Energy Harvesting in Opportunistic Relaying Network with Multiple Antennas

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Summary

In this paper, we study a dual-hop opportunistic decode-and-forward (DF) wireless energy harvesting relaying network with multiple-antennas over $\kappa-\mu$ fading channels. The multiple antennas are considered at the source and destination and communication happens from the source to the destination via a selected energy-constrained relay from among all relays available in the network. In this system, the relay has no external source of power, therefore, it harvests the energy from the radio-frequency (RF) signals that are transmitted by the source node. Using the harvested energy, the selected relay decodes and transmits the source information to the destination. Considering a time-switching-based relaying (TSR) protocol, the performance of the considered system is evaluated for a various number of relays and for a different combination of antennas. The $\kappa-\mu$ fading model is a broad fading model and has some particular cases, namely, Rician, Nakagami-m, and Rayleigh. Hence, these results are broad and are applicable to evaluate the system performance for various fading scenarios.

Keywords:
Energy harvesting, relay selection, multiple-antennas, time-switching-based relaying, $\kappa-\mu$ fading, outage probability.

1. Introduction

Wireless energy harvesting in a dual-hop relaying system is a breakthrough technology in which a relay harvests energy from the radio-frequency (RF) signals [1-13]. Wireless energy harvesting is a lucrative method to increase the network lifetime [1]. Energy and information are concurrently carried by the RF signals, hence, RF signals can be used to harvest the energy to recharge the battery or to operate the network [2]. Energy harvesting in a dual-hop relaying is studied extensively in [1-13] and references therein.

Two important techniques are presented in the literature for energy harvesting in a dual-hop relaying system: time switching-based relaying (TSR) and power splitting-based relaying (PSR) method [3]. In the PSR and TSR protocols, time and power are divided into two parts at the relay node, one for energy harvesting and second for information processing [3].

Energy harvesting based-on DF relay systems were studied in several works [3-13]. In [3] and [4], using TSR and PSR protocols, energy harvesting in DF relaying network was investigated for Rayleigh fading channels. Energy harvesting relay with an interference-aided scheme was evaluated in Rayleigh fading environment [5]. In [6], relay selection schemes were introduced in a dual-hop relaying network to increase the diversity order and system performance was evaluated over non-identical Rayleigh fading channels.

The spatially random relays in DF energy harvesting relaying system was studied over Rayleigh fading channels in [7]. Further, in [8], relay selection aided DF relaying system was investigated where each relay has an energy storage device and they transmit the information when charged fully. Using a non-linear energy harvester, the performance of a partial relay scheme was evaluated in [9]. In [10], the system performance was analyzed for mixed $\kappa-\mu$ and $\eta-\mu$ fading fading channels. In [11], a dual-hop relaying network with beamforming has been investigated over $\kappa-\mu$ shadowed fading channels where the system performance was evaluated in a delay-limited transmission mode for different shadowing and fading parameters.

The system performance in a delay-tolerant transmission mode for a dual-hop energy harvesting relaying system over $\kappa-\mu$ shadowed fading channels was studied in [12]. Recently, the system performance of a dual-hop DF wireless energy harvesting relaying system with hardware impairments and beamforming was investigated in $\eta-\mu$ fading environment [13].

In the above-aforementioned works, relay selection schemes in DF relying systems were studied for classical fading channels. Despite the importance of the opportunistic relaying with beamforming and generalized $\kappa-\mu$ fading channels, the system performance was not analyzed for $\kappa-\mu$ fading environment.

In this work, a dual-hop opportunistic energy harvesting DF relaying network is considered. The source and destination are armed with multiple-antennas and each relay is equipped with a single antenna. The source sends its

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information with multiple-antennas via one of the selected relay based on the average SNR to the destination. The destination collects all signals sent by the relay to the destination. Each relay is assumed as an energy-constrained device which harvests energy from the RF signals that RF signals are sent by the source. A TSR method is assumed at the relay node for energy harvesting and information processing. In a delay-limited transmission mode, the system performance is analyzed for the $\kappa-\mu$ fading channels in terms of the outage probability and achievable throughput. The $\kappa-\mu$ fading model contains Rician, Nakagami-m, and Rayleigh as distinctive cases. Hence, our results said to be general and different scenarios can be deduced from it such as Rayleigh/Rayleigh, Nakagami-m/Nakagami-m, Rician/Rician, and combinations of these fading links.

We arranged this paper as follows: we delineated the system and channel models in Section 1. In Section 2, we described the outage probability and throughput metrices for our system. In Section 4, simulation results are shown. Lastly, this paper is condensed in Section 5.

2. System and Channel Models

2.1 System Model

A relaying network is considered as shown in Fig. 1, where multiple relays denoted as R_i $(i = 1, 2, \ldots, R)$ are trying to assist a source to send information to a destination.

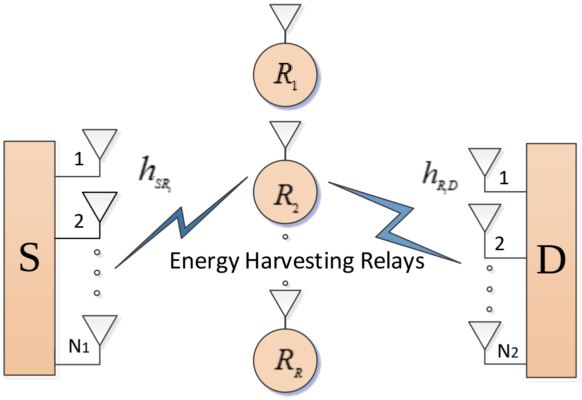

Fig. 1 System model

In this network, each relay is armed with a single-antenna whereas the source and destination are armed with multiple-antennas, N_1 and N_2, respectively. It is assumed that the source is unable to communicate the destination directly and each node know the channel state information (CSI). A time-switching-based relaying (TSR) protocol is assumed at each relay node. The source-relay and relay-destination channel gains are represented by $h_{\mathrm{SR_i}}$ and $h_{\mathrm{R}_i\mathrm{D}}$, respectively, with mean λ_1 and λ_2. Fig. 1 shows the transmission block structure for information processing and energy harvesting in the TSR protocol, where block time is denoted by T in which time the message is transferred from the source to destinaiton node and α is the fraction of the block time. A TSR protoocl switches the received signal from the source node in $\alpha:(1-\alpha)T$ proportion. In the portion α, a relay harvestes energy and the rest of the portion $(1-\alpha)T$ is devided into two parts, $(1-\alpha)T/2$ is utilized for the source-relay transmission and $(1-\alpha)T/2$ is utilized for the relay-destination transmission [4].

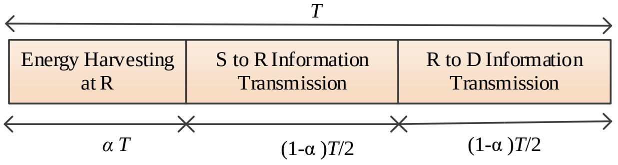

Fig. 2 Transmission block structure of the TSR protocol.

Using the transmit beamforming technique (i.e., maximum-ratio transmission technique) [15], the source beamforms the signals to the relay. The received signal from the relay node is given by [3]

$$y_{R_i} = \sqrt{P_s}\mathbf{h}^{\dagger}_{SR_i} w_1 x + n_{a,r} \tag{1}$$

where $w_1 = \frac{\mathbf{h}_{SR_i}}{\|\mathbf{h}_{SR_i}\|}$ [5], $(\cdot)^{\dagger}$ symbolizes conjugate transpose, $\|\cdot\|$ designates the Euclidean norm, P_s indicates the transmit power of the source, $n_{a,r}: (0,\sigma^2_{a,r})$ and $n_{c,r}: (0,\sigma^2_{c,r})$ represent the AWGN at the relay node and RF to baseband signal conversion. According to TSR protocol, the received signal at the relay node is conveyed to the energy harvester and information processor for time αT and $(1-\alpha)T/2$, respectively. From (1), the harvested energy duering time αT is obtained as

$$E_h = \eta P_s \|\mathbf{h}_{SR_i}\|^2 \alpha T, \tag{2}$$

where η is the energy conversion efficiency. Consequently, the harvested power, P_r, can be written by [3]

$$P_r = \frac{E_h}{(1-\alpha)T/2} = \frac{2\eta P_s \|\mathbf{h}_{SR_i}\|^2 \alpha}{(1-\alpha)}. \tag{3}$$

The relay forwards the received signal with the harvested power P_r to the destinaiton node. The destination unify the received signal via the receive beamforming technique (i.e., maximum-ratio transmission technique) as

$$\mathbf{y}_D = \sqrt{P_r}\mathbf{h}^{\dagger}_{R_iD}\mathbf{w}_2 x_r + \mathbf{n}_{a,d} + \mathbf{n}_{c,d} \tag{4}$$

where $\mathbf{w}_2 = \frac{\mathbf{h}_{R_iD}}{\|\mathbf{h}_{R_iD}\|}$ [15], x_r is the relay signal, $\mathbf{n}_{a,d}: (0,\sigma_{a,d}^2\mathbf{I}_{N_2})$ and $\mathbf{n}_{c,d}: (0,\sigma_{c,d}^2\mathbf{I}_{N_2})$ are the AWGNs, respectively, at the destination antennas and RF-to-baseband conversion, respectively. Using (1), the SNR at the relay node can be written as

$$\gamma_{R_i} = \frac{P_s\|\mathbf{h}_{SR_i}\|^2}{\sigma_{a,r}^2+\sigma_{c,r}^2}. \tag{5}$$

The SNR at the destination node is obtained by

$$\gamma_{R_iD} = \frac{2\eta\alpha P_s\|\mathbf{h}_{SR_i}\|^2\|\mathbf{h}_{R_iD}\|^2}{(\sigma_{a,d}^2+\sigma_{c,d}^2)(1-\alpha)}. \tag{6}$$

2.2 Channel Model

A general fading model, the $\kappa-\mu$ fading model, is able to model the small scale variation of the fading signal in the presence of a line-of-sight (LoS) [16]. For a j-th ($j = 1, 2$) link (i.e., source-relay or relay-destinaiton), the probability distribution function (PDF) of γ_j (instantaneous SNR) can be written as [eq. (2), 14]

$$f_{\gamma_j}(x) = \mu_j(\psi)^{\frac{N_j\mu_j+1}{2}}\left(\frac{1}{N_j\kappa_j}\right)^{\frac{N_j\mu_j-1}{2}} \mathrm{x}^{\frac{N_j\mu_j-1}{2}} \mathrm{e}^{-N_j\mu_j\kappa_j-\mu_j\psi_j x}$$
$$= \mathrm{I}_{N_j\mu_j-1}\left(2\mu_j\sqrt{N_j\kappa_j\psi_j x}\right) \tag{7}$$

where $\psi_j = (1+\kappa_j)/\overline{\gamma}_j$, $\overline{\gamma_j}$ denotes the average SNR of the j-th hop, $\Gamma(.)$ represent the Gamma function [16], $I_v(.)$ shows the v-th order modified Bessel functionof the first kind [16] and parameters μ_ℓ and κ_ℓ are the fading parameters.

The $\kappa-\mu$ fading model has some special cases, namely, Nakagami-m ($\kappa_j \to 0$ and $\mu_j = m_j$), Rician ($\kappa_j = K_j$ and μ_j =1), and Rayleigh ($\kappa_j \to 0$ and μ_j =1) fading [14].

3. Performance analysis

3.1 Outage probability

A dual-hop opportunistic energy harvesting DF relaying network is in an outage when one of both links (or hops) goes in an outage. In an opportunitic relaying scheme, a relay node that has highest instantaneous end-to-end SNR of the channel from the source to relay R_i and from relay R_i to the destination is selected. Mathematically, the best relay, R_b, as

$$R_b = \arg\max_{i=1,2,\ldots,R} \gamma_{SR_i}. \tag{8}$$

The outage probability for the considered system is evaluated by [7]

$$P_{out} = \prod_{i=1}^{R}\left\{1-p_R\left[\min\left(\gamma_{R_i},\ \gamma_{R_iD}\right)>\gamma_{th}\right]\right\}$$
$$= \left(1-p_R\left[\min\left(\gamma_{R_i},\ \gamma_{R_iD}\right)>\gamma_{th}\right]\right)^R \tag{9}$$

where $p_R[.]$ indicates the outage probability, $\gamma_{th} = 2^U - 1$, and U is the fixed transmisisn rate in bits/second/Hz.

3.2 Throughput analysis

The throughput of the considered dual-hop energy harvesting opportunistic DF relaying system in a delay-limited transmission mode is given by [13]

$$\tau = \frac{(1-P_{out})U}{2} \tag{10}$$

5. Numerical Results and Discussion

In this section, the system performance is evaluated of an energy harvesting opportunistic relaying system with beamforming over $\kappa-\mu$ fading channels where the selected relay harvests energy from the RF signals which are sent by the source. Our results are general; therefore, these results can give insights into different design options. But in this paper, we focus only to evaluate the performance in terms of relays, antennas, and fading parameters. It should be noted that the optimal value of time switching ratio and throughput are obtained when system achieves maximum throughput. Unless otherwise stated, the system parameters are given as: $P_s = 1$, $\eta = 1$, $\lambda_1 = \lambda_2 = 1$, and noise variances $= 0.01$.

Fig. 3 shows the outage performance versus time switching ratio for the considered system in terms of the different number of relays. It is seen that the system performance increases with increasing the number of relays. The performance becomes better with increasing time-switching ratio from 0 to an optimal value (when system achieves maximum throughput) and the system performance decreased when the value of the time-switching ratio increases from its optimal value to 1.

In Fig. 4, the throughput performance is presented with respect to the time switching ratio for various antennas combinations. The outage probability decreases with increasing number of antennas. The outage performance is also cross-examined for different antennas combinations at the source and destination. It is observed that when a large number of antennas are equipped at the source compared to the destination provides higher throughput gain.

Fig. 5 depicts the throughput performance versus time switching ratio for a different number of relays and for a different number of antennas at the source and destination.

Here, outage performance is cross-compared between the number of relays and the number of antennas. It is seen that a large number of antennas at the source provides a higher throughput gain compared to a large number of relays.

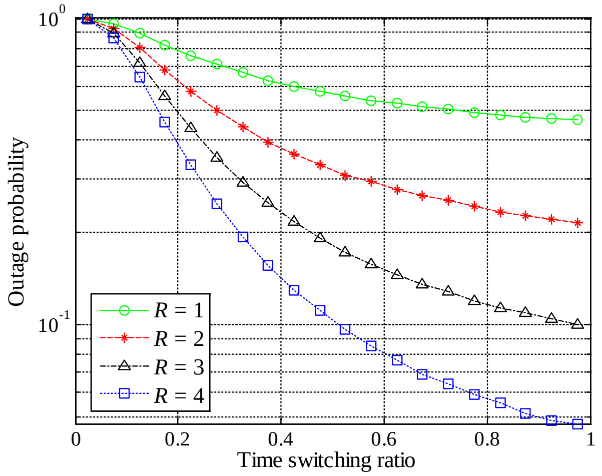

Fig. 3 Outage probability versus time switching ratio α when $N_1 = N_2 = 1$, and $\mu_1 = \mu_2 = 1$, and $\kappa_1 = \kappa_2 = 1$.

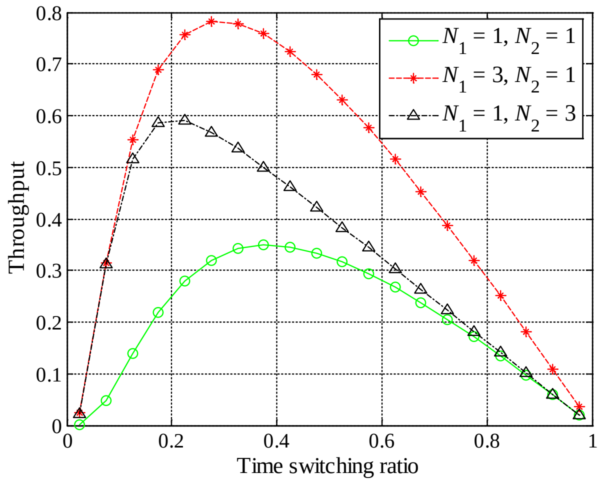

Fig. 4 Throughput versus time switching ratio α for different number of antennas when $R = 1$, and $\mu_1 = \mu_2 = 1$, and $\kappa_1 = \kappa_2 = 1$.

6. Conclusion

In this paper, an opportunistic energy harvesting DF relaying system with beamforming is studied. Based on the TSR protocol, the system performance in terms of the outage probability and throughput is analyzed in a delay-limited transmission mode over $\kappa - \mu$ fading channels. It is concluded that the system performance increases with increasing the number of relays and number of antennas. It is also observed that the increasing number of antennas at the source is more beneficial than the increasing number of antennas at the destination and relays.

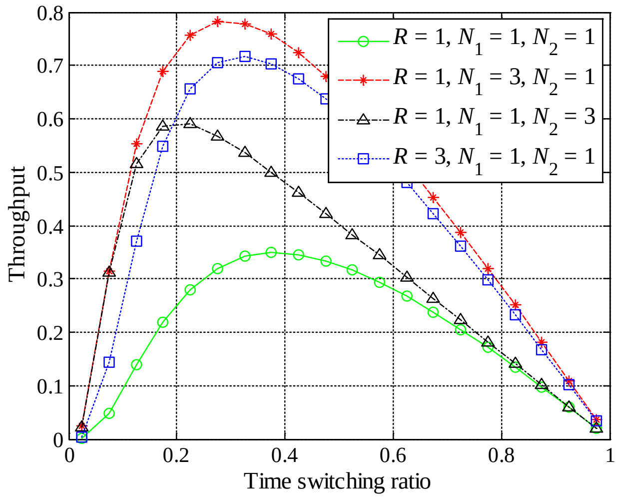

Fig. 5 Throughput versus time switching ratio α for different number of relays and antennas when $\mu_1 = \mu_2 = 1$, and $\kappa_1 = \kappa_2 = 1$.

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References

[1] Sudevalayam, S., and Kulkarni, P.: Energy harvesting sensor nodes: survey and implications, IEEE Commun. Surveys Tuts., 13(3), pp. 443–461, Third Quart. 2011.

[2] Lu, X,. Wang, P., Niyato, D., Kim, D. I., Han, Z,: Wireless networks with RF energy harvesting: A contemporary survey, IEEE Commun. Surveys Tuts., 17(2), pp. 757–789, Second Quart. 2015.

[3] Nasir, A. A., Zhou, X., Durrani, S., Kennedy, R. A.: Throughput and ergodic capacity of wireless energy harvesting based DF relaying network, Proc. of IEEE ICC pp. 4066-4071, Jun. 2014.

[4] Wang, X., Liu, J., Zhai, C., Ma, S., Wang, W.: Energy efficiency relay networks with wireless power transfer from a multi-antenna base station, Trans. Emerging Tel. Technol., 27(4), pp. 533–543, Sep. 2016.

[5] Gu, Y., Aïssa, S.: RF-based energy harvesting in decode-and-forward relaying systems: ergodic and outage capacities, IEEE Trans. Wirel. Commun., 14(11), pp. 6425–6434, Nov. 2015.

[6] Do., N. T., Bao., V. N. Q., An. B.: Outage performance analysis of relay selection schemes in wireless energy harvesting cooperative networks over non-identical Rayleigh fading channels, Sensors, 16(3), pp. 1–16, Feb. 2016.

[7] Ding. Z., Krikidis, I., Sharif, B., Poor, H. V.: Wireless information and power transfer in cooperative networks with spatially random relays, IEEE Trans. Wirel. Commun., 13(8), pp. 4440–4453, Aug. 2014.

[8] Krikidis, I.: Relay selection in wireless powered cooperative networks with energy storage devices, IEEE J. Selec. areas on Commun., 33(12), pp. 2596–2610, Dec. 2015.

[9] Hoang, T. M., Duy, T. T., Bao, V. N. Q.: On the performance of non-linear wirelessly powered partial relay selection networks over Rayleigh fading channels, Proc. of IEEE 3rd National Foundation for Sc. and Technol. Development Conf. on Inform. and Comput. Sc., pp.6-11, Sep. 2016.

[10] Badarneh O.S, Almehmadi F.S, Ansari I.S, Yang X.: Wireless energy harvesting in cooperative decode-and-forward relaying networks over mixed generalized $\eta-\mu$ and $\kappa-\mu$ fading channels. Trans. Emerg Tel. Technol. doi: 10.1002/ett.3262: pp.1–18, 2017.

[11] Hussain, A., Kim, S.-H., Chang, S.-H.: Non-linear energy harvesting relaying with beamforming and hardware impairments in $\kappa-\mu$ shadowed fading environment, Trans. Emerg. Tel. Technol., doi.org/10.1002/ett.3303, pp.1-13, March 2018.

[12] Hussain, A., Ali, I., Ahmed, Z., and Kim, S-H., “Energy harvesting relaying network in a delay-tolerant transmission mode over κ-μ shadowed fading channels”, International Journal of Computer Science and Network Security (IJCSNS), vol.18, no.3, pp. 119-125, March 2018.

[13] Hussain, A. Ahmed, Z. Rajput, U., Abbas, F., and Ali, I. “Energy harvesting relaying network with hardware impairments in $\eta-\mu$ fading environment”, International Journal of Computer Science and Network Security (IJCSNS), vol.18, no.4, pp.63-68, April 2018.

[14] Hussain, A. Kim, S.-H., Lee, K., Chang, S.-H., and Kim, D.I., “Performance analysis of dual-hop variable-gain relaying with beamforming over $\kappa-\mu$ fading channels,” IET Communications, vol. 11, no. 10, 2017.

[15] Hussain, A., Kim, S.-H., Chang, S.-H.: Dual-hop variable-gain AF relaying with beamforming over $\kappa-\mu$ shadowed fading channels, Proc. of IEEE GLOBECOM, pp. 1–6, 2016.

[16] Gradshteyn, I. S., Ryzhik, I. M., Table of integrals, series, and products. 7th ed. San Diego, CA, USA: Academic, 2007.

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