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Joint relay-user selection in energy harvesting relay network with direct link[☆]

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In this paper, a joint relay-user selection (JRUS) scheme is proposed for an amplify-and-forward full-duplex (FD) relay network which includes one source node, multi-relay node and multi-user node, and the direct link between the source node and the user node is considered to convey information. Each FD relay node is energy-constrained and the simultaneous wireless information and power transfer technology is employed to harvest energy. A power splitter at each FD relay node splits the received signals into two components for energy harvesting and information processing. The implementation of the proposed JRUS scheme includes two steps: (1) the optimal user node is selected according to signal-to-noise ratio of the direct link between the source node and the user nodes; (2) the optimal energy harvesting relay node with optimal power splitting (PS) factor is picked out based on signal-to-interference-plus-noise ratio of the relaying link. The outage probability of the investigated relay network with the JRUS scheme is derived. In order to characterize the diversity order, we further present the asymptotic outage probability at high SNR. Moreover, the optimal PS factor of each relay node is calculated by minimizing the outage probability of the reconstructed relay network. Finally, numerical results demonstrate the accuracy of our performance analysis and the efficiency of the proposed scheme.

1. Introduction

Recently, energy harvesting (EH) has attracted much attention in green communication due to its ability to prolong the lifetime of energy-constrained wireless networks. Some traditional EH techniques can collect energy from the external resources, such as solar energy, wind power and tidal energy [1]. However, these external resources can be easily affected by the weather, and cannot provide a steady supply of energy. Because of this defect, an original EH technology, simultaneous wireless information and power transfer (SWIPT), which depends on radio-frequency (RF) signals and can carry energy and information on the same signals, is proposed [2].

Since the relay node is capable of increasing the transmission reliability as well as the cell coverage, thus the SWIPT technology in the context of EH relay network has been paid much attention. In [3], the authors analyze the outage probability of energy-constrained relay network with adopting the SWIPT technology, and it is compared with the performance of the conventional self-powered relay network. The authors investigate the outage performance of SWIPT half-duplex (HD) relay system with adopting the power-splitting (PS) scheme, and two scenarios are considered, battery-less and battery-equipped [4]. Later in [5], the authors design the source/relay precode for the SWIPT technology in multiple-input multiple-output (MIMO) EH relay network, where the relay node works on HD mode. In [6], a PS based EH method is proposed in the HD multi-relay network, which aims at maximizing the system throughput. The authors in [7] investigate the outage performance of the EH multi-relay multi-destination HD-relay network, which indicates the EH technique can improve the lifetime of the energy-constrained relay network. However, such a transmission incurs significant loss in spectral efficiency due to the HD-relay. With the advance in self-interference mitigation techniques, the full-duplex (FD) technique, which can receive and transmit signal simultaneously over the same frequency band to improve the spectrum efficiency, has attached much attention [8,9]. In [10], the authors investigate the EH relay networks, in which the relay nodes work on FD mode. In [11], the optimal PS factor and ergodic capacity are analyzed for PS-based FD relay network. Moreover, the PS based operation adopted at the relay node has potential to fully exploit FD property compared with the time-splitting (TS) scheme applied at the FD relay, as the relay node can simultaneously receive and transmit signals [12]. Thus, we focus on the PS based EH FD-relay network model in this paper.

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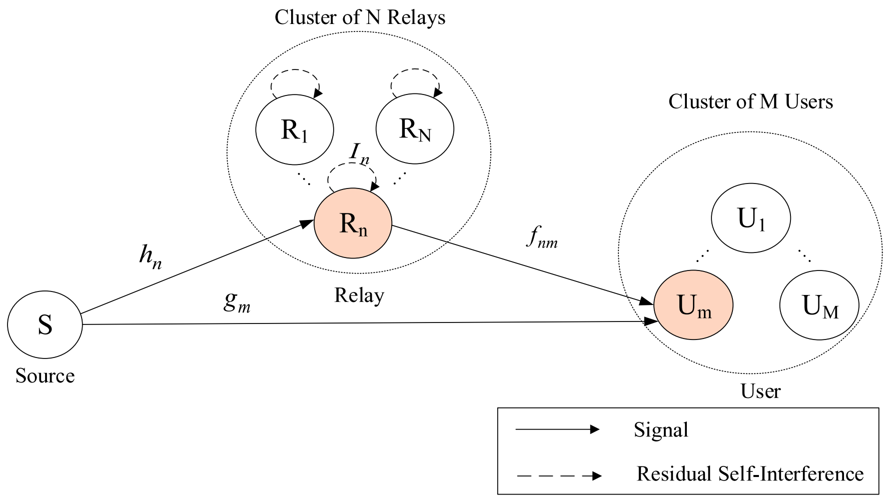

Fig. 1. The system of a MRMU EH relay network in the presence of the direct link.

In a practical multi-relay multi-user (MRMU) system, the diversity performance can be improved by properly selecting a subset of relays and users due to the inherent multi-user and cooperative diversity. Some existing literatures are conducted on EH HD-relay networks [7,13]. In [13], the authors investigate the EH relay network with the help of HD-relay to transmit information between one source node and one destination node. The work of [7] proposes two complexity relay–destination selection schemes to reduce the amount of channel estimations for the EH HD-relay network. The FD-relay is investigated in the energy-constrained relay network [14], however, only one relay node and one destination node are considered. Meanwhile, it is noted that the direct link in the relay network improves the valuable diversity gains as well as the system reliability. The authors in [15] study one-relay one-user FD-relay network and find that the diversity order can be increased with considering the direct link between the source node and the user node. In [13], the authors investigate the outage performance for SWIPT relay network with considering the direct link, which only includes one relay node. However, there are few works about MRMU scenario in EH FD-relay networks in the presence of the direct link, and the performance of this scenario is still an open problem.

In this paper, we consider a PS based EH MRMU network. In the considered MUMR network, the source node and the user nodes are equipped with one antenna, while each relay node is equipped with two antennas and works on FD transmission mode, where one antenna for receiving and another for transmitting. Meanwhile, the direct link between the source node and the user node is taken into consideration to convey information. Aiming at the considered network model, we propose a joint relay-user selection (JRUS) scheme. In the proposed selection scheme, the optimal user node is firstly selected from M candidates according to signal-to-noise ratio (SNR) of the direct link. Then the optimal relay node is selected from N candidates according to signal-to-interference-plus-noise ratio (SINR) of the relaying link. We show that the diversity order of the JRUS scheme is $N+M$. Based on the network reconstructed by the JRUS scheme, the outage probability of the EH FD-relay network is derived, including exact and asymptotic expressions. Note that each relay node is energy constrained and the SWIPT technology is used to harvest energy. The optimal PS factor is obtained by minimizing the derived outage probability.

Notations. We use Pr(.) indicates probability, $\mathbb{E}\{\cdot\}$ denotes expectation and $\mathcal{CN}(0,\sigma^2)$ denotes the circularly symmetric complex Gaussian distributed vector with zero mean and variance σ^2.

2. System model

As shown in Fig. 1, we investigate an EH amplify–forward (AF) relay network, which consists of one source node S, N relay nodes R_n, $(n=1,2,\ldots,N)$, and M user nodes U_m, $(m=1,2,\ldots,M)$. In the considered relay network, the source node and each user node are equipped with one antenna, while each relay node is equipped with two antennas and works on FD mode, one for receiving and the other for transmitting. Meanwhile, it is assumed that the direct link between the source node and the user node exists and can be exploited to convey information.

The source node intends to transmit its information to the selected user node with the help of the selected relay node. The transmitted power of the source node is P_s. The selected relay node is assumed to be energy constrained, such that it has to harvest energy from the source node and then amplifies the received signals to the selected user node simultaneously using the received energy. At the selected relay node, the received signals are split according to the power ratio of $\alpha_n : (1-\alpha_n)$, $\alpha_n \in [0,\ 1]$, for EH and information processing (IP), respectively.

Each channel link undergoes independent frequency-flat Rayleigh fading [16], and h_n, f_{nm}, g_m denote the channel coefficients from $S \to R_n$, $R_n \to U_m$, $S \to U_m$, respectively. More precisely, all the fading channel coefficients are reciprocal, which are modeled as independent complex Gaussian distribution, i.e., $h_n \sim \mathcal{CN}\left(0,\sigma_{SR}^2\right)$, $f_{nm} \sim \mathcal{CN}\left(0,\sigma_{RU}^2\right)$, $g_m \sim \mathcal{CN}\left(0,\sigma_{SU}^2\right)$, respectively. $\mathcal{CN}\left(0,\sigma^2\right)$ denotes the complex Gaussian distribution with zero mean and the covariance σ^2. Each relay node performs imperfect loop interference mitigation, and there still exists the residual self-interference (RSI). The RSI channel is also modeled as Rayleigh fading channel, and the corresponding channel coefficient is denoted by I_n, which follows Gaussian distribution with zero mean and the variance σ_{rsi}^2 [17].

3. Joint relay-user selection scheme

Due to the FD operation at the relay node, the whole information transmission occurs during the whole time block T as shown in Fig. 2. The detailed process of the JRUS scheme is expressed. The source node firstly broadcasts the signal x_s to both the relay nodes and user nodes. Thus, the received signal at the nth relay node and the mth user node can be expressed as

$$y_n^R = \sqrt{P_s} h_n x_s + \sqrt{P_r} I_n x_n^R + n_R, \tag{1}$$