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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

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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.

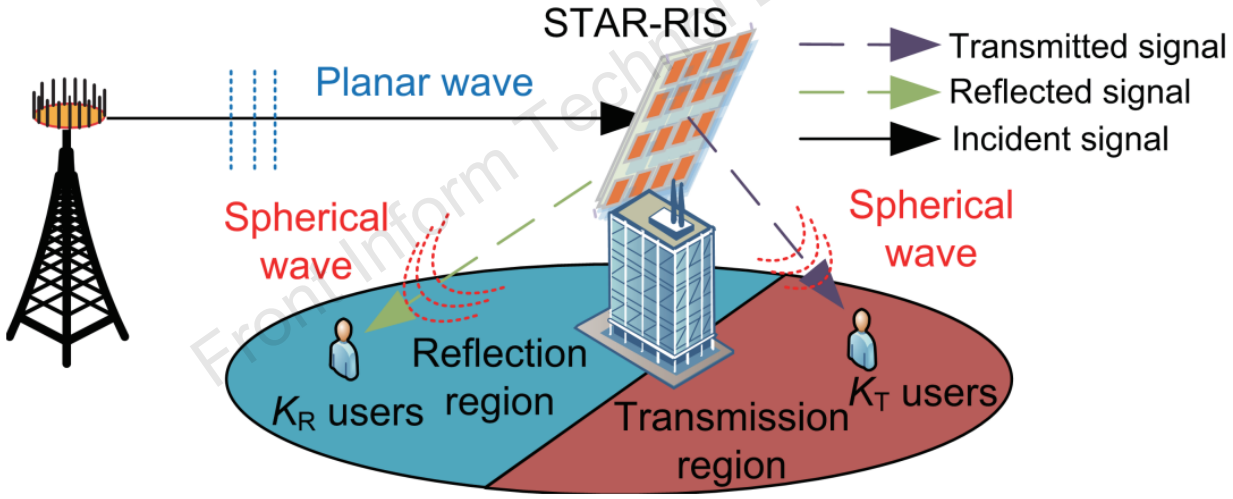

Fig. 1 System model of STAR-RIS-assisted near-field wideband communication network (STAR-RIS: simultaneously transmitting and reflecting reconfigurable intelligent surface)

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

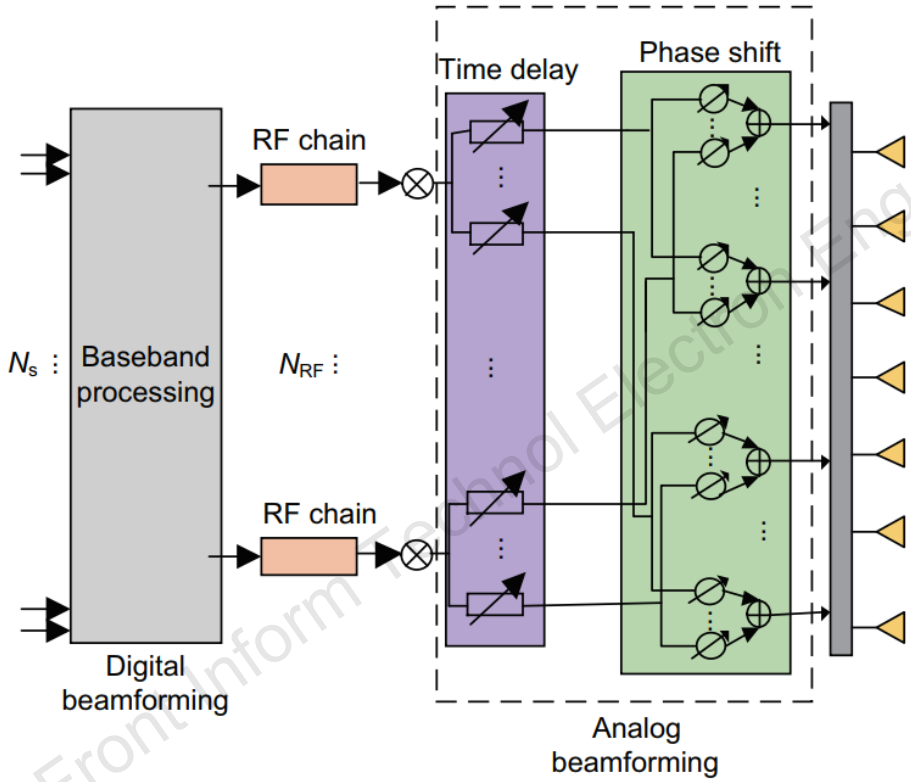

Fig. 3 Delay-phase hybrid precoding architecture

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

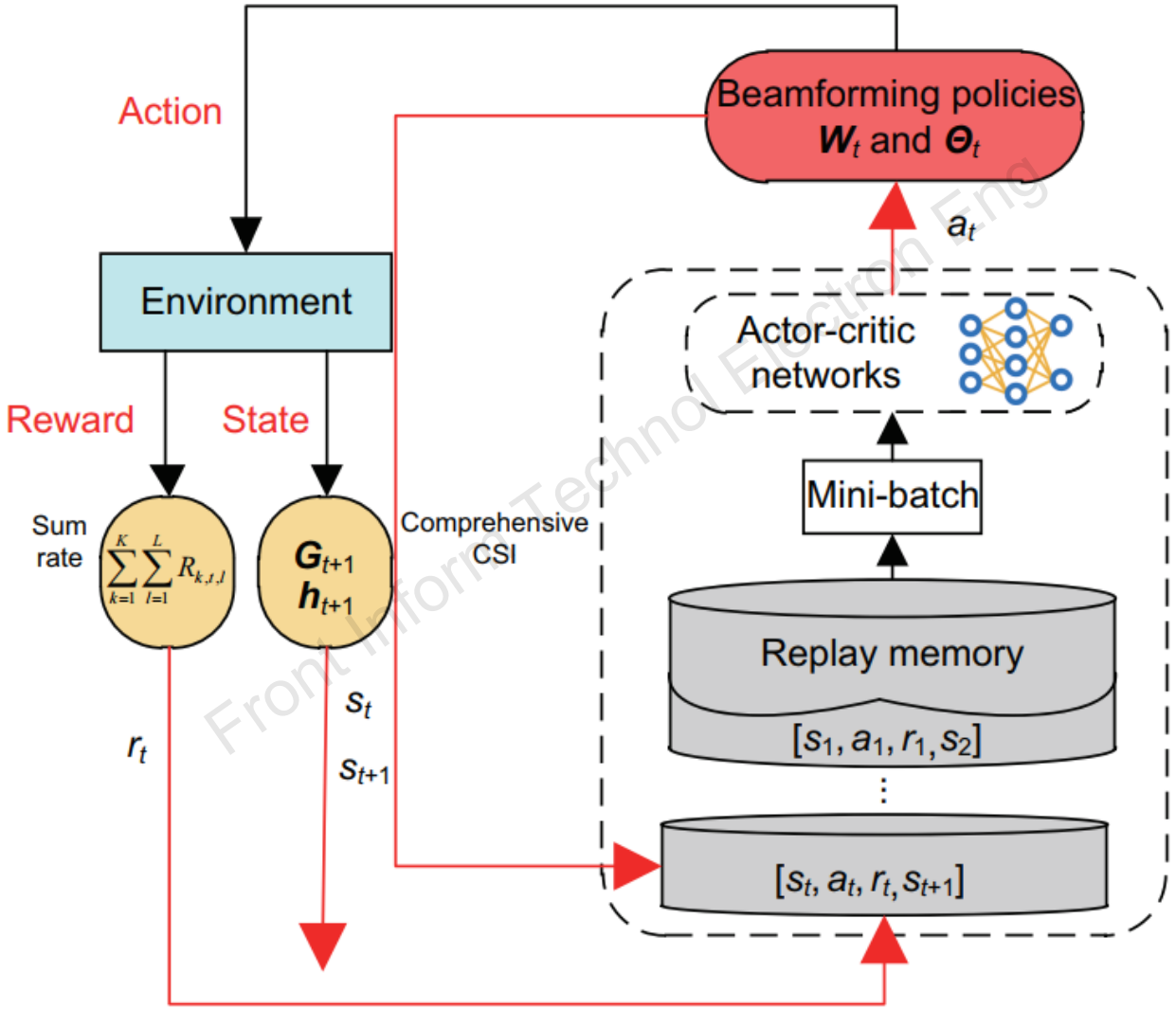

Fig. 4 Structure of the proposed SD3 algorithm

Results

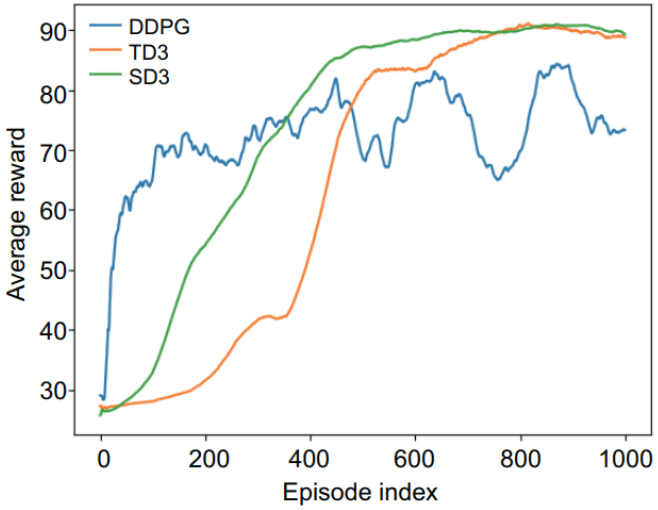

Fig. 5 Performance of different algorithms

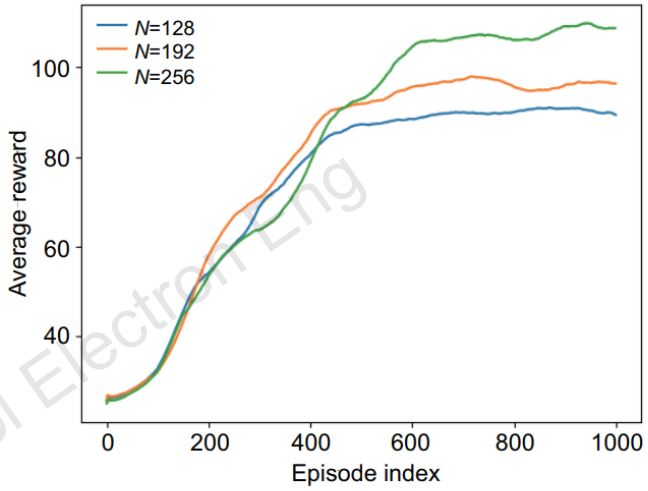

Fig. 7 Average rewards under different numbers of STAR-RIS elements

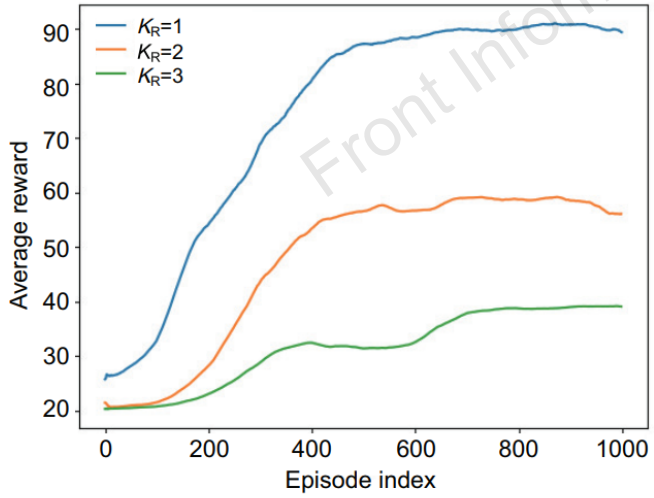

Fig. 9 Average rewards under different numbers of reflection users

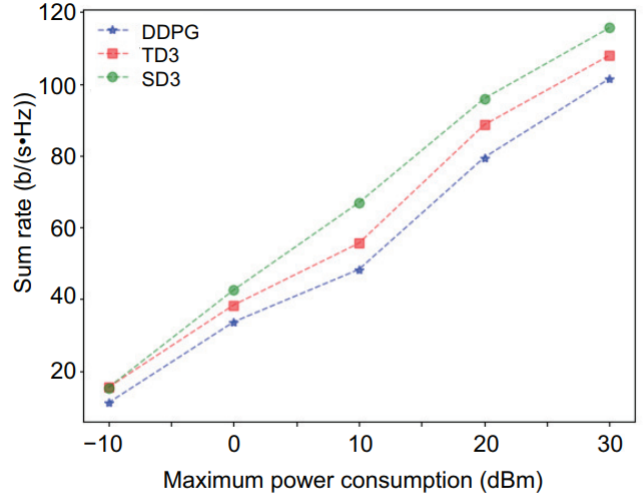

Fig. 10 Sum rate as a function of the maximum power consumption

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.

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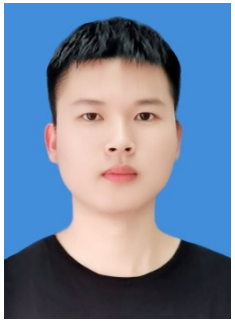

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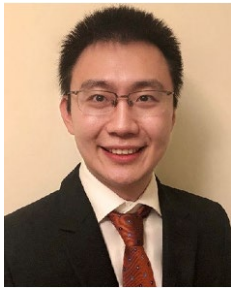

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