by

$$P_o = \int_0^{\gamma_{th}} f_s(s)\,\mathrm{d}s \tag{4}$$

Putting $f_s(s)$ from (3), the expression can be obtained as

$$P_o = \frac{m^m}{\bar{\gamma}^m \Gamma(m)\beta^m} \int_0^{\gamma_{th}} s^{m-1} e^{-\frac{ms}{\bar{\gamma}\beta}} \mathrm{d}s \tag{5}$$

Integrating (5) and using the following relation in our calculation ("Table Integr. Ser. Prod.," 2000),

$$\int_0^{\upsilon} t^{u-1} e^{-\tau t} \mathrm{d}t = \tau^{-u} g(u, \tau\upsilon) \tag{6}$$

where u is a positive real value.

The expression for outage probability gives

$$P_o = \frac{1}{\Gamma(m)} g\left(m, \frac{m\gamma_{th}}{\beta\bar{\gamma}}\right) \tag{7}$$

where $g(\cdot, \cdot)$ is the incomplete gamma function.

3.2 Average bit error rate

The ABER is a vital system performance analysis for the wireless communication system. ABER can be obtained by taking the average of conditional bit error rate over the PDF of output SNR is given by

$$P_e(s) = \int_0^{\infty} p_e(\varepsilon \mid s) f_s(s)\mathrm{d}s \tag{8}$$

In the case of coherent modulation, the expression for conditional BER is given as $p_e(\varepsilon \mid s) = Q\left(\sqrt{2as}\right)$ with $Q\left(\sqrt{2as}\right) = \frac{1}{2\sqrt{\pi}}\Gamma\left(\frac{1}{2}, as\right)$ the Gaussian Q-function expressed in terms of the incomplete gamma function. Here, $a = 0.5$ for coherent frequency shift-keying and $a = 1$ for coherent phase shift-keying (Aalo, 1995). Substituting $p_e(\varepsilon \mid s)$ and $f_s(s)$ into (8), the expression for ABER can be obtained as

$$P_e(s) = \frac{m^m}{2\sqrt{\pi}\beta^m \bar{\gamma}^m \Gamma(m)} \int_0^{\infty} s^{m-1} \Gamma\left(\frac{1}{2}, as\right) e^{\frac{-ms}{\bar{\gamma}\beta}} \mathrm{d}s \tag{9}$$

Solving the above integral using ("Table Integr. Ser. Prod.", 2000, (6.455.1)), the final expression for ABER can be given as

$$P_e(s) = \frac{m^{m-1}\Gamma(m+0.5)}{2\left(m+a\beta\overline{\gamma}\right)^m \Gamma(m)} \sqrt{\frac{a\beta\overline{\gamma}}{\pi\left(m+a\beta\overline{\gamma}\right)}} \times {}_2F_1\left(1, m+0.5; m+1; \frac{m}{m+a\beta\overline{\gamma}}\right) \tag{10}$$

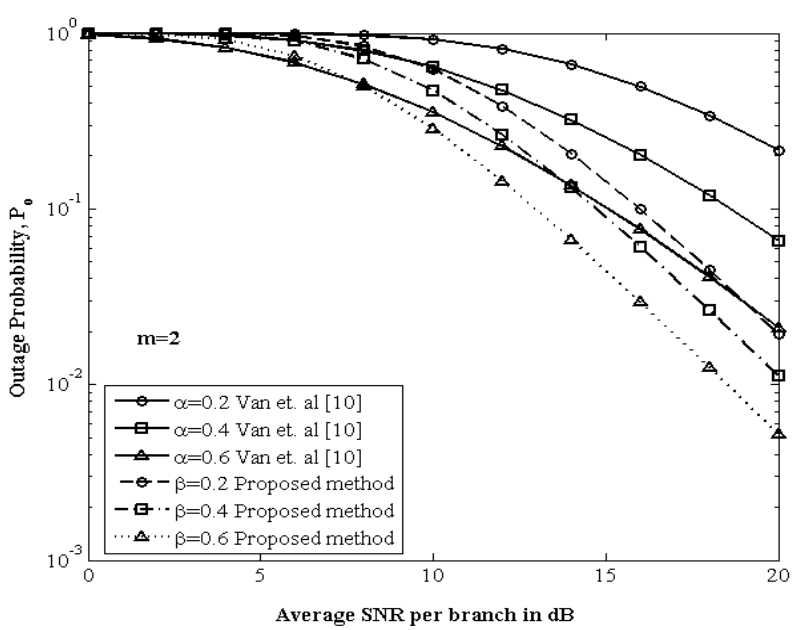
where, ${}_2F_1(\cdot;\cdot;\cdot;.....;)$ is the hypergeometric function.

This is the closed-form mathematical expression for OP and ABER involving gamma function and hypergeometric function, which can be evaluated by using Mathematica.

4 Numerical results and discussion

In this section, we have presented the numerical results for outage probability and ABER as discussed in the preceding section. Equation (7) is used to obtain the outage of the proposed system. Figure 2 shows the comparison of outage probability with respect to average SNR between the proposed system considering different variables of power splitter factor $(\beta = 0.2, 0.4, 0.6)$ with $m = 2$ and the work reported by Van et al. (2016) for time switching fraction $(\alpha = 0.2, 0.4, 0.6)$ has been discussed. We have compared the plotted curve between the proposed method as in Equation (7) and Van et al. (2016, Equation(8)). As the value of α and β increases, the proposed curve gives significant improvement. However, our model's results give better performance than Van et al. (2016).

Figure 2 Comparison of the outage probability vs average SNR between the proposed method and Van et al. (2016) for Nakagami-m fading channel



Similarly, in Figure 3, the comparison is shown for the outage v/s average SNR between the proposed method and Van et al. (2016). From the plot, we observed that by keeping $\beta = 0.2$ and varying *m*, the receiver suffers more outage. It is clearly seen that as the value of m increases, the proposed method shows good performance compared to that reported in Van et al. (2016).

Figure 3 Comparison of the outage probability vs average SNR between the proposed method and Van et al. (2016) with m variables and keeping β constant

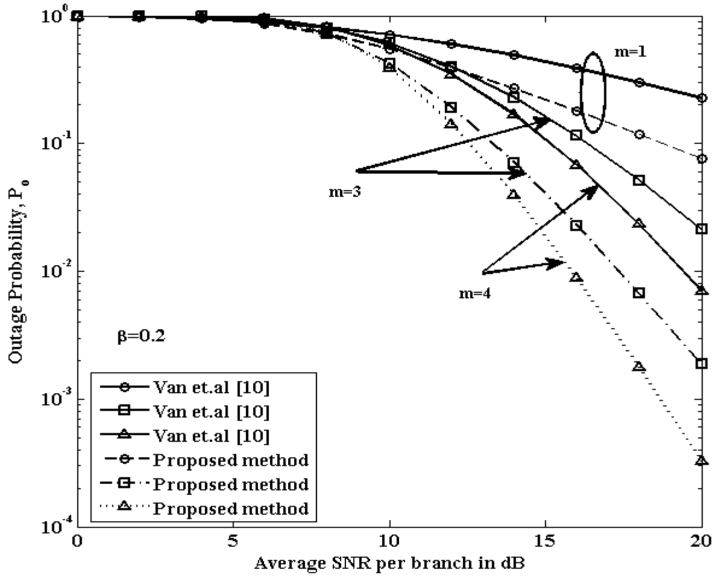
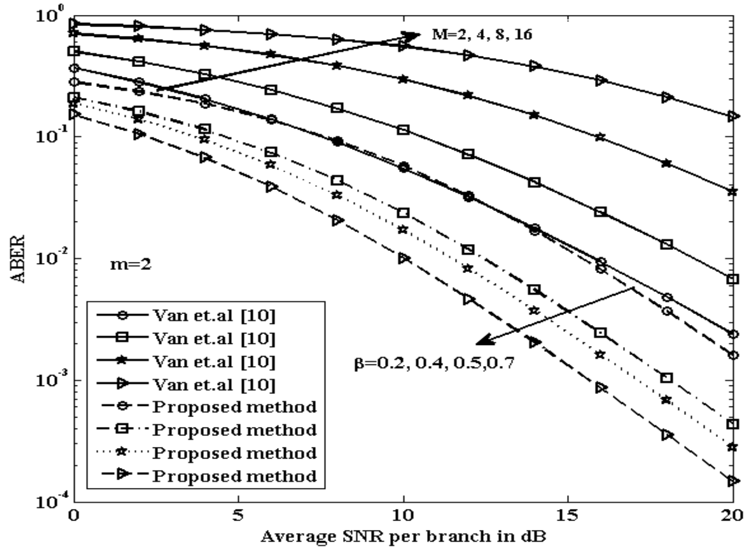
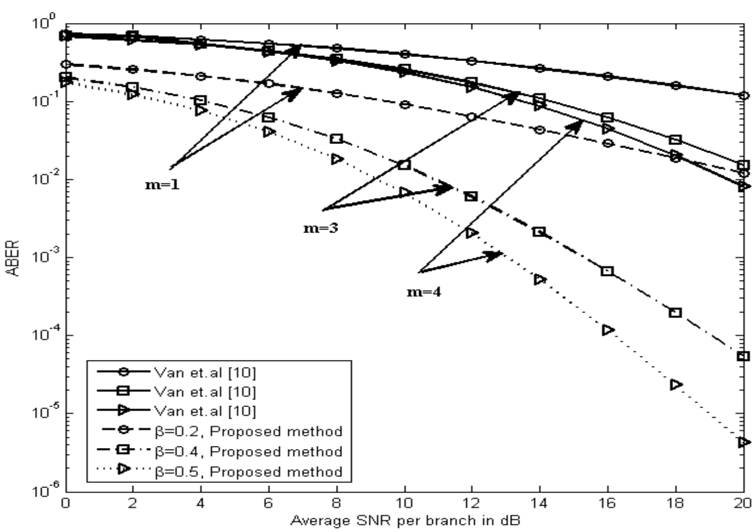


Figure 4(a) and (b) shows the ABER v/s average SNR between the proposed method and that reported in Van et al. (2016) for BPSK modulation schemes over Nakagami-m fading channel. In Figure 4(a) and (b), we have compared equation (10) of the proposed method with Van et al. (2016, Equation (14)). Figure 4(a) shows that keeping $m = 2$ and varying β of the proposed method and M (i.e., modulation order) reported by Van et al. (2016), the ABER curve decreases with β increases and ABER increases as M increases. This clearly shows that improvement is more significant for the proposed method compared to Van et al. (2016). In Figure 4(b), the fading parameter m and power splitter factor β vary with SNR. It is clear from the figure that ABER decreases with an increased value of m and β. However, the decrement is more significant in the proposed method as compared to Van et al. (2016).

Figure 4 Comparison of ABER vs average SNR over Nakagami-m fading channel between the proposed method and that reported by Van et al. (2016) for BPSK with: (a) having m constant and β variables and (b) keeping both m and β varying



(a)



(b)

5 Conclusion

This paper presents the performance of outage probability and ABER over Nakagami-m fading channel, considering the power splitting technique using a PDF-based approach. An expression for outage probability and ABER has been derived and compared with that reported in Van et al. (2016). We have shown that the system's performance improves for a high value of fading parameters and power splitter factor. The proposed analysis for outage probability and ABER provides better performance in comparison with Van et al. (2016). The analytical expressions given in this paper are very useful for estimating the performance of the wireless system over Nakagami-m fading environment. The proposed method is correlated by various performance measures, which show significant improvement.

References

Aalo, V.A. (1995) 'Performance of maximal-ratio diversity systems in a correlated nakagami-fading environment', *IEEE Transactions on Communications*, Vol. 43, No. 8, pp.2360–2369, https://doi.org/10.1109/26.403769

Al-Hussaini, E.K. and Al-Bassiouni, A.A. (1985) 'Performance of MRC diversity systems for the detection of signals with nakagami fading', *IEEE Transactions on Communications*, Vol. 33, No. 12, pp.1315–1319, https://doi.org/10.1109/TCOM.1985.1096243

Ashraf, N., Sheikh, S.A., Khan, S.A., Shayea, I. and Jalal, M. (2021) 'Simultaneous wireless information and power transfer with cooperative relaying for next-generation wireless networks: a review', *IEEE Access*, Vol. 9, pp.71482–71504, https://doi.org/10.1109/ACCESS.2021.3078703

Chen, Z., Chi, Z., Li, Y. and Vucetic, B. (2009) 'Error performance of maximal-ratio combining with transmit antenna selection in flat nakagami-m. fading channels', *IEEE Transactions on Wireless Communications*, Vol. 8, No. 1, pp.424–431, https://doi.org/10.1109/T-WC.2009.080207

Choi, K.W., Hwang, S.IL., Aziz, A.A., Jang, H.H., Kim, J.S., Kang, D.S. and Kim, D.I. (2020) 'Simultaneous wireless information and power transfer (SWIPT) for internet of things: novel receiver design and experimental validation', *IEEE Internet of Things Journal*, Vol. 7, No. 4, pp.2996–3012, https://doi.org/10.1109/JIOT.2020.2964302

Grover, P. and Sahai, A. (2010) 'Shannon meets tesla: wireless information and power transfer', *IEEE International Symposium on Information Theory – Proceedings,* pp.2363–2367, https://doi.org/10.1109/ISIT.2010.5513714

Liu, L., Zhang, R. and Chua, K.C. (2014) 'Multi-antenna wireless powered communication with energy beamforming', *IEEE Transactions on Communications*, Vol. 62, No. 12, pp.4349–4361, https://doi.org/10.1109/Tcomm.2014.2370035

Mishra, D., De, S., Jana, S., Basagni, S., Chowdhury, K. and Heinzelman, W. (2015) 'Smart RF energy harvesting communications: challenges and opportunities', *IEEE Communications Magazine,* https://doi.org/10.1109/MCOM.2015.7081078

Nasir, A.A., Zhou, X., Durrani, S. and Kennedy, R.A. (2013) 'Relaying protocols for wireless energy harvesting and information processing', *IEEE Transactions on Wireless Communications,* https://doi.org/10.1109/TWC.2013.062413.122042

Simon, M.K. and Alouini, M.S. (2005) *Digital Communication over Fading Channels*, 2nd ed., https://doi.org/10.1002/0471715220

Song, C., Ling, C., Park, J. and Clerckx, B. (2014) 'MIMO broadcasting for simultaneous wireless information and power transfer: weighted MMSE approaches', *2014 IEEE Globecom Workshops, GC Wkshps 2014*, Vol. 12, No. 5, pp.1151–1156, https://doi.org/10.1109/Glocomw.2014.7063588

Table of Integrals, Series, and Products (2000) *Table of Integrals, Series, and Products*, https://doi.org/10.1016/b978-0-12-294757-5.x5000-4

Van, P.T., Le, H.H.N., Le, M.D.N. and Ha, D.B. (2016) 'Performance analysis in wireless power transfer system over nakagami fading channels', *International Conference on Electronics, Information, and Communications, ICEIC. 2016*, Danang, Vietnam, Vol. 2, No. 1, pp.8–11, https://doi.org/10.1109/Elinfocom.2016.7562971

Varshney, L.R. (2008) 'Transporting information and energy simultaneously', *IEEE International Symposium on Information Theory – Proceedings*, Toronto, ON, Canada, https://doi.org/10.1109/ISIT.2008.4595260

Zhong, C., Chen, X., Zhang, Z. and Karagiannidis, G.K. (2015) 'Wireless-powered communications: performance analysis and optimization', *IEEE Transactions on Communications*, Vol. 63, No. 12, pp.5178–5190, https://doi.org/10.1109/TCOMM.2015.2488640

Zhou, X., Zhang, R. and Ho, C.K. (2013) 'Wireless information and power transfer: architecture design and rate-energy tradeoff', *IEEE Transactions on Communications*, Vol. 61, No. 11, pp.4754–4767, https://doi.org/10.1109/TCOMM.2013.13.120855