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Outage performance of double-relay cooperative transmission network with energy harvesting

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ABSTRACT

The double-relay cooperative user transmission network with energy harvesting is investigated and time switching-based double-relay cooperative transmission (TSDRCT) protocol is designed in this paper. In such a system, a source node transmits information to its destination node with the help of two energy harvesting cooperative nodes. The system outage probability is analyzed and an explicit expression for the outage probability is derived for decode-and-forward (DF) relay protocols, then simulation experiments are provided. The simulation results demonstrate the accuracy of the theoretical analysis, and also show that the proposed TSDRCT with energy harvesting relay is much better than traditional non-cooperative scheme in term of outage performance, and it does not increase system energy consumption.

1. Introduction

Energy harvesting (EH) has been investigated as a promising technology to overcome the energy scarcity problem in energy constrained wireless communication systems, especially for wireless sensor networks or other networks with fixed energy supplies. Compared with conventional EH sources such as solar, wind, vibration, thermoelectric effects or other physical phenomena [1], which rely on external energy sources that are not components of communication networks, a new operation of EH which collects energy from ambient radio-frequency (RF) signals has been proposed, called simultaneous wireless information and energy transfer (SWIET). It is based on the fact that RF signals can carry energy and information at the same time. SWIET will be a sustainable solution to overcoming the bottleneck of energy constrained wireless networks [2,3]. Recently, even the jamming signals can be exploited for energy harvesting by legitimate users as a power supply [4], and the interferences signals are re-utilized as the energy for wireless network [5].

Cooperative communication, a technique to combat the fading effects inherent to the wireless channel, has been shown to be capable of increasing the energy efficiency of energy-constrained networks [6]. Relays usually use signal processing techniques such as decode-and-forward (DF) and amplify-and-forward (AF) to process and forward the desired signals to the destination devices. Plenty of works have applied SWIET to cooperative wireless communications. Some of them focus on AF relaying networks [7–12]. Energy harvesting in AF-MIMO system is studied in [7] and [8]. The authors in [9] investigated time switching-based relaying (TSR) protocol and power splitting-based relaying (PSR) protocol. In [10], authors introduced the time-switching cooperative multiuser transmission (TSCMT) protocol and the power-splitting cooperative multiuser transmission (PSCMT) protocol for the multiuser transmission network with an EH cooperative relay. In [11], two and three time slot transmission schemes (2TS and 3TS) were proposed for relaying networks with EH. In [12], the authors derived the analytical expressions for the outage probability and the ergodic capacity for two-way relay networks. Performance of an AF relay system using energy harvesting in fading channels are analyzed [13].

Some works focus on DF relay networks [2,14–20], a relay network with EH was introduced in [2], where multiple source–destination pairs were considered, and a power allocation scheme was given to achieve a better tradeoff between system performance and complexity. The TSR and the PSR schemes for a DF relay network in wireless network with energy harvesting were given in [14]. A time switching-based network coding relay (TSNCR) protocol and a power splitting-based relay protocol (PSR) was proposed in [15] and [16]. In [17], a multiuser cooperative network with EH was investigated. In [18], the performance of an

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energy harvesting system with multiple antennas has been studied. In [19], energy harvesting for two-hop orthogonal frequency division multiplexing (OFDM) system with PS receiver architectures was studied. The authors in [20] investigated the outage probability of an energy harvesting (EH) relay-aided cooperative network for both AF and DF relay protocols.

These schemes were focused on the single-relay, two way communication systems. In [21–25], multiple energy harvesting relays with different relay protocols were considered in the co-operative networks, but only one relay was chosen to forward the transmission. It is confirmed that the relay power is better used when it adds a cooperative branch than when it adds a hop in an existent branch [26]. In this paper, we also focus on cooperative communication for the double-relay network with energy harvesting and information transfer and a scenario is considered where a source transmits independent information to destination with the help of two energy constrained relays. According to [27], AF technology is less complicated than the DF technology, but it results in more noise and interferences at destination devices and may impose high peak power levels due to the amplification of overall signals, which makes DF relay more practical, especially for energy limited devices, therefore the decode-and-forward (DF) relay protocol is also adopted in our work rather than AF. In this paper, we try to study double-relay, two-hop communication systems with energy harvesting for DF relay protocols. Our main contributions can be summarized as follows.

- Firstly, we propose a time switching-based double-relay cooperative transmission (TSDRCT) to enable the simultaneous information processing and energy harvesting at the DF relay.
- Secondly, for the proposed protocol, we theoretically analyze the system outage performance and derive an explicit expression for the system outage probability.
- Thirdly, based on the analytical outage probability, we study the impact of the source power and relay location on the outage performance of the system.

The rest of the paper is organized as follows. Section 2 describes the system model. In Section 3, the proposed TSDRCT protocols and performance analysis for the system are given. Numerical simulation results are shown in Section 4. Finally, the conclusion is followed in Section 5.

2. System model

The system model under consideration is shown in Fig. 1. It is composed of a source S, a destination D and two energy-constrained relays (referred to as R_1 and R_2). We assume that S has its own internal energy source and wants to transfer independent information x to destination D with the help of two energy constrained DF relays. It is assumed that there is a direct link between the source and the destination. The relays R_1 and R_2 rely on external charging thus harvest energy from the received RF signals transmitted from S, and use all the harvested energy to help the transmissions from S to D. We assume the processing power at the relay is negligible as compared to the power used for signal transmitting. This assumption is often used in practical systems [9,12,21]. We also assume that all the terminals have a single antenna and operate in a half-duplex mode.

Let $h_{s,d}$, h_{s,r_1}, h_{s,r_2}, $h_{r_1,d}$, $h_{r_2,d}$ denote the complex channel coefficients of S to D channel, S to R_1 channel, S to R_2 channel, R_1 to D channel and R_2 to D channel respectively. We assume that all the channels are quasi-block fading channel, and following Rayleigh fading. The receiver side CSI is assumed to be perfect, which is in line with the previous work in this research field [2,9,7,12]. Also, the channels are modeled as follows: $h_{s,d} \sim CN\left(0, \Omega_{s,d}\right)$, $h_{s,r_1} \sim CN\left(0, \Omega_{s,r_1}\right)$, $h_{s,r_2} \sim CN\left(0, \Omega_{s,r_2}\right)$, $h_{r_1,d} \sim CN\left(0, \Omega_{r_1,d}\right)$, and $h_{r_2,d} \sim CN\left(0, \Omega_{r_2,d}\right)$. Specifically, let $d_{s,d}$, d_{s,r_1}, d_{s,r_2}, $d_{r_1,d}$, and $d_{r_2,d}$ denote the distance from S to D, from S to R_1, from S to R_2, from R_1 to D, and from R_2 to D, respectively. As a result, $\Omega_{s,d} = d_{s,d}^{-m}$, $\Omega_{s,r_1} = d_{s,r_1}^{-m}$, $\Omega_{s,r_2} = d_{s,r_2}^{-m}$, $\Omega_{r_1,d} = d_{r_1,d}^{-m}$, and $\Omega_{r_2,d} = d_{r_2,d}^{-m}$, where m denotes the path loss exponent.

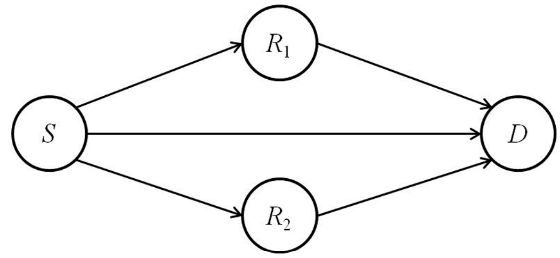

Fig. 1. Double-relay cooperative communication system model.

3. Time switching-based double-relay cooperative transmission (TSDRCT) protocol

In this section, we consider the time switching receiver architecture and try to detail the proposed cooperative protocol, and then analyze the system outage performance for it.

3.1. Protocol description

The transmission process and key parameters in the proposed TSDRCT protocol are shown in Fig. 2(a). For a time period T, let ρ $(0 \le \rho \le 1)$ denotes the time assignment factor, such that the ρT part is assigned for R_i to harvest energy from S. The remaining part $(1-\rho)T$ is used for the information transmission, which is equally divided into two parts. During the first $(1-\rho)T/2$ durations, S broadcasts information x with power P, then R_1, R_2 and D can receive the signal. In the second $(1-\rho)T/2$ duration, R_1 and R_2 use all the energy harvested from S to broadcast the signal x, respectively.

The relay receiver in TSDRCT protocol is shown in Fig. 2(b). Each received RF signal y_r from S at the relay is firstly sent to the energy harvesting receiver (during the ρT time) and then to the information receiver (during the $(1-\rho)T/2$ time for TSDRCT). Note that y_r is corrupted by two noises, where $n_{r,a}$ is introduced by the receiving antenna which is modeled as a narrowband Gaussian noise, and $n_{r,c}$ is the sampled additive noise due to the RF band to baseband signal conversion.

3.2. Outage probability analysis for the TSDRCT protocol

In this section, we will analyze the outage probability for the transmission from S to D. As illustrated in Fig. 3, S broadcasts its information x with power P, both R_1, R_2 and D can received it. The received signals $y_{s,d}$ at D, and the received signals y_{s,r_i} at R_i $(i = 1, 2)$ are given as follows respectively:

$$y_{s,d} = \sqrt{P} h_{s,d} x + n_{s,d} \tag{1}$$

$$y_{s,r_i} = \sqrt{P} h_{s,r_i} x + n_{s,r_i} + n_{c_1,r_i} \tag{2}$$

where x denotes the sampled and normalized information signal from S. $n_{s,d}$ and n_{s,r_i} denote the baseband additive white Gaussian noise (AWGN) with variance $\sigma_{s,d}^2$ and σ_{s,r_i}^2 introduced by the relay's receiving antenna respectively, and n_{c_1,r_i} denotes the sampled AWGN with variance σ_{c_1,r_i}^2 introduced by the conversion from RF band signal to baseband signal from S.