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Editorial:

Reconfigurable intelligent surfaces for wireless communications

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Reconfigurable intelligent surface (RIS) is a two-dimensional artificial material with reconfigurable electromagnetic characteristics. Since the phase, amplitude, polarization, and frequency responses of electromagnetic waves at each element can be independently adjusted by changing the biasing signals of tunable devices embedded in the RIS elements, it is possible to reshape the wavefront of the spatial electromagnetic waves in a programmable way. Therefore, RIS provides powerful capability to control the wireless propagation environment and improve the performance of wireless communication networks, along with the advantages of low complexity, simple structure, and low cost, showing great potentials for many applications including wireless coverage extension, wireless coverage enhancement, and wireless system capacity improvement. There are several important technical points in the development of RIS-aided wireless communication technology.

1. Low power consumption and low-cost design of RIS hardware

In the development of RIS, power consumption and system cost are two crucial factors for their large-scale deployment in the future. The control and driven circuits along with their tunable components usually account for the majority of the system power consumption. The effective cost control of the microwave materials and radio frequency (RF) components is also important. The good balance among power consumption, cost, and performance highly depends on advanced design techniques and innovative solutions.

2. RIS beamforming design under new hardware architectures and models

With the advancement of RIS technology, the configurations of RIS hardware and networks are becoming increasingly diverse. The combination of RIS with amplify-and-forward (AF) relay holds the promise of balancing the relationship between hardware cost and communication rate. The emergence of a new type of RIS, capable of simultaneous transmission and reflection, facilitates complete coverage over 360°. Moreover, the broadband channel model and realistic power consumption model of RIS support the joint RIS beamforming and energy efficiency optimization.

3. New applications and standardization considerations for RIS

The introduction of RIS technology brings a new dimension to the physical-layer communication security. Protocols for physical-layer key generation based on RIS can enhance key capacity through dynamic optimization of reflection patterns. Optimizing base station transmission power and RIS passive beamforming has the potential to mitigate interference.

Furthermore, the imperative need for standardization discussion and engineering research for RIS is evident. From a standardization perspective, comparing the performance of RIS with that of the network-controlled repeater (NCR) in 3GPP release-18 (R18) is intriguing, and providing an overview from the engineering application perspective for RIS is highly meaningful.

To summarize, the future application of RIS in wireless communication is still hindered by various challenges as stated above. To this end, *Frontiers of Information Technology & Electronic Engineering* organized a special issue on RIS system implementation and applications to wireless communications. This special issue covers hot topics covering physical implementation, software algorithms, and standardization considerations. After rigorous review processes, 12 papers including two review articles and 10 research articles are selected.

Up to now, significant advancements have been achieved for RIS. Yajun ZHAO provided an overview of RIS engineering applications, focusing primarily on their typical features, classifications, and deployment scenarios. The author analyzed the challenges faced by RIS and proposed potential solutions. For completeness, the author also reviewed two key technical points, RIS-assisted non-orthogonal multiple access (NOMA) and RIS-based transmitter, followed by discussion on future trends and challenges for RIS.

Simultaneously transmitting and reflecting reconfigurable intelligent surfaces (STAR-RISs) have been attracting significant attention in both academia and industry for their advantages of achieving 360° coverage and enhanced degrees of freedom. Yuanwei LIU and his collaborators identified the fundamentals of STAR-RISs by discussing the hardware models, channel models, and signal models. The authors summarized three representative categorizing approaches of STAR-RISs from the phase shift, directional, and energy consumption perspectives. They also investigated both the independent and coupled phase shift beamforming design of STAR-RISs, and proposed a general optimization framework to achieve near-optimal performance.

Junwei WU and his collaborators presented a fast and efficient approach to realize complex beams using semidefinite relaxation (SDR) optimization and digital coding metasurfaces. To find the optimal array weighting vector, they transformed the non-convex optimization problem into a convex one using the SDR technique and the rank minimization theory. As typical application examples, complex beam patterns with cosecant, flat-top, and double shapes were designed and verified by experimental measurements. The approach will be of significance for beamforming systems in radar, remote sensing, and wireless communication.

RIS is a promising technology that can improve the communication quality of the users in cell-edge regions with low power consumption. Xiao LI and her collaborators proposed an alternative optimization algorithm to enhance the energy efficiency of a RIS-assisted multi-cell system. This algorithm is based on a realistic RIS power consumption model and optimizes the transmit beamforming vectors at the base station and RIS phase shift matrix. Simulation results demonstrated that the proposed algorithm is effective in optimizing the energy efficiency of the system.

Due to the advantages of low cost and low consumption, RIS has become popular to improve communication quality. However, the rate enhancement obtained via RIS, which is a passive reflector, is limited. Relay has a strong signal processing capability, while its cost is high. Considering the benefits of relay and RIS, Feng SHU and his collaborators proposed a hybrid network consisting of an AF relay and a RIS, which balances hardware cost and rate performance. By jointly optimizing the beamforming matrix at the AF relay and the phase shift matrices at RIS, the proposed hybrid network harvested better rate performance compared to the benchmarks.

Liang JIN and his collaborators presented a joint RF front-end and digital back-end anti-jamming scheme based on a metasurface antenna array. The metasurface antennas can rapidly switch patterns while receiving signals so that every single channel can be equivalent to multiple channels and increase the array's degrees of freedom. The proposed scheme worked well under high-power jamming conditions by suppressing jamming at the RF front end and using a low-precision analog-to-digital converter (ADC).

Lixia XIAO and her collaborators proposed a digital-to-analog converter (DAC) free architecture for digital RIS structure. Using a low-power single-pole four-throw (SP4T) switch to control the reflection coefficients of RIS elements, a two-bit phase shifter was realized for passive beam steering. A novel modulation scheme was then developed to explore the cost effectiveness of the architecture. Simulation and experimental results confirmed the feasibility of the proposed algorithm, which is promising to reduce the power consumption and hardware cost of RIS systems.

RIS indicates different coupling responses for the subcarriers in the frequency domain of the wideband system. Zhengchuan CHEN and his collaborators devised a multi-user multiple-input single-output orthogonal frequency division multiplexing (MISO-OFDM) system assisted by the RIS with a wideband model. They focused on solving the problem of user fairness under the anisotropic attenuation of subchannels and the crowding of users. They demonstrated that the minimum rate of the users can be significantly enhanced through joint optimization on subcarrier allocation, transmit precoding, and passive beamforming of RIS.

Sheng SUN and his collaborators proposed a multi-mode communication system based on the technology of spin and orbital angular momentum multiplexing. The communication system is composed mainly of two reflective metasurfaces, in which the metasurface can convert incident spherical waves into vortex beams carrying different modes and polarizations. Owning to the orthogonality between these generated vortex beams, the system achieved independent communication of four channels at the same time. The experimental results showed a good degree of isolation between four channels. The proposed communication system can promote the development of 6G communications.

Wireless networks are susceptible to malicious jamming, which significantly impacts their legitimate communication performance. Kui XU and his collaborators presented a novel approach to counteract malicious jamming in wireless networks through a RIS-assisted anti-jamming communication system. They focused on optimizing the transmitting power of the base station and the passive beamforming of RIS to enhance anti-jamming performance. Considering the dynamic and unpredictable nature of a smart jammer, the joint optimization problem was formulated as a Markov decision process, and a learning framework based on the double deep Q-network (DDQN) was proposed to tackle this problem.

Pattern-reconfigurable antenna has the capability of reconfigurable antenna patterns. Kaizhi HUANG and her collaborators presented a novel approach to pattern-reconfigurable antennas using a RIS-based architecture. The proposed pattern-reconfigurable antenna based physical layer key generation protocol enabled effective mitigation of multi-path fading and boosted secret key capacity through dynamic optimization of the antenna pattern.

For successful standardization in 6G, RIS needs to learn from former techniques in 5G. Yifei YUAN and his collaborators compared the performance of RIS with that of the NCR in 3GPP R18. They first theoretically analyzed the received signal power and signal-to-noise ratio (SNR) performances for RIS and NCR. Then, they simulated the reference signal received power (RSRP) and signal-to-interference-and-noise ratio (SINR) performances at a system level for RIS and NCR in FR1 and FR2 bands. The authors provided several insights for engineering applications based on the comparison between RIS and NCR.

The papers included in this special issue provide in-depth discussions on a wide range of subjects from different perspectives for practical applications of RISs in wireless communications. We hope they can generate inspiration for researchers and engineers in these areas.

Finally, we would like to express our special thanks to all the authors and reviewers for their support and valuable contributions to this issue. We also would like to thank the editorial staff and the Editors-in-Chief for their great efforts in organizing this special issue.

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