

Ji WANG, Jiayi SUN, Wei FANG, Zhao CHEN, Yue LIU, Yuanwei LIU, 2024.
Deep reinforcement learning for near-field wideband beamforming in STAR-RIS networks. *Frontiers of Information Technology & Electronic Engineering*, 25(12):1651-1663. <https://doi.org/10.1631/FITEE.2400364>

Deep reinforcement learning for near-field wideband beamforming in STAR-RIS networks

Key words: Deep reinforcement learning; Near-field beamforming; Simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS); Wideband beam split

Corresponding author: Zhao CHEN

E-mail: zhao_chen@tsinghua.edu.cn

 ORCID: <https://orcid.org/0000-0002-8817-8270>

Motivation

- In practical applications, the electromagnetic characteristics of simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS) elements limit the independent adjustment of transmission coefficients (TCs) and reflection coefficients (RCs). As a result, a hybrid approach combining continuous and discrete control is adopted for passive beamforming at the STAR-RIS. To address this, we propose a deep reinforcement learning (DRL) framework for joint beamforming design.

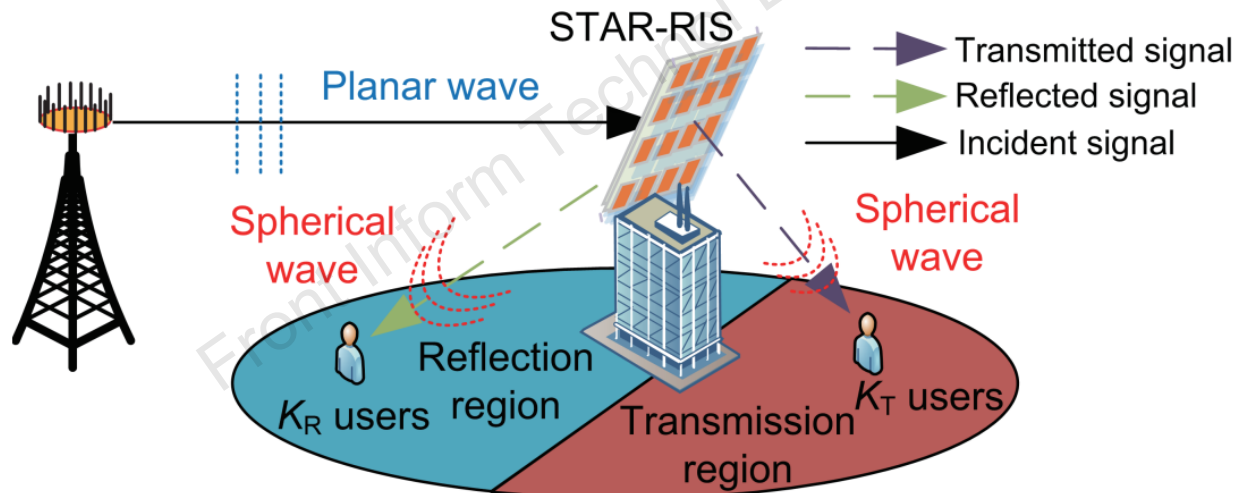


Fig. 1 System model of STAR-RIS-assisted near-field wideband communication network (STAR-RIS: simultaneously transmitting and reflecting reconfigurable intelligent surface)

Main idea

- To address the coupled nature of the STAR-RIS phase-shift model, the passive beamforming design is formulated as a problem of hybrid continuous and discrete phase-shift control, and the proposed algorithm controls the high-dimensional continuous action through hybrid action mapping.
- To mitigate the beam split issue in wideband communication, the delay-phase hybrid precoding structure is introduced to facilitate wideband beamforming.
- To address the issue of biased estimation encountered by deep deterministic policy gradient (DDPG) and twin delayed DDPG (TD3) algorithms, a softmax operator is introduced into the proposed algorithm to mitigate this bias.

Method

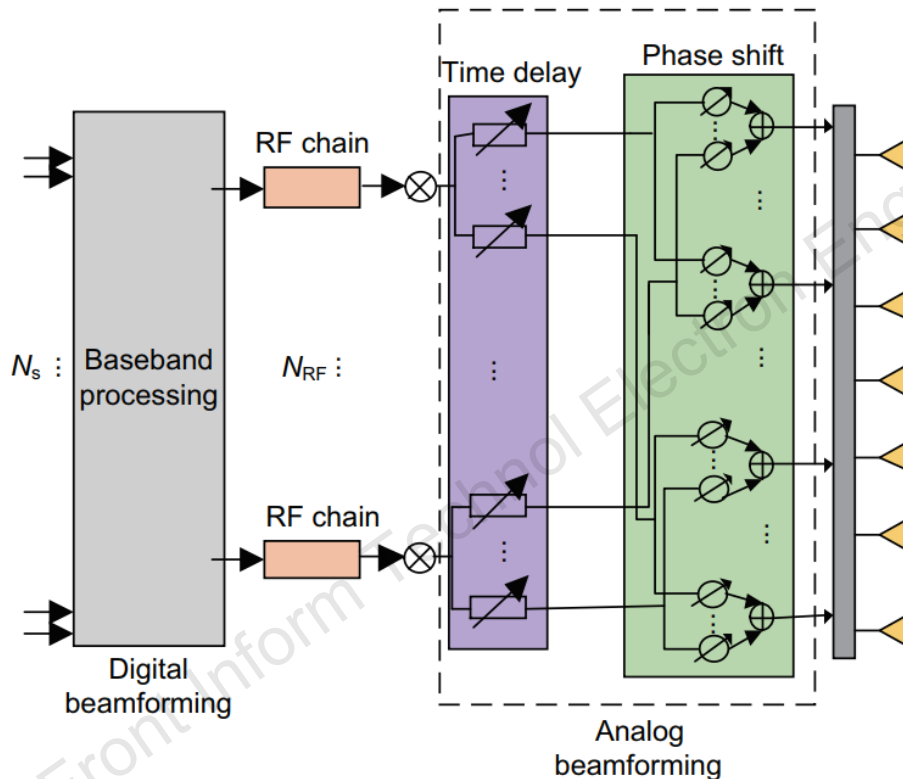


Fig. 3 Delay-phase hybrid precoding architecture

Low-dimensional digital beamforming performs fine-grained processing to handle inter-user interference and multi-stream multiplexing, ensuring signal quality and reliability.

High-dimensional analog beamforming uses a phase-shifting network to adjust the general direction and spatial coverage of the signal, responsible for generating the physical beams. Time-delay elements provide frequency-dependent phase shifts that better align with frequency-dependent steering vectors, thus cost-effectively mitigating the beam-splitting phenomenon.

Method

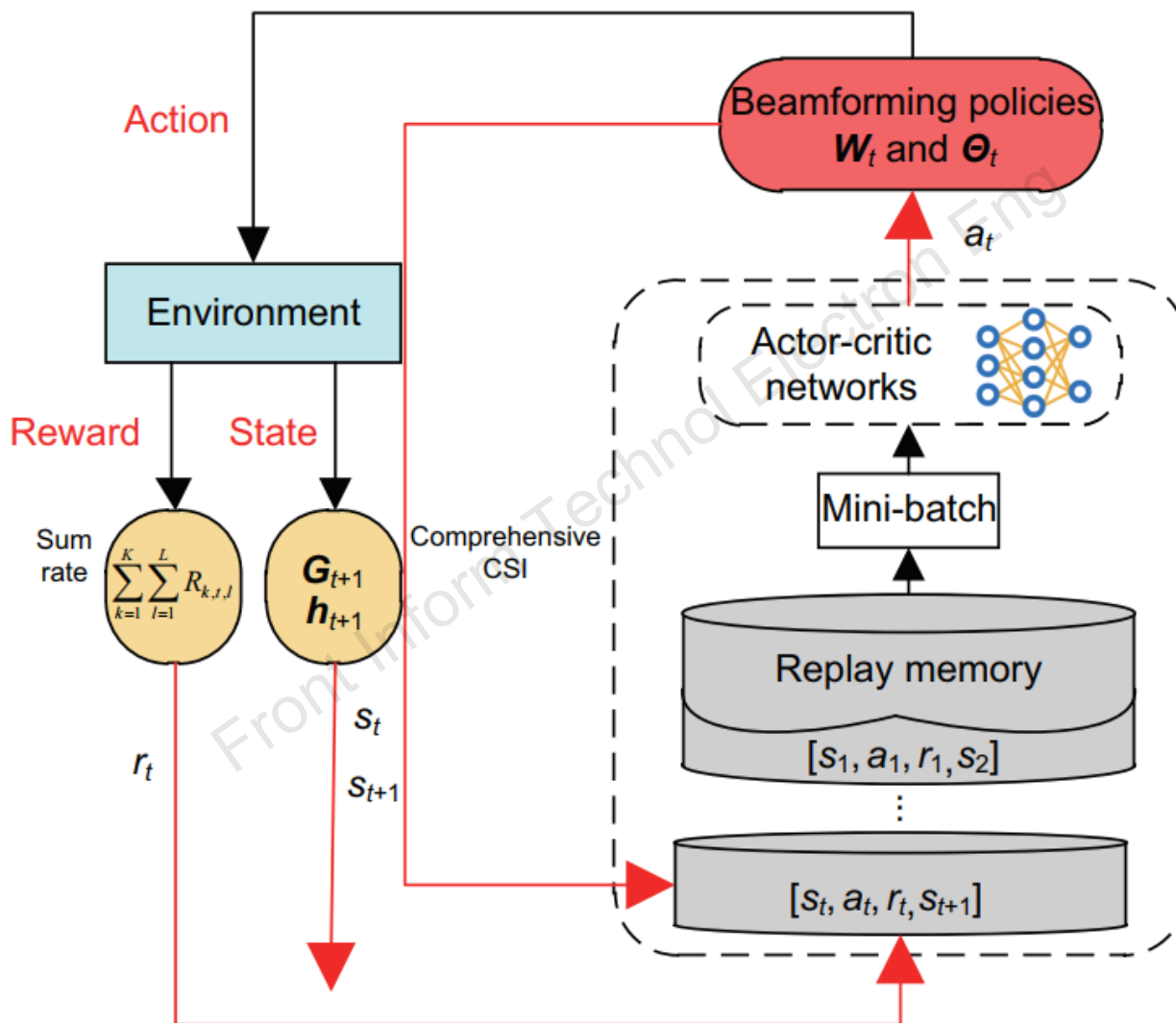


Fig. 4 Structure of the proposed SD3 algorithm

Results

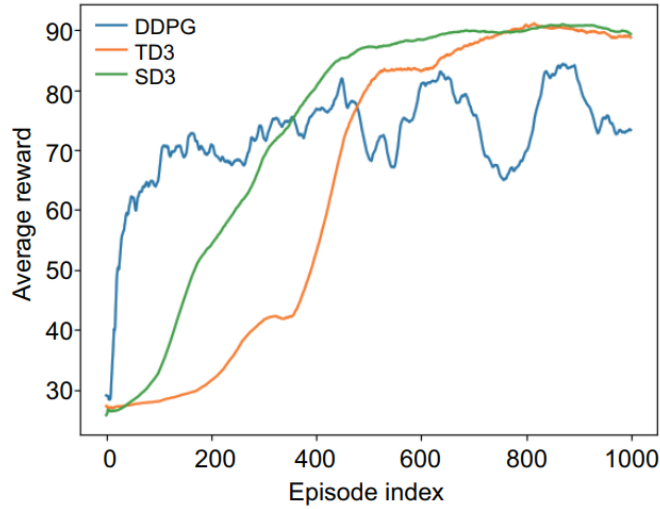


Fig. 5 Performance of different algorithms

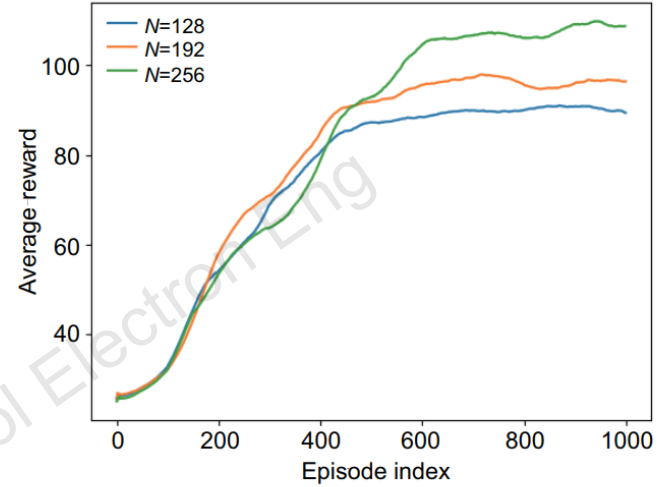


Fig. 7 Average rewards under different numbers of STAR-RIS elements

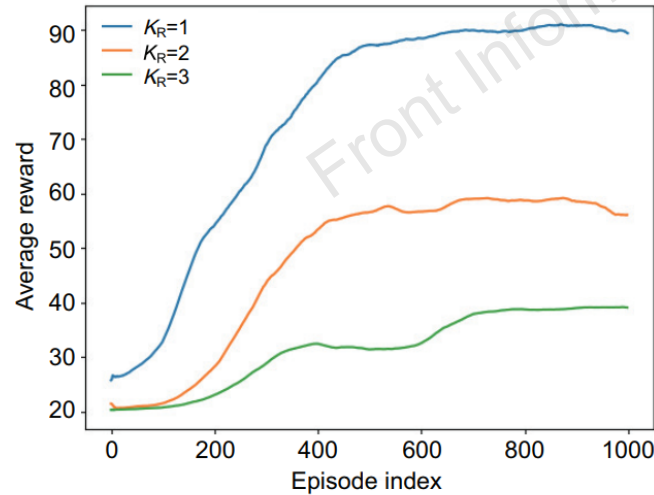


Fig. 9 Average rewards under different numbers of reflection users

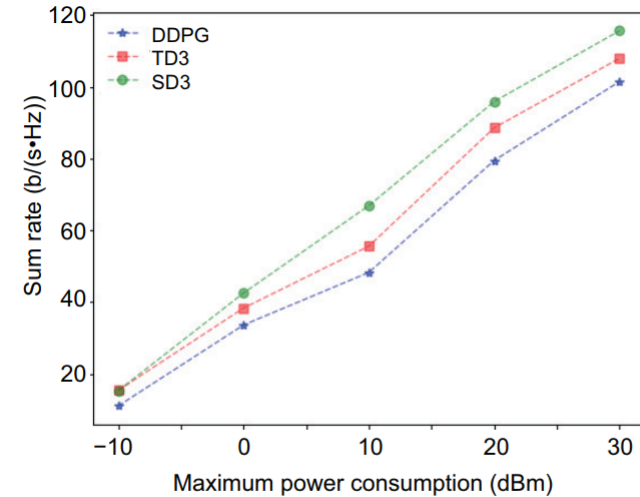


Fig. 10 Sum rate as a function of the maximum power consumption

Conclusions

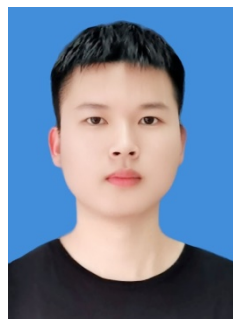
In this study, we employed a DRL framework to jointly design active and passive beamforming for a multi-user downlink communication system assisted by an STAR-RIS. Accounting for the coupled phase shifts of the STAR-RIS and hybrid beamforming structure of the BS, we introduced a robust DRL algorithm, SD3, to address the joint beamforming design challenge. The simulation results and analysis demonstrated that the SD3 algorithm outperforms other algorithms such as DDPG and TD3 in complex communication scenarios, and overcomes overestimation and underestimation issues.



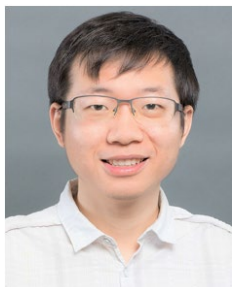
Ji WANG received the B.S. degree from the School of Electronic Information and Communications, Huazhong University of Science and Technology, Wuhan, China, in 2008, and the Ph.D. degree from the School of Information and Communications Engineering, Beijing University of Posts and Telecommunications, Beijing, China, in 2013. He is currently an associate professor with the Department of Electronics and Information Engineering, College of Physical Science and Technology, Central China Normal University, Wuhan. Prior to that, he held postdoctoral positions with the School of Electronic Information and Communications, Huazhong University of Science and Technology, and the Department of Electrical Engineering, Columbia University, New York, USA. His research interests include 5G/6G networks and machine learning.



Jiayi SUN is currently pursuing his Master's degree at the College of Physical Science and Technology, Central China Normal University. He obtained his Bachelor's degree from Hubei University of Arts and Science in 2022. His research interests include deep learning and wireless communications.



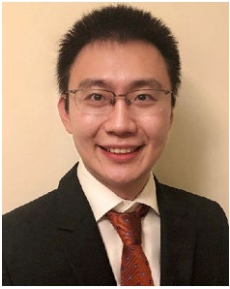
Wei FANG is currently pursuing his Master's degree at the College of Physical Science and Technology, Central China Normal University. He obtained his Bachelor's degree from Hubei University in 2022. His research interests include deep learning and wireless communications.



Zhao CHEN received the B.S. and Ph.D. degrees in electronic engineering from Tsinghua University, Beijing, China, in 2010 and 2015, respectively. He was a post-doctoral researcher with the Department of Electrical and Computer Engineering, Illinois Institute of Technology, Chicago, IL, USA, and the Department of Electrical Engineering, Columbia University, New York, NY, USA, in 2016 and 2017, respectively. Since 2020, he has been an assistant professor with Beijing National Research Center for Information Science and Technology, Tsinghua University. His research interests include applications of coding theory, optimization, and statistical learning in wireless communications, mobile computing, and information security.



Yue LIU received the B.Sc. degree from Beijing University of Posts and Telecommunications, Beijing, China, in 2010, and the Ph.D. degree in electronic engineering from the Queen Mary University of London, London, UK, in 2014. She joined the MPI-QMUL Information Systems Research Centre, Macau, SAR, China, as a researcher, in 2014, and then she has been a lecturer with the Faculty of Applied Sciences, Macao Polytechnic University, Macau, China, since 2016. Her research interests include AI-driven cellular networks, reinforcement learning, deep learning, 6G networks, radio resource management (RRM), and RF signal sensing.



Yuanwei LIU received the Ph.D. degree in electrical engineering from the Queen Mary University of London, London, UK, in 2016. He was with the Department of Informatics, King's College London, London, UK, from 2016 to 2017, where he was a postdoctoral research fellow. He has been a senior lecturer (associate professor) with the School of Electronic Engineering and Computer Science, Queen Mary University of London, since August 2021, where he was a lecturer (assistant professor) from 2017 to 2021. His research interests include non-orthogonal multiple access, reconfigurable intelligent surface, integrated sensing and communications, and machine learning.

Front Inform Technol Electron Eng