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Beamforming design for RIS-aided amplify-and-forward relay networks

Key words: Reconfigurable intelligent surface; Amplify-and-forward (AF) relay; Beamforming; Phase shift; Semidefinite programming; Successive convex approximation

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Motivation

- The hybrid network can not only make full use of the advantages of relay and RIS, but also maintain a balance between cost and rate performance. Compared to a RIS-aided network, a hybrid RIS and DF relay network can achieve the same rate improvement with a smaller number of RIS elements.

- To our knowledge, studies in the literature pertaining to hybrid networks focus on decode and-forward (DF) relay and RIS, and there are few studies dealing with a hybrid network consisting of amplify-and-forward (AF) relay and RIS. Considering the benefits of the hybrid relay and RIS network, the present study discusses a RIS-aided AF relay network.

System model

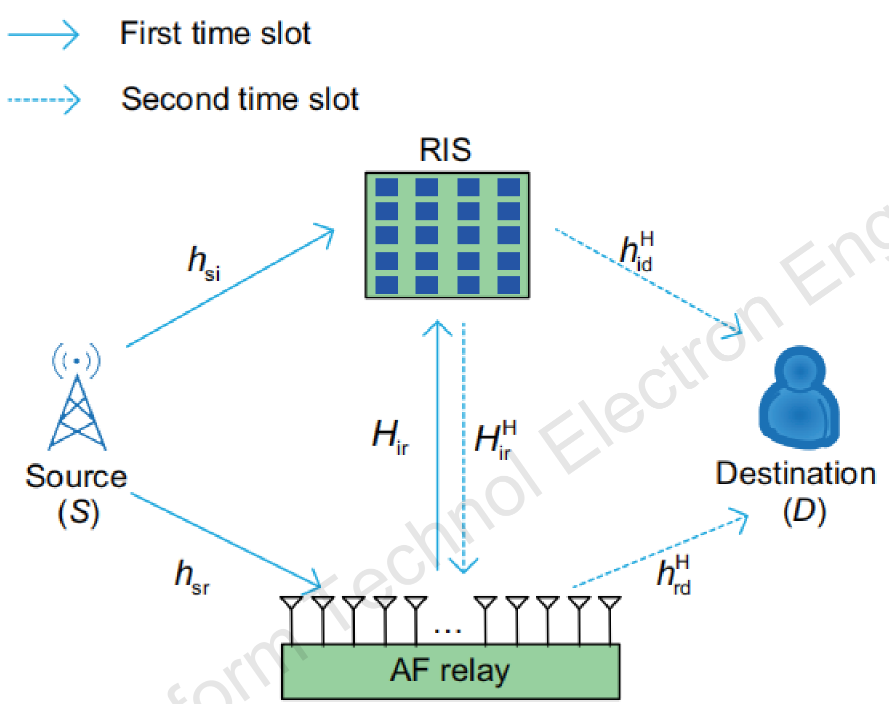


Fig. 1 A RIS-assisted AF relay wireless system

The achievable rate can be defined as

$$R = \frac{1}{2}\log_2(1 + \frac{\gamma_s |(\mathbf{h}_{rd}^H + \mathbf{h}_{id}^H \mathbf{\Theta}_2 \mathbf{H}_{ir}^H)\mathbf{A}(\mathbf{h}_{sr} + \mathbf{H}_{ir}\mathbf{\Theta}_1 \mathbf{h}_{si})|^2}{\|(\mathbf{h}_{rd}^H + \mathbf{h}_{id}^H \mathbf{\Theta}_2 \mathbf{H}_{ir}^H)\mathbf{A}\|^2 + 1}).$$

Main idea

- Since the optimization variables (i.e., the beamforming matrix at AF relay and the reflection-coefficient matrices at RIS) are coupled, a high-performance alternating optimization (AO) method based on Charnes–Cooper transformation and semidefinite programming (CCT-SDP) is proposed.

- The optimization variables in the proposed CCT-SDP method are matrices, involving an extremely high computational complexity. To reduce the complexity, a low-complexity maximizing SNR scheme based on Dinkelbachs transformation and SCA (DT-SCA) is presented.

CCT-SDP Method

➢ Problem formulation

$$\max_{\boldsymbol{V}_1,\boldsymbol{V}_2,\boldsymbol{A}} \frac{\gamma_{\mathrm{s}}\mathrm{tr}(\boldsymbol{V}_1\boldsymbol{H}_{\mathrm{sir}}^{\mathrm{H}}\boldsymbol{A}^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}^{\mathrm{H}}\boldsymbol{V}_2\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}})}{\mathrm{tr}(\boldsymbol{V}_2\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\boldsymbol{A}^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}^{\mathrm{H}})+1}$$

$$\begin{aligned}\text{s.t. } & V_1(n,n)=1, V_2(n,n)=1, \forall n=1,2,\cdots,N+1,\\ & \gamma_{\mathrm{s}}\mathrm{tr}(\boldsymbol{V}_1\boldsymbol{H}_{\mathrm{sir}}^{\mathrm{H}}\boldsymbol{A}^{\mathrm{H}}\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}})+\|\boldsymbol{A}\|_{\mathrm{F}}^2\le\gamma_{\mathrm{r}},\\ & \mathrm{rank}(\boldsymbol{V}_1)=1,\ \boldsymbol{V}_1\succeq\boldsymbol{0},\\ & \mathrm{rank}(\boldsymbol{V}_2)=1,\ \boldsymbol{V}_2\succeq\boldsymbol{0},\end{aligned}$$

➢To solve such a non-convex problem, vectorization and trace function are applied to convert the problem into a fractional or linear optimization problem. After dropping rank-one constraints, the optimization problem can be addressed using the CCT-SDP algorithm. Finally, rank-one solutions are recovered using the Gaussian randomization method. The highest order of computational complexity is M^{13} and $N^{6.5}$ FLOPs.

DT-SCA method

- Problem formulation

$$\max_{\boldsymbol{v}_1,\boldsymbol{v}_2,\boldsymbol{A}} \quad \frac{\gamma_{\mathrm{s}}|\boldsymbol{v}_2^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}}\boldsymbol{v}_1|^2}{\|\boldsymbol{v}_2^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\|^2+1}$$

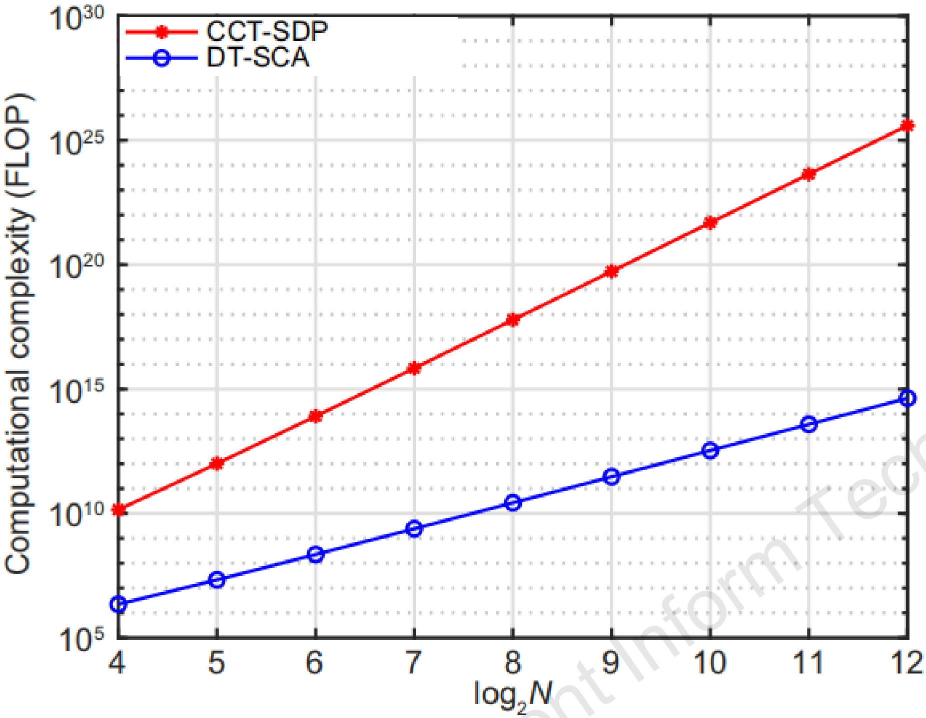
$$\text{s.t.} \quad |v_1(i)|=1,\ |v_2(i)|=1,\ \forall i=1,2,\cdots,N,$$

$$v_1(N+1)=1,\ v_2(N+1)=1,$$

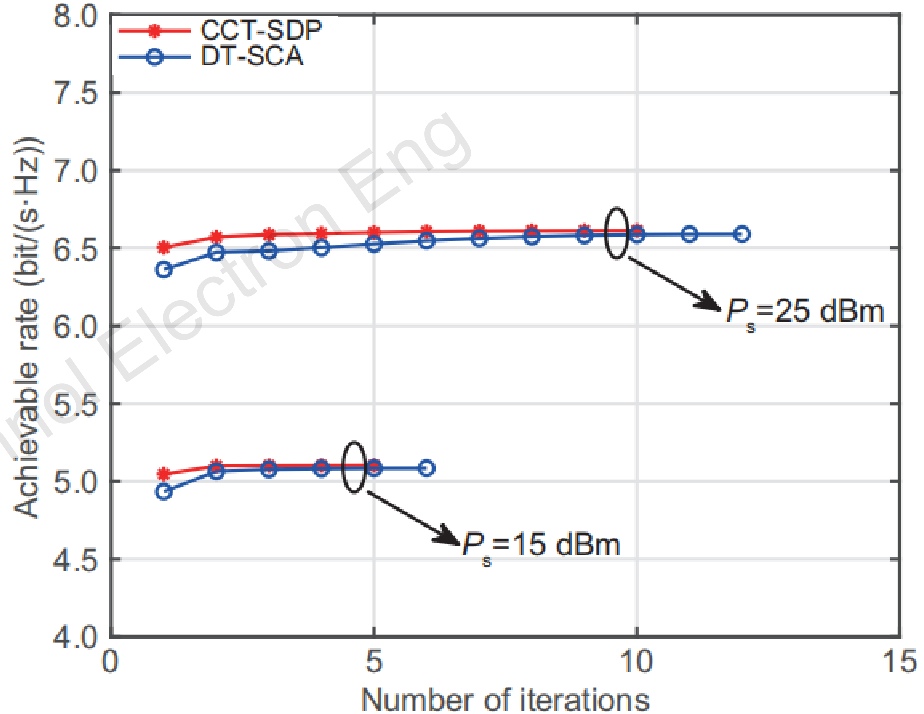
$$\gamma_{\mathrm{s}}\|\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}}\boldsymbol{v}_1\|^2+\|\boldsymbol{A}\|_{\mathrm{F}}^2\le\gamma_{\mathrm{r}},$$

- By performing DT and first-order Taylor approximation, the non-convex optimization problem is transformed into a convex problem. Since the optimization variables are vectors, the complexity of the DT-SCA method (i.e., O($M^6 + N^{3.5}$)) is much lower than that of the CCT-SDP method.

Simulation results

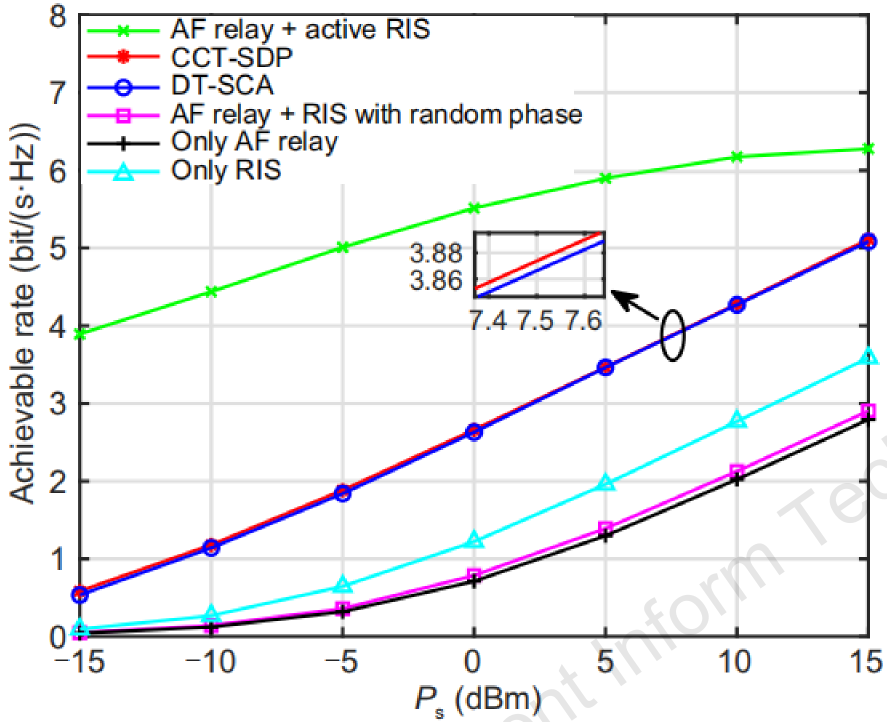


Computational complexity versus *N*

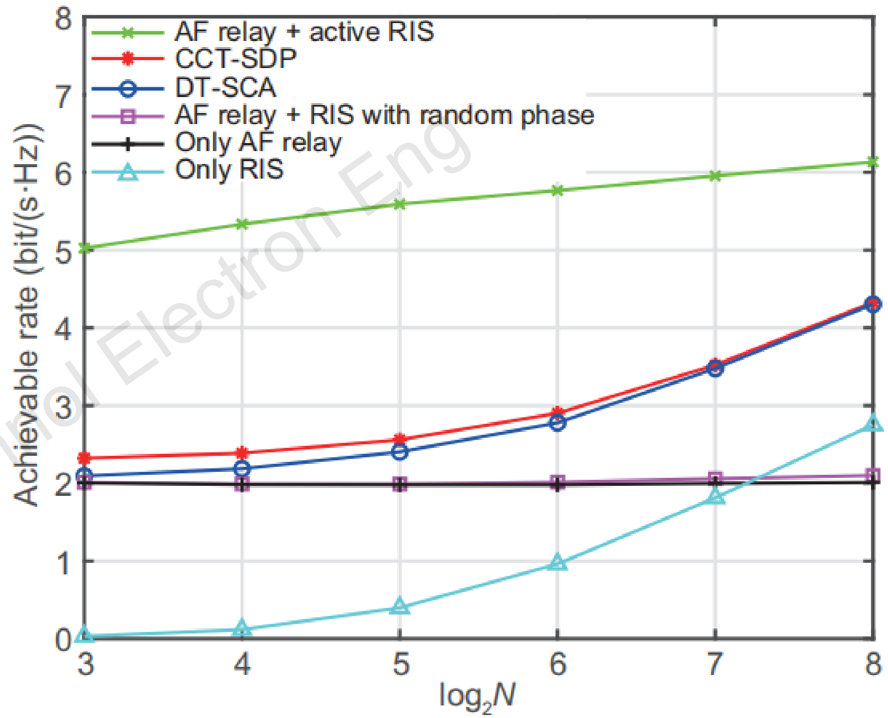


Convergence of the two proposed methods

Simulation results



Achievable rate versus P_s



Achievable rate versus N

Conclusions

- The present study investigated a RIS-aided AF relay wireless network. Two AO methods namely CCT-SDP and DT-SCA were proposed to jointly optimize the beamforming matrix at AF relay and phase-shift matrices at RIS.

- Simulations verified that the proposed CCT-SDP and DT-SCA schemes are convergent, and apparent rate improvement can be achieved. Additionally, it was proved that the rate performance achieved by the low-complexity DT-SCA method is slightly lower than that of the high-performance CCT-SDP method.

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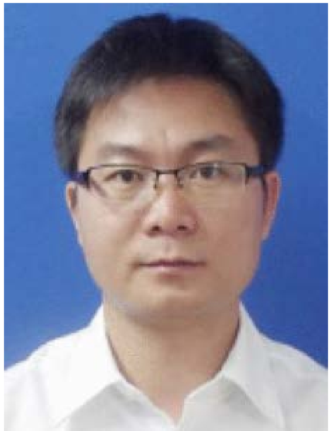

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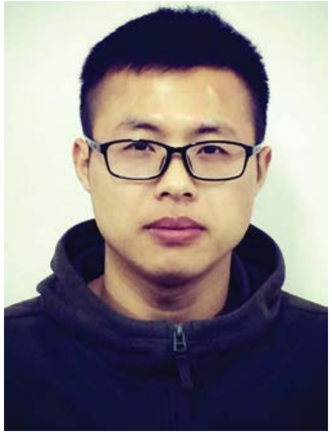

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