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

Reference
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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.

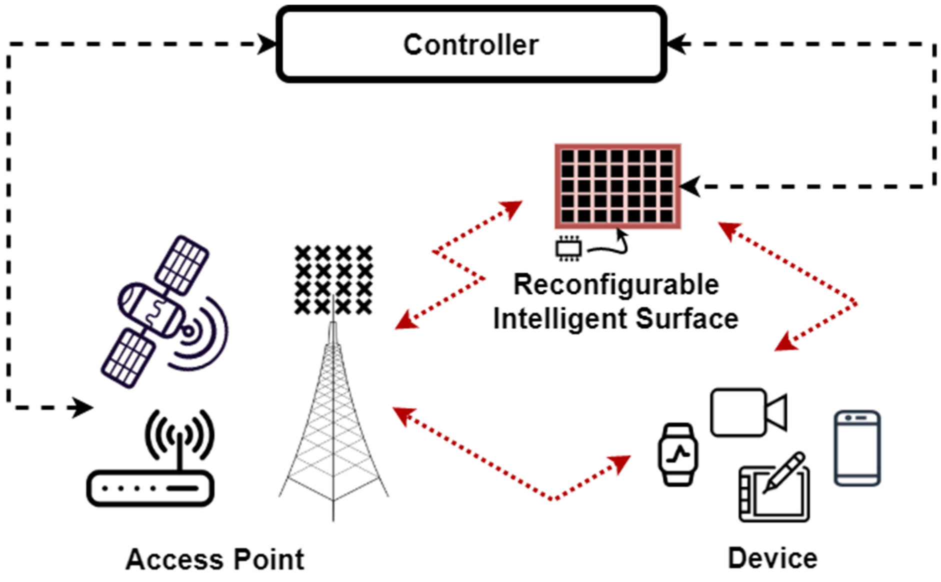

Figure 4.0-1: Illustrative diagram of RIS, a new type of network node where its response can be adapted to the status of the propagation environment through control signalling

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.

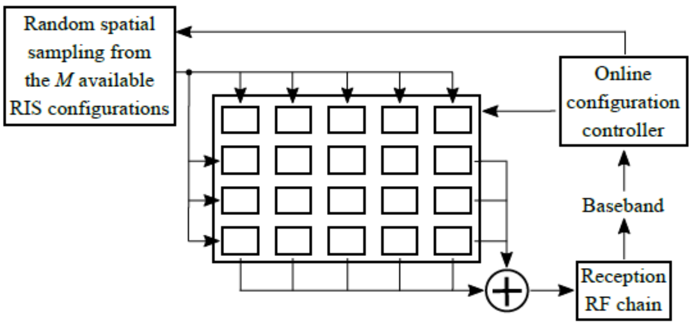

Figure 4.3.6-1: Block diagram of a RIS hardware architecture including a single active reception RF chain, enabling the sensing of the impinging signal in baseband

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.

Deployment scenarios, use cases and relevant recommendations are in many cases described separately for different frequency ranges, since the channel conditions for FR1 and FR2 are different.

The operating frequency and channel arrangements presented in this clause are based on the frequency ranges and operating bands defined in 3GPP TS 38.104 [i.3].

4.4.1 RIS bandwidth of influence

Since the bandwidth of signals reflected by RIS might be different compared to that of the incident signal, when considering the working frequency of RIS it is necessary to also consider the unwanted emissions created by RIS reflections. The unwanted emissions may cause interference to different bands than the incident signal.

The working frequency bands in clause 4.4.0 are described by the incident signal. The characteristics of potential unwanted emissions generated by RIS are described in 3GPP TS 38.104 [i.3].

4.4.2 Sub-6GHz band (FR1)

The corresponding frequency range for FR1 is 410 MHz - 7 125 MHz. FR1 is sometimes referred to as sub-6 GHz in some references and literature, while in fact it has now been extended to 7,125 GHz due to additional spectrum allocations.

The operating frequency bands belonging to FR1 for NR are defined in Table 5.2-1 in 3GPP TS 38.104 [i.3], where both TDD and FDD bands are considered supported for RIS operations.

In cellular networks such as the LTE and NR, frequency bands in FR1 are envisaged to carry much of the traditional cellular mobile communications traffic and provide good coverage.

4.4.3 mmWave band (FR2)

The corresponding frequency range for FR2 is 24 250 MHz - 71 000 MHz. FR2 is sometimes referred to as millimeter wave (mmWave) in some references and literature.

The operating frequency bands belonging to FR2 for NR are defined in Table 5.2-2 in 3GPP TS 38.104 [i.3], where both TDD and FDD bands are considered supported for RIS operations.

In cellular networks such as the NR, frequency bands in FR2 are aimed to provide ultra high data rate since larger bandwidth can be provided in higher frequencies.

4.4.4 Terahertz band

TeraHertz (THz) bands are defined as the frequency region between 0,1 THz and 10 THz. Sub-THz bands are sometimes referred to as the lowest part of the THz spectrum between 0,1 THz and 0,3 THz. In these frequencies, only TDD deployments are being considered.

Despite the fact that most immediate RIS applications are envisaged for FR1 and FR2 frequencies as currently defined in 3GPP specifications, THz and sub-THz communications are gaining traction for future beyond-5G networks due to their intrinsic high bandwidth and data rate support. Since communication at these frequencies is inherently short-ranged and characterized by unreliable intermittent links impaired by blockage and absorption, a continuous Line of Sight (LoS) link should be guaranteed. Thus, RIS deployments can play a key role in customizing the propagation environment to ensure a continuous LoS link. Moreover, the deployment of multiple RIS can provide richer multipath characteristics to an otherwise single-rank channel by creating additional signal path(s) artificially, thus improving its spatial multiplexing capabilities. Furthermore, deployment of RIS could be used to extend coverage of communications for very high frequency range such as in sub-THz and THz bands.

As in some cellular networks such as the 5G NR, THz communications can exploit synergies with the lower bands in FR1 and FR2 to maximize network coverage.

4.4.5 Unlicensed bands

In both FR1 and FR2, unlicensed bands have been allocated in different regions. For RIS to operate in these unlicensed bands, channel access mechanisms may need to be considered. Similar to cellular networks such as LTE and NR, depending on the regional requirements and deployment scenarios, multiple channel access mechanisms can be considered for RIS operation in unlicensed bands. One such example is that an active RIS may perform Listen Before Talk (LBT) based channel access to operate in unlicensed band. The controlling node for RIS, for example a BS or a UE, could configure RIS to perform such channel access mechanism. Another important aspect for RIS in unlicensed bands is to operate within the power limits such as maximum EIRP limits that are typically based on the regulatory and standards requirements.

4.5 Communication duplex mode

4.5.1 TDD

For TDD mode, it is well known that there exists channel reciprocity between DL and UL channels which utilize the same frequency band. Whether RIS preserves channel reciprocity depends on the fabrication methods. In the cases where reciprocity holds for RIS TDD systems, the same configuration of RIS, such as phase shifts and amplitudes, or in other words beam directions, can be used in both the DL and the UL. Specifically, in the TDD mode, RIS can receive downlink transmission from the network and reflect to UE(s) in one time unit (for example, one or multiple OFDM symbols) and it can receive uplink transmission from UE(s) and reflect to the network in another time unit. The reception/reflection in UL and DL may occur on same frequency but in different time units. In addition, a guard period may be configured for RIS when switching between DL/UL to ensure that the UL and DL reflection/reception at the RIS do not interfere. For the TDD, two modes can be included: reciprocity-constrained mode and reciprocity-non-constrained mode. Typically, channel reciprocity can be maintained for most of the RIS hardware implementations. However, as one possibility, depending on the fabrication methods of RIS, reciprocity may not always be maintained. Therefore, to operate in reciprocity-constrained mode, channel reciprocity can be maintained by at least configuring the phase shifts at the RIS elements to reflect UL/DL towards BS/UE such that the BS/UE can transmit DL/UL and receive UL/DL using the same respective beams. For the reciprocity-non-constrained mode, channel reciprocity may not need to be maintained and the phase shifts at RIS can be configured independent of the UL/DL beams at the UE/BS. In Figures 4.5.1-1(a) and 4.5.1-1(b), illustrations are provided for the two cases of reciprocity constrained and reciprocity-non-constrained mode.

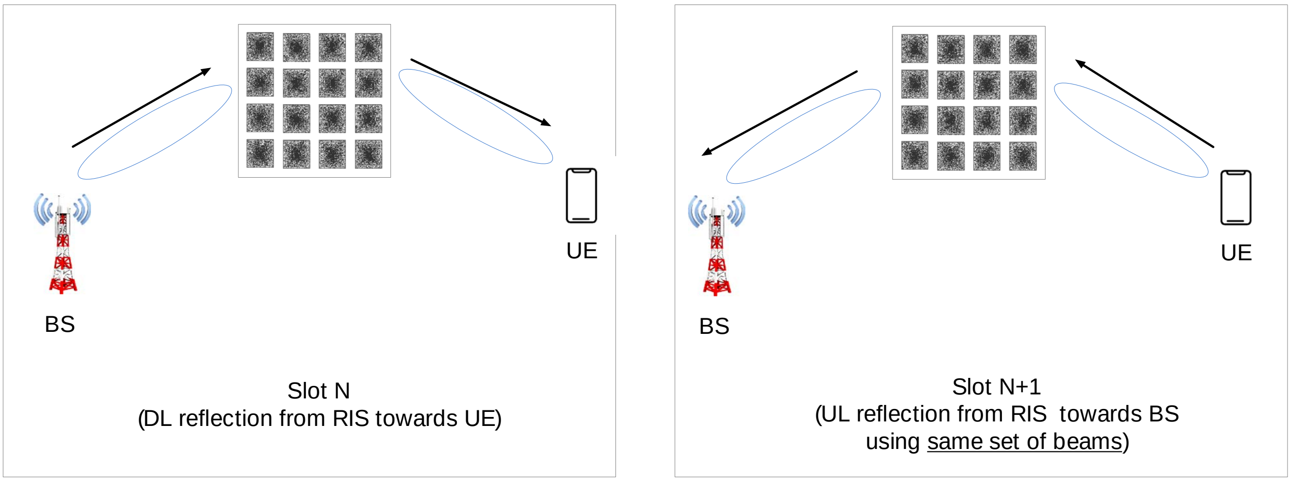

Figure 4.5.1-1(a): Illustration of TDD communication with reciprocity-constrained mode at UE using same set of phase shifts for UL and DL at RIS

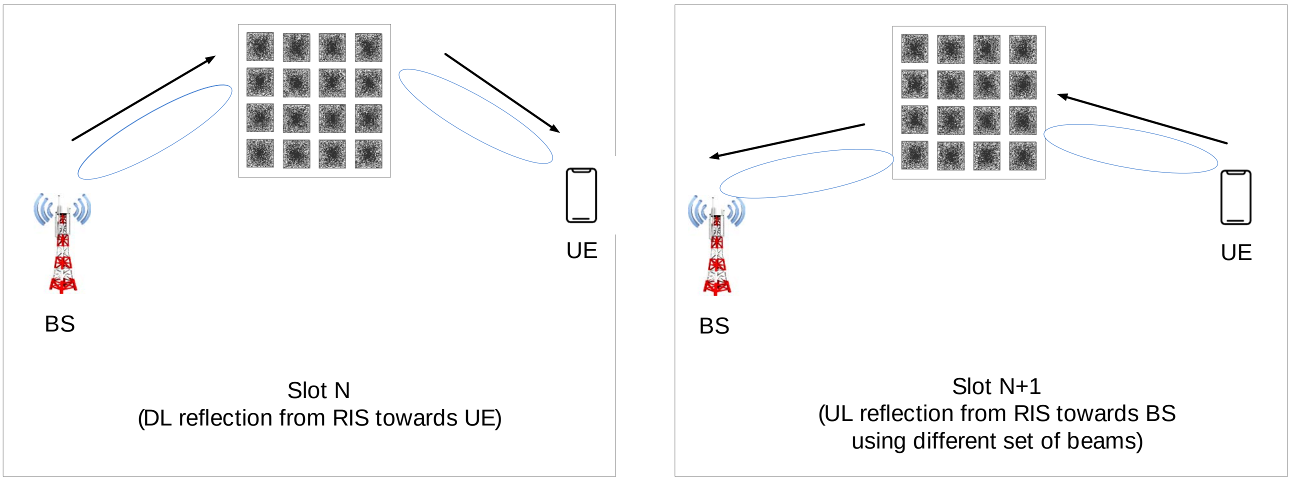

Figure 4.5.1-1(b): Illustration of TDD communication with reciprocity-non-constrained mode at UE using different set of phase shifts for UL and DL at RIS

4.5.2 FDD

For FDD mode, DL and UL channels utilize different frequency bands. Hence channel reciprocity does not hold for RIS FDD systems. In such cases, using the same configuration of RIS, such as phase shifts and amplitudes, or in other words beam directions, in the DL and the UL may lead to performance degradation. RIS design and operation in FDD bands therefore requires additional consideration.

4.5.3 Full duplex

For full-duplex mode, RIS can reflect DL and UL channels on the same frequency bands at the same time. In such cases, RIS may additionally contribute to further interference to DL and UL channels in comparison to half-duplex systems. Therefore, this may require some additional consideration to minimize interference and realize the benefits of full duplex. An illustration for full-duplex mode RIS is shown in Figure 4.5.3-1 where the RIS is in communication with one base station and two UEs.

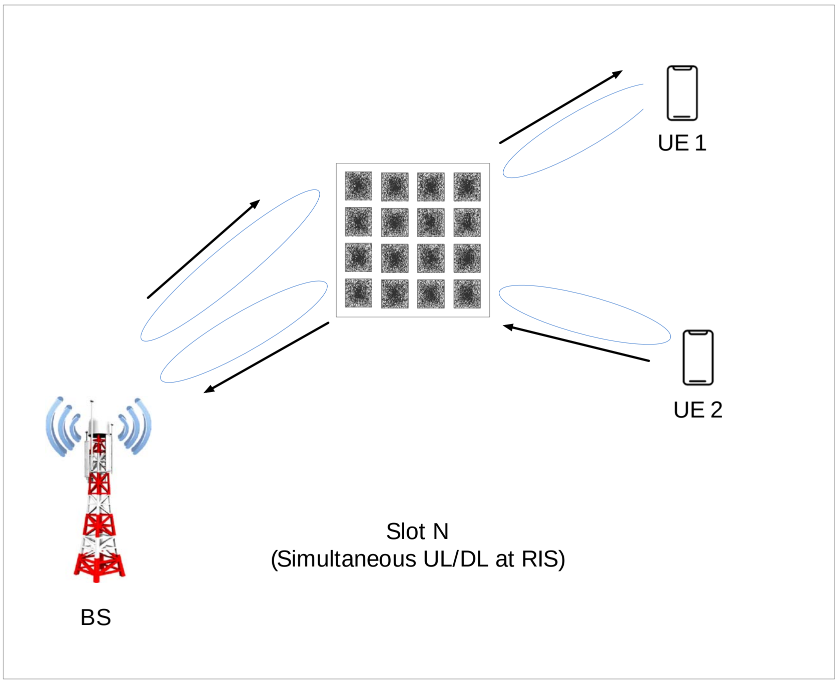

Figure 4.5.3-1: Illustration of full-duplex mode at RIS

5 Description of use cases

5.0 General description

RIS is envisaged as a new enabling candidate wireless technology for the control of the radio signals between a transmitter and a receiver in a dynamic and goal-oriented way, turning the wireless environment into a service. This has motivated a host of potential new use cases targeting at:

a) the enhancement of various system KPIs; and

b) the support of new wireless technology applications and capabilities.

These include enhancements to the capacity, coverage, positioning, security, and sustainability, as well as the support of further sensing, wireless power transfer, and ambient backscattering capabilities. The present document specifies some of the key use cases where RIS deployment may provide enhancements or new functionalities.

5.1 Coverage enhancement

Due to the influence of obstacles such as buildings and trees, the wireless signal coverage is uneven and the problem of weak coverage often occurs in the actual mobile communication system. Weak coverage areas may be small and discrete, however their adverse effects may be serious. Terminals in these areas may not be able to obtain guaranteed quality-of-service. Deploying more access points in the weak coverage area is a method of high cost and low efficiency. RIS provide a low-cost and easy-to-implement method. By deploying RIS in the appropriate location, line-of-sight propagation paths between the access point and the RIS as well as between RIS and the terminal can be established in the weak coverage area to achieve coverage enhancement.

Simple reflecting RIS may be sufficient to provide robust communication links toward end terminals, but in more demanding scenarios, use cases involving more advanced RIS hardware architectures, like ones performing coherent/non-coherent modulation, baseband measurement collection, and consequently sensing, or acting as decode-and-forward relays may prove more effective despite their increased cost. RIS can enhance the cell coverage in many realistic scenarios listed as follows. Figure 5.1-1 demonstrates the most common and intuitive application of RIS, i.e. serving as a solution to blockage issues, which applies to both outdoor and indoor scenarios.

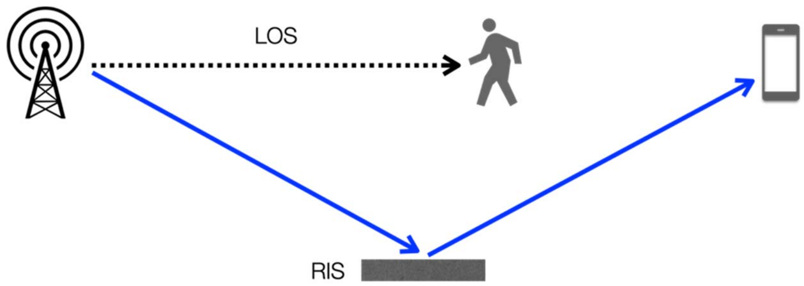

Figure 5.1-1: RIS as a solution to blockage

Figure 5.1-2 illustrates a quite common variant of the blockage problem, in which the BS deployed in one corridor needs to serve UEs in a perpendicular hallway. Due to the high penetration loss, such a link is not feasible without the assistance of RIS. In addition, to avoid blockages in a complicated environment, multiple RIS can be configured in a cascaded manner for coverage extension, as shown in Figure 5.1-3.

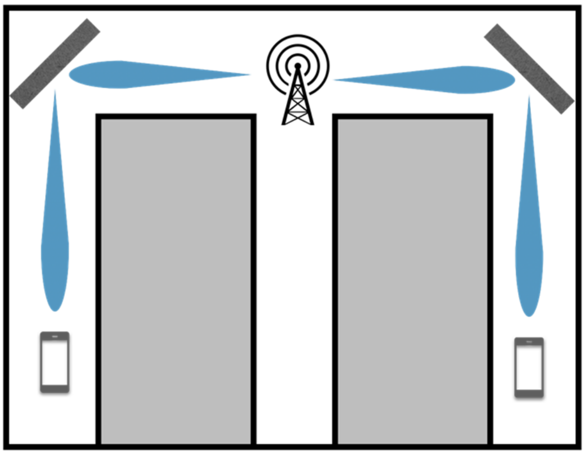

Figure 5.1-2: RIS redirects beams to form link between BS and UE in different hallways

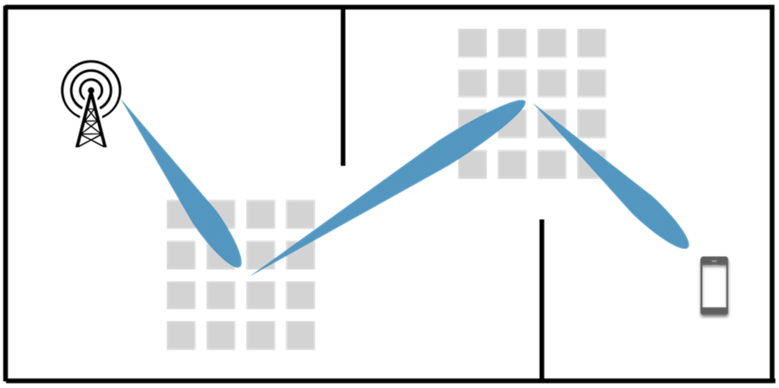

Figure 5.1-3: Cascading RIS links assist UEs to form links with BSs regardless of blockage

Figure 5.1-4 shows an outdoor scenario, in which a BS on the roof of a building needs to serve a UE in street canyon. Given the ordinary antenna radiation pattern, the downtilt angle, and the building blockage, the quality of service provided to the UE can be expected to be poor. Using a huge RIS installed on the wall of the opposite building can effectively reflect the signal to the blind spot, thus enhancing the cell coverage.

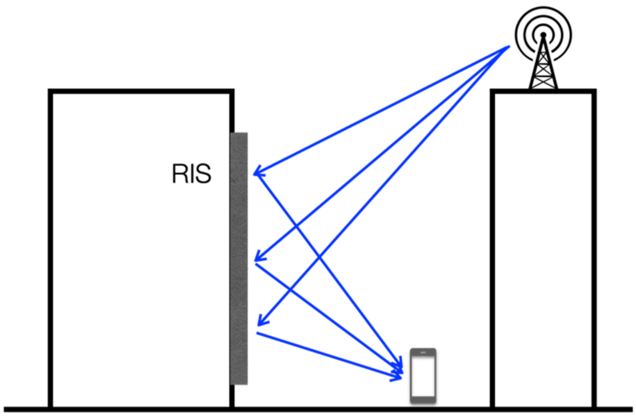

Figure 5.1-4: BS serves UE in street canyon using large RIS on building walls

Figure 5.1-5 shows an example coverage enhancement application of RIS in an Outdoor To Indoor (O2I) scenario, in which BS can serve UE in underground garage with the help of RIS links, given the extraordinary blockage and O2I loss.

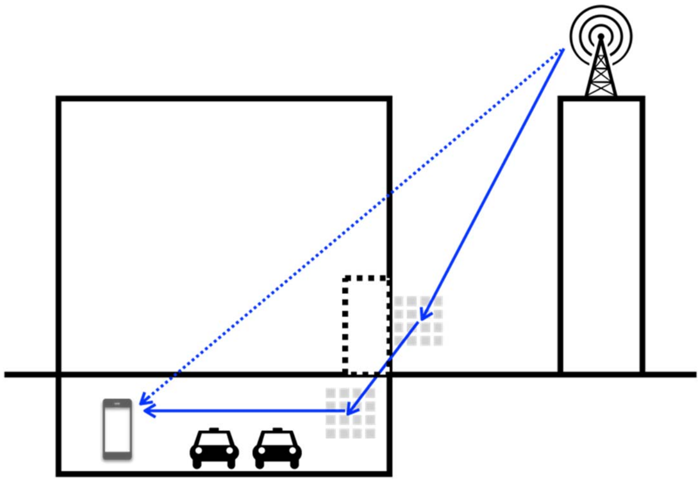

Figure 5.1-5: RIS application in an O2I scenario, in which BS serves UE in underground garage using RIS

5.2 Spectral efficiency

In wireless communication networks, channels between the transmitter antennas and the receiver antennas may have strong correlation, which limits the number of eigen channels for parallel data transmission. By deploying RIS, the channel correlation problem can be alleviated. With more eigen channels, the communication networks can obtain higher spatial multiplexing gains and spectral efficiency. In particular, the increased received signal power that enhances coverage also translates into increased spectral efficiency. However, there are several additional mechanisms by which a RIS may increase spectral efficiency. In various scenarios, for example at higher frequencies, the channel is often dominated by one or two paths. With the addition of a RIS, the available degrees of freedom in the channel increases, and the spatial multiplexing rank can be increased. Beyond improving the signal power and rank of the desired terminal, a RIS can also be used to suppress interference, e.g. co-channel and inter-cell interference. Just like a RIS is capable of signal boosting towards a certain area, a RIS may also be capable of signal nulling. The general link topology of these use cases is illustrated in Figure 5.2-1. In addition, as a configurable component that affects the communication channel, RIS potentially provides a new degree of freedom for multiple access. An example of RIS multiple access is demonstrated in Figure 5.2-2, in which different BS/UE links can utilize different sub-arrays on a RIS panel. It has been argued that adding a RIS may have beneficial effects on the channel distribution and rate of fading, for example from a fast-fading Rayleigh distribution without RIS to a slower-fading Rician distribution with RIS. Such effects may positively impact both spectral efficiency and reliability, for example through more efficient link adaptation.

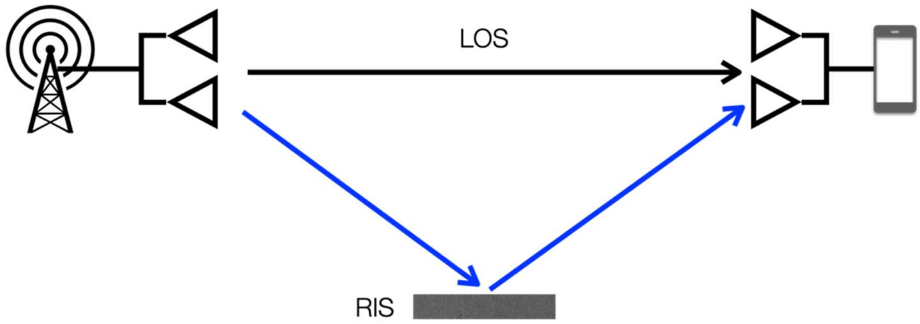

Figure 5.2-1: Utilizing RIS with MIMO: multiplexing and interference management

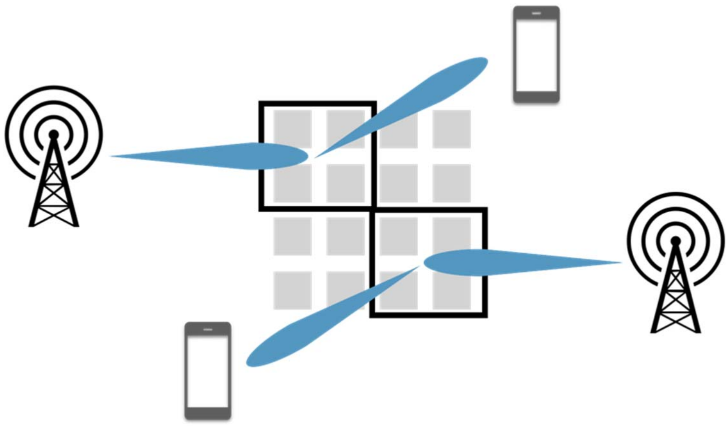

Figure 5.2-2: RIS multiple access

5.3 Beam management

In wireless communication systems such as NR, beam management is widely used to mitigate signal propagation losses during wireless transmission. Beam management is aimed at establishing and maintaining a set of beam pair links between the transmitter and the receiver, which can improve the system's spectral efficiency and provide a cost-effective solution with reliable coverage, especially in high frequency bands.

The RIS beamforming can be realized by adjusting element's reflecting angle. RIS will manage different group of elements pointed to different user and the signal strength of it will be proportional to the number of elements. Compared with massive MIMO, less power is used by RIS to reach a same beamforming gain. Similar to MIMO, a multiple-elements RIS can produce beams to focus the signal at specific users or towards certain directions. The reflective elements on RIS can send the same signal with equal wavelengths, therefore the targeted beam is provided with enhanced signal strength in a specific direction.

Beam management is one of the most essential blocks for aiding communication, particularly in higher frequency range such as FR2 (24,25 GHz - 71 GHz). Typically, multiple beams are configured by network and from the configured set of beams, one or more beams are indicated to the UE for downlink and/or uplink. Due to dynamic variables in the environment, the path between the BS and the UE(s) may be blocked and this may lead to the issue of beam blockage, more so in FR2. For this reason, multiple TRPs can be deployed by network to provide an additional/alternative set of beams from another TRP. However, deploying multiple TRPs require network planning and increased cost for network deployment. RIS can provide an alternative solution or further complement multiple TRP based deployment. RIS elements can be configured to adjust the properties of the reflecting signal in terms of phase, amplitude, polarization, etc. With optimal configuration, highly direction beams can be reflected from RIS towards the intended target receiver. Essentially, with RIS deployment, additional/alternative beams can be configured and dynamically indicated. Moreover, this can be done in both cost and energy efficient manner.

5.4 Physical layer security

The uncontrolled propagation of confidential signals caused by the uncertainty of wireless propagation channels is one of the reasons that affect the security of communication systems. Building an intelligent and controllable wireless propagation environment by deploying RIS can effectively avoid the leakage of confidential signals to eavesdroppers and improve the security of communication systems.

As is illustrated in an example scenario in Figure 5.4-1 without RIS, the data sent to a UE can be easily leaked to eavesdroppers via natural reflections by the wall, ceiling, etc. To solve this problem, RIS can redirect the reflections to a "trusted region", which hence reduces the data leakage to potential eavesdroppers and enhances the communication security.

RIS, as many other technologies with high potential for wireless applications, can also be deployed in malicious ways, that is, an eavesdropper may install a RIS to benefit from its capability to provide a strong wireless link towards a legitimate system, thus enabling the successful decoding of the legitimate transmitted data. In such cases, the adoption of only artificial noise transmissions by the legitimate system may be incapable of guaranteeing secrecy, necessitating also the consideration of a legitimate RIS.

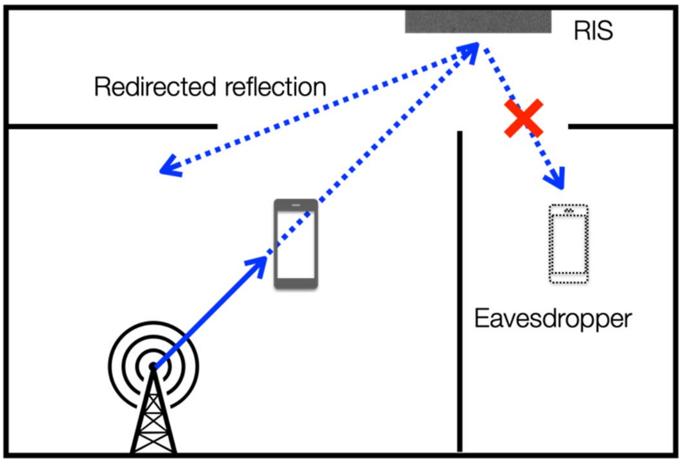

Figure 5.4-1: Utilizing RIS for secure communication

5.5 Localization accuracy

Positioning service is already available in the traditional wireless communication systems. However, the accuracy is limited by the location, availability of LoS and number of BS. Compared with deploying BS, deploying RIS is more flexible and the cost is lower. With the assistance of RIS, the communication networks can obtain higher spatial resolution and positioning accuracy. The positioning accuracy of indoor scenario can also be improved by the deployment of RIS.

5.6 Sensing capabilities

In the future 5G advanced and 6G wireless networks, many new applications strongly impose requirements on both the communication and sensing performance. The Integrated Sensing And Communication (ISAC) systems are envisioned as a promising technology where the network has the capability to collect and extract information from the environments. Generally, sensing mainly depends on the Line of Sight (LoS) link between the transmitter and the target for the cellular based ISAC system. It is quite challenging to sense targets without LoS connections. And in the legacy system, only either Base Station (BS) or User Equipment (UE) can be considered as valid entity to conduct the sensing operation. Such services are only available in the localized region and additional set-up (including RFs) may be required. Moreover, the sensing performance (e.g. localization) of BS will be decreased with the increase of target distance from the receiver. By deploying RIS, a LoS link can be established to provide the sensing service for the NLoS areas and an extra LoS reflected link can be provided by the RIS to sense the target from a different angle, thus the sensing performance of the RIS-assisted networks can be significantly improved. Further, the different type and capabilities of assisted RIS, e.g. the fully-passive RIS and the semi-active RIS, can be considered according to the different scenario requirements of the RIS-assisted ISAC systems.

5.7 Energy efficiency

5.7.1 Wireless power transfer

Wireless power transfer has been proposed to enhance the use time of devices powered by batteries. The RIS can realize the power transfer between the BSs and users when the signals are blocked between the transmitter and energy harvesting users. With the assistance of RIS, the users can not only receive the communication signal, but also the harvested energy from the RIS, permitting a reduction of transmit power and improving the energy efficiency.

5.7.2 Energy harvesting

Current wireless networks have been designed primarily for communications purposes, in turn allowing other use cases such as communications-based positioning. Therefore, in existing wireless networks, even low-power devices such as Internet of Thing (IoT) devices, wireless sensors, and Machine to Machine (M2M) type devices still rely on an external power source, e.g. a battery, for communication. Since radio waves can carry both information and energy, RIS is a promising component in self-sustained wireless networks because RIS can enhance both information and energy transfer performance. For example, RIS may be partitioned and some of RIS elements or partitions could be utilized for collecting radio-frequency energy from the environment, while other RIS elements or partitions could be used for aiding communication. Deployment of the RIS could be simplified, one of the main reasons is that it does not rely on external power source(s) if energy harvesting for RIS is possible. In some cases, RIS may be integrated onto IoT devices to harvest the energy and directly power such devices. Signal energy may also be focused to other devices for enhanced energy harvesting at the devices.

5.7.3 Power saving

With the highly demand data rate requirements of future wireless networks, the energy consumption has been a great concern. Many energy-efficient solutions have been developed to ensure green and sustainable wireless networks. The network performance in terms of coverage and data rates can be significantly improved by deploying RIS, less BS transmit power and fewer BSs would be required in the RIS-assisted scenario to achieve a given coverage or data rate target. RIS-assisted deployments can be an attractive solution to enhance network performance, while reducing network energy consumption and improving network energy efficiency compared with legacy amplify-and-forward relay solutions. Similarly, deploying RIS can also improve the energy efficiency of users considering the uplink transmission assisted by the RIS. In other words, RIS can be considered as an energy efficiency enabler for the future wireless communication networks.

The available RIS hardware architectures can be classified into passive, hybrid, semi-active and active types according to their capabilities to manipulate the impinging signal. A passive RIS consists of passive or nearly passive components that might not require dedicated power supply, enabling connectivity for massive connections with extremely low power consumption and minimal complexity. An active and semi-active RIS, on the other hand, may embed radio-frequency circuits, signal processing units or power amplifiers.

The RIS power consumption depends mainly on the type and resolution of its individual reflective elements. Both passive and active RIS are designed to consume less power than the traditional solutions such as micro BSs or relays. Although the active RIS requires additional power dissipation to support its active load impedance, its basic operating mechanism remains the same as that of passive RIS, directly reflecting the incident signal and making the required adjustments at electromagnetic level.

Using RIS as a part of new solution for indoor and outdoor radio access networks will help to reduce the power consumption of the network. Specifically, to provide coverage to a given area, RIS-assisted networks require less BSs to be deployed.

5.7.4 EMF exposure minimization

Another perspective of the power consumption is the ElectroMagnetic (EM) exposure to human bodies. There are requirements for arbitrary low EM thresholds for certain services and/or in certain areas, as required by some customers or the regulatory bodies of some regions. Thus, one of the potential requirements for next-generation networks is to limit the level of transmission power to meet requirements for low EMF exposure, while guaranteeing the network performance.

Using RIS as network nodes can help limiting EMF exposure in two different ways. Using RIS can help to provide coverage and enhance transmission without significantly increasing the transmission power of the network and/or the user equipment, and thus, limiting the EM exposure level around the BS and/or close to the UE. Certain optimization can also be carried out jointly for BSs and RIS to meet strict EM constraints in special deployment scenarios.

5.8 Link Management

5.8.1 Programmable Wireless Data Centers

Agile network management system in data centers can require advanced technological solutions, such as RIS, to alleviate the cabling cost and boil down the overall connection complexity. Each server placed in the data center is connected with a wireless connection component enabling communication via directive wireless propagation via the physical propagation elements of the RIS. RIS can be placed on the rear panel of the racks as well as walls and ceiling to dynamically and remotely control directive wireless communication links, e.g. TeraHertz or mmWave technologies, between different servers within a single rack i.e. intra-rack connection management, and between different racks, i.e. inter-rack connection management, as shown in Figure 5.8.1-1.

Given the daunting complexity of setting-up and controlling such a system, machine-learning-based approaches can be deployed to automate the multiple processes required in a systematic manner. This RIS-based solution can enable a new level of automation in data-centers (re-)configuration as well as resilience to hardware failures and upgrades.

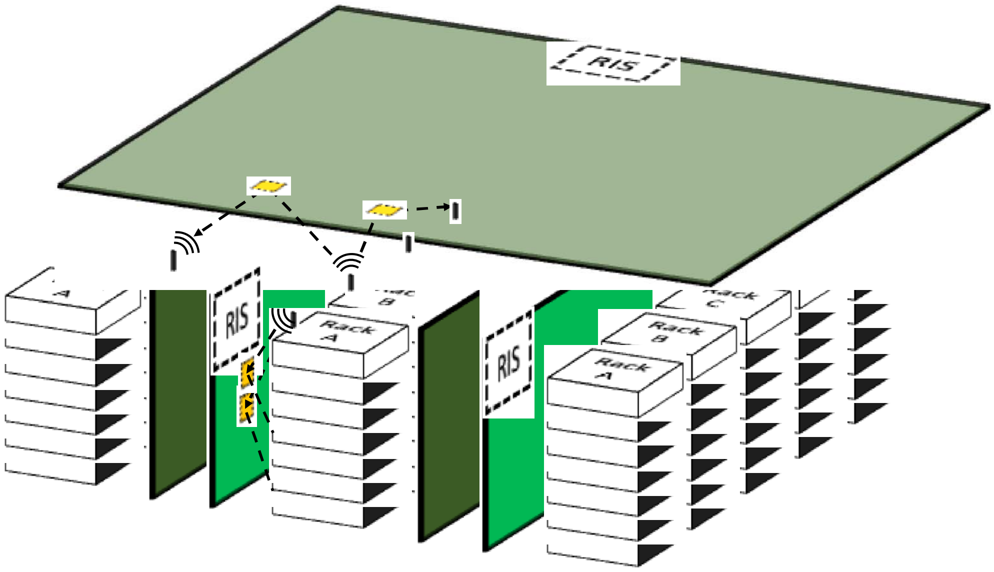

Figure 5.8.1-1: Programmable wireless data centers with RIS installed

6 Deployment scenarios

6.0 General description

Whilst there are clear benefits and capabilities offered by RIS, its deployment still remains on the conceptual level. RIS may require a very large number of unit-cells to achieve significant performance gains. This in turn renders the effective configuration of the RIS response in a dynamic fashion challenging. RIS may also require rapid channel sounding operations to estimate channels between the RIS, TRPs, and UEs. However equipping RIS with signal processing capabilities would increase the deployment cost due to hardware, but also reduces the attractiveness of RIS in terms of ease of deployment, as well as increasing the complexity of the algorithms and protocols needed for its seamless integration. It is therefore important to develop a clear understanding of where RIS may serve as an attractive deployment solution versus other technologies.

6.1 Operating environment

6.1.1 Indoor scenarios

For indoor scenarios, line-of-sight transmission cannot be guaranteed in some areas such as corridors, corners and stairs. In addition, shadow fading may be serious due to the influence of obstacles such as human bodies and furniture. Deploying RIS on the surface of walls or furniture can establish additional transmission links to improve coverage, increase received signal strength as well as SNR. Data rates can be improved for individual users and the overall system throughput can be improved as well. Indoor scenarios such as automated industrial factories may also benefit from the improvements in localization accuracy.

6.1.2 Outdoor scenarios

For outdoor scenarios, mobile terminals and UEs at the edge of the cell or in the shadow area may suffer serious propagation loss including path loss and shadow fading caused by obstacles such as buildings or trees. RIS can be deployed on the facade of the building or along with base stations to establish additional transmission links. In this way, the performance of these terminals can be significantly improved.

In outdoor environment, mobility can become more significant than indoor scenarios, especially considering that UEs on high speed trains can travel at a speed of 350 km/h. In this case, dynamically reconfigurable phase shift matrices on RIS are needed for fast beam tracking.

6.1.3 Hybrid scenarios

Hybrid deployment scenarios for RIS involve both indoor and outdoor environment, or describe a mixed environment which is hard to be characterized by any single scenario.

One example of hybrid scenario is the outdoor to indoor scenario. It is challenging for base stations deployed outdoors to serve indoor users due to the signal attenuation introduced by the walls or window glasses. The attenuation is more significant in FR2. One conventional solution is to deploy micro-BS inside the building, which is of high cost. In this scenario, RIS are placed on facades of buildings or are manufactured as transparent surfaces which can also be used as window glasses. The RIS placed on facades can reflect signals to indoor environment of another building. RIS used as window glasses, which are usually transparent, can focus the incident signals into certain areas in the room and achieve good coverage. The focus points of such transparent RIS can be pre-configured according to indoor environment or dynamically changed based on real-time demands.

6.2 RIS deployment

6.2.1 Static RIS

In a typical deployment, the RIS is mounted on a stationary structure, such as a building wall.

In such a deployment, the radio channel between a stationary base station and the RIS is largely static. The radio channel between the RIS and a UE as well as between the base station and the UE may experience fast fading due to movements at the UE side.

6.2.2 Nomadic RIS

6.2.2.0 Description

Nomadic deployment option assumes possibility for RIS to change its physical location or orientation in time. In some deployments, the RIS may be mounted on a non-stationary structure, such as a train or a vehicle. For nomadic deployment of RIS, multiple scenarios are considered depending on where the RIS is integrated including personal RIS, UE-integrated RIS, vehicle-integrated RIS.

In such a deployment, the radio channel between a stationary base station and the RIS as well as between the base station and the UE may experience fast fading due to a moving RIS and a moving UE. However, if the UE is moving with the non-stationary structure, for example if the UE is in the train, the radio channel between the RIS and UE may fade relatively slowly. On the other hand, if the UE is not moving with the non-stationary structure, the RIS to UE channel may fade rapidly as well.

6.2.2.1 Personal RIS scenario

In the personal RIS scenario, RIS is owned by an end-user, and the user can change the location of RIS based on his own preferences without asking a permission from the network and without notifying the network. Typically, personal RIS is a physically small device that is located in indoor areas, for example, home or office spaces. The deployment option of multiple personal RIS within the same indoor area could also be considered.

6.2.2.2 UE-integrated RIS scenario

In another scenario, RIS could be integrated into a user device, e.g. a mobile device. In this case, mobility of the device implies the mobility of RIS, including the dynamic change of both position and orientation.

6.2.2.3 Vehicle-integrated RIS scenario

Another common scenario for RIS deployment is placement of RIS on mobile vehicles such as cars, trains, buses, etc. In this case, the mobility of the vehicle determines the mobility of the RIS. Depending on the vehicle type, size, and location of operation, one or multiple RIS can be integrated onto vehicle's windows, roof, etc. Such nomadic RIS deployments could be facilitated by network operators, enterprise owners (operating the vehicles) and end-users (for personal vehicles).

6.3 RIS control plane

6.3.0 Description

The RIS control plane comprises a large set of functions, which run to trigger RIS configurations at different time scales and to acquire instantaneous RIS states. Control plane functions can be defined according to the RIS management as per the following categories:

i) BS Centralized management;

ii) BS Distributed management;

iii) autonomous RIS; and

iv) UE-controlled RIS.

The RIS control plane controls a set of RIS and is responsible for the channel quality improvement for the selected DL/UL/SL links in the dedicated area.

The following functionality can be supported by the RIS control plane:

1) Channel measurements between RIS and network nodes, between RIS and mobile devices.

2) Positioning measurements.

3) RIS control mode selection.

4) RIS configuration selection, providing the selected configuration to the RIS.

5) Gathering and conveying to the RIS controller the relevant status information of data and control planes (e.g. users data buffer states, traffic patterns, resource allocation decision, QoS information, etc.)

RIS control plane can allow the abstraction of logical functions from the underlying physical technology. In this architecture option, link layer may comprise of links implemented based on different physical/MAC technologies, operating on different bands (in-band, out-band), being wired or wireless. RIS control plane can implement a specific scheduling mechanism for signalling within the RIS control plane.

RIS control plane can comprise of functions to determine the optimal RIS management category and corresponding controlling node(s). When the control link between the current controlling node(s) and RIS are drastically changed, for example, due to channel variations, then the current RIS management category and/or controlling node(s) may not be optimal anymore. Therefore, updating the RIS management category and/or controlling node(s) can be performed by control plane functions. For example, as illustrated in Figure 6.3.0-1, in state 1, UE-controlled RIS is applied for RIS management and UE1 is controlling the RIS. In state 2, UE1 has moved away from the RIS, and the control link quality is degraded. Therefore, the RIS management category is updated to network-controlled mode (BS centralized/distributed management) and RIS is now controlled by BS1. This updated is supported by RIS control plane function. In state 3, another UE, UE2 has moved close to the RIS and provides the best control link quality. Therefore, RIS management category is updated to UE-controlled mode and RIS is now controlled by UE2.

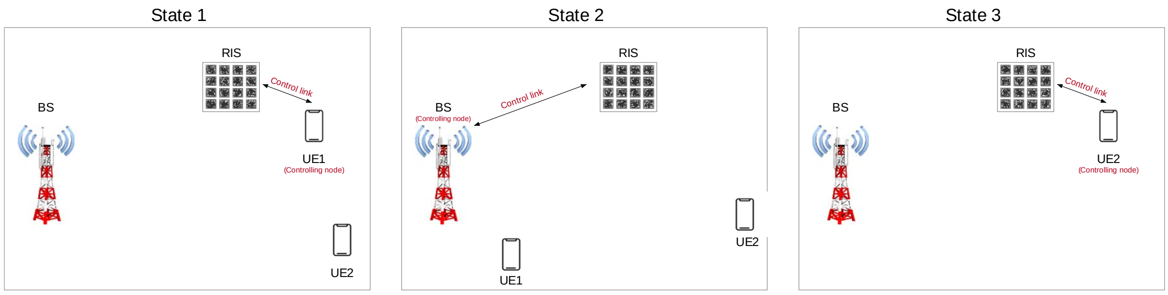

Figure 6.3.0-1: Illustration of updating the RIS management

Different criteria can be considered to determine whether the current management category and/or current controlling node needs to be updated.

6.3.1 Centralized management

Centralized management of RIS at the network side can assign and update one or multiple base stations to provide the necessary configuration for RIS. Essentially, the control plane is located at a central node, where the measurements and/or feedback information is processed, and corresponding decisions are made to update RIS configuration. Up on determining the updated RIS configurations, the central node shares the information with the BS(s) and instructs them to provide the updated configuration to RIS. In case of centralized management, coordination among the participating BS(s) is not necessary.

6.3.2 Distributed management

Distributed management of RIS at the network side is handled locally by the participating BS where the RIS control plane is located. The BS communicating with the RIS is responsible for processing the measurements and/or feedback information and making the decisions to update RIS configuration. For the distributed management, multiple BSs may communicate with RIS and in such cases coordination among the participating BS(s) is necessary to avoid any conflict. In addition, multiple RIS can be managed by multiple distributed BSs, based on cooperative schemes, in order to achieve the optimization of the network's system metric, such as improving the achievable sum-rate performance.

6.3.3 Autonomous RIS

Autonomous RIS is capable of optimizing the gain of a reflected beam between a base station and a user equipment without requiring dedicated control-plane functions.

Autonomous RIS can require power sensing capabilities, falling into the Hybrid RIS category, as per clause 4.2.3 of the present document.

Autonomous RIS can acquire a power profile through a sequential activation of probing beams. In particular, an autonomous RIS can obtain the angular position of the base station and the user equipment by identifying power profile peaks in the acquired power profile. The autonomous RIS can locally compute the optimal configuration and autonomously trigger it based on the angular positions.

6.3.4 UE-controlled RIS

In an indoor deployment scenario, RIS can be deployed as part of a personal network or local access network. The local access or personal network can be the one operating in unlicensed spectrum such as a WiFi® network or the one operating in licensed spectrum such as a Customer Premises Network (CPN) 3GPP TR 22.858 [i.1] or Personal Internet of Things Network (PIN) 3GPP TR 22.859 [i.2]. As CPN and PIN are identified as small-scale, personal networks within the coverage area of a public network, the personal network entities such as evolved Residential Gateway (eRG) for CPN and PIN element with management capability for PIN are responsible for network management and/or control aspects. For WiFi® networks, the WiFi® access point(s) that provide(s) the coverage is responsible for network management and control aspects. Moreover, it is expected that the UEs belong to these personal and local access networks may have either direct or indirect connections or both.

In the case of a RIS-integrated WiFi® network, the WiFi® access point may enable one of the UEs connected to the WiFi® network to control RIS in order to establish and maintain a connection with other UE(s) in unlicensed spectrum.

In the case of a RIS-integrated CPN, the eRG may enable one of the UEs belonging to the CPN to control RIS to establish and maintain a connection with other UE(s) within the CPN.

In the case of RIS-integrated PIN, the PIN element with management capability can enable one of the PIN Elements which can be a 3GPP or non-3GPP device to control RIS to establish and maintain a connection with other PIN Element(s) within the PIN.

In both cases for CPN and PIN, the eRG or PIN element with management capability can configure the RIS for a specific operating frequency range. In case of operating in a licensed spectrum, the initial authorization for operating in a licensed spectrum is needed to be provided by the network.

7 Requirements

7.1 Hardware Cost

A main motivation for RIS is the low cost compared to legacy deployment solutions such as full-stack cells, small base stations, relays, and repeaters. Therefore, a main requirement for RIS is the low hardware cost.

This can include (not limited to) the following costs:

a) production;

b) assembly;

c) components.

Productions costs can be significantly reduced via advanced printing techniques. Assembly costs depend on the circuit complexity. Multiple-substrates layout can bring additional complexity that, in turn, translates into higher assembly costs. Finally, RIS is supposed to adopt low-cost electronic components. Mostly, passive RIS require passive components that are supposed to be inexpensive.

Requirements related to hardware cost are summarized in Table 7.1-1.

Table 7.1-1: Hardware requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
Device cost	Lower cost than relays and repeaters	Including the cost of production, assembling and components
Signal processing	Analog and digital processing is required for advanced signal processing and channel estimation	Whether RIS needs to receive and demodulate the signals
RIS type	Active RIS, passive RIS, hybrid RIS	Depending on type of RIS, the hardware cost can vary

7.2 Ease of Deployment and Maintenance

The low total cost of a RIS is not only based on the low-cost hardware, but also on the low-cost deployment and maintenance. Therefore, deployment and maintenance of a RIS are required to be easy.

The ease of deployment includes such aspects as fixed/wireless backhaul (e.g. for control signalling), power supply, complexity of RIS setup, and others.

Requirements related to ease of deployment and maintenance are summarized in Table 7.2-1.

Table 7.2-1: Deployment and maintenance requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
RIS controller	Support cellular/WiFi®/Bluetooth®/RAT	Backhaul and control interface of RIS may impact the ease of deployment and maintenance
RIS power supply	Support passive mode/power cable/battery/energy harvesting	Maintaining and providing power supply
Mobility	Support deployment on vehicles/trains/UAVs	Whether a RIS can move and where it is mounted can also have an impact on the deployment and maintenance of RIS

7.3 Signal Power Boosting

Some of the important use cases for RIS include those targeted at coverage enhancement and increased spectral efficiency. For such cases, it is important that the RIS adds a path with sufficient gain compared to if the RIS was not deployed. Hence, the level of signal power boosting on the RIS-aided path compared to a baseline is an important requirement.

The signal power boosting level depends on many factors such as the size of the RIS, the number of RIS elements, the RIS configuration flexibility, and others.

Requirements related to power boosting for a given target area of influence of the RIS are summarized in Table 7.3-1.

Table 7.3-1: Power boosting requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
RIS dimensioning	The RIS path is expected to have comparable gains to the path without RIS	The size of RIS and the number of elements impacts the power boosting capability of the RIS
Re-radiation power amplification	Active if the signal needs to be significantly boosted	Whether power amplifiers are active or not impacts the power boosting capability for RIS
Efficiency	-2 dB	The RIS hardware power loss between input and output signals

7.4 Reconfigurability

An essential aspect of a RIS is the reconfigurability property. The RIS configuration may be provided by an external entity such as a base station or a UE, or autonomously by the RIS controller itself.

The RIS configuration may be static, for example if a RIS is deployed to extend coverage to a coverage hole. To achieve even better performance, the RIS configuration should be optimized for the served UE(s). To this end, dynamic and/or semi-static RIS reconfiguration is needed, since a served UE may move and since multiple UEs may be served by a RIS.

Therefore, reconfigurability requirement can include the following aspects:

a) rate;

b) resolution;

c) scope.

Reconfigurability rate identifies the time from one triggered configuration to the next one. It can range between being very high, e.g. below 1 ms, and very slow or quasi-static, e.g. above tens of seconds. Resolution identifies the types and the number of available configurations the controller can trigger. It can be defined according to the size of the communication bus, e.g. number of bits. Finally, reconfigurability scope can specify the number of antenna elements or cells the controller can configure simultaneously.

Requirements related to reconfigurability are summarized in Table 7.4-1.

Table 7.4-1: Reconfigurability requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
Configuration flexibility	1-3 bits	The granularity of RIS phase shifters
Polarization	Single or dual polarization	RIS could be polarization sensitive or insensitive, or even transform polarization
Reconfiguration rate	Ranging from quasi-static configuration to symbol-level reconfiguring rate	The rate of changing RIS configuration
Reconfiguration latency	Compatible with the scheduler	The delay of applying RIS configuration
Number of supported configurations/codebooks	Example codebook size is 16 (4 bits)	Equal to bits supported by the communication bus
Number of RIS elements configured simultaneously	The total number of existing RIS elements can range from 10 s to more than 1 000	The number of independently configurable RIS elements, depending on the total number of RIS elements and the RIS partitioning (e.g. some existing RIS is configured column-wise)

7.5 Interoperability

An important requirement for RIS is interoperability with different network operators and users. In addition to RIS deployment by network operators, RIS may also be deployed by third part enterprises or end-users. Therefore, it is crucial for RIS to provide its essential capability requirements to allow for interoperability.

Requirements related to interoperability are summarized in Table 7.5-1.

Table 7.5-1: Interoperability requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
Carrier frequency	FR1/FR2/sub-THz/THz	
Bandwidth	Hundreds of MHz to GHz	
Operating mode	Reflection/transmission can be supported	
Duplex mode	Full-duplex	
Unlicensed Operation	Supported or not	
Reciprocity	Uplink and downlink reciprocity	

7.6 Regulatory requirements

Based on the regional or standards regulations, it is necessary to also provide the necessary requirements for RIS.

Regulatory requirements are summarized in Table 7.6-1.

Table 7.6-1: Regulatory requirements for RIS and corresponding aspects of design

Requirements	EXAMPLE values and configurations	Comments
Electromagnetic field exposure	Subject to corresponding standards	
Maximum EIRP in unlicensed bands	If unlicensed operation supported	For RIS to operate in unlicensed bands, separate/reduced EIRP limits might be needed based on regulatory and standards requirements

History

Document history		
V1.1.1	April 2023	Publication