Prof. Liang Xiao
Editor
IEEE Transactions on Communications

Re: Decision on TCOM-TPS-20-1501 (Intelligent Reflecting Surface-Aided SWIPT: Joint Waveform, Active and Passive Beamforming Design)

Dear Prof. Liang Xiao and Reviewers,

We would like to express our appreciation for the time and effort dedicated to the reviewing of our paper. The manuscript has been revised carefully based on your valuable comments and suggestions. In particular, we attempted to clarify the motivations and contributions of this work. To answer the questions and concerns, we include a point-to-point response below, which also describes all modifications made to the manuscript. We hope that the revisions and explanations are to the editor's and reviewers' satisfaction.

Best Regards,

Yang Zhao, Bruno Clerckx and
Zhenyuan Feng

Reviewer 1

Comment 1.1 — *This paper assumed that the perfect channel state information (CSI) of the whole system is available at the base station. However, since the IRS is in general not equipped with a radio frequency chain, the accurate CSI of the reflecting links established by the IRS is very challenging to obtain. The reviewer wonders if the proposed algorithm can also be applied to a case where the imperfect CSI of the network is available at the base station.*

Response: Thank you for pointing out the issue of CSI acquisition in presence of IRS. Practical protocols based on element-wise on/off switching [1], joint training sequence and reflection pattern design [2] and compressed sensing [3] have been developed to estimate the cascaded AP-IRS-user link for specific applications, yet channel estimation and codebook design for multi-carrier SWIPT remain unresolved and are beyond our current scope. The proposed algorithm is based on the assumption of cascaded CSIT (not individual AP-IRS and IRS-user ones) and can be readily extended to the imperfect CSIT case, where the joint waveform and beamforming design is based on a quantized CSI feedback.

Comment 1.2 — *This paper considered a relatively simple system model where there is only one user in the system. However, in practice, there can be many users co-existing in the SWIPT systems and there may also be two different and independent quality of service requirements: energy harvesting requirement and information decoding requirement. It could be better if the authors can clarify if the proposed algorithm can be employed in a more general case where the base station and the IRS cooperate to serve multiple users in the same time slot.*

Response: We appreciate your suggestion on IRS-aided multi-user SWIPT and believe it would be very promising. To extend the current work, we would first need to tackle the waveform and active beamforming design for a multi-user SWIPT system. For a multi-carrier network, each subcarrier only serves one information user but may serve all power user simultaneously (as whole received signal can be used for energy harvesting), and it involves an additional resource allocation problem that cannot be solved by the proposed GP algorithm.

To see the reason, recall that in the single-user scenario, the optimal information beamformer and power beamformer coincide at MRT [see TODO] with corresponding waveform as

$$\boldsymbol{w}_{\mathrm{I/P},n} = s_{\mathrm{I/P},n} \frac{\boldsymbol{h}_n}{\|\boldsymbol{h}_n\|} \tag{1}$$

which decouples the design in the spatial domain (beamformer) and frequency domain (power allocation $s^2_{\mathrm{I/P},n}$) thus satisfy $\boldsymbol{h}_n^H \boldsymbol{w}_{\mathrm{I/P},n} = \|\boldsymbol{h}_n\| s_{\mathrm{I/P},n}$. Apparently, picking $s_{\mathrm{I/P},n}$ as nonnegative value would maximize (27) and make (28) a real-value optimization problem, thus enable GP tools.

However, this is not generally the case in a multi-user scenario. For any optimal information and power waveform $\boldsymbol{w}^\star_{\mathrm{I},n}, \boldsymbol{w}^\star_{\mathrm{P},n}$ on subband n, they generally cannot be decoupled as (1) because users have different channel response, and the optimization should be performed over complex field. Some attempts were made for WPT in [4], but the extension to SWIPT is not straightforward as the power splitting ratio at all users require a joint update as well.

Extending our problem to the multi-user case would require first to solve relevant problems in the non-IRS case above. It is not the intention of this paper and may be considered in our further research.

Comment 1.3 — *It is well known that after employing semidefinite programming for handling the phase shift matrix at the IRS, it is very unlikely to obtain a rank-one phase shift matrix without any further modification. The reviewer notices that the authors proposed the Gaussian randomization method to ensure* *a rank-one solution. Also, the convergence of the proposed overall algorithm also relies on the unit-rank solution. Therefore, to make this paper more comprehensive and convincing, it is suggested to provide more results (such as figures, tables, and data analysis) in the simulation part to show that the rank-one solution can always be obtained even without applying the Gaussian randomization. As this is a very important and interesting conclusion to the colleagues working in the same area, it could be better if the authors can further discuss, interpret, and clarify this in a remark.*

Response:

Comment 1.4 — *The figures in the current version are relatively small, it is suggested to provide larger figures to help the readers better understand the results.*

Response: We apologize for the inconvenience. The figures would be amplified in future versions.

Comment 1.5 — *In the current version, the authors claimed that by applying semidefinite relaxation and omitting the rank-one constraint, the performance loss is negligible. The reviewer wonders if this is because of the relatively simple system model, as there is only one single user who has both power and information requirements. It could be better if the authors can further discuss this issue for a more general multiple user scenario.*

Response:

Reviewer 2

Comment 2.1 — *New RIS models are now being adopted as in [5] where it has been shown that the reflected signals depend on the direction of the arriving signal and this needs to be included in the analysis for realistic quantification.*

Response:

Comment 2.2 — *Why is MRT considered as precoder by (25) rather than optimizing it? Is it globally optimal too?*

Response:

Comment 2.3 — *Some strong assumptions like perfect CSI availability limit the practical utility of the proposed analytical results.*

Response:

Comment 2.4 — *All the assumptions and relaxations adopted used in the derivation of results as in (23) need to be explicitly mentioned along with appropriate justification for the same.*

Response:

Comment 2.5 — *Some transformations have been made while solving the original problem, but it has not been explicitly mentioned whether it is equivalent to transformation or not.*

Comment 2.6 — *Are the proposed solutions locally optimal or globally optimal? It is not clear whether the convergence of proposed solution methodologies is local or global? Also, how fast is it?*

Response:

Comment 2.7 — *The time complexity of the proposed algorithms, especially involving branch and bound methods, seems to be high especially applications assuming perfectly CSI availability as the coherence times are practically pretty low. So, the authors would like to justify it so that the proposed solution can be obtained over relatively short coherence intervals.*

Response:

Comment 2.8 — *How practical is it to consider lossless reflection from the RIS? Specifically, by considering the magnitude to be 1, the reflection losses at the RIS have been ignored.*

Response:

Comment 2.9 — *Minor comment: The size of all the numerical results figures is too small.*

Response:

Reviewer 3

Comment 3.1 — *First of all, motivations of studying the IRS on SWIPT is very unclear to me. Please clarify.*

Response:

Comment 3.2 — *Also, the contributions of this work are rather unclear, and thus, those should be better mentioned.*

Response:

Comment 3.3 — *Please explain the derived results more intuitively for better understanding.*

Response:

Comment 3.4 — *Authors assumed the unrealistic situation: the channels are assumed to be perfectly known. However, in practice, the channel should be estimated, e.g., as studied in [6], [2]. It would be much better to discuss the channel estimation issue by citing the above references.*

Response:

Comment 3.5 — *More simulation results should be added to better and aggregately validate the effectiveness of the proposed method.*

Response:

Comment 3.6 — *The sizes of figures are too small.*

Response:

References

[1] Q.-U.-A. Nadeem, A. Kammoun, A. Chaaban, M. Debbah, and M.-S. Alouini, "Intelligent Reflecting Surface Assisted Wireless Communication: Modeling and Channel Estimation," *arXiv preprint arXiv:1906.02360*, pp. 1–7, 2019.

[2] J.-M. Kang, "Intelligent Reflecting Surface: Joint Optimal Training Sequence and Refection Pattern," *IEEE Communications Letters*, vol. 24, no. 8, pp. 1784–1788, aug 2020. [Online]. Available: https://ieeexplore.ieee.org/document/9081935/

[3] P. Wang, J. Fang, H. Duan, and H. Li, "Compressed Channel Estimation for Intelligent Reflecting Surface-Assisted Millimeter Wave Systems," *IEEE Signal Processing Letters*, vol. 27, pp. 905–909, 2020.

[4] Y. Huang and B. Clerckx, "Large-Scale Multiantenna Multisine Wireless Power Transfer," *IEEE Transactions on Signal Processing*, vol. 65, no. 21, pp. 5812–5827, 2017.

[5] S. Abeywickrama, R. Zhang, Q. Wu, and C. Yuen, "Intelligent Reflecting Surface: Practical Phase Shift Model and Beamforming Optimization," *arXiv preprint arXiv:2002.10112*, feb.

[6] C. You, B. Zheng, and R. Zhang, "Intelligent reflecting surface with discrete phase shifts: Channel estimation and passive beamforming," *arXiv*, 2019.