Reconfigurable-Intelligent-Surface-Assisted B5G/6G Wireless Communications: Challenges, Solution, and Future Opportunities

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The authors discuss RIS-assisted channel estimation issues involved in B5G/6G communications including channel state information acquisition, imperfect cascade CSI for beamforming design, and co-channel interference coordination, and develop a few possible solutions or visionary technologies to promote the development of B5G/6G.

Abstract

Power consumption and hardware cost are two of the main challenges for realizing beyond fifth generation (B5G) and sixth generation (6G) wireless communications. Recently, the emerging reconfigurable intelligent surface (RIS) has been recognized as a promising tool for enhancing the propagation environment and improving the spectral efficiency of wireless communications by controlling low-cost passive reflecting elements. However, current cellular communications were designed on the basis of conventional communication theories, significantly restricting the development of RIS-assisted B5G/6G technologies and leading to severe limitations. In this article, we discuss RIS-assisted channel estimation issues involved in B5G/6G communications including channel state information (CSI) acquisition, imperfect cascade CSI for beamforming design, and co-channel interference coordination, and develop a few possible solutions or visionary technologies to promote the development of B5G/6G. Finally, potential research opportunities are discussed.

Introduction

Beyond fifth generation (B5G) and sixth generation (6G) communication provide huge improvements in terms of data rates, reliability, high throughput, and low latency requirements. However, due to the wide deployment of millimeter-wave (mmWave) and massive multiple-input multiple-output (MIMO) technologies, the required hardware complexity and large power consumption become major implementation challenges [1]. In general, large antenna arrays are accompanied by many radio frequency (RF) chains followed by multiple analog-to-digital converters (ADCs). Therefore, as the power consumption of ADCs grows exponentially with the number of quantization bits, reducing the power consumption has attracted considerable attention.

As a remedy, the reconfigurable intelligent surface (RIS) concept and its various counterparts have emerged as a powerful and cost-effective solution to tackle these challenges [2]. In simple tangible terms, a RIS consists of a large number of abundant reconfigurable reflective elements [3], which can be divided into active and passive RIS cases. The active RIS can adjust the phase shifts and amplify the received signal attenuated, but cost is expensive. In light of this, we focus on passive RIS in this article. By adjusting the phase shifters (PSs) of passive RIS reflective elements, the incident signals can be dynamically adjusted to support diverse user requirements without deploying additional mobile stations (MSs) or in-cell relay stations [4, 5]. As a result, it has ultra-low power consumption and low-cost hardware compared to that of the amplify-and-forward (AF) relay-assisted systems relying on active transmission devices or base stations (BSs). From the design and implementation perspective, a passive RIS has attractive characteristics such as having a low profile and being flexible and lightweight; as a result, it can be deployed in existing cellular wireless networks without requiring any change to existing infrastructure, user terminals, as well as operating standards. These significant advantages make RIS a promising research direction for B5G/6G [6–9]. However, current cellular communications designed and operated based on previous postulates may not be suitable for future RIS-assisted B5G/6G communication services, since optimal control of the RIS is the acquisition of the channel state information (CSI) required for beamforming, and co-channel interference will be inevitable for explosive growth in data storage capabilities and rapid B5G/6G communication. Thus, it is difficult to directly apply previous technologies to RIS-assisted communication scenarios. To support new demands in future RIS-assisted B5G/6G communication scenarios, the following three challenges should be discussed as follows:

- **RIS-assisted channel estimation:** Accurate CSI acquisition is critically dependent on the number of reflecting elements of the RIS. Due to the lack of baseband processing capabilities at the RIS, a large dimension of RIS is designed for the RIS-assisted system, which is very unfavorable for the deployment of RIS. Therefore, how many reflecting elements of RIS should be satisfied with the accurate CSI acquisition is the bottleneck of the application of RIS-assisted MIMO systems.

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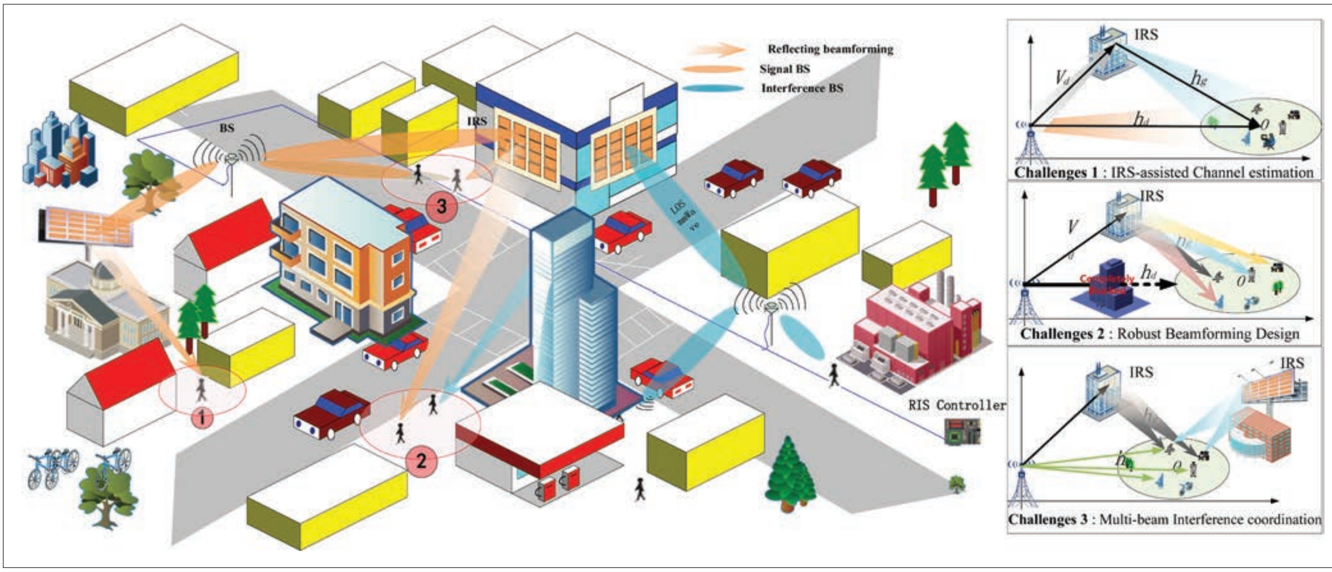

FIGURE 1. Typical RIS applications in B5G/6G networks and challenges.

- **RIS-assisted beamforming design:** A major challenge with RIS-assisted beamforming is the acquisition of the cascade CSI required between transmitter and receiver. However, the locations of users are changing and environmental properties are varying, which may lead to an error existing in the beamforming design. Therefore, the other main issue is to achieve the optimal beamforming design, while keeping the error of cascade channel estimation below a tolerable level.
- **RIS-assisted co-channel interference coordination:** Regarding the throughput gain of a RIS-assisted system, the coordinated CSI is adopted to design its transmit/receive beamforming, where different BSs are enabled to share their CSI. As directional beamforming increases, co-channel interference will become an increasingly challenging issue in B5G/6G ultra-dense networks. Therefore, future B5G/6G communications call for rigorous interference coordination methods to overcome the impact of co-channel interference.

These various challenges of RIS-assisted mmWave MIMO communications motivate the necessity to perform a comprehensive review of RIS for realizing B5G/6G communications. This review focuses on the three aforementioned key challenges and provide the fundamental solution for channel estimation and its implementations, imperfect cascade CSI for beamforming design, and RIS-assisted co-channel interference coordination. In the following section, we provide an overview of standard developments of RIS technologies. Following that, we introduce the hybrid multiobjective evolutionary programming for RIS-assisted B5G/6G communication systems. Then we detail the imperfect cascade CSI for a RIS-assisted hybrid beamforming (HBF) design and highlight the potential benefit of HBF design. We further consider the deep-learning-based methods to train the shared CSI, which can share the channels to avoid co-channel interference. Finally, we outline future research directions.

Overview of RIS-Assisted Future B5G/6G Communications

We consider a RIS-assisted B5G/6G mmWave network, which is depicted in Fig. 1. Due to the high path attenuation, mmWaves can be easily blocked by obstacles, which limits their practical implementation. To tackle this issue, RIS-assisted mmWave networks are envisioned and expected to play an important role in future B5G/6G wireless communications.

In terms of the requirements in B5G/6G, we expect to enhance the coverage area and guarantee diverse quality of service (QoS) requirements. By leveraging the reconfigurability of RIS, the transmission performance of wireless networks has been verified via realistic simulations and experiments. Therefore, numerous works in the literature have investigated RIS-assisted mmWave communications including the theoretical basis, physical design of metasurfaces, physical architecture, as well as the corresponding channel modeling at different operational frequencies. Following on, the analysis of models, algorithms, and performance optimization have been provided in RIS-assisted systems. An organization of passive RIS challenges and potential solutions are provided in Fig. 2.

Compared to these works, our study conducts an investigation of passive RIS for the above-mentioned three potentially disruptive problems, as illustrated Fig. 1. To support new demands in future B5G/6G network scenarios, this article emphasizes plausible solutions to ensure that future wireless networks are practically realizable.

RIS-Assisted Channel Estimation

In the B5G/6G communications, the throughput gain in RIS-assisted mmWave communications is highly reliant on the availability of CSI, the acquisition of which still remains a challenge for RIS with a large number of passive elements. In particular, to reduce the hardware requirements, the reflecting coefficient of RIS usually has no transmission/processing capability. Therefore, the passive feature of RIS makes it rather difficult to estimate RIS-user equipment (UE) and RIS-BS channels.

Passive RIS implementation	Challenges	Potential solutions
Channel estimation	• High channel estimation overhead; • Limitations on the number of RF chains; • Pilot contamination due to strong LoS paths between the BS and RIS; • Deployment under uncertain LoS and NLoS connections in 3D space;	• Overhead reduction by exploiting the sparsity property of mmWave and CS; • Passive RIS-assisted channel estimation protocol design tailored for B5G/6G; • Multi-objective evolutionary approach (MOEA for LoS and NLoS propagation pathes estimation;
Robust beamforming design	• Increased overhead for RIS elements; • The impact of UAV wobbling on accurate CSI acquisition; • Computation complexity of solution algorithm;	• Robust beamforming design with CSI error models; • Overhead reduction by grouping adjacent reflecting elements forming sub-surfaces; • Multi-objective evolutionary, or deep learning methods for multi-user passive beamforming;
Co-channel interference coordination	• Random distributions of RISs and ground users; • Coordination design under complicated mathematical model; • Co-channel interference modeling and analysis; • Average- and the ergodic rate modeling and analysis to capture the large-scale fading component;	• Probability density function (PDF) or cumulative distribution function (CDF) design for relaxing co-channel interference; • Multi-objective evolutionary strategy for solving interference co-channel model; • Edge computing approach for obtaining a sub-optimal passive RIS;

FIGURE 2. Design challenges and potential solutions for passive RIS.

Technology / Metric	Two-timescale	Codebook-based	Deep learning-based	Rank-based	Sparsity-based	MOP
Reliability	Good	Good	Poor	Moderate	Moderate	Good
Complexity	Depend on RIS elements	Depend on the size of codebook	Depend on trained dataset	Depend on propagation paths	Depend on propagation paths	Depend on population size
Accuracy	High	Depend on designed codebook	Depend on trained dataset	Moderate	Moderate	High
Delay	Good	Depend on the size of codebook	Good	Poor	Moderate	Good
Scenario	Quasi-static	N/A	N/A	mmWave or THz	mmWave or THz	Highly dynamic

FIGURE 3. Comparison of related channel estimation approaches.

Specifically, when a BS with M antennas is considered to serve K UEs with the help of the N reflecting elements of RIS, it is observed from [10] that the number of channel coefficients involved in designing the RIS reflection coefficients is $KMN + KM$. Most existing schemes require the individual computational cost of both the BS-RIS channel and the RIS-UE channel, which involves both quasi-static and dynamic movable RIS scenarios. For typical RIS-assisted communication, the cascaded BS-RIS-UE channel can be established based on the transmitting/receiving pilot signals, and the corresponding cascaded channel can be extremely high-dimensional. Fortunately, this overhead can be reduced by the two-scale channel estimation in [11]. The authors ingeniously propose a two-timescale channel estimation framework to reduce pilot overhead, when a quasi-static RIS scenario is considered between BS and RIS. The pilot overhead, relying only on the number of reflecting elements, is very useful for a quasi-static RIS scenario. In light of this, the codebook-based scheme is developed in which the performance is dependent on the codebook being designed. It is worth mentioning that location-based RIS configurations do not need the CSI to be acquired per channel coherence time but much more slowly [12]. However, for a highly dynamic scenario, such as aerial RIS, RIS is mounted on unmanned aerial vehicles (UAVs) to enable three-dimensional signal reflection. The UAV mobility-induced variation of the angles of arrival/departure (AoAs/AoDs) prompts BS-RIS channel to be estimated frequently. More importantly, the pilot overhead for the highly dimensional mobile RIS is prohibitively high. To reduce the pilot overhead in a highly dynamic scenario, deep learning is introduced to combat the large size of the BS-RIS channel. Another solution to reduce the pilot overhead is to utilize the sparse and low-rank property of the mmWave channel when the cascaded channel is established. Figure 3 compares related RIS-assist channel estimation approaches. These solutions have their respective strengths and shortcomings. Therefore, how to accurately estimate the passive RIS-assisted channel with a large number of reflecting elements is still an open problem in B5G/6G.

Problem Formulation

We consider RIS-aided downlink communications in ***challenge 1*** of Fig. 1, where K single-antenna UEs are randomly distributed throughout the cell, where a RIS with M reflective elements are arranged in a uniform planar array (UPA) structure for enhancing the performance. The phase shifts of the RIS are designed to adjust the propagation directions of the incident signals. To fully realize a substantial training overhead reduction, the inherent sparsity of the mmWave channel is exploited to formulate the cascade channel construction by exploiting compressed sensing (CS) [13]. Under the proposed framework, the cascaded channel estimation problem is formulated as a CS-based sparse reconstruction problem, which includes three conflicting objectives: the measurement error, the number of reflecting elements, and the sparsity constraint. In particular, the reflecting elements of RIS design are a major bottleneck for accurate CSI acquisition. The reason is that a large number of RIS units is integrated into B5G/6G communication, which can lead to an increase in the pilot requirements. Since the three objectives of the optimization problem conflict with each other, many potential technologies are developed to solve the channel estimation. However, there are restrictions and limitations among these technologies; for example, a deep-learning-based scheme can obtain receivable CSI, but lots of samples were used in training the network model, which leads to high hardware cost. In addition, the alternating optimization scheme is another potential technology, but the three variables are strongly coupled together, which result in difficulty solving it.

To support new demands, we formulate a new potential technology, the multi-objective optimization problems (MOPs), to overcome this challenge. Then the corresponding hybrid multi-objective evolutionary algorithm (MOEA) based on differential evolution (DE) is developed to solve the MOPs. To significantly reduce the computational cost of the selection process, we first develop a local search to generate new promising solutions by exploiting the iterative hard-thresholding scheme. Next, an angle-based selection operator is used to determine the best Pareto front (PF) in the knee areas, which is crucial for diversifying the search. According to the proposed hybrid MOEA, the estimated solution of channel is determined in the PF set, which have a good trade-off among the sparsity constraint, the number of reflecting elements, and the measurement error, while providing encouragement to its performance.

Simulation Results

In Fig. 4, the normalized mean square error (NMSE) performance comparison of the proposed scheme is described to achieve the trade-off among measurement error, the number of reflecting elements, and the sparsity constraint. We assume that an RIS consists of M = 256 reflecting elements. The UE is close to the RIS and far from the BS. The hybrid MOEA exploits the hybrid evolutionary-based strategy for diversifying the search along the weak PF set, which can achieve effective performance improvement. Furthermore, Fig. 4 shows the best solutions obtained by the hybrid evolutionary algorithm that lies on the Pareto-optimal front. It is very clear that the solution is determined in the knee region of the Pareto-optimal front. Therefore, the pilot sequences can be reflected between the BS and the UEs such that the RIS-assisted CSI can be estimated accurately by using a multi-objective evolutionary scheme. Figure 5 summarizes the computational complexity of existing methods. Note that the proposed approach results in a much simpler model that is suitable for a passive RIS scenario.

Discussion

As discussed above, acquiring accurate CSI for B5G/6G mmWave MIMO systems is very time-consuming and expensive. CS provides a promising tool for reducing the pilot overhead, with the potential of MOEA to accurately estimate the channel in the RIS-assisted MIMO systems. The approach can achieve superior performance and low complexity. Therefore, we conclude that the RIS-assisted channel estimation is effective using CS and a multi-objective optimization method; we anticipate that this framework will be very appealing in the future B5G/6G wireless networks.

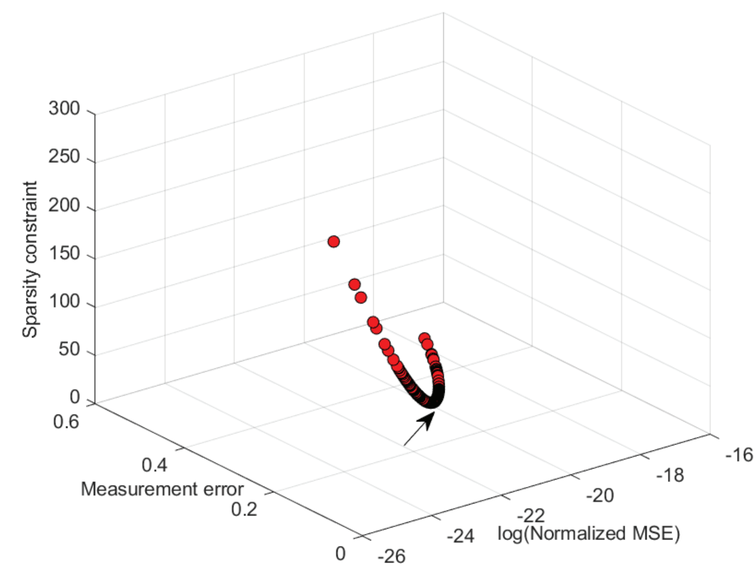

FIGURE 4. Relationship between reconstruction error, normalized MSE, and the sparsity of the solutions

Method	Model	Computational Complexity	Additional comments
Two-time scale-based scheme [11]	General channel model	$O((M+N)^3 + (N+M)^2K)$	
Codebook-based scheme [12]	End-to-end model	$O(T_{cbook} N_p N_{sym} K)$	
Deep learning-based scheme [5]	Under-determined linear signal model	$O\left(E\left(K\mathcal{T} + \sum_{l=1}^{L} F_l U_l U_{l-1}\right)\right)$	E has no upper bound
Proposed	Multi-objective evolutionary model	$O(sCKN_p M_{path} + NMK)$	

Notation: T_{coh} = the channel coherence time; M = the number of RIS elements; M_{path} = the number of paths in the RIS-user link; M_{grd} = the number of discrete grid points; C = a constant that depends on the adopted compressed sensing; T_{cbook} = codebook size, N_p = pilot symbols of length N_{sym} are sent; T_{loc} = the value in general depends on the adopted localization; E = number of epochs; $\mathcal{T}$ = complexity of tentative estimation (linear system, including matrix multiplications and inversions) [5]; L = number of hidden layers; U_l = number of neurons (or kernels, in the case of CNNs) in the l-th layer, F_l = kernel size of the l-th convolutional layer; N= number of BS antennas; K= number of users; s = the size of the population.

FIGURE 5. A computational complexity comparison between existing methods and the proposed channel estimator..

RIS-Assisted Imperfect Cascade CSI Acquisition for Beamforming Design

As described in the introduction, RIS-assisted mmWave communications can effectively enhance the coverage. However, most prior studies mainly focus on the design of beamforming under perfect knowledge of CSI, which often relies on an over-idealistic assumption in practical scenarios, such as time-selective fading environments or channel offset in block fading and other uncertain factors. In fact, design of beamforming suffers from substantial performance degradation if an error exists in the estimation of CSI [14]. As a result, considering the imperfect cascade CSI for the RIS-assisted mmWave MIMO system via robust beamforming design is crucial from a practical perspective.

Problem Formulation

We investigate robust beamforming design for a RIS-aided mmWave MIMO system based on imperfect cascade CSI, as illustrated in ***challenge 2*** of Fig. 1. RIS reflecting elements are deployed to assist information transmission. The reflec-

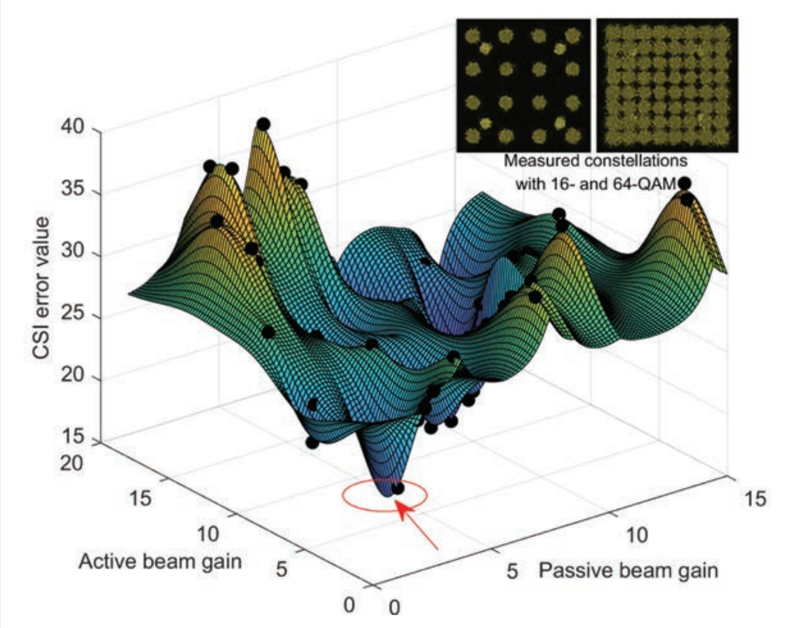

FIGURE 6. Pareto front obtained as the multi-objective framework. Top right: measured constellation plots for 16-QAM and 64-QAM data.

tion beamforming and active beamforming are jointly designed to achieve better transmission performance. The single-UE (SU) and multi-UE (MU) reception modes of a RIS-assisted mmWave MIMO system are considered, respectively. For the SU scenario, existing mechanisms consider joint design of active beamforming and reflecting beamforming to minimize the transmit power of the system, while ensuring that the achievable rate of each UE satisfies the QoS requirement under the error estimation of the CSI case. The formulated problem is non-convex, and is usually considered a challenging problem to solve due to the multi-variable constraints.

To address this issue, a convex-concave procedure (CCP) with the first-order Taylor expansion is generally used in the optimization problem in which the inequalities of matrix is transformed by linearlizing the rate approximately. However, this approximation transformation gives rise to extremely weak solutions. What is more, the RIS deployment may influence the system performance due to regarding the large-scale path loss. If RIS is close to the BS/UE, the line of sight (LoS) path loss is minimized, but the excessive path loss originated from non-LoS (NLoS) connections becomes obvious. On the other hand, if RIS is far from the BS/UE, the probability of NLoS connections is reduced, but this leads to an improved signal attenuation due to the longer communication distance. Therefore, it is urgent to establish an appropriate solution for high-reliability capacity B5G/6G communication.

By taking advantage of multi-objective optimization techniques, it is possible that the communication system can provide trade-off points among active beamforming, passive beamforming, and uncertainty CSI error. The decision makers can select an appropriate solution according to the B5G/6G communication requirement. It is worth mentioning that a Pareto optimal solution can be obtained by exploring the evolutionary algorithms, which still remain largely unknown and unexplored. The hybrid evolutionary algorithm is developed in this article, and it is hoped that this scheme provides a favorable guide for future research. Finally, these optimization techniques are subsequently extended to the MU case where a robust hybrid beamforming design is achieved. The sum received power of the MU can be maximized through jointly designing active and passive beamforming schemes.

Simulation Results

For simulation, we consider that the MUs are distributed in a cluster uniformly and randomly, and the locations of the BS are away from the users, and RIS is used to assist the link. The path loss factor is considered. To verify the uncertain CSI error, the error bound of the CSI is defined with the cascade CSI uncertainty factor to control the measurement error.

As indicated by Fig. 6, the hybrid evolutionary algorithm obtains a set of Pareto solutions for beamforming design, which is a trade-off including passive beamforming, active beamforming, and uncertainty CSI error. Optimal PF is determined in the direction of the arrow. Due to the uncertainty in movement of the users, the transmission between the RIS and users may cause uncertainty in channel interference. To verify this issue, imperfect user position (or the corresponding AoA/AoD) is considered to replace the imperfect channel coefficients. In simulation, 16- and 64-quadrature amplitude modulation (QAM) are considered to modulate mmWave 5G NR waveform signals. The received signal at the phased array AoD is down converted and demodulated using a signal analyzer running the analysis software. The simulated beamforming gain with imperfect user position is very close to the calculated measured beamforming gain. The corresponding constellation diagrams with 16- and 64-QAM modulated waveforms are provided in the top right of Fig. 6, which satisfies the 5G modulation requirement defined by the Third Generation Partnership Project (3GPP). This indicates that the hybrid evolution is beneficial for the RIS-assisted system to design robust hybrid beamforming. Therefore, decision makers may be inclined toward a large value of uncertain CSI error. The approach claims that it can realize more practical and flexible beamforming design and trade-off performance based on B5G/6G requirements. Simulation results verify that the hybrid evolutionary algorithm has superior trade-off performance.

Discussion

In B5G/6G systems, directional beamforming is designed to overcome strong attenuations. However, the imperfect cascade CSI inevitably causes RIS-assisted beam misalignment. From this perspective, the imperfect cascade CSI needs to be developed for robust beamforming design. From the above theoretical analysis and simulation results, we argue that incorporating multi-objective optimization techniques into the combination of imperfect CSI and the beamforming design strategy is an effective and reliable strategy for future RIS-assisted B5G/6G communications.

RIS-Assisted Shared CSI for Co-Channel Interference Coordination

For ultra-dense B5G/6G networks, co-channel interference is inevitable in practical communication scenarios (e.g., in offices, commercial towers and shopping malls). It is thus critical to take into account the shared CSI of different BSs to avoid co-channel interference in future ultra-dense B5G/6G networks. Therefore, in this section, we investigate how to design a co-channel interference coordination scheme with the help of shared CSI for ultra-dense interference networks. The theoretical results offer important insights for RIS-assisted ultra-dense B5G/6G networks.

Problem Formulation

Let us consider an RIS-assisted mmWave network with an intercell interference scenario, as illustrated in ***challenge 3*** of Fig. 1, where multi-antenna BSs simultaneously serve K independent UEs with the help of the RIS. The RIS consists of M reflecting elements and is mounted on the walls of buildings. There are two BSs with multiple antennas, which are referred to as the BS and BS_1. We assume that the signal BS serves the intended UE, and BS_1, which serves its own UE_1, causes interference to the intended UE. To address the co-channel interference issue, the BS_1-UE channel, the BS-UE channel, and the interference BS-UE_1 channel are considered in this scenario.

According to the structural properties of a passive RIS, we develop two tractable optimization problems that exploit the average rate and the ergodic rate under the shared CSI. However, the corresponding optimization problems are non-convex and challenging to solve. To tackle this issue, we divide the optimization problem into multiple training modules by exploiting the offset learning-based channel estimation techniques. Inspired by the powerful learning capability of multi-objective optimization techniques, a double multi-objective evolutionary algorithm with local search strategy is developed to build a shared channel between the BS and BS_1. It is noted that applying the local search-based evolutionary strategy to the co-channel interference coordination problem can generate a series of independent Pareto solutions in the objective space, which can be appropriately combined to provide improved throughput gain of the system and interference coordination. Moreover, combined with the results of the interference coordination analysis, it is interesting to observe that incorporating a local search-based evolutionary strategy into co-channel interference coordination problem can handle the shared channel in an ultra-dense RIS-assisted mmWave system.

Simulation Results

Here, we present the performance comparison of the local search-based evolutionary strategy with the DLA-based scheme [15] and full precoding without RIS. We assume that the BS, BS_1, UE, and RIS are located at (0, 0), (550 m, 0), (d_{SU}, 0), and (d_R, d_{RU}), respectively. Due to extensive obstacles and scatterers, the distance-dependent path loss exponents are $\alpha_{SU} = 2.1$, $\alpha_U = 3$, and $\alpha_{RU} = 2.3$. On the other hand, the location of the RIS is deployed between the BSs and the RIS, where the corresponding the path loss is $\alpha_{SR} = \alpha_{IR} = 2$.

Simulations are performed without any array calibration and equalization. The BS is equipped with $N = 256$ transmitting antennas, and the number of channel paths is $L = 8$. The results expectedly confirm the superiority of our design. In the following, the design of hybrid beamforming under shared CSI is provided. We compared the proposed method with the scheme in [3] as well as a fully digital decoder without RIS. Results indicates that the proposed evolutionary scheme can strike a balance between the lowest consumption and the minimum channel interference.

Discussion

In future B5G/6G, multi-beam interference will inevitably increase with the increase of terminal equipments. Therefore, it is crucial to explore the shared channel for the interference coordination scheme. Inspired by the stability of the multi-objective evolutionary techniques, it is shown that the multi-objective evolutionary-based co-channel interference coordination is capable of fully leveraging the reflective elements of RIS and improving the system performance. Therefore, we conclude that the co-channel interference coordination with the multi-objective evolutionary technique is an option for future communication systems.

According to the structural properties of a passive RIS, we develop two tractable optimization problems that exploit the average rate and the ergodic rate under the shared CSI. However, the corresponding optimization problems are non-convex and challenging to solve.

Open Research Issues and Opportunities

RIS-assisted multi-tier computing: Multi-tier computing is a novel communication architecture for RIS-assisted mmWave networks. Their integration with RIS can significantly promote rapid development of the B5G/6G wireless communications through offloading the computationally intensive tasks to the edge server. However, RIS-assisted multi-tier computing causes a large channel pilot overhead and affects the free mobility of UEs in the RIS-assisted system. Therefore, the RIS-assisted multi-tier computing problem should be studied by considering the limitations of CSI.

RIS-assisted carrier frequency offset (CFO) estimation: The achievable performance is very sensitive to the CFO induced by the mismatch between transceiver oscillators. However, the introduction of RIS further aggravates multiple-access channel interference, which may significantly degrade the system performance. Therefore, reliable CFO needs to be estimated to mitigate multiple-access channel interference. Hence, establishing RIS-assisted CFO modeling and developing a corresponding algorithm is crucial to the accomplishment of future B5G/6G communications.

Sensing RIS-assisted communication: Active RISs equipped with sensing elements have attracted extensive attention recently, and is one of the currently most popular topics. Compared to passive RISs, sensing RISs offer remarkable improvement in communications performance. However, active amplifier elements introduce additional noise, referred to as RIS noise, into the system, and should be accounted for while designing systems with active RISs.

RIS-assisted unmanned integrated sensing and communication (ISAC): Since competing sensing links are prone to severe deterioration in cell edge areas, RIS can provide an on-demand flexible platform for deploying ISAC to improve the throughput of wireless networks. Thus, the joint channel estimation of competing sensing and passive beamforming design of RIS should be investigated further to provide numerous wireless services for the next generation of wireless communications.

Conclusion

In this article, the RIS-assisted mmWave MIMO communication framework has been established to achieve smart and reconfigurable wireless environments. To address three key challenges, the channel estimation scheme has been investigated first to reduce the training overhead in RIS-assisted mmWave MIMO systems. Then the imperfect cascade CSI has been established for robust beamforming design. Furthermore, RIS-assisted co-channel interference coordination is established to improve the average rate and ergodic rate of the system. Finally, major potential research directions and challenges are also discussed. Furthermore, it must be admitted that RIS-assisted mmWave MIMO communications are in their infancy with numerous open research issues, and a long road ahead to solve these questions.

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Biographies

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