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A Simple Beamforming Design for Secure in MIMO SWIPT System

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Abstract
This paper investigates the beamforming design for secure transmission in multiple-input multiple-output (MIMO) communication systems with simultaneous wireless information and power transfer (SWIPT), where the energy harvesting (EH) receivers may eavesdrop the confidential information send to the information decode (ID) receiver. To solve the non-convex problem, we propose a simple solution, which is to choose a beamforming matrix part first, then find the rest of the beamforming matrix by solving the convex problem. Finally, numerical results are provided to validate our proposed algorithm.

Keywords *- MIMO, SWIPT, EH, ID, Secure rate.*

INTRODUCTION

Recently, simultaneous wireless information and power transfer (SWIPT) has attracted increasing interests, where the same radio frequency (RF) signals are used for transmitting both energy and information. To prolong the operation time of devices in 5G low-power energy-constrained networks, including wireless sensor networks (WSNs) and Internet of Things (IoTs), SWIPT has been regarded as one of the most promising technologies [1], [2]. Different from traditional wireless communications, SWIPT integrates energy harvesting (EH) with communication devices, which enables wireless devices to decode information or convert received RF signals into direct current power according to its own need [3].

In SWIPT, the transmitter sends signals to the information decode (ID) receivers and the EH receivers harvest energy from these signals. Thus, the EH receiver easily eavesdropped on the ID receiver's information. The problem is how to communication with ID receivers while minimize eavesdropping of the EH receivers. Authors in [4] studied the joint subcarrier allocation policy and power splitting ratio selection algorithm for downlink co-located downlink multiuser orthogonal frequency-division multiple access SWIPT systems. In [5], the MIMO harvest-and-jam were used to secure amplify-and-forward relay networks by designing the beamforming matrices. In [6], the authors considered the secure of MIMO SWIPT and by maximize achievable secrecy rate under transmit power constraint and EH constraint.

Motivated by these above observations, in this paper, we investigated the secure transmission in MIMO SWIPT system which consists of a transmitter and two receivers (an ID and an EH). The formulated problem is non-convex and cannot be solved directly. Through an equivalent reformulation, we propose a simply algorithm, wherein the problem is handled by solving a convex problems in an alternating method. Finally, numerical results are provided to validate our proposed algorithm.

Notations: Boldface lowercase and uppercase letters denote vectors and matrices, respectively. The set of all n-by-m complex matrixes is denoted by $\mathbb{C}^{n\times m}$. |a| denotes the modulus of complex number a. For a vector **b**, $|\mathbf{b}|_F$denotes the Frobenius norm. The conjugate transpose, rank, trace, and determinant of the matrix **A** are denoted as$\mathbf{A}^H$, $\mathrm{rank}(A)$, $\mathrm{Tr}(\mathbf{A})$, and $\det(\mathbf{A})$, respectively. $\mathbf{A} \succcurlyeq 0$ Means A is a positive semidefinite (PSD) matrix. The symbol **I** denotes the identity matrix and **0** denotes a zero vector or matrix.

SYSTEM MODEL

Considering a MIMO system with one transmitter, one information decoding (ID) receiver, and one (energy harvesting as well as eavesdropping) EH receiver, as shown in Fig. 1. The transmitter is equipped with $N_t\geq 1$ antennas, while the ID receiver and the EH receiver are both equipped with $N_r\geq 1$ antennas. Both the information and the energy are transmitted over the same frequency band. Denote $\mathbf{x} = \mathbf{w}_i s_i + \mathbf{w}_e s_e$ is the baseband transmitted signal, where, $\mathbf{w}_i$ and $\mathbf{w}_e$are the information beamforming vector and the energy beamforming vector to be designed; $s_i \sim CN(0,1)$ and $s_e \sim CN(0,1)$ is circularly symmetric complex Gaussian (CSCG) random information bearing signal and the CSCG energy bearing signal.

The signals received by the ID receiver and the EH receiver is then given by:

$$\mathbf{y}_i = \mathbf{Hx} + \mathbf{n}_i,$$
$$\mathbf{y}_e = \mathbf{Gx} + \mathbf{n}_e, \qquad (1)$$

Where, $\mathbf{H} \in \mathbb{C}^{N_t\times N_r}$ and $\mathbf{G}\in \mathbb{C}^{N_t\times N_r}$ denote the complex conjugated channel matrices between the BS and the ID receiver and the EH receiver, respectively, $\mathbf{n}_i \sim CN(0,\sigma_i^2)$ and $\mathbf{n}_e \sim CN(0,\sigma_e^2)$ are Gaussian noises introduced at the ID and the EH respectively. Assuming the channels are quasi-static fading while at each fading state, both **H** and **G** are known to the transmitter.

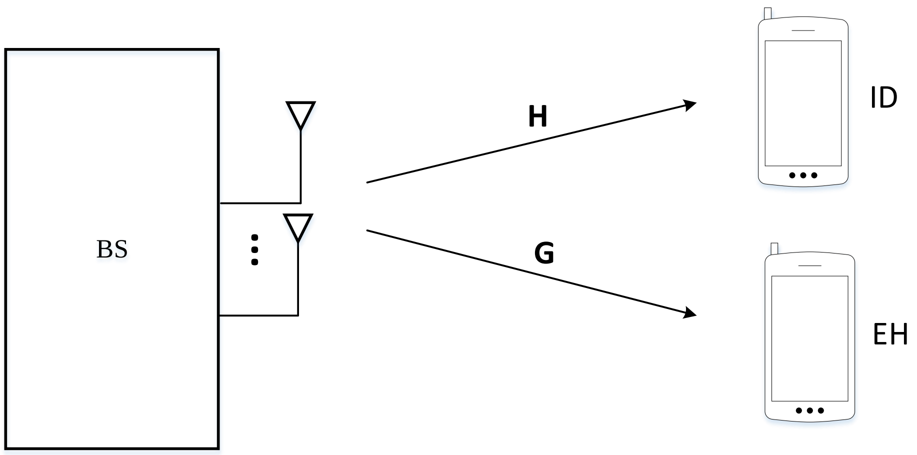

Fig: 1. *A system for simultaneous information beam forming and energy beamforming.*

From (1), the SINR (Signal-to-Interference-Plus-Noise Ratio) at ID and EH receiver can be defined as

$$SINR_{ID} = \frac{\mathbf{H}^H\mathbf{W}_i\mathbf{H}}{\mathbf{H}^H\mathbf{W}_e\mathbf{H}+\sigma_i^2\mathbf{I}}, \qquad (2)$$

$$SINR_{EH} = \frac{\mathbf{G}^H\mathbf{W}_e\mathbf{G}}{\mathbf{G}^H\mathbf{W}_i\mathbf{G}+\sigma_i^2\mathbf{I}}, \qquad (3)$$

Where,$\mathbf{W}_i = \mathbf{w}_i^H\mathbf{w}_i$, $\mathbf{W}_e = \mathbf{w}_e^H\mathbf{w}_e$, and $\mathbf{W}_i, \mathbf{W}_e \succcurlyeq 0$. The data rate between the BS and the ID receiver is is given by

$$R_i = \log\det(\mathbf{H}^H\mathbf{W}_e\mathbf{H} + \sigma_i^2\mathbf{I} + \mathbf{H}^H\mathbf{W}_i\mathbf{H}) - \log\det(\mathbf{H}^H\mathbf{W}_e\mathbf{H} + \sigma_i^2\mathbf{I}), \qquad (4)$$

And the wiretapped rate between the BS and the EH receiver are defined as

$$R_e = \log\det(\mathbf{G}^H\mathbf{W}_i\mathbf{G}+\sigma_e^2\mathbf{I} + \mathbf{G}^H\mathbf{W}_e\mathbf{G}) - \log\det(\mathbf{G}^H\mathbf{W}_i\mathbf{G}+\sigma_e^2\mathbf{I}). \qquad (5)$$

The EH receiver harvested power can be

derived to be

$$E = \xi \mathrm{Tr}(\mathbf{G}^H(\mathbf{W}_i + \mathbf{W}_e)\mathbf{G}), \quad (6)$$

Where, $\xi \in (0,1]$ is the energy conversion efficiency of the transducers used at the EH receiver. Without loss of generality, in the rest of this paper we assume that is $\xi = 1$.

The achievable secrecy rate at the ID receiver can be formulated as

$$R_s = [R_i - R_e]^+, \quad (7)$$

Where, $[x]^+ = \max(0, x)$.

SECRECY RATE OPTIMIZATION

Based on (6) and (7), the secrecy rate maximization problem can be formulated as

$$\begin{aligned} &\underset{\mathbf{W}_i,\mathbf{W}_e}{\text{maximize}}\; R_s \\ &s.t \quad \mathrm{Tr}(\mathbf{W}_i + \mathbf{W}_e) \le P \\ &\qquad \mathrm{Tr}(\mathbf{G}^H(\mathbf{W}_i + \mathbf{W}_e)\mathbf{G}) \ge Q, \\ &\qquad \mathbf{W}_i, \mathbf{W}_e \succcurlyeq 0 \end{aligned} \quad (8)$$

where P is the transmit power limit and Q denotes the required energy harvesting threshold at EH receiver.

Clearly, the above problem is non-convex and hard to solve from the global optimality point of view. Therefore, we propose an alternative optimization algorithm to solve the above problem by reformulating it into two independent sub problems. Firstly, $\mathbf{W}_e$ is designed by the orthogonal-projection method. Then for given $\mathbf{W}_e$, the covariance matrix $\mathbf{W}_i$ can be optimized based on the dual optimization.

A. The designation of $\boldsymbol{W}_e$

To completely cancel the interference to ID receiver, we design $\mathbf{W}_e$ in the null space of channel matrix $\mathbf{H}$. Define the singular value decomposition (SVD)

$$\mathbf{H} = \mathbf{U}_H \mathbf{\Sigma}_H \mathbf{V}_H^H, \quad (9)$$

Where $\mathbf{U}_H \in \mathbb{C}^{M\times M}$, $\mathbf{V}_H^H \in \mathbb{C}^{N\times N}$ are the unitary matrices. Thus the optimal structure of $\mathbf{W}_e$ can be formulated as:

$$\mathbf{W}_e = \mathbf{V}_e \mathbf{\Phi}_e \mathbf{V}_e^H, \quad (10)$$

Where, $\mathbf{V}_e = \left(\mathbf{I}_{N_t} - \mathbf{H}^H(\mathbf{H}\mathbf{H}^H)^{-1}\mathbf{H}\right)\mathbf{V}_H^H$, and $\mathbf{\Phi}_e$ is a diagonal matrix, whose elements are optimized to satisfy the minimum harvesting energy constraint of ID receiver. For simplicity, $\mathbf{\Phi}_e$ is chosen by

$$\mathbf{\Phi}_e = \frac{Q}{tr(\mathbf{G}\mathbf{V}_e\mathbf{V}_e^H\mathbf{G})}\mathbf{I}_{N_t}. \quad (11)$$

B. The Optimization of $\boldsymbol{W}_i$

To completely cancel the information to EH receiver, we design $\mathbf{W}_i$ in the null space of channel matrix $\mathbf{G}$. Define the singular value decomposition (SVD)

$$\mathbf{G} = \mathbf{U}_G \mathbf{\Sigma}_G \mathbf{V}_G^H, \quad (12)$$

Where $\mathbf{U}_G \in \mathbb{C}^{M\times M}$, $\mathbf{V}_G^H \in \mathbb{C}^{N\times N}$ are the unitary matrices. Thus the optimal structure of $\mathbf{W}_i$ can be formulated as:

$$\mathbf{W}_i = \mathbf{V}_i \mathbf{\Phi}_i \mathbf{V}_i^H, \quad (13)$$

Where, $\mathbf{V}_i = \left(\mathbf{I}_{N_t} - \mathbf{G}^H(\mathbf{G}\mathbf{G}^H)^{-1}\mathbf{G}\right)\mathbf{V}_G^H$, and $\mathbf{\Phi}_i$ is a diagonal matrix, whose elements are optimized to satisfy the maximum transmit power constraint of ID receiver.

$$\begin{aligned} &\max_{\mathbf{\Phi}_i} \quad \log\det(\mathbf{I} + \mathbf{H}^H\mathbf{W}_i\mathbf{H}) \\ &s.t \quad \mathrm{Tr}(\mathbf{\Phi}_i) \le P \\ &\qquad \mathbf{\Phi}_i \succcurlyeq 0 \end{aligned}, \quad (14)$$

Where, $\tilde{\mathbf{H}} = \mathbf{H}\mathbf{V}_i$. The Lagrangian function of this convex problem is given by

$$\begin{aligned} L = &\log\det\left(\mathbf{I} + \tilde{\mathbf{H}}\mathbf{\Phi}_i \mathbf{H}^H\right) \\ &-\mu(\mathrm{Tr}(\mathbf{\Phi}_i) - P) - \mathrm{Tr}(\mathbf{\Psi}\mathbf{\Phi}_i), \\ &\mu \ge 0, \mathbf{\Psi} \succcurlyeq 0. \end{aligned} \quad (15)$$

Where, positive semidefinite matrix $\mathbf{\Psi}$ is a slack variable to guarantee that $\mathbf{\Phi}_i$ is positive semidefinite. Real non-negative value μ is a slack variable to satisfy the energy harvesting constraint.

The Karush-Kuhn-Tucker (KKT) conditions can be defined as [7]

$$\begin{array}{rcl} \tilde{\mathbf{H}}^H\left(\mathbf{I} + \tilde{\mathbf{H}}\mathbf{\Phi}_i \mathbf{H}^H\right)^{-1}\tilde{\mathbf{H}} & = & \mu\mathbf{I} + \mathbf{\Psi} \\ \mu(\mathrm{Tr}(\mathbf{\Phi}_i) - P) & = & 0 \\ \mathrm{Tr}(\mathbf{\Psi}\mathbf{\Phi}_i) & = & 0 \\ \mu & \ge & 0 \\ \mathbf{\Psi} & \succcurlyeq & \mathbf{0} \end{array}, \quad (16)$$

From KKT, we get

$$\mathbf{\Phi}_i = (\mu\mathbf{I} + \mathbf{\Psi})^{-1} - \tilde{\mathbf{H}}^{-1}\mathbf{H}^{-H}, \quad (17)$$

Let the SVD, $\tilde{\mathbf{H}}\tilde{\mathbf{H}}^H = \mathbf{U}_{\tilde{\mathbf{H}}}\mathbf{\Sigma}_{\tilde{\mathbf{H}}}\mathbf{U}_{\tilde{\mathbf{H}}}^H$, where $\mathbf{\Sigma}_{\tilde{\mathbf{H}}} = diag\{h_1, \dots, h_{N_r}\}$ is a diagonal matrix of the eigenvalues. Assuming $\mathbf{\Psi}$ can be decomposed as $\mathbf{\Psi} = \mathbf{U}_{\tilde{\mathbf{H}}}\mathbf{\Sigma}_{\mathbf{\Omega}}\mathbf{U}_{\tilde{\mathbf{H}}}^H$, where $\mathbf{\Sigma}_{\Psi} = \mathrm{diag}\{\psi_1, \dots, \psi_{N_r}\}$ is a diagonal matrix of non-negative singular values of $\mathbf{\Psi}$. Hence,

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$\mathbf{\Phi}_i = \mathbf{U}_{\widetilde{\mathbf{G}}}\left((\lambda\mathbf{I}+\mathbf{\Sigma}_{\mathbf{\Psi}})^{-1}-\mathbf{\Sigma}_{\widetilde{\mathbf{H}}}^{-1}\right)\mathbf{U}_{\boldsymbol{H}}^{H}$, (18)

To guarantee that $\mathbf{\Phi}_e$ is a positive semidefinite matrix, the constraint below must be satisfied:

$h_i \geq \lambda + \psi_i,\ i = 1,..N_r,$ (19)

Substituting $\mathbf{\Phi}_i$ into KKT conditions (16), we have

$\mathrm{Tr}(\mathbf{\Psi}\mathbf{\Phi}_i) = \mathrm{Tr}\left(\mathbf{\Sigma}_{\mathbf{\Psi}}\left((\lambda\mathbf{I}+\mathbf{\Sigma}_{\Omega})^{-1}-\mathbf{\Sigma}_{\widetilde{\mathbf{H}}}^{-1}\right)\right) = 0,$ (20)

Since each of the diagonal matrices in the trace contains non-negative elements on its diagonal, therefore it can be concluded that

$\psi_i(\lambda+\psi_i-h_i) = 0,$ (21)

This means

$\psi_i = \begin{cases}\lambda - h_i, if\ \lambda - h_i > 0\\ \quad 0, other\end{cases},$ (22)

Because of ω_i is non-negative, $\mathbf{\Phi}_\mathrm{i}$ can be described as

$\mathbf{\Phi}_i = \mathbf{U}_{\widetilde{\mathbf{H}}}\,\mathrm{diag}\left(\left[\frac{1}{\lambda}-\frac{1}{\psi_1}\right]^+,\ldots,\left[\frac{1}{\lambda}-\frac{1}{\psi_{N_r}}\right]^+\right)\mathbf{U}_{\widetilde{\mathbf{H}}}^{H},$ (23)

Where, $[x]^+ = \max(0,x)$. the energy harvesting constraint requires that

$\sum_{i=1}^{N_r}\left[\frac{1}{\lambda}-\frac{1}{\psi_i}\right]^+ = P,$ (24)

Which is an eigenvalue water-filling used in [8]. Thus the procedure is eigenvalue water-fill up to a fixed level.

In the next example, we examine the secrecy and information rates performance of the proposed. For comparison purpose, we introduce the very basic sub-optimal scheme named plain maximum ratio transmission (MRT) which ignores the presence of EH receiver. Hence, the transmit covariance matrix is defined as

$\mathbf{W}_\mathbf{i}^{\mathrm{MRT}} = \frac{\boldsymbol{P}}{|\mathbf{H}|_F^2}\mathbf{H}\mathbf{H}^H,$ (25)

along the direction of the ID receiver's channel.

NUMERICAL RESULT

In this section, some numerical simulation results are presented to show the efficiency of our proposed beamforming design. The parameters used in the simulation are listed as follows. The transmit and receive antennas are set as $N_t = 4$ and $N_r = 2$, respectively. The channel realization $\mathbf{H}$ and $\mathbf{G}$ are i.i.d. Gaussian distributed. We assume that all receivers' noise power is identical as $\sigma_i^2 = \sigma_e^2 = 1$. The minimum harvesting energy requirement is -5dB. Each point in all figures is averaged over 1000 channel realizations.

In Fig.2, we compare the information rate of MRT and the proposed versus the transmission power. The simulation result demonstrates that compared with MRT beamforming design, the proposed provides lower information rate. The reason is that MRT design ignores the presence of EH receiver and all transmission power is dedicated to the ID receiver.

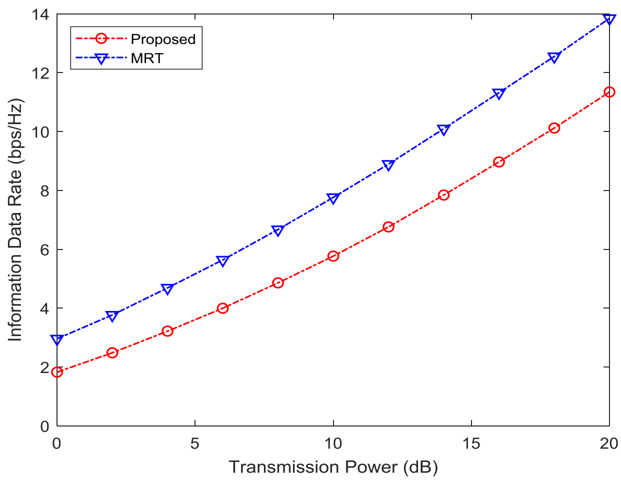

***Fig: 1.** The information data rate versus the transmission power.*

The secrecy rate versus the transmission power is plotted in Fig. 3. It can be seen that the proposed results outperformed. It is because the wiretapped rate between the BS and the EH receiver reduce secrecy rate in MRT method.

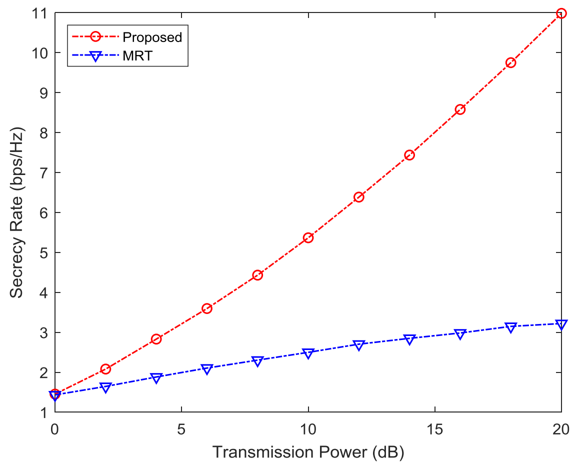

Fig: 2. *The secrecy rate versus the transmission power.*

CONCLUSIONS

This paper studied the transmit beamforming for secure MIMO SWIPT system. Note that the EH receiver is also a potential eavesdropper; hence we formulate the secrecy rate maximization problem with the energy harvesting and the transmission power constraints. Finally, the simulation results indicate the good security performance of the proposed method.

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REFERENCES

1. X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, 2015, November, “Wireless network with RF energy harvesting: A contemporary survey,” IEEE Commun. Surveys Tuts., vol. 17, no. 2, pp. 757-789.
2. K. Xiong, C. Chen, G. Qu, P. Fan, and K. B. Letaief, 2017, June, “Group cooperation with optimal resource allocation in wireless powered communication networks,” IEEE Trans. Wirel. Commun., vol. 16, no. 6, pp. 3840-3853.
3. K. Xiong, P. Fan, C. Zhang, and K. B. Letaief, 2015, August, “Wireless information and energy transfer for two-hop non-regenerative MIMO-OFDM relay networks,” IEEE J. Sel. Areas Commun., vol. 33, no. 8, pp. 1595-1611.
4. M. Zhang and Y. Liu, 2016, January, “Energy harvesting for physical-layer security in OFDMA networks,” IEEE Trans. Inf. Forensics Security, vol. 11, no. 1, pp. 154–162.
5. H. Xing, K. K. Wong, Z. Chu, and A. Nallanathan, 2015, December, “To harvest and jam: A paradigm of self-sustaining friendly jammers for secure AF relaying,” IEEE Trans. Signal Process., vol. 63, no. 24, pp. 6616–6631.
6. X. Zhao, J. Xiao, Q. Li, Q. Zhang, and J. Qin, 2015, November, “Joint optimization of AN-aided transmission and power splitting for MISO secure communications with SWIPT,” IEEE Commun. Lett., vol. 19, no. 11, pp. 1969–1972.
7. Boyd, Stephen; Vandenberghe, Lieven, 2004, Convex Optimization.

8. Cambridge, Cambridge University Press.
9. T. Yoo, A. Goldsmith, 2006, May, "Capacity and power allocation for fading MIMO channels with channel estimation error," IEEE Transactions on Information Theory, vol.52, no.5, pp.2203-2214.

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