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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

Corresponding author: Feng SHU
E-mail: shufeng0101@163.com
ORCID: https://orcid.org/0000-0003-0073-1965

# 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

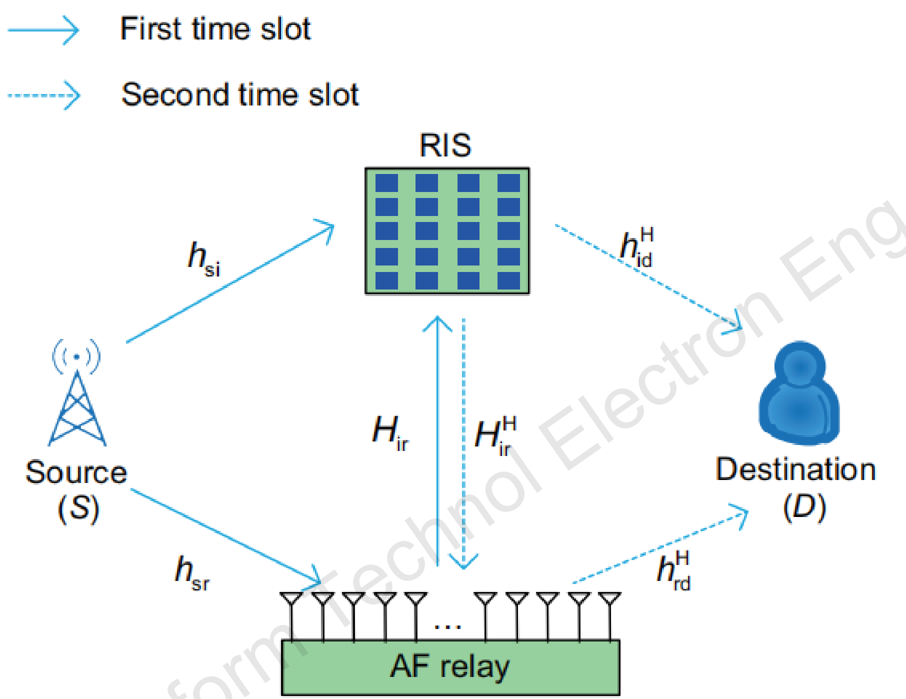



Fig. 1 A RIS-assisted AF relay wireless system



The achievable rate can be defined as

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

# 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.

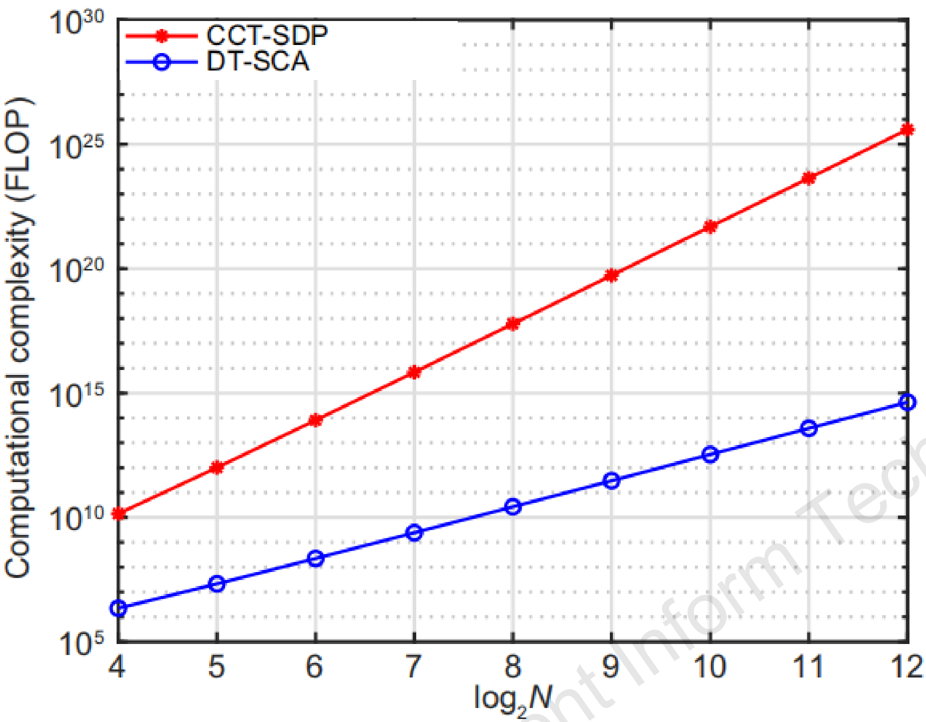
# DT-SCA method

- Problem formulation

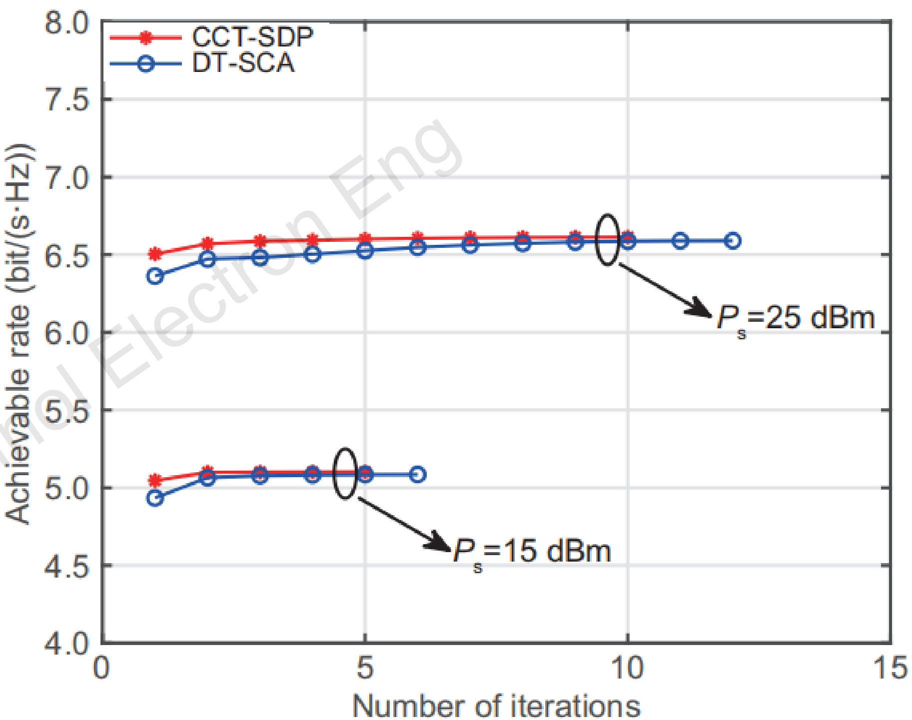
$$\begin{aligned}
\max_{\boldsymbol{v}_1,\boldsymbol{v}_2,\boldsymbol{A}} \quad & \frac{\gamma_{\mathrm{s}}|\boldsymbol{v}_2^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}}\boldsymbol{v}_1|^2}{\|\boldsymbol{v}_2^{\mathrm{H}}\boldsymbol{H}_{\mathrm{rid}}\boldsymbol{A}\|^2+1} \\
\text{s.t.} \quad & |v_1(i)|=1,\ |v_2(i)|=1,\ \forall i=1,2,\cdots,N, \\
& v_1(N+1)=1,\ v_2(N+1)=1, \\
& \gamma_{\mathrm{s}}\|\boldsymbol{A}\boldsymbol{H}_{\mathrm{sir}}\boldsymbol{v}_1\|^2+\|\boldsymbol{A}\|_{\mathrm{F}}^2\le\gamma_{\mathrm{r}},
\end{aligned}$$

- 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

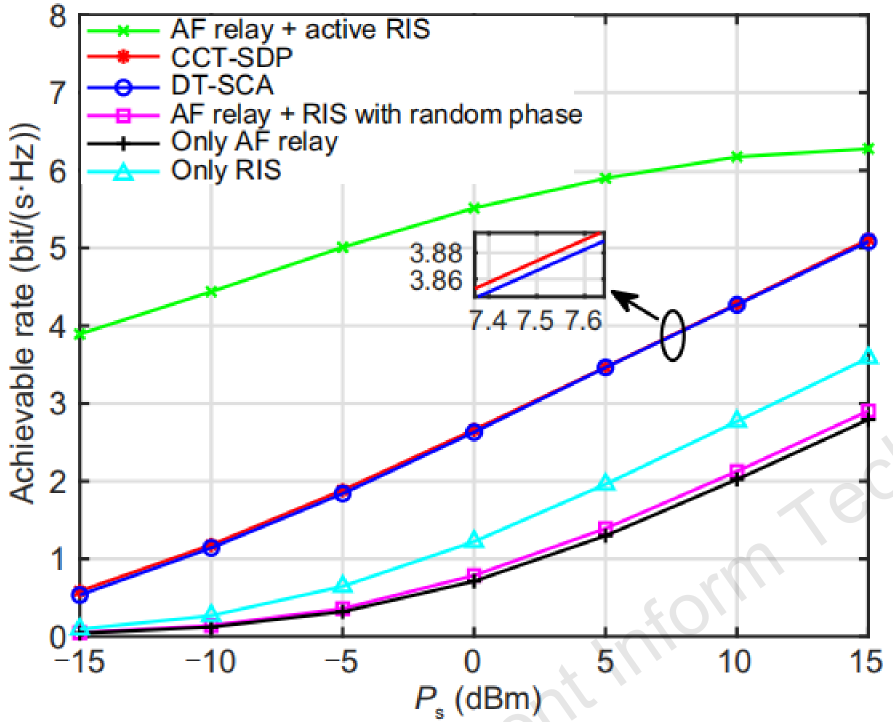



Computational complexity versus $N$

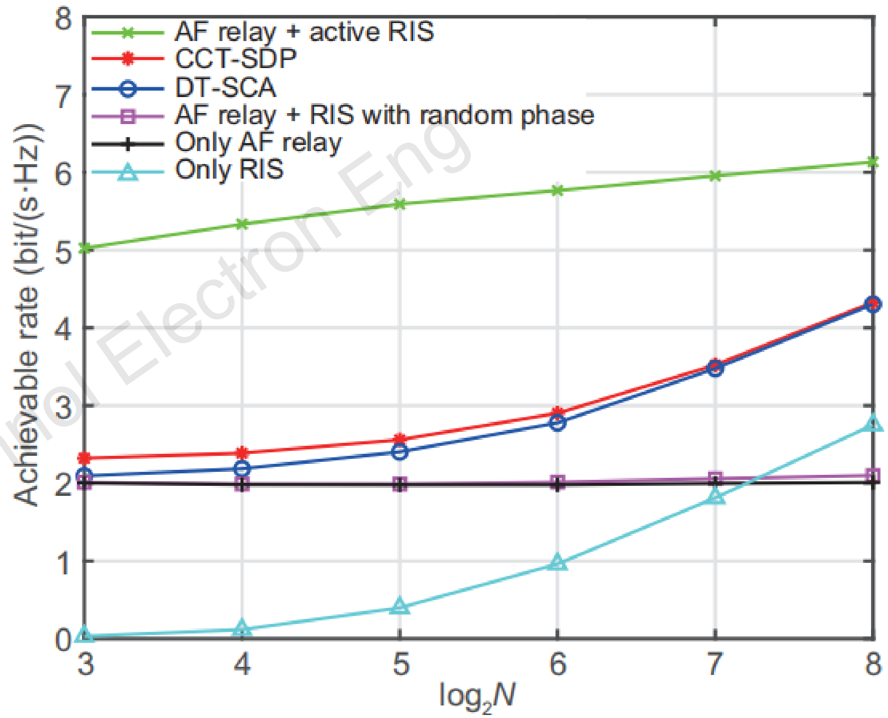



Convergence of the two proposed methods

# Simulation results




Achievable rate versus $P_s$




Achievable rate versus $N$

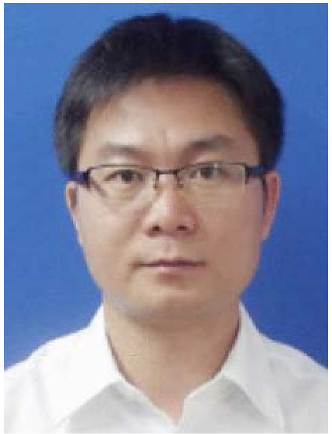
# Conclusions

- 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.

Xuehui WANG received the MS degree from Hainan University, China, in 2020, where she is currently pursuing the PhD degree with School of Information and Communication Engineering. Her research interests include wireless communication, signal processing, and IRS-aided relay systems.

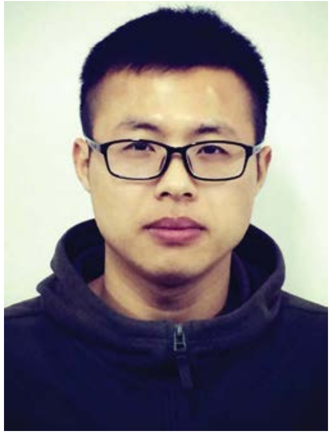
Feng SHU was born in 1973. He received the BS degree from Fuyang Teaching College, Fuyang, China, in 1994, the MS degree from Xidian University, Xi'an, China, in 1997, and the PhD degree from Southeast University, Nanjing, China, in 2002. From Sept. 2009 to Sept. 2010, he was a visiting postdoctoral fellow with University of Texas at Dallas, Richardson, TX, USA. From July 2007 to Sept. 2007, he was a visiting scholar with the Royal Melbourne Institute of Technology (RMIT University), Australia. From Oct. 2005 to Nov. 2020, he was with the School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing, where he was promoted from an associate professor to a full professor of supervising PhD students in 2013. He is with the School of Information and Communication Engineering and the Collaborative Innovation Center of Information Technology, Hainan University, Haikou, China, and also with the School of Electronic and Optical Engineering, Nanjing University of Science and Technology. He has authored or co-authored more than 300 journal papers with more than 150 papers on IEEE journals and more than 220 ISI-indexed papers. He has been granted more than 40 Chinese patents and is also a PI or co-PI for seven national projects. He was included in the Leading-Talent Plan of Hainan Province in 2020 and the Fujian Hundred-Talent Plan of Fujian Province in 2018, and was awarded the Mingjian Scholar Chair Professor in 2015. He was an *IEEE Trans Commun* exemplary reviewer for 2020, an editor of *IEEE Syst J* from 2019 to 2021, and an editor of *IEEE Access* from 2016 to 2018. He is currently an editor of *IEEE Wirel Commun Lett*. His research interests include wireless networks, wireless location, and array signal processing.



Riqing CHEN received the BE degree in communication engineering from Tongji University, Shanghai, China, in 2001, the MS degree in communications and signal processing from Imperial College London, London, UK, in 2004, and the PhD degree in engineering science from University of Oxford, Oxford, UK, in 2010. Since 2014, he has been with Fujian Agriculture and Forestry University, Fuzhou, China. His current research interests include UWB communications, cloud computing, wireless modulation, and transmission security.


Peng ZHANG is a postgraduate student in the School of Information and Communication Engineer at Hainan University, Haikou, China. His research interest is IRS-aided relay systems.

Qi ZHANG received the MS degree in electronic and communication engineering from Hainan University, China, in 2021, where he is currently pursuing the PhD degree with the School of Information and Communication Engineering. His research interests include wireless physical-layer security, massive MIMO, signal processing, and integrated sensing and communication.



Guiyang XIA received the MS and PhD degrees from Bohai University, Jinzhou, China, in 2016, and Nanjing University of Science and Technology, Nanjing, China, in 2021, respectively. He is currently an associate professor with the School of Information and Artificial Intelligence, Anhui Agriculture University, Hefei, China. His research interests include signal processing for wireless communication, secure-reliable transmission, space-air-ground integrated network, and finite-alphabet input systems.

Weiping SHI received the MS degree from Chongqing University of Posts and Telecommunications, China, in 2014. She is currently pursuing the PhD degree with the School of Electronic and Optical Engineering, Nanjing University of Science and Technology, China. Her research interests include IRS-aided wireless communication and physical-layer security.



Jiangzhou WANG has been a professor with University of Kent, UK, since 2005. He has published over 400 papers and four books in the area of wireless communications. He was a recipient of the Best Paper Award from IEEE GLOBECOM 2012. He was an IEEE distinguished lecturer from 2013 to 2014. He was the technical program chair of the 2019 IEEE International Conference on Communications, Shanghai, the Executive Chair of IEEE ICC 2015, London, and the Technical Program Chair of IEEE WCNC 2013. He has served as an editor for a number of international journals, including *IEEE Trans Commun* from 1998 to 2013. He is a fellow of the Royal Academy of Engineering, UK, and a fellow of IET.