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• LETTER •
Special Focus on Challenges and New Insights for Network Security in 5G-and-Beyond

Probabilistic constrained robust secure transmission for wireless powered heterogeneous networks

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Dear editor,

Physical-layer security (PLS) has been regarded as a prominent technique to achieve secure communications for heterogeneous networks (HetNets) with simultaneous wireless information and power transfer (SWIPT) [1]. Meanwhile, the stochastic channel state information (CSI) error will decrease the PLS performance of HetNets with SWIPT. However, the existing robust PLS researches considering stochastic CSI error focus on the traditional single-tier network [2, 3], which do not consider the existence of various types of co-channel interference (CCI) in HetNets with SWIPT. Therefore, these previous studies cannot be extended to secure HetNets with SWIPT straightforwardly. In fact, by designing a transmission scheme properly, such as the cross-tier cooperation between the macrocell base station (MBS) and the femtocell base stations (FBSs), the CCI can be used to facilitate efficient power transfer and secure communications. However, the design will become difficult and complicated if considering the existence of stochastic CSI error, which motivates our work in this study.

In this study, we consider a two-tier downlink HetNet with SWIPT under the stochastic CSI error. The MBS and FBSs serve the corresponding macrocell users (MUs) and femtocell users (FUs) on the same frequency resource, respectively. Moreover, some energy receivers (ERs) harvest energy from FBSs. In other words, the ERs can be seen as one type of FU, which do not receive information from FBSs. Therefore, FBSs can acquire the CSI of ERs. However, owing to the ambient useful and interference signals, ERs may act as potential Eves wiretapping the confidential messages for an MU. To secure the communication, we exploit the CCI and propose a robust artifical noise (AN)-aided transmission scheme applied at the MBS and FBSs. Furthermore, to design the information beamforming, energy transmission and AN vectors jointly, we formulate the problem of minimizing the total transmit power of system under the probabilistic quality-of-service (QoS) constraints on MUs, FUs and Eves, and the probabilistic EH constraints on ERs. To address it, we first convert the original optimization problem into an equivalent form. Then, we apply the Bernstein-type inequality and S-procedure to transform original probabilistic constraints into efficiently tractable linear matrix inequality (LMI) constraints, respectively. Furthermore, by applying the quadratic equality constraint, rank-one solutions can be reconstructed.

System model. We consider a two-tier downlink HetNet with SWIPT. There is one N_M-antenna MBS and N N_F-antenna FBSs, where the MBS serves M MUs while each FBS serves K FUs, $N_M > M$ and $N_F > K$. Meanwhile, B ERs harvest energy from N FBSs, which act as po-

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tential Eves wiretapping the confidential message intended for an MU. To enhance the secrecy and EH performance, AN is injected at the MBS and FBSs simultaneously.

Without loss of generality, we assume that MU_1 is wiretapped. For the sake of clarity, we define the nth FBS as FBS_n, the mth MU as MU_m, the kth FU of FBS_n as FU_{nk}, and the bth Eve or ER as E_b, respectively. Then, the received signal at MU_m, FU_{nk} and E_b is given in Appendix A, and the signal to interference plus noise ratio (SINR) of MU_m, FU_{nk} and E_b are respectively expressed in Appendix B.

Meanwhile, in practical network, it is difficult for the MBS and FBSs to obtain the perfect CSI of corresponding users owing to the channel estimation and feedback errors. In this study, we consider the stochastic CSI error model, where CSI error is stochastic and follows a certain distribution. Then, the actual channels in (A1)–(A3) of Appendix A can be respectively expressed in Appendix C.

Robust design. Our interest is to study the joint information beamforming, energy transfer and AN design under the stochastic CSI error case, such that the total transmit power of system is minimized while satisfying the probabilistic QoS constraints on MUs, FUs and Eves, and the probabilistic EH constraints on ERs. Hence, the problem of minimizing the total transmit power can be formulated as the following optimization problem in Appendix D.

However, owing to the non-convexity and the fact that probabilistic functions have no closed-form expressions, the formed problem is hard to solve. Meanwhile, owing to the existence of cross-tier interference, the former study on the scenario of single-base station (BS) with CSI uncertainty cannot be applied to solve it. In this study, we cope with this problem by means of the equivalent transformation, the quadratic equality constraint [4], Bernstein-type inequality [5] and S-procedure [6] in Appendix D. Furthermore, the analysis of signaling overhead and complexity can be found in Appendix E.

Simulation results and analysis. We provide the simulation results to evaluate the performance of the proposed methods. The specific simulation parameters setting is in Appendix F.

Figure 1 shows the total transmit power of system in various methods versus the CSI error ε_e with $\gamma_u = 12$ dB, $\gamma_e = -9$ dB and $\phi = 32$ dBm. As shown in Figure 1, the "Perfect CSI" method has the constant value in total power consumption because it does not take the CSI error into consideration. The total power consumed by four robust methods increases correspondingly with the rise of ε_e, and the disparity between the robust methods and the "Perfect CSI" method also becomes larger correspondingly. It can be explained that more additional power will be needed to guarantee the robustness as ε_e increases. In addition, the Bernstein-type inequality-based methods achieve higher performance than the S-procedure-based methods with the increase of ε_e, which shows the Bernstein-type inequality-based reformulation is less conservative.

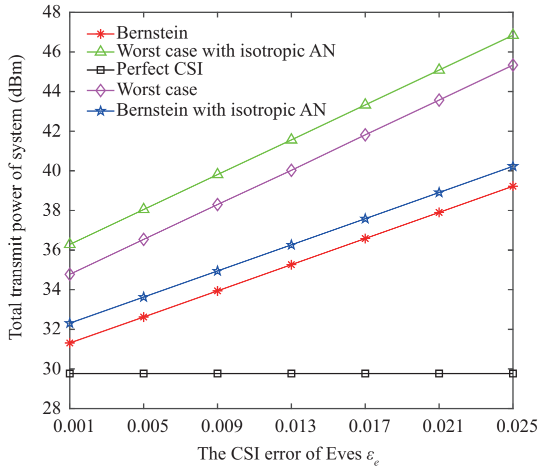

Figure 1 (Color online) System performance versus CSI error of Eves.

Conclusion. In this study, we explored the joint design of information beamforming, energy transfer and AN for secure SWIPT in a two-tier HetNet with stochastic CSI error. Our aim is to minimize the total transmit power of system subject to the probabilistic QoS constraints on MUs, FUs, Eves and the probabilistic EH constraints on ERs. We first acquired an equivalent form of the originally non-convex problem by equivalent transformation. Then, we utilized the Bernstein-type inequality and the S-procedure to recast the transformed constraints into two different deterministic ones, respectively. Simulation results validate the effectiveness and the security of our scheme.

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Supporting information Appendixes A–F. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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