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White Paper on Potential Standardization Work for Reconfigurable Intelligent Surface

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Preface

Reconfigurable Intelligent Surface (RIS) has been widely studied in both academia and industry in recent years. A series of RIS prototypes have been launched by colleges and companies in different regions, and various tests & verifications have been done. Based on the field trial, a promising coverage/capacity performance gain can be observed. All these progresses reveal the potential capability of RIS for future wireless network.

In 2025, the study on 6G in 3GPP will be initiated. This white paper, therefore, aims to bridge the gap between academic exploration and industrial implementation by proposing practical directions for RIS-related standardization. Through the collaborative input of various companies and research institutes, it provides insights into different RIS architectures, outlines high-level design principles, and proposes potential standardization work across system architecture, control information, reference signal, and beam management. It is hoped that this white paper can serve as a foundation to facilitate industry consensus and accelerate the inclusion of RIS into global 6G standardization activities.

Contents

1 Introduction

In recent years, series of studies on RIS have been launched in standard development organizations, including European Telecommunications Standards Institute (ETSI) and China Communications Standards Association (CCSA), as illustrated in Fig.1.

In ETSI, Reconfigurable Intelligent Surface (RIS) Industry Specification Group (ISG) systematically advances RIS technology standardization through three phases to support 6G network development.

Phase I focused on technical potential evaluation and standardization requirements, releasing three core reports. The "RIS Use Cases, Deployment Scenarios and Requirements Report" [1] defines 11 application scenarios, analyzes anti-blocking and anti-eavesdropping characteristics in millimeter wave bands and addresses deployment challenges in hybrid indoor-outdoor environments. The "Technological Challenges and Impact on Architecture and Standards Report" [2] proposes two architectural solutions including an integrated architecture that replaces traditional massive MIMO phase shifters and power amplifiers with RIS to reduce hardware costs, and a distributed architecture that dynamically adjusts signals in weak coverage areas. The "Communication Models, Channel Models, Channel Estimation, and Evaluation Methodology Report" [3] establishes a reflection coefficient optimization model under periodic boundary conditions, supports near-field and far-field path loss analysis, and introduces dynamic Area of Influence (AoI) - Bandwidth of Influence (BoI) collaborative optimization methods to mitigate interference and eavesdropping risks.

Phase II expanded research on hardware implementation and testing standardization. Key efforts include RIS unit design, metasurface and prototype validation. It explores multi-domain optimization, and develops beam focusing and dynamic phase adjustment technologies for large-aperture RIS in near-field scenarios. Unified testing standards for beam accuracy, reflection efficiency, and environmental adaptability are also defined.

Phase III aims to integrate RIS into 3GPP standards by studying functional synergies between RIS and Network-Controlled Repeater (NCR), exploring Frequency Range 3 (FR3) band applications, and advancing integrated sensing and communication use cases. A priority reassessment of RIS is planned for the 2025 3GPP 6G workshop, targeting inclusion in 5G-Advanced and 6G core standards.

In CCSA, a research project named “RIS Wireless Technology Research” was launched in 2020. Field trials in 5G-A mid-band Non Line of Sight (NLoS) scenarios demonstrated over 40% edge user rate improvement. Collaborative efforts with universities developed AI-driven low-complexity beamforming and channel estimation algorithms, while validating hardware solutions using diodes, liquid crystals, and graphene materials across diverse frequency bands.

In 2023, a new research project “RIS Engineering Key Technology Research” was launched to address commercialization barriers. This research addressed hardware imperfections and complex scenario adaptation challenges that were previously overlooked in theoretical studies. The project focused on multi-band RIS hardware design for channel modeling based on real-world measurements. It developed compensation algorithms for high-frequency path loss/dispersion, compared cost-effectiveness of centralized and distributed deployment, and formulated multi-operator interference coordination strategies. By establishing technical evaluation metrics and system-level validation platforms, it drived RIS commercialization and provided empirical support for 3GPP standardization. The project was successfully concluded in April 2025.

In 3GPP, the study on RIS was first proposed in Rel-18 in 2021 and attracted companies’ interests. However, corresponding study item for RIS was not included due to some concerns on practical challenges, e.g., robustness and maturity. Then, in Rel-19, there were about 10 companies proposing to introduce the study on RIS, including channel modeling, system model, control mechanism. Currently, while standardization studies on RIS have not yet commenced in 3GPP, growing industry interest in the technology is becoming evident. However, since the time allocation on the first Release of 6G is expected to be very tight, the priority for RIS standardization may be not that optimistic, additional collaborative efforts across the industry are still needed to promote the standardization process of RIS.

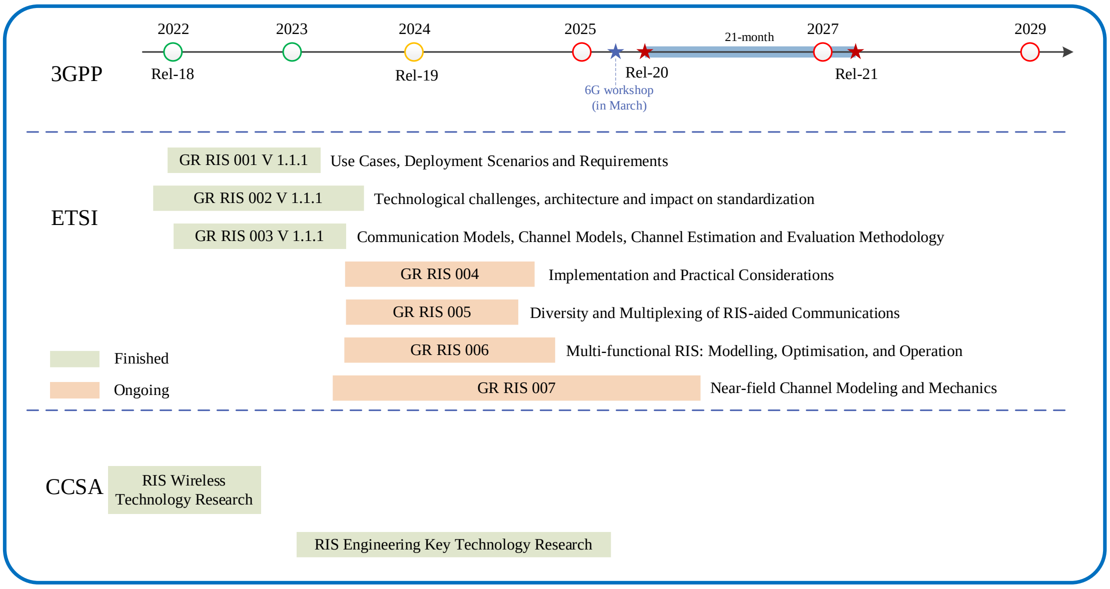


Fig.1. Timeline for study on RIS in standard development organizations

2 Potential RIS types from standardization perspective

Generally, there are three types of RIS taking the potential standardization impact on BS (Base Station) and UE (User Equipment) into account, noted as FT-RIS (Fully Transparent RIS), HT-RIS (Half Transparent RIS) and NT-RIS (Non-Transparent RIS), respectively [4]. While from UE perspective, both FT-RIS and HT-RIS are UE-transparent, and NT-RIS is UE-non-transparent. It should be noted that the term “transparent” here doesn’t indicate the feature of physical material, it indicates whether it is transparent to BS/UE from standardization perspective.

For FT-RIS, no protocol design is needed since neither BS nor UE can detect such kind of RIS, i.e., there will be no specification impact. The whole communication system will treat FT-RIS as a part of the environment, e.g., walls. As illustrated in Fig. 2 (a), one potential usage of FT-RIS is to improve cell-specific coverage. One potential winning point of FT-RIS compared to other similar techniques (e.g., repeater, relay) lies in: no energy consumption at all. However, it has some drawbacks. Firstly, it needs to be designed for a specific target scenario (i.e., customized product), which may limit the market size. Secondly, it is difficult to balance the coverage range and coverage gain. Since FT-RIS needs to concentrate the power of signal into a finer direction to compensate for the path loss as well as improve the received signal power, resulting in a limited coverage range. If a larger coverage range is expected, a larger size of RIS is needed, which may degrade deployment flexibility. Anyway, FT-RIS has no specification impact, thus is not the focus of this white paper.

For HT-RIS, the architecture maintains UE transparency while enabling BS-aware control. As depicted in Fig. 2 (b), this configuration supports time-division coordinated transmission through BS scheduling. To achieve this functionality, HT-RIS requires the following core functional components: a dedicated controller for real-time RIS configuration, and an integrated communication module establishing BS-RIS control link. The power supply architecture presents critical implementation challenges, where wired power solutions would severely constrain deployment flexibility - a paradoxical limitation given that existing wired infrastructure could support alternative network enhancement solutions. Recent measurements reveal that

PIN diode-based RIS modules consume 5.8-14.8W for 100-1000 unit configurations in active state [5]. This power budget is expected to decrease through controller optimization and metamaterial advancements. The successful implementation of energy harvesting technologies, e.g., solar, RF, to address power issues would fundamentally transform HT-RIS's commercial viability.

For NT-RIS, it is “visible” to both BS and UE, and it can be considered as an enhancement of HT-RIS. From network deployment perspective, deploying NT-RIS will require the new interfaces and protocols to connect with other network nodes, including but not limited to BS, UE and other RIS. From functionality perspective, NT-RIS may have the potential to realize at least the following additional functions as illustrated in Fig. 2 (c), i.e., RIS-UE link Channel State Information (CSI) estimation, and UE-based activation of RIS. For the CSI estimation of RIS-UE link, NT-RIS may transmit reference signal to UE to obtain the channel state information of RIS-UE link, which can help BS to realize a joint design of precoding matrix at BS side and beamforming at RIS side. For the UE-based RIS activation, when there is UE near around RIS, it can be activated by the UE to improve the efficiency. However, these additional functions are in price of complexity and cost. Moreover, designing new interfaces between NT-RIS and other network nodes may need additional procedures and additional signalings. As a consequence, the NT-RIS may not be affordable at the initial stage.

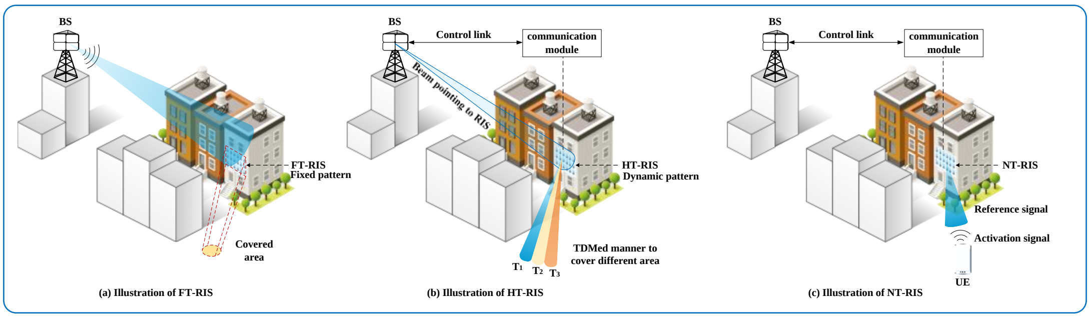


Fig. 2. Illustration of basic framework of RIS assisted wireless communication [4].

3 High-level principles of standardization design

For wireless communication, it’s important to ensure security, controllability, efficiency and interference management in order to meet the requirements of International Telecommunication Union (ITU). In this section, some high-level principles are provided.

3.1 Security principle

Security is a cornerstone in the standardization of RIS systems, as RIS has the potential to interact with the network without fully functioning as traditional RF devices. Identification and authorization [6] are essential to ensure that only valid and trusted RIS devices can participate in the network operations. To this end, the security framework must incorporate reliable mechanisms for authentication, access control, and secure signaling, tailored to RIS-specific deployment and operation modes.

For Network-controlled RIS, identification and authorization procedures can follow a similar model as the one adopted in 3GPP Rel-18 for NCR [7]. Upon network initialization, the BS broadcasts RIS-supported information, after which the RIS performs a simplified random access procedure. Upon completing the Radio Resource Control (RRC) setup procedure, the RIS transmits an indication of its identity and capability. The BS then forwards this information to an RIS-capable AMF, which verifies and authorizes the RIS. Once authorized, the RIS is eligible to participate in Network-controlled beamforming and scheduling.

For UE-controlled RIS, security measures must ensure that only authorized UE can control the RIS [8]. This can be achieved either by allowing the UE to explicitly request authorization to control an RIS, or by having the network proactively assign RIS control rights to selected UEs based on predefined criteria. In either case, secure signaling must be used for configuration, and the RIS must validate the control entity before accepting instructions.

To mitigate security risks, each RIS must possess a unique and verifiable identity. All control communications, whether between BS and RIS or between UE and RIS, must be protected against tampering, spoofing, and unauthorized access using established secure protocols. Additionally, fine-grained access control should be supported to allow the network to enforce control policies based on context, usage scope, and time validity.

By ensuring proper identification and authorization procedures, the network maintains full visibility and control over RIS deployments, preventing unauthorized devices from disrupting wireless operations and enabling reliable RIS-assisted communication.

3.2 Controllable principle

In general, RIS needs to operate in a controlled manner, i.e., Network-controlled or UE-controlled.

For Network-controlled RIS, network determines the behavior of RIS based on scheduling status, channel conditions, etc., and informs RIS when to use which beam for signal forwarding. Under such mode, RIS only needs to receive control information to determine the corresponding forwarding beam, and no local calculation for the best beam is needed, resulting in a low-complexity implementation.

For UE-controlled RIS, it is the UE that determines the control information for RIS. The network can authorize UE to configure a nearby RIS for a specific operating frequency range. Then, the UE can transmit the control information to RIS based on its requirement.

3.3 Simplification Principle

The simplified design of RIS, from the perspectives of both hardware design and standardization design, can benefit the commercial deployment of RIS technology.

For standardization design, it needs to minimize the potential standardization effort to facilitate the progress. Thus, it's better to reuse what we have to achieve this. For example, the channel model of RIS, can refer to the sensing channel model in Integrated Sensing and Communications (ISAC), via exploring the similarity of their cascaded channels. In some cases, RIS may perform with the simplest capability, and thus can be seen as one type of relay, e.g., NCR. In these cases, the standardization of RIS can refer to NCR. In addition, aiming at a unified RIS controlling framework at the beginning of RIS standardization would be preferred to make the framework compatible for the potential different kinds of RIS weights, diverse RIS types, single/multiple RIS deployment and configuration periodicity etc.

For hardware design, the simplification of RIS can also help the corresponding standardization work. In practical scenarios, RIS may not always need to operate at full capability. RIS with reduced capability may have better energy efficiency with equivalent performance. For instance, if RIS is required only to cover part of the area, there is no need for RIS to have the capability of covering the full area. In conclusion, RIS hardware can be much simplified with reduced capability, when the coverage area is limited, a low-bit-quantization can meet the requirements.

3.4 Step-by-Step Principle

The standardization roadmap for RIS should adopt a phased approach to ensure systematic progress.

In the initial phase, efforts should prioritize three key pillars: defining core RIS functionalities, establishing key performance metrics, and validating fundamental technologies. The target scenario can be indoor coverage enhancement and outdoor hotspot areas.

Following the maturation of these foundational elements, subsequent standardization should focus on developing dynamic control protocols, multi-RIS coordination, and scenario-specific performance evaluation. These advancements would facilitate applications in ultra-dense networks, high-speed mobility, low altitude coverage.

After that, some more enhanced functionality can be considered including AI-driven control interfaces, energy-efficient optimizations. This phased progression ensures comprehensive standardization while maintaining technical feasibility and market relevance across deployment timelines.

3.5 Consistency Principle

When introducing RIS into the network, it needs to consider the consistency between them, including at least operation bandwidth and time granularity.

For operation bandwidth, on one hand, the bandwidth of RIS should cover that of network; while on the other hand, the impact of RIS on the electromagnetic wave out of the bandwidth should be restricted, ensuring minimal leakage into other operators' bands.

For time granularity, it also needs to consider the alignment between RIS and network. Typical time granularity in wireless system including frame-level, sub frame-level, slot-level, symbol-level, and it may depend on RIS capability to support the specific time granularity. To this end, RIS needs to know the exact frame structure and be synchronized with the network.

4 Potential Standardization Work

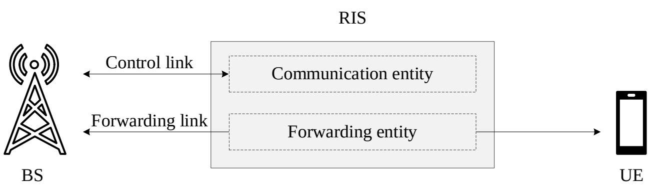
In this section, potential standardization work of RIS are provided, both NW-controlled RIS and UE-controlled RIS are considered.

4.1 System architecture

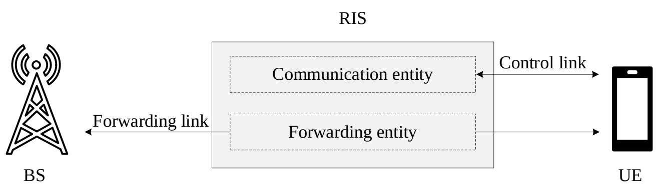
To date, 3GPP has standardized multiple relay-related techniques encompassing Integrated Access and Backhaul (IAB), Radio Frequency (RF) repeater, NCR, among which the system architecture of RIS is most similar with that of NCR. The main difference between RIS and NCR lies in: firstly, there is only one forwarding link instead of two links among BS, RIS and UE; Secondly, the function entity to forward the signal is different. RIS utilizes nearly passive electronic elements, e.g., PIN nodes, while NCR utilize antennas and RF components to form the forwarding beam. In this section, we consider two kinds of architectures for RIS: Network-controlled RIS and UE-controlled RIS.

For Network-controlled RIS, RIS is controlled by BS and the system architecture is illustrated in Fig. 3 (a), where communication entity is for information exchanges between RIS and BS via control link, and forwarding entity is for RIS to forward uplink and downlink signal between BS and UE via forwarding link.

For UE-controlled RIS, RIS is managed by UE as depicted in Fig. 3 (b), where the functionality entity is basically the same as that of Network-controlled RIS. The main difference lies in the control method, where the control link can be based on different interfaces with treating RIS as a special BS or UE. Potential usage of such kind of UE is to provide personal transmission enhancement e.g., in house, office, shopping mall.



(a)



(b)

Fig. 3. System architecture for RIS: (a) Network-controlled RIS; (b)UE-controlled RIS

Besides, if more than one RIS is deployed in one cell, careful coordination is needed to prevent interference as well as maintain the performance.

4.2 Control Information

The design of control information is the core part for RIS standardization, since it directly impacts the functionality and potential performance of RIS. Considering there may be hundreds or thousands of RIS elements, it is unrealistic for BS to control each element of RIS due to the large signalling overhead. Instead, a possible approach is to control the forwarding beam of RIS.

For both Network-controlled & UE controlled RIS, a beam index can be utilized to indicate the expected beam of RIS, the indication can be dynamic, semi-static or periodic according to the related scheduling. The index can be designed within Transmission Configuration Indicator (TCI) framework. And simple beam sweeping can be considered to determine the proper beam [9].

Some enhanced control information may include: ON/OFF information, indicating whether RIS can be turned into an energy saving mode; UL/DL TDD configuration information, indicating the detailed UL/DL slots and symbols. Moreover, further considerations for RIS with potentially enhanced structures might also be included. For better tradeoff between cost & power & performance, some hybrid RIS structures with fixed and configurable beam vectors might also be considered. In this case, multi-level beam indication might be necessary.

4.3 Reference signal

When NCR is merged into the 5G wireless networks to extend the cellular coverage, it is expected to be transparent to the users. The beam training procedure is adopted and the candidate beam set is configured by OAM (Operation Administration and Maintenance) without any impact on RS design. Considering the large scale of RIS element matrix, a large set of candidate beams would be involved in the beam training procedure requiring for enlarging Reference Signal (RS) ports/resources. A multiple-step beam training procedure to support the hierarchical RIS beam set [10] can be considered to reduce the RS and time overhead in the design of 6G protocols.

In 6G networks, RIS can be used not only in the coverage enhancement scenario, but also in multi-user coherent transmission and assisted sensing scenarios which requires more elaborate manipulation about RIS beam. There is a need to acquire more channel information, e.g. the frequency domain information, Angle of Arrival (AoA) and Angle of Departure (AoD) at the RIS side, by distinguishing the RIS cascade channel and ordinary scattering paths during the channel measurement. Inspired by the space-time modulation proposed in [11], an additional phase information, e.g. an Orthogonal Cover Code (OCC) in the time domain, can be superposed on each CSI-RS symbols/resources. The CSI of RIS cascaded channel can be estimated with the help of OCC decompression. Furthermore, the different OCC codeword could configure to different RIS subarrays, and AoA and AoD at the RIS side can be determined according to the phase variance among RIS subarrays.

4.4 Beam management

With the implementation of RIS, the equivalent link from BS to UE is divided into two hop links: from BS to RIS and from RIS to UE. If a beam failure occurs on one hop link, it will lead to a beam failure of the entire link. Therefore, the beam failure recovery of the RIS system will be more tough. Since RIS has no signal processing function, it cannot detect and report the beam failure event of the link. The UE can only detect and report beam failure events that occur in the equivalent channel. Since UE cannot determine which link is failed, and can only detect all new beams or new beam combinations of the two channels, this will result in the need to measure a lot of new beams or beam combinations. When UE capability is limited, the probability of detecting a new beam will be largely reduced, or the quality of the new beam detected will be poor. Therefore, it is necessary to enhance the cascade beam failure recovery scheme under the RIS system.

One possible solution is to use RIS to judge the specific location of beam failure, reducing the latency and complexity of beam recovery, achieve fast beam switching and solve the problem of high frequency beam occlusion. This method assumes that RIS has a simple signal transmission function and can send RIS beam measurement signals to the UE for measuring the quality of RIS beams to assist in confirming the location where beam failures occur.

5 Conclusion

This white paper analyzes three potential RIS types from standardization perspective—FT-RIS, HT-RIS, and NT-RIS—explaining their distinct impacts on BS, UE, as well as their application scenarios. It then presents five high-level principles for standardization design: the security principle to ensure trusted device access and secure signaling; the controllable principle to make RIS operate under a controlled manner; the simplification principle to reuse existing standards and streamline hardware design; the step-by-step principle to phase technical validation and scenario expansion; and the consistency principle to align operational bandwidth and time granularity with legacy systems. Finally, the paper focuses on four areas of potential standardization work, including system architecture design considering both Network-controlled and UE-controlled RIS, control information & signaling, RS, and enhanced beam management to address cascade link failures.

This white paper aims to foster industry consensus to accelerate the harmonization of standardization processes for RIS. It's hoped that RIS can be included in global 6G standardization activities, and finally integrated into 6G networks, driving wireless communication toward an era of intelligent, energy-efficient, and ubiquitously connected systems.

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