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Transmission strategies for wireless powered MIMO relay systems

Wu Fahui[1], Xiao Lin[2] (✉), Yang Dingcheng[2], Laurie Cuthbert[3]

1. Jiangxi Province Key Laboratory of Intelligent Information Systems, Nanchang University, Nanchang 330031, China
2. Information Engineering School, Nanchang University, Nanchang 330031, China
3. Information Systems Research Centre, Macao Polytechnic Institute, Macao SAR 999078, China

Abstract

This paper studies a multiple input multiple output (MIMO) simultaneous wireless information and power transfer (SWIPT) relay system, in which the source node (SN) send information and energy simultaneously to the relay node (RN), and the RN forward the received signal to the destination node (DN) powered by harvested energy. In particular, we consider two SWIPT receiver designs, namely power splitting (PS) and antenna switching (AS) in the relay system. For each design, iterative algorithms based on convex optimization technique are proposed to maximize the system rate. Furthermore, in order to strike a balance between computational complexity and system performance, based on the AS scheme, we propose a low complexity optimization method for PS scheme where a suboptimal PS ratio is given. Numerical results are provided to evaluate the performance of the proposed algorithm for MIMO SWIPT relay systems. It is shown that the performance of the proposed suboptimal method approaches that of the optimal PS scheme.

Keywords SWIPT, energy harvesting, relay, power splitting, antennas switching

1 Introduction

Recently, energy harvesting (EH) from ambient radio frequency (RF) signals has drawn significant attention. EH as it is a promising solution to prolong the lifetime of energy constrained wireless networks, for example sensor based wireless networks. Since it is has practical value for enabling both wireless data and wireless energy transmission, EH has a promising future for green communications. SWIPT was first proposed in Ref. [1], where SWIPT in a point-to-point single antenna additive white Gaussian noise (AWGN) channel was studied from an information-theoretic standpoint. In Ref. [2], Grover et al. extended Ref. [1] to frequency-selective single antenna AWGN channels, where a non-trivial tradeoff between information rate and harvested energy is shown by varying power allocation over frequency. Optimal designs that take into account co-channel interference of wireless information and power transfer were studied in Ref. [3] to achieve different outage energy tradeoff as well as rate-energy tradeoff.

Since the application of MIMO technology could significantly enhance the transfer efficiency of both energy and information, SWIPT for MIMO channels has been investigated in Refs. [4–6]. In Ref. [4], Zhang et al. studied the performance limits of a three-node MIMO. The work in Ref. [4] was extended to cases with imperfect channel state information (CSI) at the transmitter in Ref. [5]. In Ref. [6], when the CSI was not available at the transmitter, a transmitter design based on random beamforming was proposed for a multiple-input single-output (MISO) SWIPT system with artificial channel fading generated over quasi-static channels. SWIPT has also been studied in orthogonal frequency division multiplexing (OFDM) systems in Refs. [7–9], in broadcast channels [10], and in interference channels [11–12]. In addition, in Ref. [13], Huang et al. studied SWIPT in a MIMO-orthogonal frequency division multiplexing access (OFDMA) systems and proposed a SWIPT-enabled architecture to study the

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Corresponding author: Xiao Lin, E-mail: xiaolin@ncu.edu.cn
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power control problem in broadband wireless systems.

It is well known that MIMO relay networks can markedly improve spectrum utilization and simultaneously enhance link reliability [14–15], as well as being an efficient way to provide high quality service at low cost [14–16]. More importantly, the concept of SWIPT is more applicable for short-distance applications since wireless power transfer (WPT) will suffer from high attenuation due to path-loss. MIMO relay systems involving an EH receiver were studied in Ref. [17], in which the joint optimal source and relay pre-code were designed to achieve different tradeoffs between the energy transfer and the information rate. In Ref. [18], a relaying protocol based on time switching (TS) and PS is proposed to enable EH and information processing at the relay. In Ref. [19], the throughput in a classic three-node Gaussian relay channel with decode-and-forward (DF) relaying is analyzed. More recently, EH has been extended to some more complicated relay systems. For instance, in Ref. [20], TS and PS based relay protocols has been proposed for the non-regenerative MIMO-OFDM relay system. Outage probability is analyzed for the multiple relay cooperative networks in Ref. [21]. In addition, in Ref. [22], a full-duplex relay protocol is proposed for the PS based SWIPT. Moreover, considering the coding technology for SWIPT-enabled relay systems, three rateless code-based relay protocols have been proposed, which show remarkable performance when compared with traditional non-rateless-coded systems in Ref. [23].

In this paper, we focus on a DF-based MIMO relay network, where nodes communicate with each other via an EH relay. The relaying transmission is powered by harvested energy of relay from the RF signals sent by the SN. We consider PS and AS schemes in the RN for the network. The optimal PS ratio of PS and the optimal AS scheme are analyzed. The pre-coder design for SN and the RN in different receiver designs are obtained to optimize the system performance. Moreover, the time resource allocation for system is studied and the power allocation strategy is also investigated.

The remainder of this paper is organized as follows: Sect. 2 introduces the system model and problem formulations. Sect. 3 present the optimal solutions for the formulated problems. Sect. 4 provides numerical examples to validate our results and compare the performances. Finally, Sect. 5 concludes the paper.

Notation: for a square matrix $\boldsymbol{S}$, $\operatorname{tr}\boldsymbol{S}$, $|\boldsymbol{S}|$, $\boldsymbol{S}^{-1}$, and $\boldsymbol{S}^{1/2}$ denote its trace, determinant, inverse, and square-root, respectively, while $\boldsymbol{S}\succeq\boldsymbol{0}$ and $\boldsymbol{S}\succ\boldsymbol{0}$ mean that $\boldsymbol{S}$ is positive semidefinite and positive definite, respectively. For an arbitrary-size matrix $\boldsymbol{M}$, $\boldsymbol{M}^{\mathrm{H}}$ and $\boldsymbol{M}^{\mathrm{T}}$ denote the conjugate transpose and transpose of $\boldsymbol{M}$, respectively. $\operatorname{diag}(x_1, x_2, ..., x_M)$ denotes an $M\times M$ diagonal matrix with $x_1, x_2, ..., x_M$ being the diagonal elements. $\boldsymbol{I}$ and $\boldsymbol{0}$ denote an identity matrix and an all-zero vector, respectively, with appropriate dimensions. $\mathrm{E}[\cdot]$ denotes the statistical expectation. The distribution of a circularly symmetric complex Gaussian (CSCG) random vector with mean x and covariance matrix $\boldsymbol{\Sigma}$ is denoted by $\mathcal{CN}(x,\boldsymbol{\Sigma})$, and ~ stands for 'distributed as'. $\mathbb{C}^{x\times y}$ denotes the space of $x\times y$ matrices with complex entries. $\|z\|$ is the Euclidean norm of a complex vector z, and $|z|$ is the absolute value of a complex scalar z. $\max(x,y)$ and $\min(x,y)$ denote the maximum and minimum between two real numbers, x and y, respectively, and $(x)^+ = \max(x,0)$. All the $\mathrm{lb}(\cdot)$ functions have base-2 by default.

2 System model

We consider MIMO EH cooperative network with two users and a RN as shown in Fig. 1. It is assumed that all the nodes are equipped with multiple antennas and work in the half-duplex mode, where two users equipped with $N>1$ antennas and RN equipped with $M>1$ antennas.

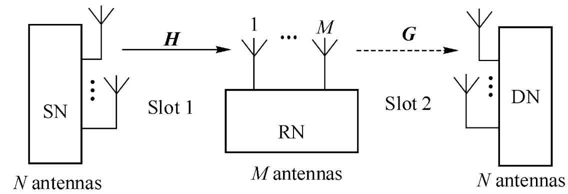

Fig. 1 System mode of SWIPT MIMO relay network

A direct link is not available and users cannot communication with each other without the assistance of the RN. The EH enabled RNs first harvest energy and receive information simultaneously through RF signals from the SN. Next, the RN uses the harvested energy as a source of transmission power to forward the decoded source information to the DN. We assume that the processing power required by the information decoding circuitry at the relay is negligible as compared to the power used for signal transmission from the relay to the destination.