RIS Technology Integration with the 5G System: Challenges and Open Questions

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***Abstract*—Reconfigurable Intelligent Surfaces (RIS) are emerging as a key technology to enhance the performance of 5G networks by enabling dynamic control over the wireless propagation environment. This paper explores the integration of RIS technology with the 5G system, highlighting the potential challenges associated with its deployment. We discuss critical issues and identify several open questions, including the need for standardized protocols, optimization techniques for multi-technology RIS scenarios, and the role of artificial intelligence in managing RIS-enhanced networks. These challenges and open questions need to be addressed to fully realize the full potential of RIS technology in next-generation wireless communication systems.**

***Index Terms*—RIS, 5G, 6G, resource allocation, RAN**

I. Introduction

6G technologies are expected to transform and overhaul communications by achieving data rates up to 1 Tbps, supporting below 1 ms latency for mission-critical applications, leveraging Terahertz (THz) frequency spectrum usage, and incorporating intelligent network management enabling self-optimization procedures. The key technologies anticipated to drive the development of 6G are expected to be Artificial Intelligence (AI) and Machine Learning (ML), THz communications, Reconfigurable Intelligent Surfaces (RIS), Massive Multiple-Input Multiple-Output (Massive MIMO) and beamforming, Integrated Sensing and Communication (ISAC), blockchain technology, as well as satellite and aerial networks.

In 5G systems, the concept of extending the Radio Access Network (RAN) with additional elements is well recognized. 3GPP defines in Rel-18 Network Control Repeaters (NCR), as outlined in documents such as 3GPP RP-213700, 3GPP TR 38.867, and 3GPP TR 38.830. NCRs act as Radio Frequency (RF) repeaters that amplify and forward incoming signals. RIS technology, in contrast to NCRs, extends beyond mere signal amplification; it enables true programmability at the far edge of the network. The adoption of RIS transforms the wireless environment from being an uncontrollable resource with stochastic behavior to one where end-to-end performance can be optimized jointly with the RAN segment operations [1], [2].

This study investigates a range of challenges associated with the integration of RIS technology with the 5G system. We also outline potential approaches for integrating RIS control and management systems with the mobile network's management system.

This paper is organized as follows. In Section II, relevant background information is presented. Section III discusses a range of challenges and open questions pertaining to the incorporation of RIS technology within the mobile network. Finally, Section IV encapsulates the main insights and outlines potential future work plans.

II. Background information

A. RIS technology

Reconfigurable Intelligent Surfaces (RISs) technology refers to programmable metasurfaces typically including an arrangement of switchable elements (e.g., matrix) facilitating the manipulation of radio signals, by enabling capabilities such as steering radio beams in a specific direction or achieving the total absorption of radio waves. RIS technology fundamentals are presented in [1]–[3]. The underlying mechanisms of RIS technology are grounded in the principles of meta-materials, which are artificially engineered structures created by connecting basic units known as unit cells. From a macroscopic viewpoint, a RIS can be characterized as a thin, planar, rectangular device, resembling a tile, composed of an array of these unit cells. The incorporation of embedded active elements within these tiles, such as PIN diodes [4] or MEMS [5], [6], enables the capability to modulate the propagation of EM waves across its surface in a software-defined manner. By the proper determination of the RIS configuration, the incident EM wave can be effectively manipulated leading to controllable beam steering, beam splitting, perfect absorption operations, modulation of the wavefront's phase, amplitude, and/or polarization, as well as wavefront sensing [7].

From a standards perspective, the main Standards Development Organization (SDO) developing global standards to define how Reconfigurable Intelligent Surfaces should be implemented and integrated into wireless communication systems is ETSI ISG RIS. Use cases, deployment scenarios and requirements are described in ETSI GR RIS001 [8], ETSI GR RIS002 [9] is about architecture and impact on standardization, while ETSI GR RIS003 [10] is about channel estimation and the design of an evaluation methodology. Further studies of ETSI ISG RIS focus on topics concerning the diversity and multiplexing in RIS-assisted communications, as well as modeling, optimization, and operation aspects.

B. Mobile network fundamentals

3GPP TS 23.501 is the main technical specification that defines the system architecture (5G-RAN and 5G-Core) of the 5G system. It outlines key concepts including network slicing, service-based architecture (SBA), and core network functions such as Access and Mobility Management Function (AMF) and Session Management Function (SMF). Key technologies and challenges in the development of 5G and beyond are explored by [11]. Description of the key features of 5G architecture, the technical underpinnings, as well as the practical aspects of 5G deployments are presented in [12] and [13].

In the RAN part, RAN disaggregation has been described in 3GPP TR 38.801. Detailed specification of the NG-RAN architecture and the different components for 5G are provided in 3GPP TS38.300 and 3GPP TS 38.401. RAN disaggregation is about providing RAN functionalities through Virtualized Network Functions (VNFs) running within VMs or containers as well as Physical Network Functions (PNFs). A gNB refers to the 5G base station for the non-disaggregated case, while for the case of RAN disaggregation, the RAN functionality is provided by virtualized Central Units (CU), virtualized Distributed Units (DU), and (physical) Radio Units (RU). For comprehensive insights into the O-RAN architecture and the technical approach considered for managing and orchestrating the disaggregated RAN according to the O-RAN alliance specification work, readers may refer to [14]. Additionally, [15] provides an overview of the architecture and components of Open RAN along with related AI use cases. RIS technology can be used to extend the RAN segment, mitigating the adverse effects of stochastic phenomena such as scattering and multipath fading that are impacting the signal reception by the UEs.

III. Challenges and Open Questions

This section analyzes several critical issues related to the integration of RIS technology within the mobile network. The relevant standardization work related to the following analysis is rather poor if not completely absent.

A. Integration with the 3GPP management plane

How to enable functionality inside the telecom operator systems (Orchestrator and OSS) to optimize the deployment and operation of the telecom Network Services (NSs) considering a RIS-based operational environment? How to manage RIS as a programmable telecom infrastructure resource and jointly orchestrate it as part of the integrated mobile network? As existing telecom networks' orchestration and management systems are used to manage "legacy" equipment such as servers, routers, switches, antennas, etc. there is a significant lack of means to manage RIS as telecom resources.

On the management plane of the mobile network, a Service-Based Management Architecture is defined by 3GPP in TS28.533. SBMA is a framework used for managing and orchestrating 5G network services using a service-based approach, aligning with the overall 5G service-based architecture (SBA) used in the 5G core network. How RIS can be modeled following the SBMA approach according to 3GPP is an open issue. To abstract the different RIS technology specifics from OSS an orchestrator like the NFVO according to the ETSI NFV-MANO architecture or the SMO according to O-RAN Alliance can be used. In this context, Network Service (NS) definitions considering RIS as part of the NS descriptors and additional control variables for decision making need to be provided in integrated orchestration mechanisms. These can be used to support the end-to-end NS establishment and jointly perform resource management when RAN is extended with RIS. In addition, the communication between the orchestrator and the RIS control component needs to support signaling related to RIS capabilities exposure, RIS configuration, RIS notifications, and RIS monitoring and management.

As depicted in Fig. 1 the following deployment options can be considered:

- Case 1: An orchestrator directly interacts with the RIS control and management plane. The orchestrator exposes an interface towards OSS and other management systems for the management of RIS resources.
- Case 2: RIS control and management information is conveyed directly to OSS.
- Case 3: RIS control and management information is conveyed to OSS through an external management system, for instance, a smart building management system.

For example, in case 1, it is essential for an integrated orchestrator, such as NFV-MANO, to support a specific set of capabilities. These capabilities include the management of RIS as network resources, the exposure of RIS functionalities, and the management of RIS-related OAM. From the orchestrator perspective, two different

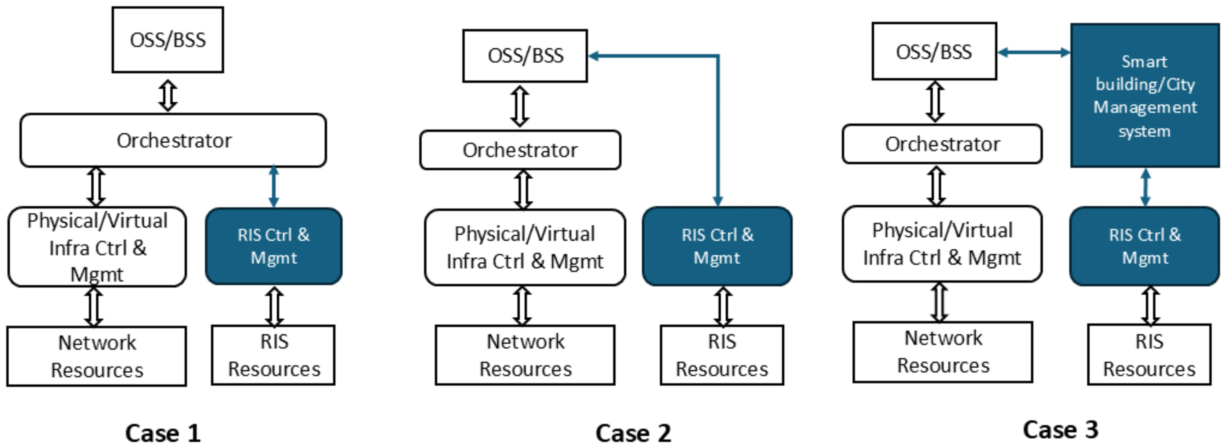

Fig. 1: Different communication models between OSS and RIS control and management plane

approaches can be considered. The first approach would be to consider RIS as an additional type of NFVI resource that can be used to extend the RAN segment one hop closer to the end user. The alternative approach entails viewing RIS as a Physical Network Function (PNF) rather than a new resource type. In this context, RIS PNFs can comprise integrated network services and be connected to other PNFs or even VNFs.

In case the O-RAN orchestration and management framework is considered as specified by the O-RAN Alliance, the RIS control and management entity can interact with the RT-RIC (controller) but also SMO (the orchestrator). The RAN Controller optimizes the configuration and applies closed-loop control, while the orchestrator supports resource management related operations. Fig. 2 provides a visual representation.

Currently, integration of RIS with existing management systems (e.g., NFV-MANO or O-RAN SMO) has been proposed in [16], nevertheless the details about the integration are still missing.

B. Signaling enhancements for RIS discovery

How to enable cell selection based on the existence of RIS deployments? How the UE can select cells with specific RIS capabilities? No mechanism is currently used to advertise RIS related information to UEs and enable cell selection in a RIS-aware manner.

RIS are expected to be uniquely identified within a PLMN, support connectivity in multiple cells, and be associated with one or more Tracking Areas. New type of signaling is required to carry RIS related information to the UE. This information is propagated by the gNB advertising the RIS elements it is authorized to use. Furthermore, in 5G, the Radio Resource Control (RRC) process is in charge of managing the radio resources and establishing and maintaining the radio connection between the UE and the 5G RAN. 3GPP TS 38.300 specification offers an overview of the NR RRC protocol architecture, procedures, and message flows. Currently, the RRC process lacks information related to RIS technology enablers.

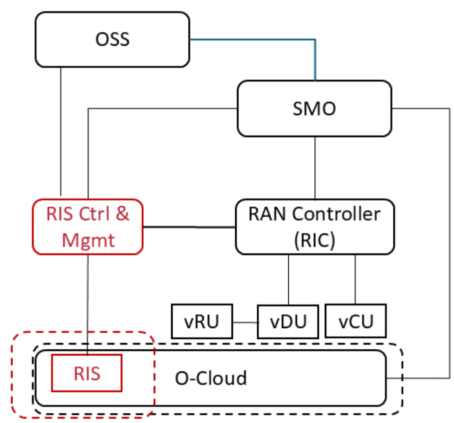

Fig. 2: RIS control and management in O-RAN

C. End-to-end QoS management

In end-to-end communication scenarios, QoS management requires a multi-faced and highly complex analysis. This complexity arises not only from the stochastics due to traffic multiplexing but also because of the stochastic nature of the propagation environment.

Considering RIS operations, an additional control point needs to be considered that can impact end-to-end QoS. As shown in Fig. 3 end-to-end communication path between a gNB and a UE through one or multiple RISs can be broken into two segments: gNB-RISs and RISs-UE.

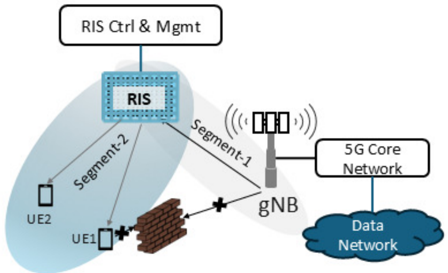

Fig. 3: End-to-end QoS management

Segment-1: depends on the QoS mechanism provided by the 5G system and how radio resources are allocated. In principle, a Resource Block (RB) is the fundamental unit used to allocate radio resources in both the time (resource block spans one slot) and frequency domains (12 consecutive sub-carriers). The sub-carrier spacing can vary based on the numerology (different configurations of the OFDM parameters) used. The duration of a slot depends on the numerology. The allocation of resource blocks is dynamic and can change from one slot to another based on the network conditions, user demand, and quality of service requirements. The scheduler in the base station (gNB) decides how to allocate resource blocks to different users and services, optimizing for factors such as throughput, latency, and fairness. Modulation and coding scheme (MCS) determines how the data bits are mapped to the radio symbols and gNB base station determines the MCS index based on the CQI index. Refer to [17] and 3GPP TS38.300 for QoS management in the RAN.

Segment-2: depends on the QoS mechanism provided by the RIS. Specific groups of RIS unit cells can significantly influence their macroscopic response [18] and deviations in the metrics of these cells impact RIS performance. One approach to enable real-time configuration updates relies on codebooks [19]. The codebook is a data structure designed to map the desired macroscopic RIS functionality to the respective microscopic configuration of RIS elements. The codebook is created initially during the RIS manufacturing phase based on computations for the optimal RIS configuration. During the operation phase, each RIS unit should have the capability to serve multiple users simultaneously with diverse requirements. Efficient resource allocation algorithms are required that can multiplex various codebook entries [20].

In addition, signal processing complexity, real-time reconfiguration, channel estimation and user mobility, pose significant hurdles for seamless RIS integration with the 5G system when it comes to end-to-end QoS management. Sophisticated joint optimization algorithms are required for the efficient reconfiguration of RISs.

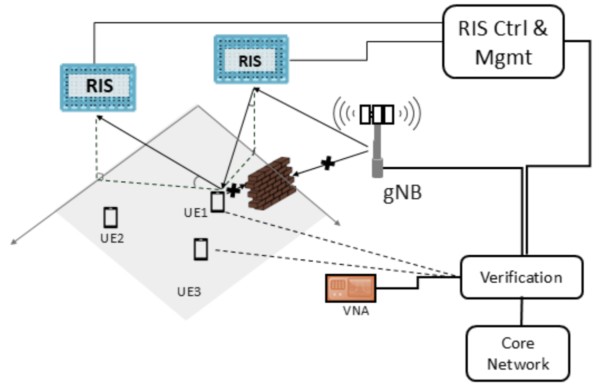

Fig. 4: RIS configuration verification

D. Lack of verification procedures

Questions that arise include the following: How to verify that a certain RIS configuration is feasible before implementing it? How to verify that the association RAN-RIS-UE fulfills its purpose by serving the UEs according to an SLA? How to verify that UEs and the RAN can support interaction with specific RISs to enable connectivity services?

To verify, for instance, if the requested configuration of the RIS elements is feasible and applicable before applying it, the configuration originator (e.g., gNB) could send the configuration requested to a verification function. Based on the information gathered from the UEs, the RISs, the gNBs, and other components such as Vector Network Analyzers (VNAs) this verification function can determine whether the requested configuration is feasible.

A verification function, as illustrated in Fig. 4 can enable end-to-end verification procedures by interacting with RIS control and management plane as well as with other entities such as the 5GS.

E. Network slicing, multi-tenancy, and RIS

How to ensure a certain level of isolation and manage network slice instances operating on top of shareable RISs? Which new functionality is required inside the Telecom operator slicing management system to manage and optimize the deployment and operation of network slices instances considering a shared RIS operational environment?

The 3GPP management system is described by several specifications, e.g., 3GPP TS 28.530, 3GPP TS 28.531, and 3GPP TS 28.533. For example, in 3GPP TS 28.530 the Network Slice as a Service (NSaaS) concept is described outlining the requirements for transitioning

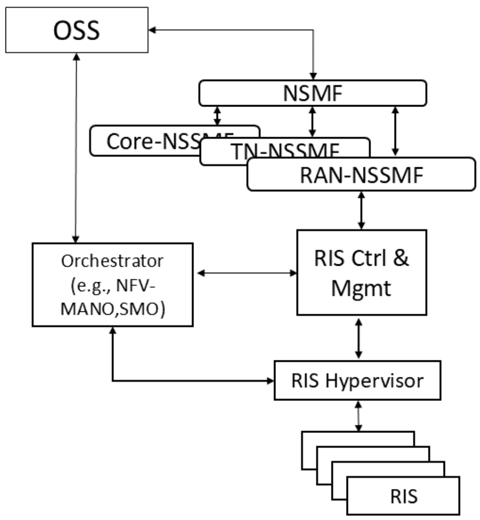

Fig. 5: Virtual RIS and Network slicing according to [21]

to a service-based slice management architecture. Additionally, [21], the concept of a Virtual Programmable Metasurface (VPM) is introduced, which bears a close resemblance to the well-known Virtual Machine concept. In such scenarios, VPM network embedding problems arise. See Fig. 5 for a visual representation of the approach described therein.

In [22] the authors introduce a resource sharing model for Programmable Wireless Environments (PWEs). The main idea focuses on the concurrent provisioning of various functionalities through the segmentation of the RIS. Each RIS tile or a group of tiles is assigned to specific tasks. An alternative approach involves the use of time duty-cycling, where each user is allocated designated time slots during which they are served by the RIS unit [23]. Furthermore, in [20], the authors proposed a strategy of sharing the entire RIS surface to meet the demands of multiple users simultaneously.

F. Concluding remark

The aforementioned list is not comprehensive, and several other aspects urge for additional investigations.

- **New RAN topology designs:** deciding the positions of radio receivers and transmitters is a complex optimization task [18]. See ETSI GR RIS002 for different deployment scenarios and topologies of RIS-integrated networks. RIS topology optimization is expected to be an active field of research.
- **AI-driven RAN optimization for intelligent resource management:** The applicability of efficient resource allocation algorithms will precipitate the adoption of the concept toward 6G [24]. Incorporating AI/ML into RIS operations presents a range of challenges, particularly concerning aspects related to data collection and data scarcity, given that RIS setups are still rare. Obtaining data to train AI models is challenging [25], some studies rely on synthetic data to train their models, such as [26] and [27]. Another critical consideration is that AI algorithms require significant computational resources, which may not always be available at the edge of the network.
- **Security concerns:** RIS operations might increase the risk of eavesdropping, where unauthorized users might intercept amplified signals more easily. Also, in case attackers can access the control plane of the RIS elements due to vulnerabilities in the control channel, traffic rerouting or signal manipulation could result in severe consequences.

IV. Conclusion and Future Work

This paper explores the integration of RIS technology into the 5G system, highlighting the potential challenges associated with its deployment. We discuss critical issues and identify several open questions. ETSI ISG RIS work on RIS covers use cases, deployment scenarios, and technical challenges, however, issues of integrating RIS with RAN management, such as signaling, control plane coordination, and interoperability, remain areas for further exploration. Furthermore, management techniques for scenarios involving multiple RISs technologies and muilti-hop communications remain relatively unexplored, while detailed models and protocols for efficient inter-RIS communication and coordination are scarce. In the AI/ML realm, many advanced works have been proposed for optimizing resource allocation in real time and others for mitigating potential security issues. Yet, there is still limited research on the comprehensive management and control of RIS using AI/ML. This gap presents a significant opportunity for future work, particularly in developing frameworks that combine AI-driven decision making with robust RIS management protocols.

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