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XXXVI Cycle

On Applications of Machine Learning in IRS NOMA Architecture for 5G and B5G

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Research context and motivation

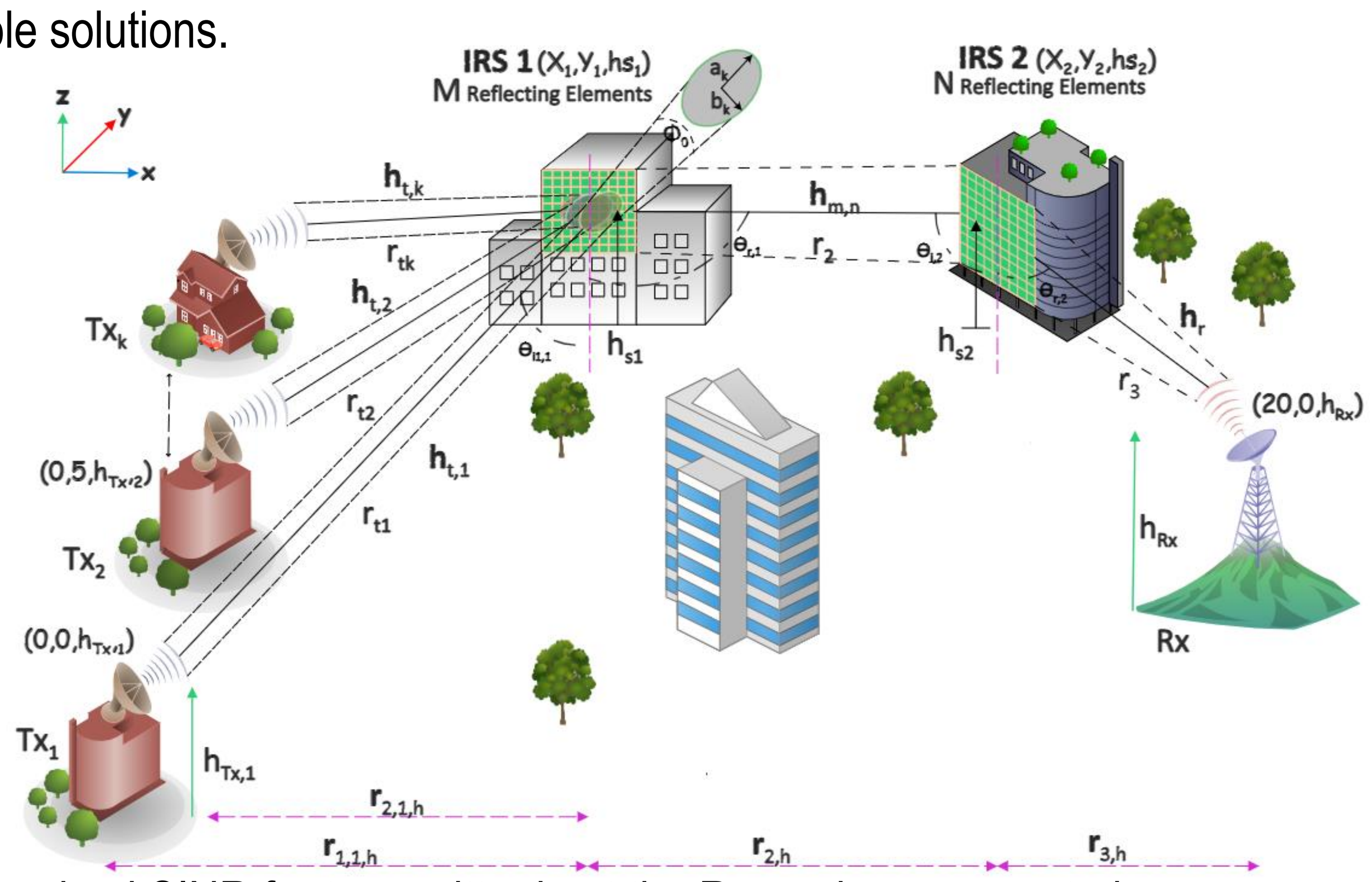
- T_{Hz} frequency bands possibly support considerable capacities and data rates. However, this is restricted by a highly dynamic and ambiguous channel. This restriction leads to severe path attenuation, high propagation losses, and sporadic wireless links, which results in very short communication distances, and increases the susceptibility to molecular absorption and blockage.

- To improve the coverage capability and spectral efficiency, this research investigates intelligent reflecting surface (IRS) as an emerging technology and promising solution. It manipulates the incident electromagnetic waves and adjusts the phase shifts of the semi-passive reflecting elements in a programmable behavior to yield a smart radio environment and enhance spectral efficiency in an energy-efficient and cost-effective manner. Many recent studies examined the IRS deployment in THz communications to inspect the power of the IRS to improve coverage and spectral efficiency.

- In this work, we examine a cascaded IRS scenario intending to maximize the sum rate of users.

Addressed research questions/problems

- The major challenge in our scheme while jointly optimizing the phases at the IRSs lies in the non-convexity due to the constant modulus constraints of the reflecting IRS elements, and computationally intractable multi-hop links. In general, the optimal solution of the np-hard problem is unknown, it is difficult to find out an analytical solution using traditional mathematical methods, and the exhaustive search is not practical for large-scale communication systems. To tackle it, we exploit a DDPG-based algorithm to obtain feasible solutions.



- The received SINR for transmitter k at the R_x can be represented as:

$$\gamma_K = \left(\frac{\sqrt{L_{total\_k}} e^{-j\boldsymbol{\Omega}3} \left| h_r^H \boldsymbol{\Phi}_N h_{m,n}^H \boldsymbol{\Phi}_M h_{t,k}^H \right|^2 e^{-j\boldsymbol{\Omega}k} P_k}{\sum_{\substack{i=1 \\ i\neq k}}^{K} \sqrt{L_{total\_i}} e^{-j\boldsymbol{\Omega}3} \left| h_r^H \boldsymbol{\Phi}_N h_{m,n}^H \boldsymbol{\Phi}_M h_{t,i}^H \right|^2 e^{-j\boldsymbol{\Omega}i} P_i + \sigma^2} \right)$$

- Furthermore, the data rate of user k is represented by:

$$R_K = log_2(1+\gamma_K)$$

- Our objective in this work is to find the values of the phase shift matrices φ of IRS_1 and IRS_2 elements that maximize the sum rate of all users given by:

$$R_{Sum} = \sum_{k=1}^{K} log_2\,(1+\gamma_K)$$

- Accordingly, the formulated problem is expressed as:

$$\max_{\emptyset} \sum_{k=1}^{K} log_2\,(1+\gamma_K) \qquad \text{C1: } |\varphi_m|^2 = 1, \forall m \in \{1,2,\ldots,M\}$$

$$\text{C2: } |\Psi_n|^2 = 1, \forall n \in \{1,2,\ldots,N\}$$

Submitted and published works

- **M. Shehab**, B. S. Ciftler, **T. Khattab**, M. Abdallah and **D. Trinchero**, "Deep Reinforcement Learning Powered IRS-Assisted Downlink NOMA," in IEEE Open Journal of the Communications Society, vol. 3, pp. 729-739, 2022,DOi: 10.1109/OJCOMS.2022.3165590.
- **M. Shehab**, I. Kassem, A. A. Kutty, M. Kucukvar, N. Onat, and **T. Khattab**, "5G Networks Towards Smart and Sustainable Cities: A Review of Recent Developments, Applications, and Future Perspectives," in IEEE Access, vol. 10, pp. 2987-3006, 2022, doi: 10.1109/ACCESS.2021.3139436.
- **M. Shehab**, **T. Khattab**, M. Kucukvar and **D. Trinchero**, "The Role of 5G/6G Networks in Building Sustainable and Energy-Efficient Smart Cities," 2022 IEEE 7th International Energy Conference (ENERGYCON), 2022, pp. 1-7, doi: 10.1109/ENERGYCON53164.2022.9830364.

Novel contributions

- To the best of our knowledge, none of the existing research papers in the literature leveraged the DRL method to solve the over-determined system of equations for the uplink cascaded IRS multiple access scenarios, which is multiple sources to the same destination.

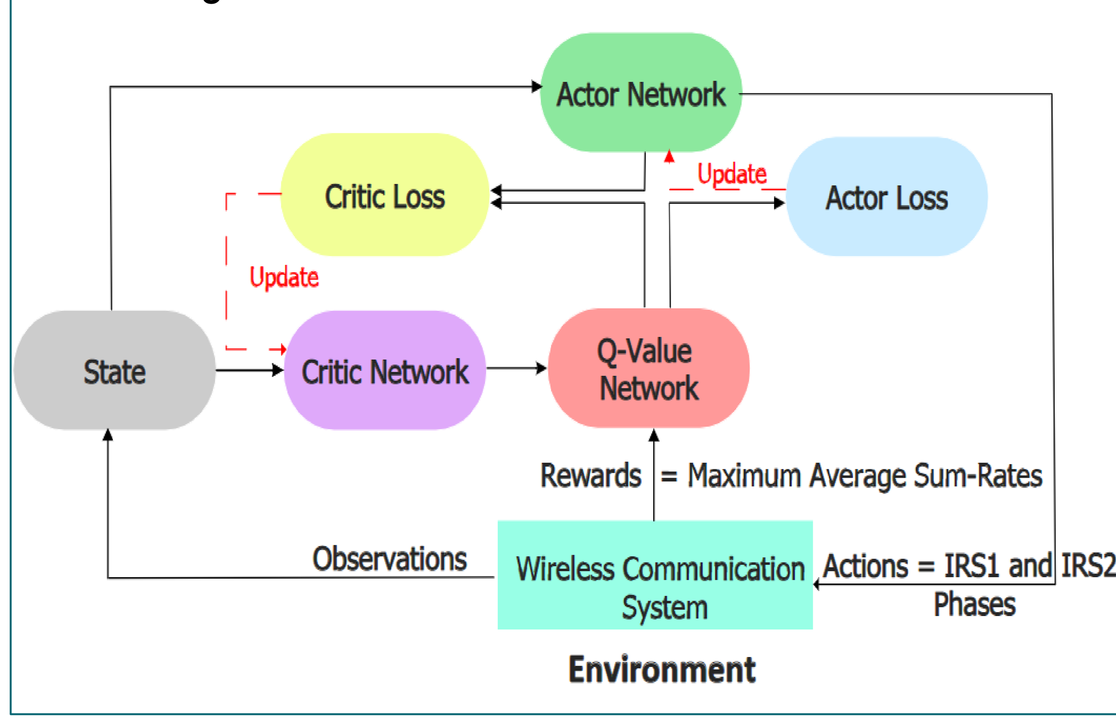
- In this research, we address the above-mentioned gap in the literature by employing DRL, in particular, deep deterministic policy gradient (DDPG), to jointly optimize the phase shifts of each IRS to maximize the sum rate of the cascaded IRS system.

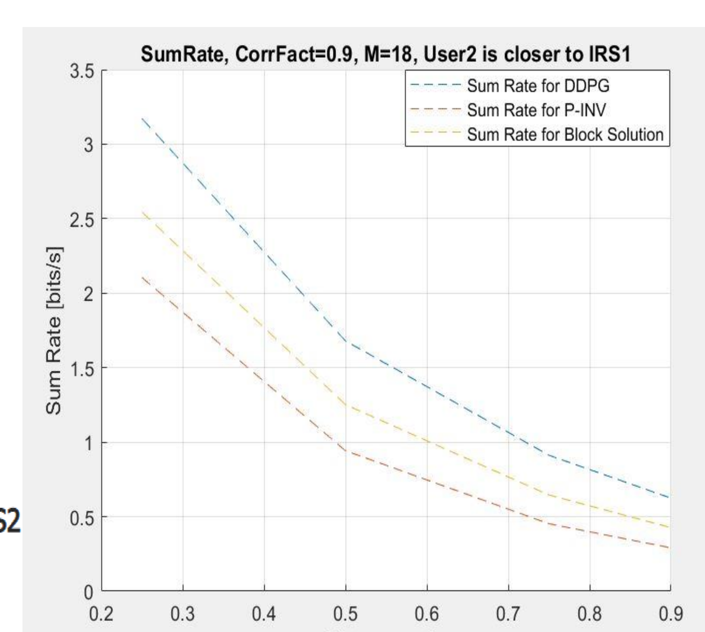
- We formulated the multi-hop IRS phase shift optimization problem, proposed DDPG based solution for the cascaded IRS problem, and solved the problem using sub-optimal mathematical methods such as pseudo-inverse and block-solution which serve as a benchmark scheme for our system.

Adopted methodologies

- We will adopt the DDPG algorithm to solve the non-convex optimization problem. DDPG can handle the non-concave problem with continuous action space. It is designed to obtain the optimum phase shifts that maximize the sum rate.

- DDPG scheme is an actor-critic neural network that consists of several key components, which include the agents, the environment, state S, the action A, and the reward R. The agents operating in our system are IRS_1 and IRS_2. The environment is the communication system model. The states S in our system are the channels between the transmitters and IRS_1, the channel between IRS_1 and IRS_2, the channel between IRS_2 and the receiver, and the sum rate of the previous state $R^{(t-1)}$ The actions A are the phases of IRS_1 and IRS_2, and the reward R is the sum-rate for the users. Our objective is to optimize the average rewards as this involves instant and future rewards.





Future work

- In the future, we will incorporate the non-orthogonal multiple access (NOMA) for the cascaded IRS scenario, and we will solve this problem with DDPG. Then we will compare the performance of DDPG in this scenario with other traditional mathematical methods.

- Further, we will investigate the scenario of Multi-agent federated DRL-based for IRS-assisted uplink NOMA. We will implement distributed multi-agent DRL-based for IRS-assisted uplink NOMA system where we will jointly optimize the power control for users and phase control for IRS in order to maximize the sum rate for users. The agents will learn from each other's experiences and reduce the convergence time.

List of attended classes

- 01NDLRV - Italian Language Level A1 (2021).
- DENG 626 - Modelling and Simulation (2020, 3)
- DENG 625 - Sustainable Development (2020, 3)
- ELEC 604 - Advanced Communication Engineering (2019, 3)
- ELEC 656 - Advanced Digital Communication (2019, 3)
- DENG 603 - Advanced Numerical Methods (2019, 3)
- DENG 602 - Applied Research methodology (2019, 3)
- ELEC 561 - Advanced Digital Signal Processing (2018, 3)
- ELEC 659 - Communication & Information Theory (2018, 3)
- DENG 621 - Graduate Seminar (2018, 3)