ETSI GR RIS 001 V1.1.1 (2023-04)

Reconfigurable Intelligent Surfaces (RIS); Use Cases, Deployment Scenarios and Requirements

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Reference
DGR/RIS-001

Keywords
3GPP, architecture, MIMO, radio

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ETSI GR RIS 001 V1.1.1 (2023-04)

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Reconfigurable Intelligent Surfaces (RIS).

Modal verbs terminology

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1 Scope

The present document identifies Reconfigurable Intelligent Surfaces (RIS) relevant use cases with corresponding general Key Performance Indicators (KPIs), deployment scenarios operational requirements for each identified use case. KPIs and operational requirements will include system/link performance, spectrum, co-existence, and security.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents are not necessary for the application of the present document, but they assist the user with regard to a particular subject area.

[i.1]	3GPP TR 22.858 (V18.2.0): "Study of enhancements for residential 5G (Release 18)".
[i.2]	3GPP TR 22.859 (V18.2.0): "Study on Personal Internet of Things (PIoT) networks (Release 18)".
[i.3]	3GPP TS 38.104 (V18.0.0): "NR; Base Station (BS) radio transmission and reception (Release 18)".

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BS	Base Station
CPN	Customer Premises Network
DC	Direct Current
DL	Downlink
DMA	Dynamic Metasurface Antenna
EIRP	Equivalent Isotropically Radiated Power
EM	ElectroMagnetic
EMF	ElectroMagnetic Field

eRG	evolved Residential Gateway
FDD	Frequency Division Duplex
FR	Frequency Range
IoT	Internet of Things
ISAC	Integrated Sensing And Communication
KPI	Key Performance Indicator
LBT	Listen Before Talk
LoS	Line of Sight
LTE	Long-Term Evolution
M2M	Machine to Machine
MIMO	Multi-Input Multi-Output
NLoS	Non-Line of Sight
NR	New Radio
O2I	Outdoor to Indoor
OFDM	Orthogonal Frequency Division Multiplexing
PIN	Personal Internet of Things Network
QoS	Quality of Service
RAT	Radio Access Technology
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surfaces
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
TRP	Transmission and Reception Point
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink

4 Definition

4.0 RIS definition

RIS is considered a key candidate wireless technology trend for future networks. RIS corresponds to a new network node composed of an arrangement of scattering elements called unit-cells, whose properties can be dynamically controlled to change its electromagnetic behaviour. The response of RIS can be controlled dynamically and/or semi-statically through control signalling such as to tune the incident wireless signals through reflection, refraction, focusing, collimation, modulation, absorption or any combination of these. An illustrative diagram of RIS is provided in Figure 4.0-1, as a new network node dynamically and/or semi-statically configured by the RIS controller, turning the wireless environment from a passive to an intelligent actor such that the channel becomes programmable. This trend will expand basic wireless system design paradigms, creating innovation opportunities which will progressively impact the evolution of wireless system architecture, access technologies, and networking protocols.

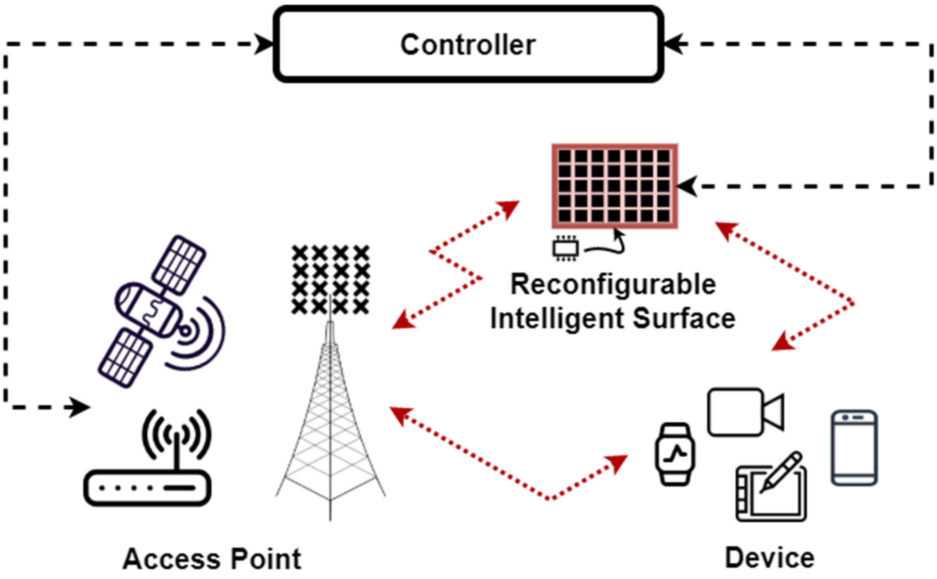

Figure 4.0-1: Illustrative diagram of RIS, a new type of network node where its response can be adapted to the status of the propagation environment through control signalling

4.1 Structure

4.1.0 General overview

RIS can be implemented using mostly passive components without requiring high-cost active components such as power amplifiers, resulting in low implementation cost and energy consumption. This allows easy and flexible deployment of RIS, with the possibility of RIS taking any shape and to be integrated onto objects (e.g. walls, buildings, lamp posts, etc.). RIS are supposed to run as nearly-passive devices and hence are unlikely to increase exposure to EMF, and in fact, they can potentially be used to reduce EM pollution in legacy deployments. These associated characteristics suggest RIS may be considered as a sustainable environmentally friendly technology solution. RIS may have different structures with considerations of cost, form factor, design and integration.

4.1.1 Metamaterials

Metamaterials and meta-surfaces is an approach to implement RIS.

Metamaterials are artificial materials whose properties can be engineered. They are typically synthesized using multiple elements made from composite materials such as metals and plastics.

A thin metamaterial layer, also called a meta-surface, could realize a desired transformation of transmitted, received, or reflected ElectroMagnetic waves. A meta-surface typically consists of periodically arranged unit cells.

The ElectroMagnetic properties of a meta-surface may be electronically tuneable using various components integrated in the surface such as PIN diodes, varactor diodes, liquid crystals, etc.

4.1.2 Reflectarray

Reflectarrays use elementary antennas as reflecting elements.

The reflection properties, such as the phase, of the elements can be changed by, e.g. varying a controllable load connected to an antenna element. The reflection of the impinging electromagnetic wave can be controlled by creating a phase gradient on the array by selecting the appropriate phase responses of the contiguous elements of the array. Hence, reflectarrays can be used to implement RIS units.

When the element spacing and antenna elements on a reflectarray are reduced, reflectarrays tend to behave as meta-surfaces.

4.2 Hardware design

4.2.0 Types of hardware design

In this clause, different types of circuit designs of RIS are provided. RIS can be seen as a generic hardware ranging from meta-surfaces able to manipulate wave propagation in very-rich scattering environments to those able to realize desired anomalous reflection beyond the well-known Snell's law. RIS can be designed to operate in different modes while exhibiting comparable energy efficiency with their reflective counterparts.

NOTE: The definition in this clause is described from manufacturing perspective, not from operating perspective. This means that a RIS defined in this clause can work under an operating mode which does not consume power, though it would still be classified as an active RIS from circuit design perspective.

4.2.1 Active RIS

The term active RIS is adopted when energy-intensive RF circuits and consecutive signal processing units are embedded in RIS. On another note, active RIS systems comprise a natural evolution of conventional massive MIMO systems, by packing more and more software-controlled antenna elements onto a two-dimensional surface of finite size.

The active RIS structure can be used to transmit and receive signals across the entire surface or using a portion of elements, making it capable of conducting more tasks than passive RIS. A RIS structure in which only a portion of the elements are capable of transmission and/or reception is sometimes called semi-active.

The discrete photonic antenna array is another practical implementation of active RIS. It integrates active optical-electrical detectors, converters, and modulators for performing transmission, reception, and conversion of optical or RF signals.

4.2.2 Passive RIS

Passive RIS acts like a passive metal mirror or wave collector which can be programmed to change an impinging EM field in a customizable way. Compared with its active counterpart, a passive RIS is usually composed of low-cost and almost passive elements that do not require dedicated power sources. Their circuitry and embedded sensors can be powered with energy harvesting modules, an approach that has the potential of making them truly energy neutral. Regardless of their specific implementations, what makes the passive RIS technology attractive from an energy consumption standpoint, is their capability to shape radio waves impinging upon them, forwarding the incoming signal without employing any power amplifier nor RF chain, and even without applying sophisticated signal processing. Moreover, in addition to half-duplex mode, passive RIS can also work in full duplex mode without significant self interference or increased noise level, and require only low-rate control link or backhaul connections. Finally, passive RIS structures can be easily integrated into the wireless communication environment, since their extremely low power consumption and hardware costs allow them to be deployed into building facades, room and factory ceilings, laptop cases, or even human clothing.

4.2.3 Hybrid RIS

A hybrid RIS is capable of reflecting their impinging signal, while simultaneously sensing a portion of it. Hybrid RIS bear the potential of significantly facilitating coherent communications without notably affecting the energy efficiency and coverage extension advantages offered by passive RIS.

An example of an implementation of a Hybrid RIS is a surface that is loaded by a varactor, whose capacitance can be changed by an external DC signal. The varying capacitance can change the phase of the reflected wave. In this way, the phase variation along the Hybrid RIS can steer the reflected beam towards desired directions.

4.3 Operating mode

4.3.1 Reflection mode

The concept of the RIS-empowered smart wireless environments initially considered only passive RIS with almost zero power consumption unit elements. Their envisioned prominent role lies on the capability of the surface to reconfigure the reflection characteristics of its elements, enabling programmable manipulation of incoming EM waves in a wide variety of functionalities. It is essential to achieve a fine-grained control over the reflected EM field for quasi-free space beam manipulation so as to realize accurate beamforming. Meta-atoms of sub-wavelength size are a favourable choice, although inevitable strong mutual coupling, and well-defined grey-scale-tuneable EM properties exist.

Conversely, in rich scattering environments, the wave energy is statistically equally spread throughout the wireless medium. The ensuing ray chaos implies that rays impact the RIS from all possible, rather than one well-defined, directions. The goal becomes the manipulation of as many ray paths as possible, which is different from the common goal of creating a directive beam. This manipulation has two kind of aims, including tailoring those rays to create constructive superposition at a target location and steering the field efficiently. These manipulations can be efficiently realized with RIS equipped with half-wavelength-sized meta-atoms, enabling the control of more rays with a fixed amount of electronic components (PIN diodes, etc.). The meta-atoms are usually half-wavelength-sized in lower frequency bands, whereas in higher frequency bands like FR2, their sizes depend on manufacturing constraints.

RIS working in reflection mode can act as a reflector in the environment, and it can be used to improve coverage, mitigate interference and increase capacity.

4.3.2 Refraction mode

The refraction mode allows incident EM waves passing through the RIS and refract them to different target directions by adjusting their phase. The main difference between refraction and the reflection mode characterized in clause 4.3.1 is the missing of the shielding layer inside the RIS panel, which enables the EM waves to pass through the panel.

One typical use case of refraction mode is outdoor to indoor scenario. In order to improve the coverage for some certain areas inside the building, the RIS will be used as the window glasses and it will focus the incident EM waves to different target areas.

4.3.3 Absorption mode

Under the absorption mode, the impinging radio wave of a certain center frequency and a certain bandwidth can, ideally, be totally absorbed and no reflection wave can be observed. The absorption mode, that allows RIS to have almost zero output waves, can be beneficial to interference mitigation, privacy and information security industry. One typical use case is to implement RIS on the building facade to shield electromagnetic wave, so that the electromagnetic wave of indoor and outdoor or different indoor rooms would be isolated from each other. RIS plane will absorb the incident wave to prevent them from penetrating building walls. The switch of RIS between absorption and refraction or reflection mode can be controlled by bias voltage.

One example of absorption RIS is graphene based RIS, which can reach nearly 100 % absorption in some given bands according to the design. The perfect absorption is achieved by electrically reconfiguring the meta atom response via the chemical potential of the graphene.

4.3.4 Backscattering mode

For a RIS in backscattering mode, the reflected wave is to cover a large area instead of an exact location. Therefore, the balance between gain and effective area is necessary for realizing wide-angle blindspot coverage. Backscattering mode can be used for passive RIS, which are manufactured to reflect an impinging EM signal into a certain direction.

4.3.5 Transmitting mode

A RIS in transmitting mode is incorporated in a radio transmitter with the RIS assisting in shaping the transmitted radio wave.

As an example, Dynamic Metasurface Antennas (DMAs) have been recently proposed as an efficient realization of extreme massive antenna arrays. DMAs have beam tailoring capabilities and facilitate processing of the transmitted and received signals in the analog domain. DMAs work in a dynamically configurable manner with simplified transceiver hardware. Additionally, compared with conventional antenna arrays, DMA-based architectures require much less power and cost. In this way, eliminating the need for complicated corporate feed and/or active phase shifters becomes possible. Another promising advantage of DMAs is that they can comprise massive numbers of tuneable metamaterial-based antenna elements fitting into small physical areas and providing wide range of operating frequencies.

DMA architecture that consists of multiple separate waveguide-fed element arrays with each connected to a single input/output port is a typical reflecting RIS. A large number of radiating elements can be accommodated in waveguides, and the sub-wavelength spaced character allows each input/output port to feed a multitude of possibly coupled radiators. For 2D waveguides, a scattered wave from each element propagates in all directions. Since the proposed waveguide is typically designed to be single mode and the wave can only propagate along one line, its analysis is much easier than 2D waveguides. Furthermore, ensuring isolation between different ports is easier in 1D waveguides than in multiple ports of a 2D waveguide.

4.3.6 Receiving mode

A RIS in receiving mode is capable of receiving and processing radio signals. This can be accomplished by embedding waveguides at each RIS element, or group of elements, to direct the impinging radio signals to reception hardware. This hardware may include, for example, a low noise amplifier, a mixer down converting the signal from RF to baseband, and an analog-to-digital converter.

In the example illustrated in Figure 4.3.6-1, an impinging EM training signal at the RIS elements is received in the RF domain via *M* RIS phase configurations, which are randomly selected through a random spatial sampling unit. This collection of spatially random analog combined versions of the impinging radio signals facilitates, for example, the application of compressed-sensing-based channel estimation techniques, enabling signal reception at the RIS with much less reception RF chains (even with one) than the number of RIS elements.

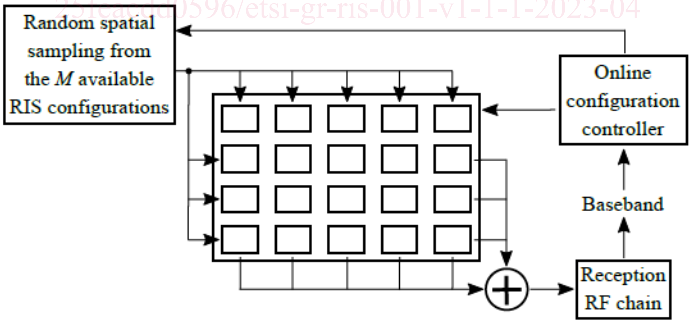

Figure 4.3.6-1: Block diagram of a RIS hardware architecture including a single active reception RF chain, enabling the sensing of the impinging signal in baseband

4.4 Operating frequency

4.4.0 Description

This clause describes possible operating frequencies for RIS to be integrated into wireless networks. Two Frequency Ranges (FR) are described, namely FR1 and FR2. Corresponding frequency range for FR1 is 410 MHz - 7 125 MHz and corresponding frequency range for FR2 is 24 250 MHz - 71 000 MHz, as defined in Table 5.2-1 in 3GPP TS 38.104 [i.3]. Many Radio Access Technologies (RATs) work on FR1, such as WiFi®, LTE and part of NR. Some RATs work on FR2, such as part of NR.