Overhead Reduction in Intelligent Reflecting Surface-aided Wireless Networks: A Review

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***Abstract*—Reconfigurable intelligent surfaces (RISs) have shown great promise in enhancing coverage, spectral, and energy efficiency in the future 6G wireless networks. Because of the passive nature of the surface, there is no signal processing unit for channel state information acquisition. In addition, due to the limited computational capabilities at the RIS nodes, the optimized RIS phase shifts must be computed and fed back from the base station (BS) before the data transmission. Therefore, overhead occurred in the channel estimation and feeding back phases pose major challenges to realizing this technology. This paper provides an overview of recent advances in overhead reduction in RIS-aided networks.**

***Index Terms*—6G, reconfigurable intelligent surfaces (RISs), overhead reduction, multiple-input multiple-output (MIMO)**

I. INTRODUCTION

Reconfigurable intelligent surfaces (RISs) are two-dimensional surfaces composed of passive meta-atoms. Through the application of bias voltage on each elements, e.g., utilizing PIN diodes, the controller can tune the phase shift and/or amplitude for each element. These diodes can be toggled between ”ON” and ”OFF” states independently within each element, enabling phase shifts and amplitude variations to the incoming signals. This adaptability facilitates RIS integration into diverse wireless systems, allowing for environment reconfiguration with minimal power consumption. Essentially, by creating reflection/refraction links, RISs can overcome obstacles and enhance communication quality in complex settings. This is achieved by manipulating electromagnetic waves to strategically redirect signals toward the intended receivers and increase signal strength, leading to enhanced data transmission and seamless connectivity in previously challenging reception areas [1], [2].

Some works were dedicated on the maximization of achievable rate, spectral, and energy efficiency in the RIS-assisted networks. In [3], the authors considered the a RIS-aided MIMO systems. They proposed a control design optimizing the covariance matrix of the transmitted signal and phase shift so that the achievable rate is minimized. The formulated problem is solved by applying the projected gradient-based algorithm. The authors in [2] investigated two problems, aiming to characterize the achievable rate region and maximize the achievable sum-rate of the IRS-assisted relaying system.

While numerous studies concentrate on maximizing achievable rates and enhancing energy efficiency, few studies have focused on lowering the channel estimation overhead or overhead of feeding back RIS phase shift. Towards this end, we provide a comprehensive overview of the recent advances in overhead reduction in RIS-aided networks.

II. OVERHEAD REDUCTION IN INTELLIGENT REFLECTING SURFACE-ASSISTED WIRELESS NETWORKS

In this part, we discuss the recent overhead-aware designs. As illustrated in Figure. 1, the overhead can exist in channel estimation, and optimized RIS phase-shift feedback. Before data transmission begins, channel estimation and configuring optimized RIS phase shifts are important. With the signal processing and power capabilities, the RIS controller is able to receive and decode configuration signals to adjust RIS phase shifts. This setup ensures the dynamic adaptability of the RIS based on the propagation channel. However, sending back optimized phase settings to the RIS before data transmission can significantly increase communication overhead, particularly for larger number of RIS elements. Most of the current works on radio resource allocation in RIS-aided networks have focused on optimizing in RIS phase shift matrix. However, the training and RIS-phase shift signaling feedback overhead have been not thoroughly investigated.

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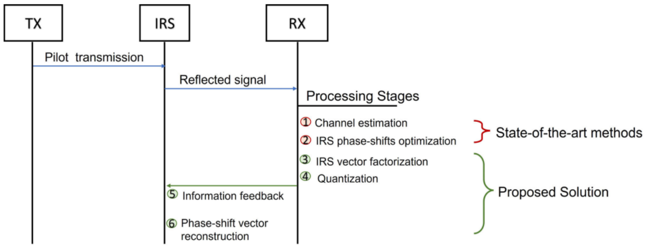


Fig. 1. Feedback overhead control framework [9].

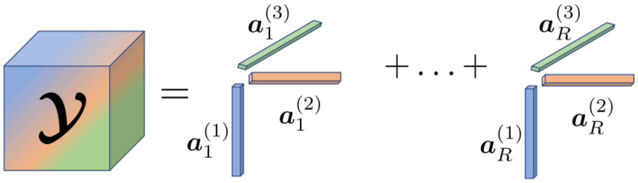


Fig. 2. Tensor decomposition [9].

A. *Overhead Reduction In Channel Estimation*

Recent efforts have been dedicated in the channel estimation overhead reduction. For instance, the authors in [4], [5] proposed an estimation scheme based on the RIS element grouping, which involves assigning identical phases to RIS elements that have highly correlated channels. In [6], the authors introduced a new two-stage method for efficient uplink channel estimation in a multi-user RIS-assisted millimeter wave (mmWave) system. In the first stage, the common BS-RIS channel is jointly estimated by all users. In the second stage, the individual UE-RIS channel is estimated by each user, thereby, the pilot overhead is reduced. In [7], to estimate the common BS-RIS channel, the authors proposed an anchor-based channel estimation approach, significantly reducing the channel estimation overhead for BS-RIS-UE channels. In [8], to reduce estimation overhead, the authors focused on sending sounding reference signals solely to estimate the dominant channel, while the CSI accuracy may decrease. Here, the dominant channel is the stronger one among direct and indirect channels. Considering the estimation error, they inserted the residual interference into the SINR formula and formulated the optimization problem that jointly optimized the RIS phase shift and MIMO precoding.

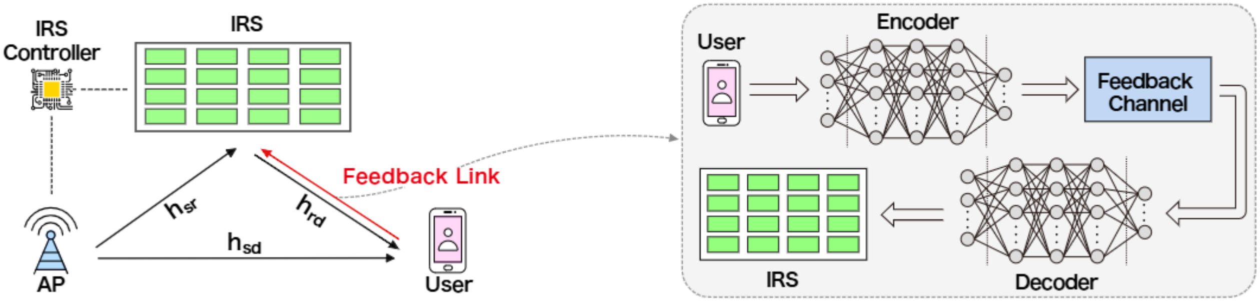
B. *Overhead Reduction In Feeding Back Optimized RIS Phase Shifts*

Existing research focuses on optimizing or quantizing the RIS phase shifts for various objectives (e.g., spectral efficiency, energy efficiency, power consumption minimization, etc.). The feedback channel is often constrained in bandwidth and cannot handle extensive RIS phase shift feedback, especially when the number of RIS elements is large. Given a considerable number of phase shifts, minimizing *overhead* for transferring the RIS phase shift is crucial. Specifically, the authors [9] focused on controlling the feedback overhead for transmitting the optimized RIS phase shift from the receiver (e.g., BS) to the RIS controller, as illustrated in Fig. 1. More specifically, they introduced a low-rank modeling technique for tuning the RIS phase shifts by representing the IRS phase shift vector employing a low-rank tensor approximation, see Fig. 2. The proposed low-rank RIS model enables to provision of more frequent feedback. Consequently, the IRS can be adjusted more frequently to respond to changes in the environment.

In [10], the authors introduce a convolutional autoencoder-based approach, which involves compressing the QPS at the receiver end and reconstructing it at the IRS end, aiming to alleviate the feedback overhead challenge, see Fig. 3. In the related work [11], the authors introduced two deep learning models based on attention mechanisms: the global attention phase shift compression network and the simplified version. More precisely, the model's efficacy was enhanced through the introduction of a novel attention mechanism. Through exploring the connection between channel and spatial dimensions, more pertinent features can be highlighted compared to existing attention models. In addition, a low-complexity asymmetric model was proposed, where the decoder's design is notably less complex compared to that of the encoder.

C. *Overhead-Aware Resource Allocation*

The authors in [12] considered a MIMO communication system of two devices with the aid of an RIS. They proposed a resource allocation strategy incorporating the feedback signaling overhead. Specifically, an overhead model is integrated into the energy efficiency and communication rate expressions. Accordingly, the authors aimed to optimize the RIS phase shifts, precoding/detection vectors, and the allocation of power and bandwidth for communication and feedback phases. The findings suggest that RIS is useful when effective feedback techniques or a limited number of antennas are utilized. Specifically, there is a threshold regarding the number of antennas and RIS elements beyond which the feedback overhead renders resource optimization less advantageous.



(a)

(b)

Fig. 3. Feedback overhead control framework [10].

III. CONCLUSION

In this paper, we provided an overview of the recent advancements in reducing the overhead result in the channel estimation and feedback signaling in RIS-enabled networks, which is essential for the successful implementation of this technology in reality.

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