

Secure transmission for multi-antenna wireless powered communication with co-channel interference and self-energy recycling[☆]

Quanzhong Li^a, Sai Zhao^{b,*}

^a School of Data and Computer Science, Sun Yat-sen University, Guangzhou, Guangdong 510006, China

^b School of Mechanical and Electrical Engineering, Guangzhou University, Guangzhou, Guangdong 510006, China

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ABSTRACT

In this paper, we investigate secure transmission resource allocation problem for multi-antenna wireless powered communication networks (WPCNs) where a full-duplex (FD) wireless device (WD) sends confidential signals to an information receiver (IR), and an energy transmitter (ET) is employed to provide radio energy to the FD WD and to jam the multiple eavesdroppers at the same time. In order to improve energy efficiency, the FD WD also collects energy from its own loop interference signals. The energy FD WD harvested is supplied to its information transmission in the same time slot. We aim to maximize the achievable secrecy rate at the IR by designing the transmit covariances of the WD and ET under the energy harvesting constraint of WD and transmit power constraints of WD and ET, respectively. Firstly, we consider perfect channel state information (CSI) of all links. Due to the non-convexity of the optimization problem, we propose a two-level optimization algorithm, the inner level optimization problem is a semi-definite programming (SDP) problem and the outer level optimization problem is a single-variable optimization problem. The optimal solution is derived and the sufficient condition to ensure that transmit beamforming having rank-one structure is also provided. Then, we consider robust secure transmit scheme design where the CSI uncertainties are modeled by the worst-case model, and S-procedure and its extension are employed to transform the semi-infinite constraint problem into finite constraint problem. Similarly, the optimal robust solution and the sufficient condition to ensure that robust transmit beamforming is optimal are provided. Simulation results demonstrate the effectiveness of our proposed strategies.

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1. Introduction

Radio-frequency (RF) enabled wireless energy transfer (WET) is a promising technology to provide continuous and stable energy supply for energy-constrained networks. The recent advance of WET enables to build wireless powered communication networks (WPCNs) [1], where wireless devices (WDs) are powered over the air by dedicated energy transmitters (ETs). Thanks to no interruption of communications by energy depletion, WPCNs are expected to have more sustainable throughput performance than conven-

tional battery-powered communication networks [2]. For WPCNs, there are two basic network models, where the IRs and ETs can be separately located [3–5] or co-located as hybrid access points [6–8]. In order to eliminate the co-channel interference between the signals from the IRs and ETs, orthogonal access (e.g., frequency division multiple access) is usually adopted [3–8], which may reduce spectrum efficiency.

As to improve the spectrum efficiency for WPCNs, co-channel energy and information transfer schemes have been proposed [9,11,12]. Considering separately located IR and ET, [9] aims to maximize the spectrum efficiency of a WPCN, where the energy and information transfer occurs over the same frequency band, and the WD operates in a full-duplex mode with simultaneous energy harvesting and information transmission. Zeng and Zhang [11] studies a wireless-powered amplify-and-forward relay network, where a full-duplex relay harvests energy from the transmitted signals of its own and the source and helps the information transmission from the source to the destination using the harvested en-

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* Corresponding author. Tel.: +86 13922112426.

E-mail addresses: liquanzh@mail.sysu.edu.cn (Q. Li), zhaosai@gzhu.edu.cn (S. Zhao).

ergy. Xu et al. [12] focuses on two separately systems including a multiuser multiple-input multiple-output (MIMO) wireless WET system and a coexisting point-to-point MIMO wireless information transmission (WIT) system, and propose a single-beam energy transmission scheme to reduce the interference from the WET system to the WIT system. All the works [9,11,12] consider multiple-antenna WD and ET, with the same objective to maximize the throughput of the WIT system by jointly design the transmit covariances/beamformers of the WD and ET.

Because of the openness of the wireless transmission medium, wireless information is susceptible to eavesdropping. Thus, secure communication is a critical issue for WPCNs. In [3] the secure transmission technology for a two-phase communication protocol based WPCN was studied, where an energy constrained node with no power of its own harvested energy from the source in the first phase and then played as jammer to transmit a jamming signal to interfere the eavesdropper in the second phase. In [3], due to two-phase communication protocol, the frequency spectrum efficiency and energy harvesting efficiency have not been fully explored. In [10], an FD WD is employed in WPCN considering physical layer security, energy harvesting and information transmission are processed simultaneously. However, in [10], only one eavesdropper is assumed wiretapping and the co-channel interference from ET to IR has not been included, which are too optimistic. To the best of our knowledge, considering co-channel interference and multiple eavesdroppers, employing multi-antenna FD WD in WPCN in order to maximize secrecy rate of system has not been investigated in literatures.

In this paper, we focus on exploring the potential advantages of employing an FD WD which simultaneously acts as information receiver and energy harvester in a multi-antenna multi-eavesdropper WPCN, aiming at improving the secrecy rate. We assume the multiple-antenna FD WD, operating in a FD mode, receiving energy from ET, and simultaneously sends confidential information to an information receiver (IR). For the purpose of enhancing secrecy rate, the ET not only powers WD, but also transmit jamming signals to eavesdroppers. However, the jamming signals cause the co-channel interference to IR. Since the transmitting signal of FD WD can be received by its own receiving antenna, self-energy recycling is enabled. The possible application of this system model could be a cognitive radio WPCN, where the primary system is a multi-user system and the secondary system is a FD WPCN. When the WD in the secondary system send intended information to IR, all the multiple users in primary system would be potential eavesdroppers. In order to maximize the achievable secrecy rate, joint design of the transmission covariances of WD and ET is studied. The main contributions of our work are summarized as below:

- We consider co-channel interferences in multi-antenna WPCN with FD WD and multiple eavesdroppers. Considering perfect channel state information (CSI), we propose a secure transmission scheme and formulated a secrecy rate maximization problem by jointly optimizing the transmission covariances of WD and ET. The formulated optimization problem is non-convex and intractable. We propose a two-level optimization algorithm, the inner level optimization problem is a semi-definite programming (SDP) problem and the outer level optimization problem is a single-variable optimization problem. The optimal solution is derived and the sufficient condition to ensure that transmit beamforming is the optimal transmit strategy for the WD is also provided.
- We consider the imperfect CSI case of the secrecy rate maximization problem. The CSI uncertainties are modeled by worst case model. The proposed robust secure optimization problem is more complicated and more challenging to solve due to the semi-infinite constraints. To make the problem tractable,

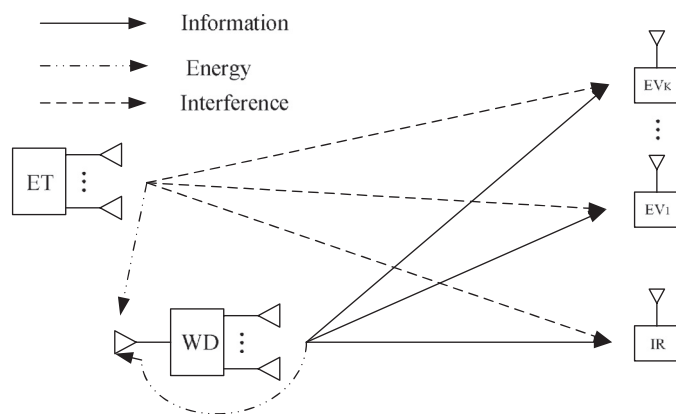


Fig. 1. The system model for secure communication over a multi-antenna WPCN with co-channel interference and self-energy recycling.

we convert the semi-infinite constraints into linear matrix inequalities (LMIs) using S-Procedure and its extension. Similar to the perfect-CSI counterpart, the robust optimal solution is derived and the sufficient condition to ensure the robust transmit beamforming to be rank-one is provided.

- In simulations, we compare our proposed schemes with benchmark suboptimal schemes. Simulation results show that our proposed schemes outperform those benchmark suboptimal schemes. We also show by simulations the probability of the transmit beamforming of WD being rank one, which verifies the rationality of our proposed sufficient conditions when the transmit strategy for the WD is optimal.

The rest of this paper is organized as follows. [Section 2](#) describes the system model and formulates the optimization problem. In [Section 3](#) and [Section 4](#), we propose secure transmit strategy with perfect and imperfect CSI, respectively. Simulation results are provided in [Section 5](#). We conclude our paper in [Section 6](#).

Notations: Boldface lowercase and uppercase letters denote vectors and matrices, respectively. The conjugate transpose, Frobenius norm and trace of the matrix $\mathbf{A}$ are denoted as $\mathbf{A}^\dagger$, $\|\mathbf{A}\|$, and $\text{tr}(\mathbf{A})$, respectively. By $\mathbf{A} \succeq \mathbf{0}$ or $\mathbf{A} \succ \mathbf{0}$, we mean that the matrix $\mathbf{A}$ is positive semidefinite or positive definite, respectively. $\mathcal{CN}(\mathbf{0}, \mathbf{A})$ denotes the distribution of a circularly symmetric complex Gaussian vector with mean vector $\mathbf{0}$ and covariance matrix $\mathbf{A}$.

2. System model and problem formulation

2.1. System model

We consider a wireless powered communication system as shown in Fig. 1, where one energy transmitter (ET) delivers wireless energy to one wireless device (WD), and at the same time the WD intends to send confidential information to a single-antenna legitimate information receiver (IR) in the presence of a number of single-antenna eavesdroppers, by using the harvested energy from the ET and the recycled self-energy from its own transmission. The ET is equipped with M antennas and plays two roles, one for energy supplier and the other for jammer to interfere the eavesdroppers. The WD has $N + 1$ antennas and operates in full duplex model, of which one antenna for energy harvesting and the other N antennas for transmitting confidential information. In practice, the WD can use a full-duplex rechargeable battery to simultaneously harvest energy and transmit information as in [9].

Denote the channels from the WD to the IR, from the WD to the k th eavesdropper, from the ET to the IR, and from the ET to the k th eavesdropper, $k \in \mathcal{K} = \{1, 2, \dots, K\}$, as $\mathbf{h}_0 \in \mathbb{C}^N \times 1$, $\mathbf{h}_k \in \mathbb{C}^N \times 1$, $\mathbf{f}_0 \in \mathbb{C}^M \times 1$, and $\mathbf{f}_k \in \mathbb{C}^M \times 1$, respectively. Assume that all

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