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Reconfigurable Intelligent Surfaces (RIS); Technological challenges, architecture and impact on standardization

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 and includes the information on:

- The technological challenges to deploy RIS as a new network entity.
- The potential impacts on internal architecture, framework and the required interfaces of RIS.
- The potential impacts on architecture, framework and the required interfaces of RIS-integrated network.
- The potential recommendations and specification impacts to standardization to support RIS as a network entity.

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] ETSI EG 203 336 (V1.2.1): "Guide for the selection of technical parameters for the production of Harmonised Standards covering article 3.1(b) and article 3.2 of Directive 2014/53/EU".

[i.2] 3GPP TR 22.858: "Study of enhancements for residential 5G".

[i.3] 3GPP TR 22.859: "Study on Personal Internet of Things (PIoT) networks".

[i.4] ETSI TS 122 261: "5G; Service requirements for the 5G system (3GPP TS 22.261)".

[i.5] ETSI GR RIS 001: "Reconfigurable Intelligent Surfaces (RIS); Use Cases, Deployment Scenarios and Requirements".

[i.6] ETSI GR RIS 003: "Reconfigurable Intelligent Surfaces (RIS); Communication Models, Channel Models, Channel Estimation and Evaluation Methodology".

[i.7] ETSI TS 138 401: "5G; NG-RAN; Architecture description (3GPP TS 38.401)".

[i.8] ETSI TS 138 300: "5G; NR; NR and NG-RAN Overall description; Stage-2 (3GPP TS 38.300)".

[i.9] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC Text with EEA relevance.

[i.10] IEC 61000-4-2: "Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test".

[i.11] IEC 61000-4-3: "Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test".

[i.12] IEC 61000-4-4: "Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test".

[i.13] IEC 61000-4-5: "Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test".

[i.14] IEC 61000-4-6: "Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test".

[i.15] IEC 61000-4-11: "Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase".

[i.16] CISPR 32: "Electromagnetic compatibility of multimedia equipment - Emission requirements".

[i.17] Recommendation ITU-R SM.329: "Unwanted emissions in the spurious domain".

[i.18] IEC 61000-3-2: "Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)".

[i.19] IEC 61000-3-12: "Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase".

[i.20] IEC 61000-3-3: "Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection".

[i.21] IEC 61000-3-11: "Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

micro-controller: entity that determine the response of RIS in the electromagnetic domain according to control information from RIS controller

RIS: entity that consists of a large number of RIS Elements and micro-controller

NOTE: The incoming signal on RIS from any direction can be shaped to any direction (including absorption) in a programmable/controllable manner.

RIS controller: entity that generates/deliver the control information to RIS (see the illustration in clause 4.1).

NOTE: Depending on the considered deployment scenario and controlling type (see clause 4.2), RIS Controller can be co-located with a network node or co-located with RIS.

RIS element: entity that facilitates shaping/tuning incoming signals/reflection coefficients

3.2 Symbols

Void.

3.3 Abbreviations

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

AoD	Angle of Departure
BS	Base Station
CPN	Customer Premises Networks
CSI	Channel State Information
CU	Central Unit
DU	Distributed Unit
EIRP	Effective Isotropic Radiated Power
LMF	Location Management Function
LOS	Line Of Sight
MIMO	Massive Input Massive Output
MU-MIMO	Multiple-Users Massive Input Massive Output
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PIN	Personal Internet of things Networks
PRAS	Premises Radio Access Station
PRS	Positioning Reference Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RIS	Reconfigurable Intelligent Surfaces
RSRP	Reference Signal Received Power
RSTD	Reference Signal Time Difference
SRS	Sounding Reference Signal
TCI	Transmission Configuration Indication
TDM	Time Division Multiplexing
UE	User Equipment
UL	Up Link

4 Deployment scenarios and operation modes

4.1 Deployment scenarios of RIS

The deployment of RIS refers to the integration of a new type of system node with reconfigurable surface technology, where its response can be adapted to the status of the propagation environment through control signalling.

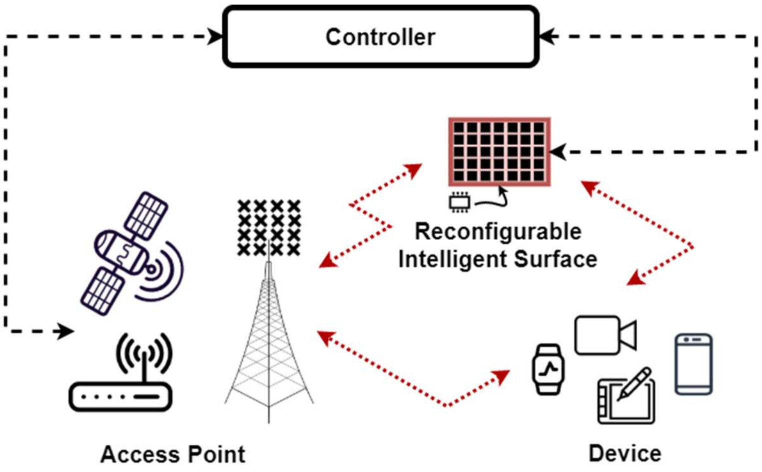


Figure 4.1-1: Illustration of deployment scenario of RIS

Deployment scenarios are determined by the user application trends and business models, as well as the maturity of RIS technologies. In ETSI GR RIS 001 [i.5], several key deployment scenarios are summarized, including indoors, outdoors, and hybrid scenarios. RISs can be deployed in a static manner, as well as a nomadic manner, serving different use cases such as vehicular communications.

4.2 Controlling type of RIS

4.2.1 Network-controlled RIS

In the network-controlled mode, the network determines the control information, which is used to control and configure RIS, based on the collected information from UE and/or RIS. The "RIS controller" may also collect data from UE and/or RIS itself and provide the collected data to the network. The "RIS controller" is deployed and owned by the network.

4.2.2 Network-assisted RIS

In the network-assisted mode, the network provides certain feedback or assistance information to the "RIS controller". The "RIS controller" can be either deployed and owned by the network or separately deployed as an authorized 3rd party component. The "RIS controller" collects information from UE and/or RIS itself. The "RIS controller" then utilizes the assistance information provided by the network and configures the RIS based on the collected information from UE and/or RIS itself.

4.2.3 Standalone RIS

In the standalone RIS controller, the "RIS controller" determine the control information, which is used to control and configure RIS, based on the collected information from UE and/or RIS itself. The "RIS controller" can be either deployed and owned by the network and can be pre-configured by the network or separately deployed as an authorized 3rd party component.

4.2.4 UE-controlled RIS

In the UE-controlled RIS, the UE determine the control information, which is used to control and configure RIS via the "RIS controller". The "RIS controller" can be either deployed and owned by the network operator or separately deployed as an authorized 3rd party component. The network authorizes the UE to configure the RIS for a specific operating frequency range including licensed and unlicensed spectrum. The UE either pre-configures the RIS or (re)configures via the "RIS controller".

4.2.5 Hybrid-Controlled RIS

In the hybrid-controlled RIS, the "RIS controller" could be split into "remote RIS controller" and "local RIS controller". The "remote RIS controller" is deployed at a part of network or the controlling UE(s) or at an authorized 3rd party entity, while the "local RIS controller" is supposed to be deployed at the RIS microcontroller (as defined in clause 5.1). The owner of the RIS control functionality can decide to split it between the remote and local entities in order to reduce the latency and communication overheads of the dynamic RIS control. The owner of the RIS control function can decide which information from the UE(s) and RIS side will be collected by the "local RIS controller" or by the "remote RIS controller". Optionally, the "remote RIS controller" can instruct the served UEs to provide assisting information to the "local RIS controller".

4.3 Capability aspect of RIS

In this clause, the general capability aspect of RIS and RIS controller according to the different controlling types in clause 4.2 is shown as follows:

- Network-controlled RIS:
    - In the network-controlled mode, the control information is fully determined by the network, the RIS only needs to be capable of tuning the coefficients and properties of RIS elements according to the control information. As for the RIS controller, it needs to receive the control information from the network and may need to feedback to the network. The RIS controller should be capable of:
        - receiving control signals from the network;
        - (optionally) transmitting signals to the network;
        - reconfiguring the coefficients of RIS elements.
- Network-assisted RIS:
    - In the network-assisted mode, the capability of RIS panel is same as the above. While for the RIS controller, in addition to receiving the control information from the network, the RIS controller can collect data and perform calculations to configure the RIS. In this case, the capability of RIS controller includes the following:
        - receiving control signals from the network;
        - reconfiguring the coefficients of RIS elements;
        - limited processing and calculating capability;
        - collecting data from UEs/RISs.
- The standalone RIS:
    - In the standalone mode, higher capabilities are needed since the control information is determined by the RIS controller. In this case, the capabilities of RIS may include the following aspects:
        - tuning the coefficients and properties of RIS elements;
        - (optionally) sensing capability (e.g. power sensing, location sensing).
    - As for the RIS controller in this mode, the RIS controller may be capable of:
        - reconfiguring the coefficients of RIS elements;
        - collecting data from UEs/RISs;
        - basic data processing and calculation.
- UE-controlled RIS:
    - In the UE-controlled mode, the control information is determined by UE. In this case, the capability of RIS can consider the following aspects:
        - tuning the coefficients and properties of each RIS elements.
    - As for the RIS controller, following capabilities aspects should be considered:
        - receiving signals from the network (e.g. initial configuration information or information of authorized UEs);
        - reconfiguring the coefficients of RIS elements;
        - receiving control signals from authorized UEs.

In addition to the RIS capability aspects for specific RIS types, as described above, additional capability aspect of RIS related to mode of operation can be considered. Depending on the RIS elements and its hardware capabilities, RIS can further report to the controlling node on whether it supports multi-functional mode of operation or not. If RIS supports multi-functional mode of operation, then it can further report specific modes, for example:

- Reflection mode.
- Refraction mode.
- Absorption mode.

Based on the reported capability for operating modes, the related control information described in clause 7.2.1 can be impacted. In case if multi-functional mode is not supported by RIS, then no additional control information signalling would be needed for operating mode indication.

4.4 Complexity aspect of RIS

The complexity aspect of RIS is related to the capability of RIS, the structure architecture, etc. As analysed in the above clause, the capability of RIS panel for the network-controlled type, network-assisted type and UE-controlled type is mainly to tune the coefficients and properties of RIS elements according to the configuration from the RIS controller, thus the complexity of these three type of RIS mainly depends on the structure architecture, hardware implementation and other aspects. While for the standalone RIS, the control information is determined by the RIS controller itself, which may require the RIS element to be configured with the sensing capability, thus to increase the complexity of RIS itself.

As for the complexity aspect of RIS controller, for network-controlled RIS and UE-controlled RIS, the RIS controller only needs to receive the control information from the network or UE and configure the RIS element according to the control information, while the RIS controller of network-assisted and standalone RIS may need additional processing and calculating capability, which causes higher complexity.

Table 4.4-1 below illustrates the complexity aspect of the four different controlled type of RIS.

Table 4.4-1: Complexity aspect of different controlled type of RIS

RIS Controlling Type	Complexity aspects of RIS	Complexity aspects of RIS Controller
Network-controlled RIS	Depends on the structure and implementation of RIS panel	Low
Network-assisted RIS	Depends on the structure and implementation of RIS panel	Medium
Standalone RIS	High, and also depends on the structure and implementation of RIS panel	High
UE-controlled RIS	Depends on the structure and implementation of RIS panel	Low

4.5 Regulation aspects of RIS

4.5.1 Regulatory aspects of RIS according to Directive 2014/53/EU

As RIS are specified as radio components of radio communication networks, they will be regarded as radio equipment to which the European Directive 2014/53/EU [i.9] (known as Radio Equipment Directive, RED) applies.

Reminder:

NOTE 1: Article 3.1(b) of Directive 2014/53/EU [i.9] states:

> *"Radio equipment shall be constructed so as to ensure….an adequate level of electromagnetic compatibility as set out in Directive 2014/30/EU."*

NOTE 2: Article 3.2 of Directive 2014/53/EU [i.9] states:

> *"Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference."*

As the basic RIS promise is to manipulate electromagnetic attributes in a wanted way, there is a need to consider RED essential requirements in particular. Thus, the following radio parameters are of interest according to ETSI EG 203 336 [i.1].

Table 4.5.1-1: RIS related essential requirements

ETSI EG 203 336 [i.1]	Essential RF parameter of interest	RIS correspondence
5.2.2	Transmitter power limits	Reflected/penetrated (see note 2) signal power limits
5.2.3	Transmitter power accuracy	To be defined if RIS offers power control capabilities
5.2.4	Transmitter spectrum mask	Reflected/penetrated signal spectrum mask
5.2.5	Transmitter frequency stability	To be defined if RIS offers carrier frequency manipulation capabilities
5.2.6	Transmitter intermodulation attenuation	Reflected/penetrated signal quality
5.2.7	Transmitter unwanted emissions	Reflected/penetrated unwanted emissions (incl. out of band and spurious domain emissions)
5.2.8	Transmitter time domain characteristics	NA
5.2.9	Transmitter transients	NA
5.3	Receiver parameters	NA (see note 1)
NOTE 1: Receiver parameters are not to be considered, as RIS does not offer dedicated reception performance, however, if so, its performance is sufficiently determined by above listed reflected (or repeated) signal performance, as the sole goal of it is the reconfigurable reflection (or repetition) of the impinging radio signal. NOTE 2: Depending on the deployment scenario the RIS is either configured to reflect the wanted impinging signal or to penetrate to its back when applied as transparent surface.		

4.5.2 Functional test approach consideration

In table 4.5.1-1 listed essential requirements can be assessed (i.e. tested) in default RIS operation mode, i.e. while illuminated by a wanted signal of interest and optional co-channel, adjacent channel or out of band interference.

By default, measurements are done over the air, i.e. in an appropriate anechoic environment using dedicated feeds and measurement probes in terms of frequency range, bandwidth and measurement sensitivity and quality.

Figure 4.5.2-1 depicts the principle RIS performance assessment setup. The impinging wave, provided by a wanted signal feed over the air, will be reflected by the RIS under test in a wanted way. The essential requirement parameters are evaluated at the maximum of the reflected wave in terms of EIRP. This is called maximum reflected EIRP (Max R-EIRP). The maximum reflected EIRP is composed of all N components (e.g. RIS unit cells) involved, determined by the impinging wave path g_n, the reflection coefficient $\alpha_n e^{j\theta_n}$ and the reflecting wave path h_n.

The feed of wanted and interfering signal is for further study and depends on the RIS use cases to be considered for regulatory performance assessment. Furthermore, unwanted emission assessment cannot be limited to the wanted reflecting angle only.

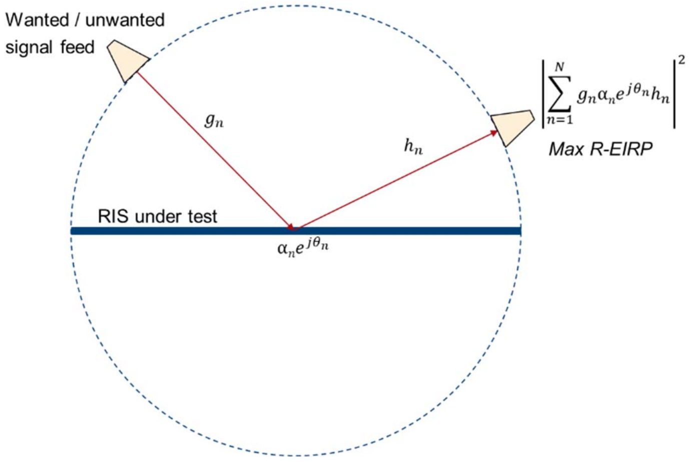


Figure 4.5.2-1: Principle RIS OTA assessment setup

4.5.3 Electromagnetic compatibility

According to Directive 2014/53/EU [i.9] mentioned in clause 4.5.1, electromagnetic compatibility is one of an important issue of RED. Therefore all of the radio equipment should pass the EMC test before being used. EMC test can be separated into Electro-Magnetic Interference (EMI) and Electro-Magnetic Susceptibility (EMS), in which EMI will test the disturbance generated by the equipment and EMS will test the behaviour of equipment under disturbance.

As the RIS will work under complicated electromagnetic environment, the EMC test is necessary to be considered and implemented. Table 4.5.3-1 illustrates the EMC test and its corresponding standard.

Table 4.5.3-1: RIS related EMC test

EMC Test	Related standard
Electro-Magnetic susceptibility EMS	
Electrostatic discharge immunity test (ESD)	IEC 61000-4-2 [i.10]
Radiated, radio-frequency, electromagnetic field immunity test (RS)	IEC 61000-4-3 [i.11]
Electrical Fast Transient/burst immunity test (EFT)	IEC 61000-4-4 [i.12]
Surge immunity test (Surge)	IEC 61000-4-5 [i.13]
Immunity to conducted disturbances, induced by radio frequency fields (CS)	IEC 61000-4-6 [i.14]
Voltage dips, short interruptions and voltage variation immunity tests	IEC 61000-4-11 [i.15]
Electro-Magnetic Interference EMI	
Radiated emission (RE)	CISPR 32 [i.16]
Radiated Spurious Emission (RSE)	Recommendation ITU-R SM.329 [i.17]
Conducted Emission (CE)	CISPR 32 [i.16]
Harmonic current emission	IEC 61000-3-2 [i.18] or IEC 61000-3-12 [i.19]
Voltage fluctuations and flicker	IEC 61000-3-3 [i.20] or IEC 61000-3-11 [i.21]
NOTE 1: The standards above are all basic standard (Testing and measurement techniques), which does not include the test limits. All of the test limits can be found from generic standard or corresponding product standard. NOTE 2: The Radiated test for RISs working under high frequency (FR2) are tested under Over The Air (OTA) environment. NOTE 3: Some EMC test method for RISs would be a bit different compared with traditional method especially for passive and hybrid RIS.	

5 Technological aspects of RIS entity

5.1 Functional module

The RIS as a whole can be modelled as the combination of at least a RIS controller and a RIS panel.

The RIS panel comprises of a group of elements, which have the capability to change the at least one of the properties of the incident radio waves including frequency, amplitude, phase and polarization. The radio wave can be at least reflected or transmitted to another direction after hitting the RIS panel, depending on the design of RIS.

The RIS micro-controller refers to a component of RIS, responsible for configuring the RIS elements to achieve a wanted way of manipulation of the incident radio wave, potentially processing any signalling received from another network node. The configuration of RIS element by the micro-controller is conveyed through control signalling from RIS controller shown in Figure 5.1-1.

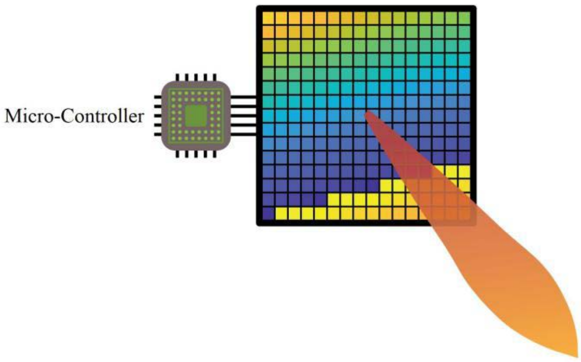


Figure 5.1-1: Illustration of a RIS comprising a micro-controller and a panel

5.2 Internal architecture and interface for RIS

5.2.1 Structure architectures for RIS

5.2.1.0 General

The major two components of the RIS are the micro-controller and RIS panel.

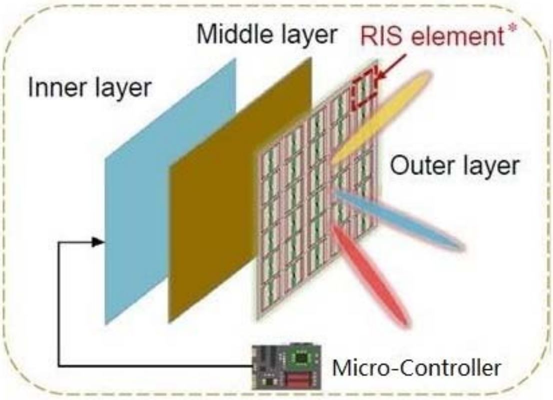


Figure 5.2.1.0-1: Illustration of RIS inner structures

The RIS panel can be modelled as a multi-layered surface where each layer is designed to achieve different functions. An example of a simple design of a three-layered reflective RIS panel is given in Figure 5.2.1.0-1. The outer layer comprises of a large number of elements, typically arranged in a form of two-dimensional arrays. The elements are usually made of small squared thin metal plates. The middle layer is intended to stop the incident radio wave from penetrating the panel, and is usually made of copper. The inner layer is connected to the RIS micro-controller and usually comprises of control circuits, which can take the power level from RIS micro-controller as input, and upon that specific power level equivalently change the response of the circuit so that the corresponding elements on the outer layer will pose a specific change on the incident radio wave.

Inside RIS, one interface is the interface between the RIS micro-controller and RIS panel to transmit the control signals.

5.2.1.1 Impedance-based structures

5.2.1.1.0 General

A RIS can be implemented at least through a single-connected or a multi-connected structure. While in a single-connected RIS structure the RIS elements are not interconnected to each other, in a multi-connected RIS structure, a RIS element is connected to other RIS elements, for example through a switch array or with fixed connections. The connections between the RIS elements may be equipped with additional impedance units. A signal impinging on a RIS element may be reflected from another RIS element or from multiple RIS elements by relying on the directional impedance network. The switch grid or fixed connections would introduce additional complexity in terms of design and configuration compared to a single-connected RIS but would provide additional degrees of freedom for tuning of the impinging signals. Some example applications of multi-connected RIS may include simultaneously transmitting and reflecting RIS and coverage extension, e.g. signal impinging on one side refracted from the back side.

5.2.1.1.1 Single-connected structure

In a single-connected RIS, each element is connected to a single impedance unit, where each impedance unit is not connected to other impedance units in the RIS. An example of a single-connected RIS structure with $N = 4$ elements and $N = 4$ RIS elements is shown in Figure 5.2.1.1.1-1. Here, RIS elements 1, 2, 3 and 4 are separately connected to impedance units Z_1, Z_2, Z_3 and Z_4, respectively.

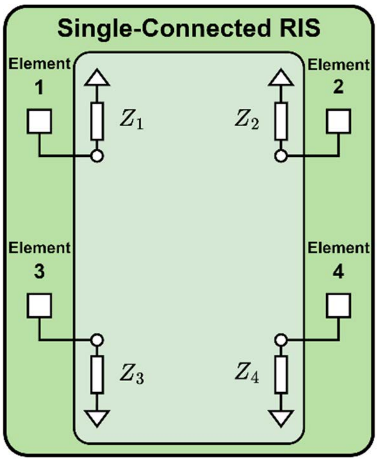


Figure 5.2.1.1.1-1: Single-connected impedance-based RIS structure

A signal impinging on RIS element 1 is reflected (from the same element) with a reflection coefficient θ_1 based on impedance Z_1. Similarly, signals impinging on elements 2, 3 and 4 are reflected with reflection coefficients θ_2, θ_3 and θ_4 based on impedances Z_2, Z_3 and Z_4, where the reflection matrix is given by the diagonal matrix $\mathbf{\Theta}$:

$$\mathbf{\Theta} = \begin{bmatrix} e^{j\theta_1} & 0 & 0 & 0 \\ 0 & e^{j\theta_2} & 0 & 0 \\ 0 & 0 & e^{j\theta_3} & 0 \\ 0 & 0 & 0 & e^{j\theta_4} \end{bmatrix}$$

5.2.1.1.2 Permutation-connected structure

Permutation-connected RIS architecture can be operated with non-diagonal phase matrices to direct signals impinging on a given element from another of the connected elements. An example of a permutation-connected RIS structure with $N = 4$ RIS elements is shown in Figure 5.2.1.1.2-1.

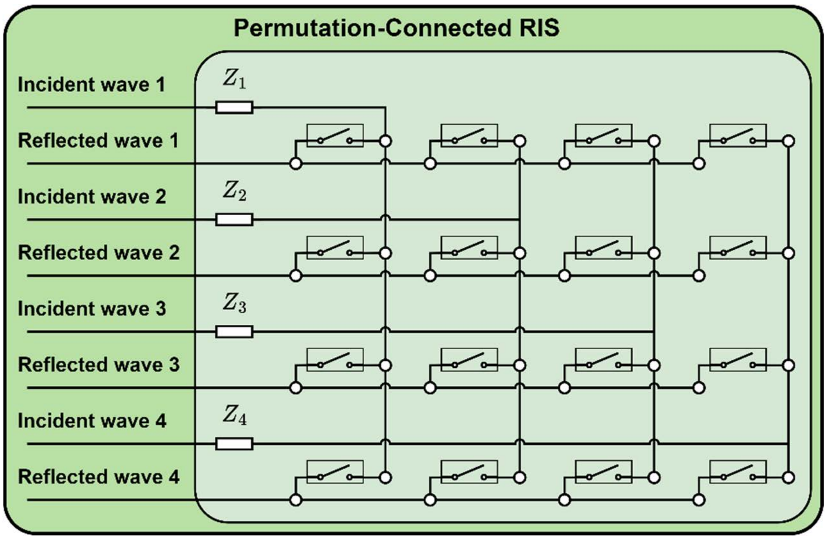


Figure 5.2.1.1.2-1: Permutation-connected impedance-based RIS structure

For example, consider a permutation-connected RIS structure with $N = 4$ elements with a phase matrix:

$$\mathbf{\Theta} = \begin{bmatrix} 0 & 0 & e^{j\theta_{1,3}} & 0 \\ 0 & 0 & 0 & e^{j\theta_{2,4}} \\ e^{j\theta_{3,1}} & 0 & 0 & 0 \\ 0 & e^{j\theta_{4,2}} & 0 & 0 \end{bmatrix}$$

where the coefficient $e^{j\theta_{3,1}}$ is at the 3rd row and the 1st column, meaning that the signal impinging on element 3 is directed to (and reflected from) element 1 with phase shift $\theta_{3,1}$.

5.2.1.1.3 Fully-connected structure

The fully-connected RIS structure is obtained by connecting every RIS element (or port) to all other ports through tunable impedance components. In the case of a lossless and reciprocal fully-connected RIS, the reflection matrix $\mathbf{\Theta}$ is a complex symmetric unitary matrix, i.e.:

$$\mathbf{\Theta} = \mathbf{\Theta}^T, \mathbf{\Theta}^H\mathbf{\Theta} = \boldsymbol{I}.$$

Since every RIS element is connected to ground and to all other elements, the circuit complexity of a fully-connected RIS (i.e. the number of tunable impedance components) is given by $C^{\text{Fully}} = N(N+1)/2$. The fully-connected RIS has the most general constraint on $\mathbf{\Theta}$ and achieves the highest flexibility. This is enabled by the circuit topology, which is characterized by the highest complexity since every RIS port is connected to all other ports. An example of a 4-element fully-connected RIS is shown in Figure 5.2.1.1.3-1. Here, the RIS element i is connected to ground through the impedance Z_i, and the RIS elements i and j are interconnected through the impedance $Z_{i,j}$.

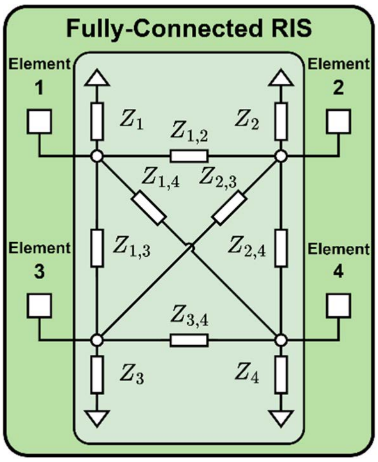


Figure 5.2.1.1.3-1: Fully-connected impedance-based RIS structure

5.2.1.1.4 Group-connected structure

The group-connected RIS structure constitutes a trade-off between the single-connected and the fully-connected to achieve a favourable trade-off between flexibility and complexity. In a group-connected RIS, the N elements are divided into G groups, each including $N_G = N/G$ elements. Each element is connected to all other elements within its group through a tunable impedance component, while there is no connection between elements in different groups. Thus, for a lossless and reciprocal group-connected RIS, the reflection matrix $\boldsymbol{\Theta}$ is a block diagonal matrix given by:

$$\boldsymbol{\Theta} = \mathrm{diag}(\boldsymbol{\Theta}_1, \boldsymbol{\Theta}_2, \dots, \boldsymbol{\Theta}_G),$$
$$\boldsymbol{\Theta}_g = \boldsymbol{\Theta}_g^T, \boldsymbol{\Theta}_g^H \boldsymbol{\Theta}_g = \boldsymbol{I}, \forall g,$$

showing that each block $\boldsymbol{\Theta}_g$ is a complex symmetric unitary matrix, for $g = 1, \dots, G$. Since the group-connected architecture is composed of G fully-connected architectures with N_G elements each, its circuit complexity is given by $C^{\text{Group}} = N(N_G + 1)/2$, depending on the group size N_G. Remarkably, the single- and fully-connected are two cases of group-connected RIS, i.e. with group size $N_G = 1$ and $N_G = N$, respectively. An example of an 8-element group-connected RIS with group size $N_G = 4$ is shown in Figure 5.2.1.1.4-1.

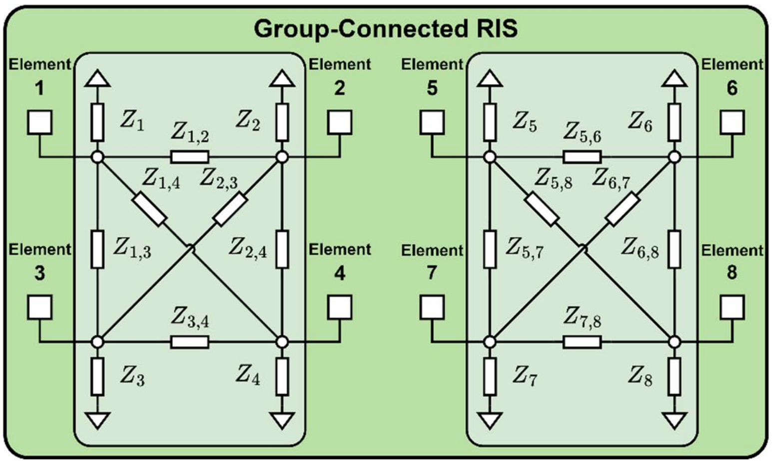


Figure 5.2.1.1.4-1: Group-connected impedance-based RIS structure

5.2.1.1.5 Tree-connected structure

In the tree-connected RIS structure, the RIS elements are connected to each other such that the graph having as vertices the RIS elements and as edges the impedance components is a tree (i.e. it is a connected and acyclic graph). Any tree-connected RIS is proved to achieve the same received signal power in a SISO system as the fully-connected RIS, while having significantly less tunable admittance components in its circuit topology. In addition, the tree-connected RIS structure is proved to be the least complex RIS structure achieving the same performance as the fully-connected RIS structure in SISO systems. Since every RIS element is connected to ground, and there are $N - 1$ interconnections between the RIS elements, the circuit complexity of a tree-connected RIS is $C^{\text{Tree}} = 2N - 1$. An example of a 4-element tree-connected RIS is shown in Figure 5.2.1.1.5-1.

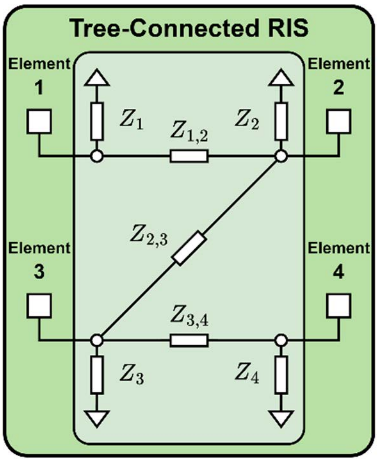


Figure 5.2.1.1.5-1: Tree-connected impedance-based RIS structure

5.2.1.1.6 Forest-connected structure

The forest-connected RIS structure has been proposed as a trade-off between the single-connected and the tree-connected to trade flexibility and complexity. In a forest-connected RIS, the N elements are divided into G groups, each having $N_G = N/G$ elements. The elements within each group are connected with each other through a tree-connected structure, while there is no connection inter-group. Forest-connected RIS can reach the same received signal power in a SISO system as group-connected RIS with the same group size, but with significantly reduced circuit complexity. Since the forest-connected architecture is composed of G tree-connected architectures with N_G elements each, its circuit complexity is given by $C^{\text{Forest}} = N(2 - 1/N_G)$, depending on the group size N_G. Remarkably, the single- and tree-connected are two cases of forest-connected RIS, i.e. with group size $N_G = 1$ and $N_G = N$, respectively. An example of an 8-element forest-connected RIS with group size $N_G = 4$ is shown in Figure 5.2.1.1.6-1.

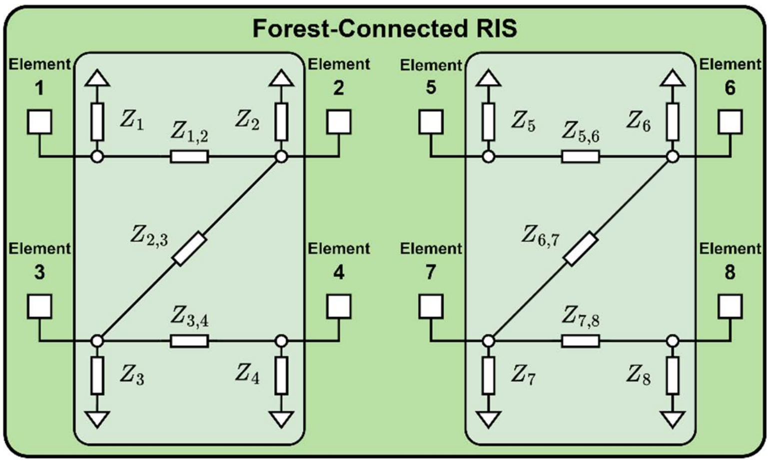


Figure 5.2.1.1.6-1: Forest-connected impedance-based RIS structure

5.3 Other technological aspects

5.3.1 Fabrication methods of RIS

There can be different ways to fabricate RIS panels, as shown in Table 5.3.1-1. Different fabrication methods essentially bring different characteristics of RISs, such as the working frequency, power consumption, costs, insertion loss, etc. The desired fabrication methods may depend on the deployment scenario, including the intended working frequency, as well as use cases.

Table 5.3.1-1 illustrates the behaviour of different hardware implementations of RISs.

Table 5.3.1-1: Different hardware implementations of RISs and their comparison over multiple KPIs

	RF-MEMS	**PN diodes**	**Varactor diodes**	**MOSFET**	**Photo-conductive**	**Ferro-electric**	**Liquid crystal**
Working frequency (GHz)	< 40	< 110	< 20	< 200	/	/	> 20
Working Voltage	High	Medium	High	High	Low	Very High	High
Power consumption	Low	Medium	High	Low	Medium	Low	Low
Time to change codebook	μs	ns	ns	ns	μs	ms	ms
Insertion loss	Low	Medium	High	Medium	Medium	/	High
Digital/analogue control	D	D	A	D	D	A	A
Cost	Medium	Low	High	Medium	/	High	/

6 Architecture of RIS-integrated network

6.1 General introduction

As a new network node, the RIS can be integrated into the network for the different usage, such as the RIS is used to improve the communication, used for sensing and localization enhancement. With the different usage and scenarios, the topology of RIS-integrated network can be different, which have been captured and analysed case by case in this clause. Besides, when integrated into the network, there may multiple RISs deployed in the network and the RIS needs to receive the control information to operate, how to control the RIS and how to select a suitable RIS are also discussed in this clause.

6.2 Topology of RIS-integrated network

6.2.1 Topology of RIS-integrated network for communication

In this clause, following topologies with different assumption on RIS capability can be considered:

Case A:

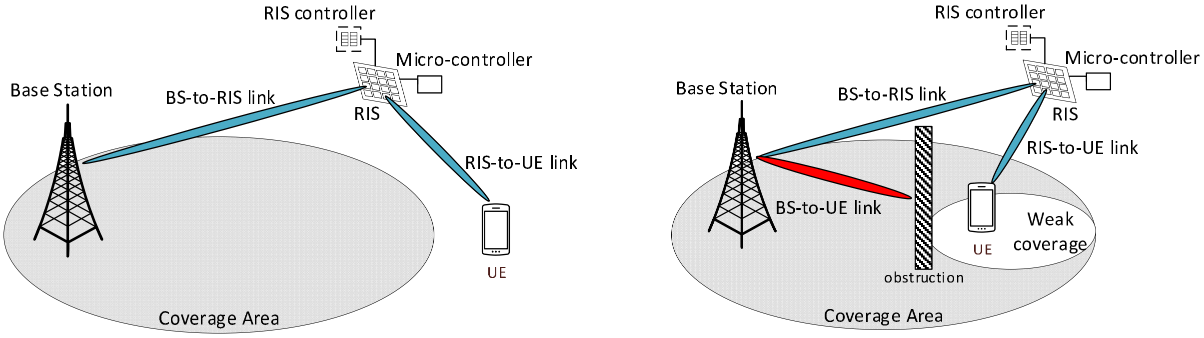
- The topology of RIS-integrated network for communication consists of two entities including RIS-based transmitter and receiver. In this case, RIS is regarded as a part of transmitter and is often co-located with transmitter. An example can be a RIS-based Massive MIMO transmitter. RIS is used to replace the conventional phase shifter and power amplifier to process the signal from a small-scale digital antenna array, with lower power consumption and cost.

Case B:

- The topology of RIS-integrated network for communication consists of three entities including transmitter, RIS and receiver. In this case, RIS is regarded as an intermediate node and is often located in distributed locations.

- For example, in cellular systems, weak coverage spots where the received signal strength of serving cell is below the level needed to maintain a reliable connectivity and coverage holes, which is similar to weak coverage but includes weak signals from both serving cell and neighbour cells, cause service performance degradation. An RIS-integrated network may overcome the weak coverage and/or coverage hole issue in the existing cellular systems by reflecting the signals to these problematic areas.

- There can be two different scenarios to utilize RIS-integrated network to enhance the coverage area of cellular networks. The first scenario considers an outdoor system where a coverage hole, as illustrated in Figure 6.2.1-1(a) or weak coverage area may exist due to an obstruction between the base station and UE, as illustrated in Figure 6.2.1-1(b). The second scenario considers an indoor system where outdoor-to-indoor signal attenuation/blockage is problematic to have a proper coverage inside buildings/behind walls, as depicted in Figure 6.2.1-1(b).



(a) coverage hole in an outdoor scenario

(b) weak coverage that can happen in both outdoor and indoor scenarios

Figure 6.2.1-1: Scenarios for RIS-integrated coverage enhancements

- In both scenarios, the topology of the RIS-integrated network for coverage enhancements consists of three main entities, namely, base station, RIS controller and RIS including the micro-controller that determines the response of RIS in the electromagnetic domain according to control information from RIS controller. In this topology, RIS is used to either extend the coverage area of the base station in order to provide connectivity/link to a UE that is outside the coverage area of the base station; or improve the received signal quality when there is a weak coverage occurs for a UE within the coverage area of base station. The considered RIS controller types in clause 4.2 in the present document can be supported in this topology.

Case C:

- Compared to Case B, in Case C, the topology of RIS-integrated network for communication consists of not only cellular network entities but also small scale, indoor, personal network entities as part of Customer Premises Networks (CPNs) [i.2], Personal Internet of Things Networks (PINs) [i.3] or Wi-Fi® networks. In this case, RIS is regarded as an intermediate node not only for indoor base station/access point but also for device-to-device communication, and is often located in distributed locations.

- In the scenario for RIS-integrated CPN, the topology consists of four entities as follows:
    - **Outdoor base station.**
    - **RIS controller and RIS** including the micro-controller that determines the response(s) of RIS in the electromagnetic domain according to control information from RIS controller.
    - **Evolved Residential Gateway (eRG)**, a gateway between the public network operator (fixed/mobile/cable) and a CPN within a residence, office or shop.
    - **Premises Radio Access Station (PRAS)**, a base station installed at a CPN primarily for use within a residence, office or shop.

- Figure 6.2.1-2 illustrates the topology of the RIS-integrated CPN. CPN is a network located within a premises (e.g. a residence, office or shop), which is owned, installed and/or (at least partially) configured by the customer of a public network operator. The residential area including residence, office or shop can be within a network coverage. The eRG and PRAS are within the residential area. The PRAS provides access to the 5G system for UEs within the residential area, and it is connected (wired or wireless) to an eRG. The eRG is connected to the same 5G system via a wireless or wireline links. Depending on the considered residential area, there can be multiple PRASs for the same residential network.

- In this topology, RIS can be used to extend the coverage within the residential area for PRAS(s) and/or for UEs that are seeking UE-to-UE communication within the residential network.

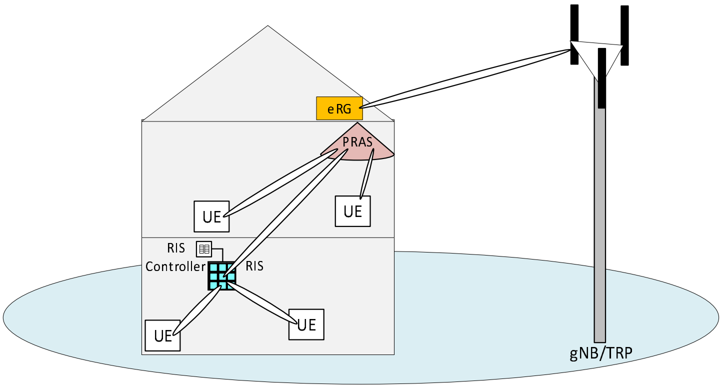


Figure 6.2.1-2: Topology of RIS-integrated residential network

- In the scenario for RIS-integrated PIN, the topology consists of five entities as follows:
  - **Outdoor base station.**
  - **RIS controller and RIS** including the micro-controller that determines the response of RIS in the electromagnetic domain according to control information from RIS controller.
  - **PIN Element,** UEs and devices authorized to communicate within a PIN.
  - **PIN Element with Gateway (GW) Capability**, a UE PIN Element that has the ability to provide connectivity to and from the 5G network for other PIN Elements that use PIN direct connections.
  - **PIN element with Management (Mgmt) Capability**, a PIN element with PIN management capability has capability to manage the PIN.
- Figure 6.2.1-3 illustrates the topology of the RIS-integrated PIN. PIN is a configured and managed group of at least one UE and one or more PIN Elements or UEs that are (pre-)authorized to communicate with each other. A PIN can be within an indoor or outdoor environment. The PIN elements may use PIN direct connections and/or they may require a relay for end-to-end communication. PIN direct connection in 3GPP licensed spectrum is direct device connection as defined in ETSI TS 122 261 [i.4]. The PIN element with Mgmt Capability receives information about PIN elements such as their identity, capability, and manages the PIN. The PIN element with GW capability is connected to a 5G system in order to provide direct or indirect connection between PIN elements and 5G network. The same PIN element can have both the Mgmt and GW capabilities. The PIN includes at least one PIN element with GW capability and one PIN element with Mgmt capability.
- In this topology, RIS can be used to extend the coverage for the PIN and/or for PIN elements that are seeking PIN direct communication within the PIN network.

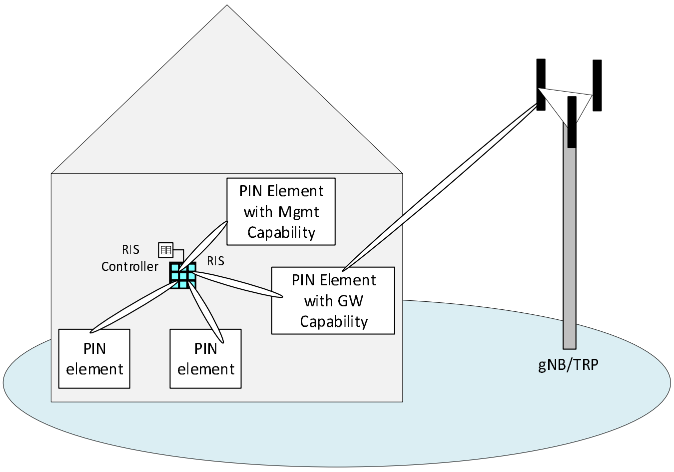


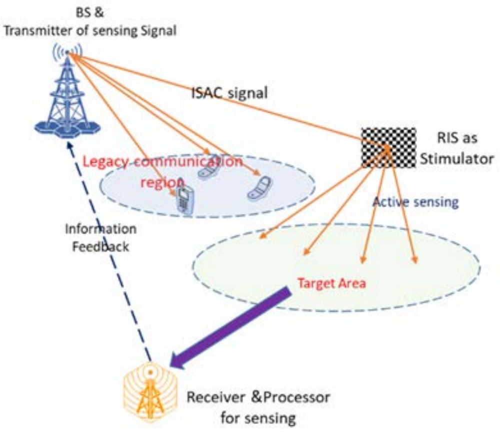
Figure 6.2.1-3: Topology of RIS-integrated PIN

6.2.2 Topology of RIS-integrated network for ISAC

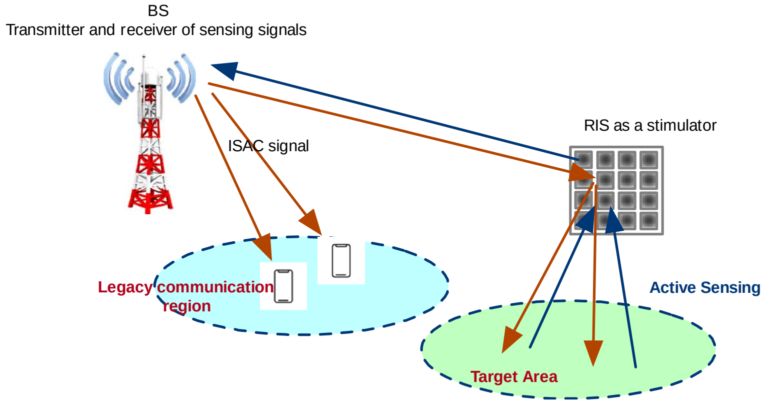
In the cellular system, the radio signal based sensing can be implemented with consideration on the RIS for both active and passive sensing mode with corresponding topologies. In this clause, topologies specific to sensing are considered. Topologies with RIS-integrated network for communication and localization are discussed separately in other clauses.

Active sensing:

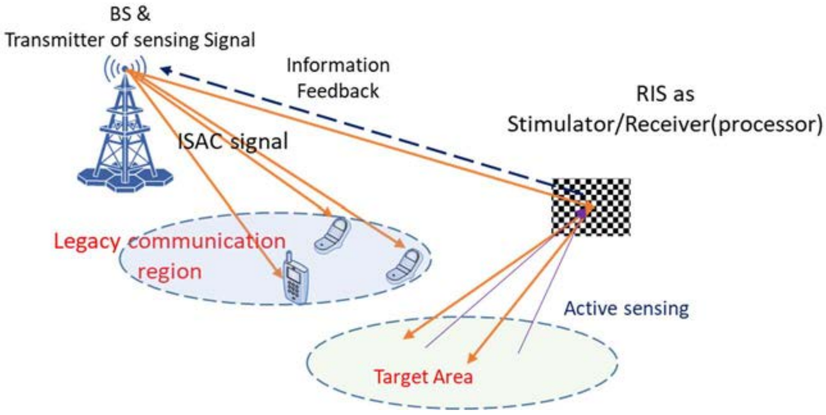
- As illustrated in Figure 6.2.2-1, two different topologies (Case-A1/A2 and Case-B) with different assumption on RIS's capability are listed:
  - Case-A1:
    - The topology of ISAC system consists of three entities including BS, RIS and additional receiver/processor. The RIS acts as the stimulator to enable the active sensing by forwarding the ISAC signal to target area. The forwarding behaviour can be controlled by network. The corresponding results will be feedback to BS by receiver/processor for sensing, which can be other entities or another RIS. This case (Case-A1) is typically referred to as bi-static sensing where the node for transmitting sensing signals and the node for receiving response signals are different nodes.
  - Case-A2:
    - The topology of ISAC system consists of two entities including BS and RIS. The RIS acts only as stimulator to enable the active sensing by forwarding the ISAC signal from the BS to the target area and also forward the response signal back to the BS. The main benefit of this case is to use a passive RIS only as stimulator and with no receiver capability. This case (Case-A2) is typically referred to as mono-static sensing where the node for transmitting sensing signals and the node for receiving response signals is the same node.
  - Case-B:
    - The topology of ISAC system consists of two entities including BS and RIS. The RIS acts as both stimulator and receiver (potential processor) to enable the active sensing by forwarding the ISAC signal to target area and receive the response signal.



Active Sensing: Case-A1



Active Sensing: Case-A2

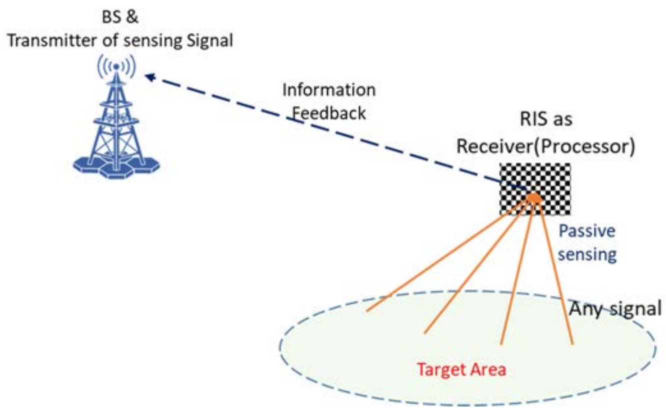


Active Sensing: Case-B

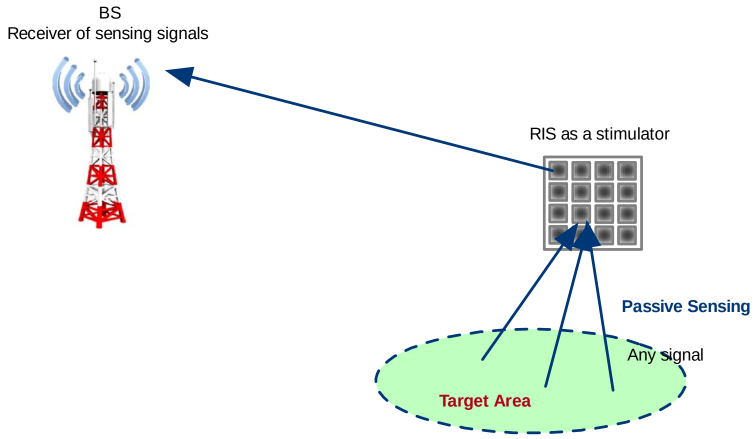
Figure 6.2.2-1: Conceptual topology of the RIS-integrated active sensing system

Passive sensing:

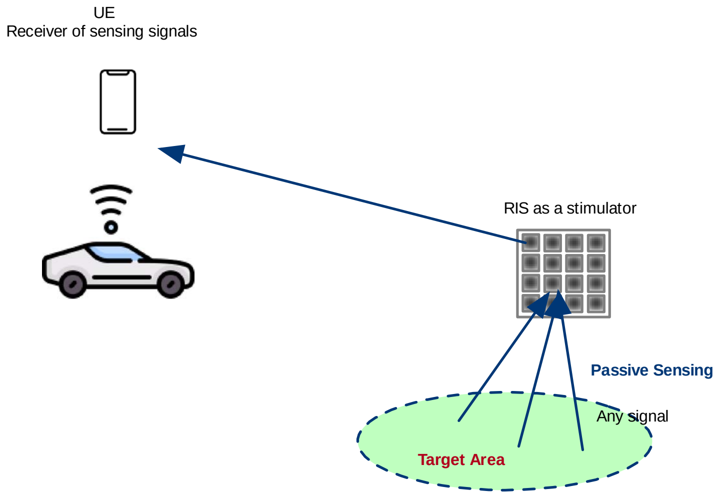
- As illustrated in Figure 6.2.2-2, two different topologies (Case-A and Case-B1/B2) with different assumption on RIS's capability are listed:
    - Case-A:
        - As illustrated in case-A for passive sensing in Figure 6.2.2-2, one topology is considered for passive sensing. In this topology, the ISAC system consists of two entities including BS and RIS. The RIS will act as the receiver to conduct the passive sensing for target area by monitoring (with forwarding or potential processing) the radio signal. The corresponding behaviour can also be controlled by network.
    - Case-B1:
        - As illustrated in case-B1 for passive sensing in Figure 6.2.2-2, another topology is considered for passive sensing. In this topology, the ISAC system consists of two entities including BS and RIS. The RIS will act as the stimulator (without any receiver capability) to conduct the passive sensing for target area by monitoring and forwarding the signal from the target area to the BS. The main benefit of this case is to use a passive RIS only as stimulator and with no receiver capability.
    - Case-B2:
        - As illustrated in case-B2 for passive sensing in Figure 6.2.2-2, another topology is considered for passive sensing. In this topology, the ISAC system consists of two entities including UE and RIS. The RIS will act as the stimulator (without any receiver capability) to conduct the passive sensing for target area by monitoring and forwarding the signal from the target area to the UE. One potential use-case for such topology is roadside detection of traffic signs and signals by autonomous vehicles.



Passive Sensing: Case-A



Passive Sensing: Case-B1



Passive Sensing: Case-B2

Figure 6.2.2-2: Conceptual topology of the RIS-integrated passive sensing system

6.2.3 Topology of RIS-integrated network for localization

6.2.3.0 General

UE localization can be enhanced in cellular network by considering the presence of RIS in the network. RIS can provide extra degrees of freedom by utilizing the controllable reflections and beamforming to enhance the positioning accuracy.

6.2.3.1 Multi base station - multi RIS scenario

In LTE/5G NR cellular network, the target-UE to be localized usually performs measurement and processing of the air interface PRS from multiple BSs, including the serving BS in case of DL positioning. The measurements including RSTD, RSRP, and AoD from multiple BSs are reported to the location server, where the transmission of PRS is configured per BS and the location estimation (triangulation) is performed. The positioning accuracy depends on multiple factors, e.g. the availability of the LoS for each BS and the number of observed BSs (anchor nodes) at the UE.

Deploying RIS within the network can be a promising tool for enhancing the positioning accuracy. As illustrated in Figure 6.2.3.1-1, RIS can extend the coverage of PRS transmitted from hidden BSs, in case of blockage, and hence increases the number of observed anchor nodes at the UE.

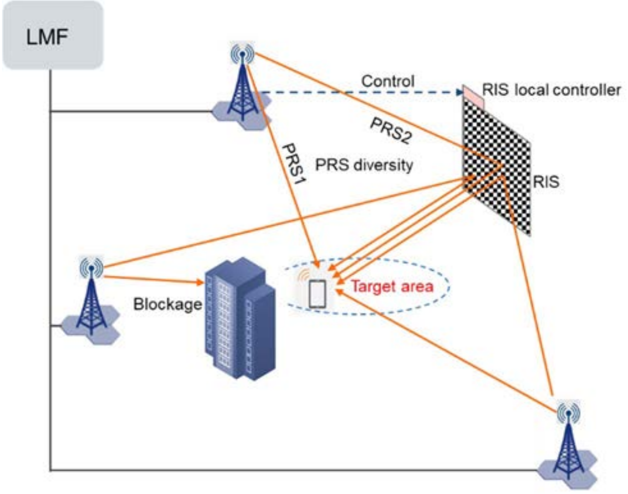


Figure 6.2.3.1-1: Conceptual topology of the RIS-integrated localization with multiple BSs

Furthermore, the multiple BSs can be configured by the LMF with multiple PRS transmission configuration for each BS. The multiple PRS transmission can be done in TDM, where in some slots a BS transmits one PRS signal at a certain resource set towards the target area, and in other slots, it beamforms another PRS towards the RIS. By proper configuration of RIS to turn on during the corresponding time slots, more diversity of PRS reception can be achieved by combining the multiple received PRSs at the UE side for each BS. In addition to PRS receive diversity, RIS itself can be seen as an extra anchor node for enhancing the positioning accuracy.

6.2.3.2 Single base station - multi RIS scenario

In some scenarios, such as indoor positioning, the deployment of the required number of BSs for positioning, to achieve a certain positioning accuracy, might be challenging. Properly placed multiple RISs connected to a BS can be deployed to enhance the positioning accuracy. For each RIS, a specific PRS is configured to be transmitted by the BS, beamformed to, and reflected by the corresponding RIS at a certain time slot as depicted in Figure 6.2.3.2-1.

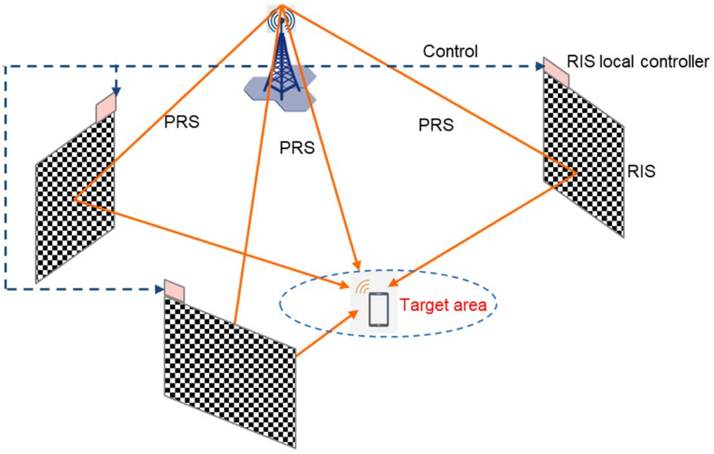


Figure 6.2.3.2-1: Conceptual topology of the RIS-integrated localization with single BS/multiple RISs

In addition to the direct LoS from the BS, reflecting different PRSs from multiple RISs provides more degrees of freedom seen as multiple anchor nodes by the UE and hence enables local estimation of UE location at the BS at RAN level. This is useful for some positioning use cases requiring low latency.

In another example, beam sweeping at RIS can be utilized for positioning using a single or multiple RISs as shown in Figure 6.2.3.2-2. The BS controls the RIS to apply beam sweeping of the PRS during different PRS slots to cover the area where the UE is expected to be located in. By reporting the measurement of the multiple PRS beams reflected from the RIS in addition to the direct beam as a reference, the BS can locally estimate the position of the UE.

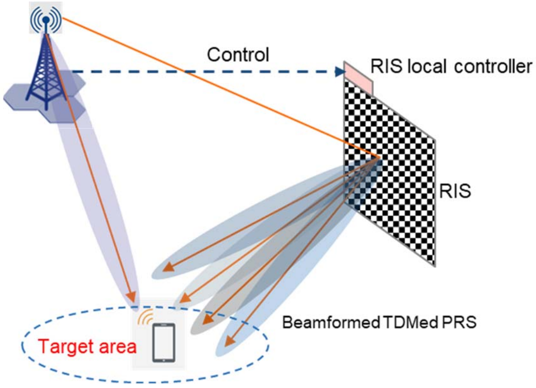


Figure 6.2.3.2-2: Topology of the RIS-integrated localization with single BS/single RIS

6.3 Functions and interface

6.3.1 Controlling of RIS

6.3.1.1 General

As a new network node, RISs need to receive proper control signals from other network nodes to ensure a joint optimization and harmonised network deployment. The method to control RISs can be divided into network-controlled RIS, UE-controlled RIS and quasi autonomous RIS.

6.3.1.2 Network-controlled RIS

Under this mode, the RISs are controlled by a single BS or a group of BSs. The base station(s) will collect necessary information such as the channel conditions, calculate the optimal beamforming factors and codebook on RIS, and inform the RIS which codebook to use. Under such mode, the RIS only receives control signals from the controlling BS(s) and applies changes accordingly, without any local calculation and thus ensures a low-cost deployment.

NOTE: Under this mode, it is possible for one base station to control multiple RISs.

6.3.1.3 Quasi Autonomous RIS

Quasi-Autonomous RIS can require power sensing capabilities, falling into the Hybrid RIS category, as per clause 4.2 of the present document.

Quasi-Autonomous RIS is capable of optimizing the gain of a reflected beam between a base station and a user equipment.

Quasi-Autonomous RIS can acquire a power profile through a sequential activation of probing beams. In particular, a Quasi-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 Quasi-autonomous RIS can locally compute the optimal configuration and autonomously trigger it based on the angular positions.

However, this type of RIS also listens to control signalling information from the network and/or the UE.

The advantage of this configuration, are the following:

- The network has a global view on the network performance and can therefore provide some useful input control information to the RIS to make sure it is jointly optimized with other nodes.
- The UE has the view on its own performance, it can therefore provide some input control information to the RIS to make sure it optimizes the UE performance.

6.3.1.4 UE-controlled RIS

6.3.1.4.0 General

For the UE-controlled RIS, UE configures and provides the required control information (as defined in clause 7.2 of the present document) to the RIS controller. Depending on the authorization from spectrum owner (usually operators of cellular networks), UE-controlled RIS can be further classified into two categories: non-transparent UE-controlled RIS and transparent UE-controlled RIS.

6.3.1.4.1 Non-transparent UE-controlled RIS

For the non-transparent UE-controlled RIS, the spectrum owner authorizes the UE to configure and control the RIS via the RIS controller. According to authorization, the UE may configure and/or update any control information to the RIS controller according to its requirements depending on the use cases and deployment scenarios. Depending on the use cases and deployment scenarios, the control information can be shared with the UE by the network and/or locally determined at the UE with necessary optimization. With authorization, UE-controlled RIS may operate in both licensed and unlicensed bands. Non-transparent UE-controlled RIS may be owned and deployed by network operators.

6.3.1.4.2 Transparent UE-controlled RIS

Transparent UE-controlled RIS can be defined as a type of RIS that do not require authorization from the spectrum owner (such as operators of network serving the UE that controls the RIS) and can be fully controlled by the UE. Transparent UE-controlled RIS operates in unlicensed bands. Transparent UE-controlled RIS may be both owned and deployed by end users.

6.3.2 RIS selection

6.3.2.0 General

BS or UE can select an RIS for the target use case based on channel measurement, e.g. if the direct channel quality degrades below the level needed to maintain reliable communication due to entering a coverage hole, or if the UE is already located in a coverage hole before connecting to the network. In such a case, selecting an RIS to serve the UE may start during the UE initial access to the network, e.g. by monitoring initial access signals. Furthermore, BS or UE can keep measuring these signals and/or other reference signals for (re-)selecting the RIS or assigning it for DL, UL, or for both.

When multiple RIS are available in the network, the BS or UE needs to optimally select one or multiple RIS to aid the communication. A few scenarios requiring RIS selection are discussed in the following clauses.

6.3.2.1 Selecting same RIS for DL and UL

In many scenarios, it is expected that the same RIS can be selected for both DL and UL transmissions, as shown in Figure 6.3.2.1-1, e.g. when the DL/UL channels are reciprocal. Selecting the same RIS for DL/UL simplifies the RIS selection procedure and requires reduced channel measurement overhead.

Same RIS may also be used for certain scenarios wherein the DL/UL channels do not allow channel reciprocity e.g. in FDD systems. In some cases, beam correspondence (or DL-UL beam reciprocity) may allow using the same beams in UL and DL. Beam correspondence may hold even in FDD when the UL and DL radio configurations are the same, e.g. when the same antenna structures are employed in UL and DL. In such cases, the same RIS can be used in both directions if the beam steering variation in UL and DL caused by the different carrier frequencies leads to a performance difference in UL and DL that is within acceptable limits.

In other cases, the RIS fabrication technology does not allow for reciprocity or beam correspondence does not hold. The use of nonreciprocal elements in these cases (e.g. nonreciprocal phase shifters) may enable different beam steering properties to the DL and UL incident waves, hence allowing the use of the same RIS for DL and UL.

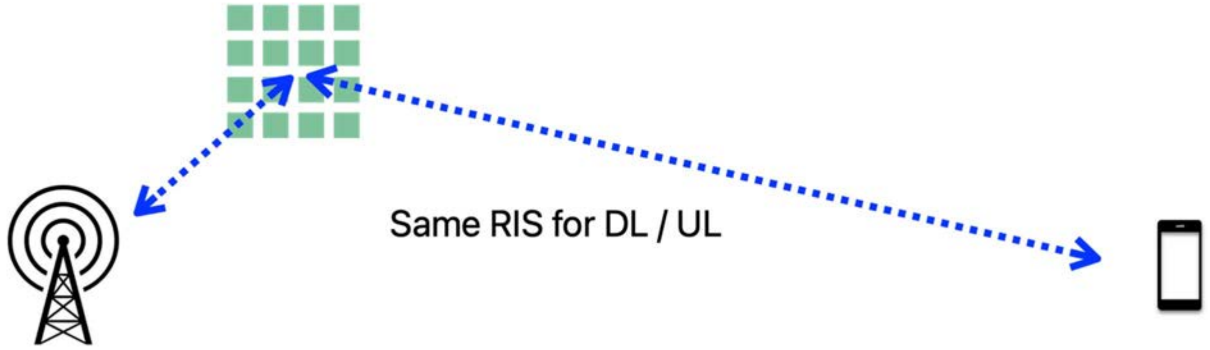


Figure 6.3.2.1-1: Using the same RIS for DL/UL

6.3.2.2 Separate RIS selection for DL and UL

In some scenarios, e.g. in FDD system, the channel reciprocity does not hold. Even when channel reciprocity holds, different beams in the DL and in the UL may be used, for example for the following reasons:

- UE UL beam switching to avoid RF exposure (e.g. MPE) when human body proximity has been sensed, as shown in Figure 6.3.2.2-1:
  - SRS-based UL beam refinement.
  - Rx-only non-codebook-based beamforming.
  - Different DL/UL UE grouping for MU-MIMO.
  - Dual-connectivity.

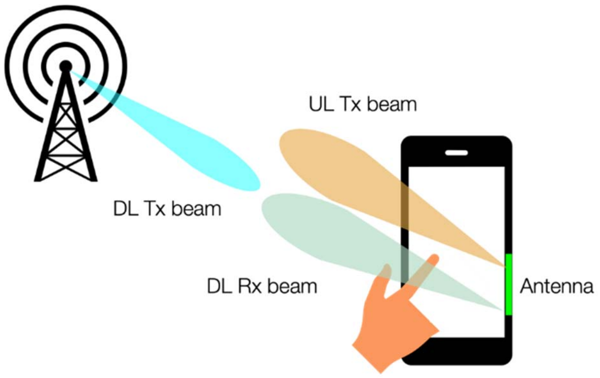


Figure 6.3.2.2-1: UE UL beam switching to avoid RF exposure

In such scenarios, separate DL and UL RIS can provide significant gains in both DL/UL performances. Instead of always using the same RIS for DL and UL transmissions, the protocol should be able to support RIS selection for DL and UL RIS as illustrated in Figure 6.3.2.2-2.

NOTE: It should still be possible to select the same RIS for both DL and UL if it is indeed the best option.

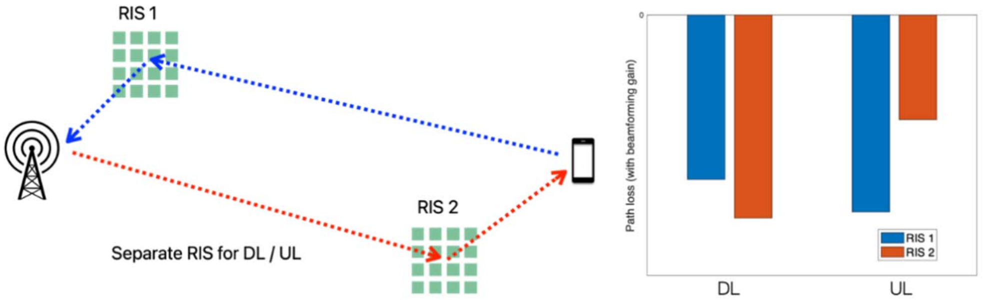


Figure 6.3.2.2-2: Using separate DL/UL RIS

6.3.2.3 Multi-Hop RIS Selection

In scenarios where single-RIS selection may be insufficient to ensure reliable communication, multi-hop RIS configurations can be leveraged to further enhance both DL and UL performance. Multiple RIS units are strategically placed between the BS and UE, allowing signals to be relayed from one RIS to another, thus overcoming coverage holes or NLoS conditions.

As shown in Figure 6.3.2.3-1, the orange lines indicate the selected path in a multi-hop RIS setup, where the signal is routed through multiple RIS units before reaching the receiver. This multi-hop approach improves coverage and communication quality by dynamically adapting to the environment and obstacles like interference or line-of-sight blockages.

In such systems, the selection process becomes more complex, requiring checking for alternative paths. By selecting optimal paths based on system performance requirements, multi-hop RIS configurations ensure robust and reliable wireless communication, especially in environments where a direct line-of-sight or single-RIS system may be insufficient.

The multi-hop RIS configuration offers enhanced coverage and performance, however, it may introduce interference challenges.

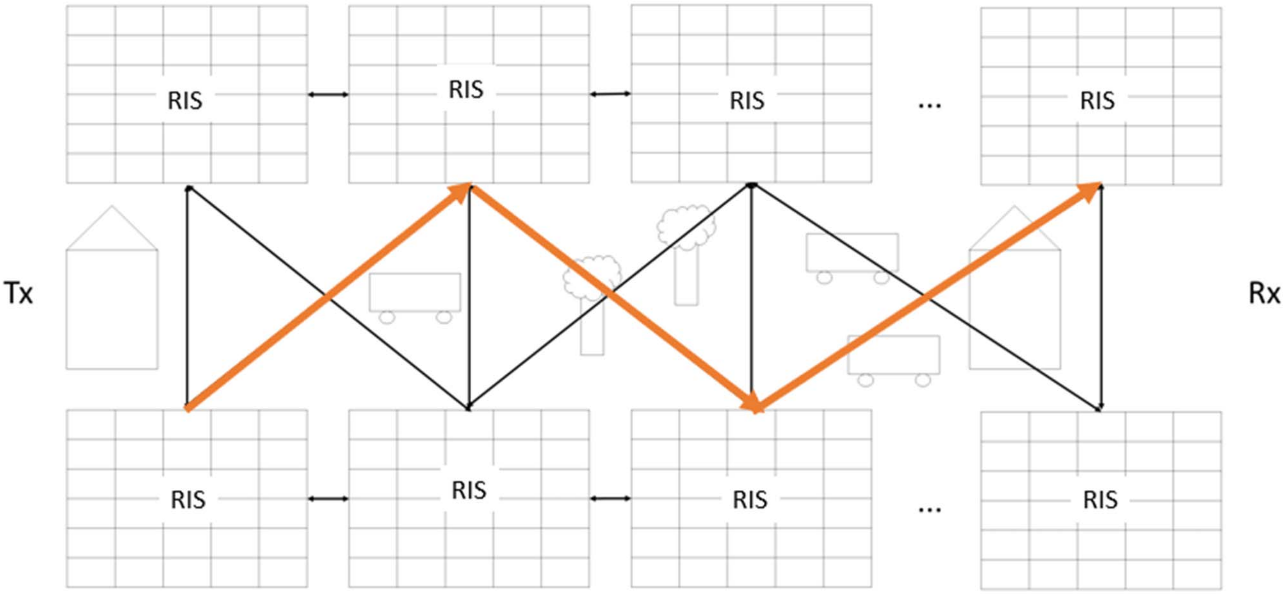


Figure 6.3.2.3-1: RIS Selection in Multi-Hop System

6.4 Potential specification impact

RIS is a new type of network node that can be integrated into a network to enhance communication performance or enable functions such as positioning and sensing, which may require specification support. Control information needs to be exchanged between the RIS and the controlling entity, which may be the network or a UE depending on the RIS control mode. In addition, new or enhanced configuration, measurement, and reporting procedures are required to facilitate RIS operation such as RIS selection when multiple RISs are deployed in the network.

7 Radio and physical layer aspect of RIS-integrated network

7.1 General introduction

In current communications systems, all control information including side control information and beamforming related signalling, such as TCI, control information for beamforming and beam management, quasi co-location configurations, etc., are based on the assumptions of transmission and reception beam pairs without the presence of a RIS node. With the inclusion of RIS into the legacy communication systems, the existing procedures will be impacted. In addition, due to integration of RIS into the system to improve communication, sensing and/or localization as captured in clause 6, side control information could be beneficial to improve RIS-integrated system operation efficiency and effectiveness. This clause captures RIS control mechanisms and requires side control information and any additional impact on other aspects of RIS-integrated systems along with the potential specification impact.

7.2 RIS control mechanism in RIS-integrated network

7.2.0 General

For RIS-integrated systems, mechanisms for exchanging control information between the network/base station and RIS and/or between UE and RIS may include side control information, such as beamforming information, on/off information, UL/DL TDD configuration information, TCI configuration, activation, indication, interference management and associated signalling, reference signal and related procedures. The introduction of RIS would impact the legacy control information and signalling designs.

7.2.1 Required control information for RIS

The required control parameters of RIS for different physical channels, different UEs, and for different time slots can be different depending on the operation mode of RIS. Some possible control parameters for controlling the RIS may include:

- **Spatial information:** Explicit or implicit phase/amplitude, directivity, beamforming information:
    - Depending on the RIS deployment for RIS-aided systems, spatial information that includes beamforming information, directivity and so on, may be needed for both base station-to-RIS and RIS-to-UE links. The indication of spatial information may be conducted as:
        - ▪ The spatial information is indicated as part of TCI framework where specific beams to be received by RIS from the base station and by UE from the RIS can be indicated. There can be various TCI states where each of them can be used to indicate specific spatial information on receiving control and/or data signalling. For example, the beamforming coefficients and phase/amplitude for RIS elements can be adjusted based on a given TCI state in order to receive data channels at RIS or at UE that has a link to the base station via RIS. The TCI states may be given for a single beam or multiple beams where the beam(s) may correspond to reference signals for channel state information, tracking, synchronization, etc.

        - The spatial information is indicated via configuration of phases/amplitudes of the RIS elements (i.e. the RIS configuration) from the network or by the UE. This means that one or more RIS configuration(s) can be indicated or configured to the RIS controller, explicitly or implicitly. The RIS capability, e.g. in terms of phase/amplitude resolution, may be taken into account. It is also necessary to indicate when a certain RIS configuration is to be applied, which is further discussed under timing information below.

- **UL/DL TDD configuration information:** for resource utilization and interference management:

    - Depending on the considered RIS deployment option such as to improve communication, sensing and/or localization, RIS may have a different UL/DL resource allocation than the network access node/base station. In case of deploying RIS to improve communication or coverage enhancements, RIS may need a different UL/DL resource allocation to effectively manage interference.

    - In legacy systems, UL/DL TDD configuration can be either cell-specific or UE-specific. The cell-specific UL/DL configuration may include dedicated slots for UL, DL and leaves out some slots and considers them as flexible slots. When UE-specific UL/DL TDD configuration is provided to a UE, the flexible slots will be used as UL and/or DL based on users need. For RIS-integrated systems, a similar slot configuration approach can be used for each RIS node. In addition to that, as multiple UEs can have a link to base station via the same RIS in an RIS-integrated network, both base station-to-RIS and UE-to-RIS links may have different UL/DL TDD configurations.

- **Timing information:** Applicability duration for a given RIS configuration, transmission alignment:

    - Depending on the RIS deployment for RIS-aided systems, there can be cases where the timing information to align transmission is needed or not. In one case where the RIS is co-located with a base station to enable RIS-aided massive MIMO transmission, timing information may not be needed, as RIS is alongside with the base station. In another case, RIS can be located away from base station to improve communication performance for a set of UEs or to enhance coverage area of a base station. In this case, as RIS is located away from base station, base station-to-RIS link may have some delay. Moreover, UEs that have a link with base station via RIS (either within base station coverage area without RIS or not) would be affected due to the delay on both base station-to-RIS link as well as UE-to-RIS link. Therefore, any timing advance adjustment for the UEs that have a link with the base station via RIS should be determined accordingly. Figure 7.2.1-1 depicts the case for two UEs at different location and have a link to base station via RIS where RIS is located away from the base station. The base station sends timing advance offset in a way that the uplink transmission from both UEs reach to RIS as well as the base station at the same time.

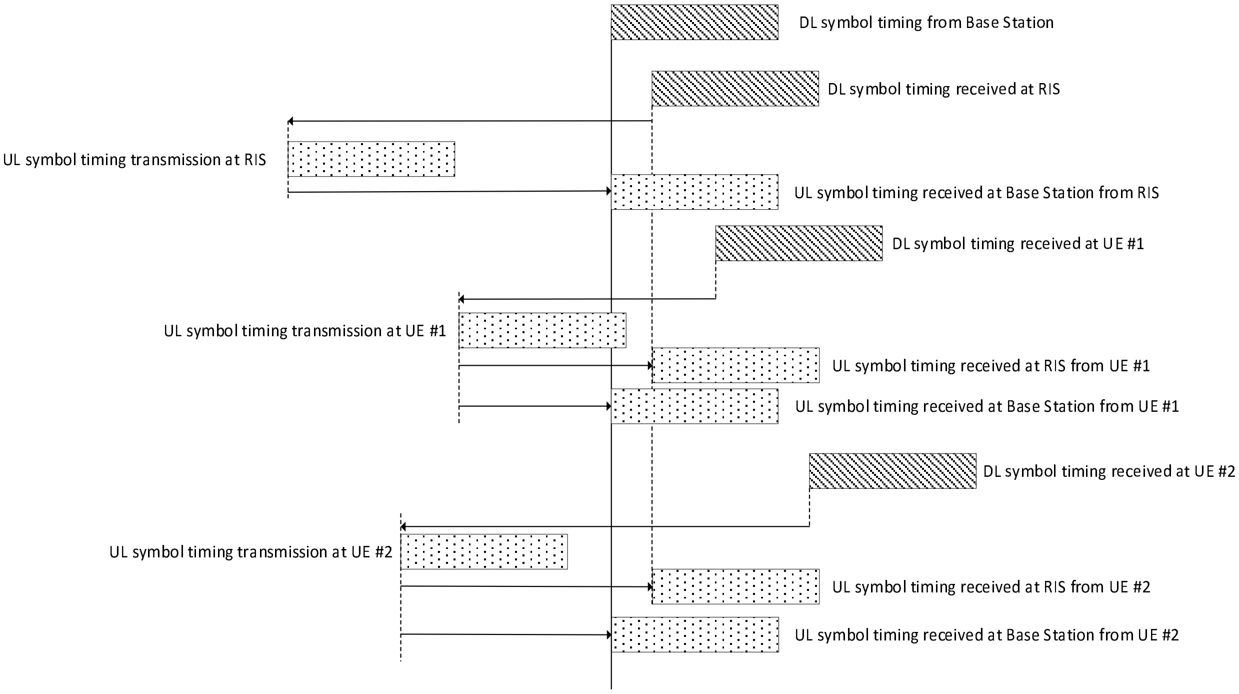


Figure 7.2.1-1: Example for timing advance offset alignment for RIS-aided system

- **ON/OFF information:** For energy and interference management:
    - In order to efficiently manage interference or improve network energy savings, ON/OFF information can be used for RIS-integrated systems. The network and/or UE(s) may need to manage multiple RISs at the same time. Hence, an RIS-specific ON/OFF indicator may be needed for efficient interference management and energy saving. In cases where an RIS is partitioned into multiple groups, ON/OFF information may be applied for different unit cell groups for the same RIS.
    - For indicating ON/OFF control information to RIS, explicit or implicit indication can be applied. With explicit indication, RIS may rely on reception of explicit signalling to determine whether the RIS (or unit cell groups within a RIS) is turned ON or OFF. On the other hand, with implicit indication, RIS may utilize other control information to determine whether the RIS is turned ON or OFF i.e. it does not need dedicated signalling for ON/OFF control information. For example, an RIS unit cell or unit cell groups can be turned OFF if no spatial information such as phase/amplitude is indicated for that unit cell or unit cell groups for indicated slot(s)/symbol(s).
- **Operating mode indication:** Indication for switching between the different supported RIS modes:
    - Different operating RIS modes can be enabled to support different deployment scenarios e.g. RIS refraction mode may be suitable for outdoor-to-indoor communication. Selecting the scenario-specific RIS operating mode may provide enhanced RIS-aided communication performance.
    - It is possible that certain types of RISs may support specific RIS operating modes. For example, a passive RIS may support reflection mode, whereas, semi-active or active RIS may support transmitting and/ or receiving mode of operation. In network-controlled RIS, BS can utilize the association between RIS types and RIS operating modes for communication and this information may also be indicated to the UE. Similarly, in UE-controlled RIS, UE can utilize the association between RIS types and operating modes, and this information may be indicated to the BS. Indication for switching between the different supported RIS modes may be needed for efficient RIS-aided communication performance.
- **Feedback information:** For capability information, ACK/NACK of receiving the control information, CSI report if RIS supports receiving/sensing mode.
- **Controlling mode indication:** Configuring/indicating the RIS with the controlling modes:
    - Depending on the deployment scenarios, use-cases, proximity of RIS to UE(s) and/or gNB, RIS can be configured with one of the RIS controlling modes among network-controlled, UE-controlled, or quasi-autonomous. Although such configuration is typically not expected to change frequently, but if the control link between the current controlling node and RIS is time-variant, then semi-static and/or dynamic indication to update the controlling mode may be needed to maintain the signalling of other required control information to RIS. In clause 6.3.0 of ETSI GR RIS 001 [i.5], RIS control plane management and the conditions under which an update of the controlling mode is required have been already described. Up on update of the controlling mode, a reconfiguration of the control information signalling may be needed. Furthermore, some exchange of RIS capability related information might need to be shared between the current controlling node and the succeeding controlling node. Generally, RIS capability aspects for different controlling types of RIS is discussed in clause 4.3. However, such controlling mode indication may not always be needed, especially, when the current controlling node and the succeeding node can exchange such information.

7.2.2 Design of control signalling

7.2.2.1 Protocol structure of control signal

The protocols and interfaces used to transmit and receive control signals are captured in this clause. Control signals are transmitted either from a BS or a UE, through the air interface, to the RIS to configure the codebook and/or other parameters for the RIS. In parallel, it is also possible for some RISs which are capable of transmitting signals, to transmit feedback to the BS or the UE.

In current designs for 5G NR networks as specified in ETSI TS 138 401 [i.7], the base station is divided into two parts, the CU and DU and the DU is responsible for transmitting and receiving signals. If RISs are controlled by the network, the control signal can be transmitted by the DU through either air interface, which is specified in ETSI TS 138 300 [i.8], or private interface. If the RIS is controlled by the UE, control signals can be transmitted through the air interface. The air interface is the interface well-defined for both BS and UE to communicate with each other through the air interface, and thus, is considered as a solution to also carry control signals for RISs. On the other hand, it is also possible to use private interfaces to carry such control signals, and the private interfaces will not be standardized.

7.2.2.2 Channel structure of control signal

The channel structure of control signal should be able to support the delivering of required control information for RIS (as described in clause 7.2.1) and other assistance information (e.g. ACK-NACK information or status report of RIS). The corresponding design of channel structure can be determined with joint consideration on several factors, e.g. RAT of network, the RIS controlling type, the time-domain behaviour of the control information, etc.:

- For network-controlled RIS:
  - In the case, if the network-controlled RIS is enabled by 5G, the existing channel structure for air interface as listed in ETSI TS 138 300 [i.8] for 5G NR can be reused as one option.
  - For example, the PDCCH is used to carry the control information for RIS in dynamic way for either one or multiple RISs. The PDSCH is for the semi-/static control information along with potential required higher layer configuration. The UL channel, e.g. PUSCH, PUCCH is required to carry other assistance information if necessary.
- For UE-controlled RIS:
  - In this case, the UE-controlled RIS can be enabled with one of following options on channel structure of control signal:
    - Option-1: The channel structure for air interface as listed in ETSI TS 138 300 [i.8] for 5G NR can be reused.
    - Option-2: The channel structure for PC-5 interface as listed in ETSI TS 138 300 [i.8] for 5G NR can be reused.
  - In the above two options, further adaption to enable the delivering of required controlling information may also be needed.

It should be noted that the aforementioned channel structure for control signalling is applicable for standardized interfaces. For private interfaces used for control signalling, the physical channel structure can be different and up to implementation.

7.3 Additional impacts on other aspects in RIS-integrated network

7.3.1 Channel measurement and feedback

Compared with the traditional communication networks, which may only involve the channel between the BS and each UE, the RIS-integrated communication network also involves the channel between the RIS and BS, and the channel between the RIS and each UE. Channel measurement for the two new channels should consider the application scenario for RIS, because the channel characteristics of the RIS-BS channel and RIS-UE channel may be different based on the different application scenarios.

One possible scenario to consider is when the RIS is deployed on the facade of a building or other fixed locations and does not move. In this case, the RIS-BS channel is semi-static, while the RIS-UE channel is dynamic since the UE is likely to move. Channel measurement for the RIS-BS channel can be done at longer intervals because the coherence time is extended and the main energy may be concentrated on the LOS path. On the other hand, the coherence time for the RIS-UE channel is shorter than the RIS-BS channel, caused by the mobility of the UE and channel measurement for the RIS-UE channel should be done in a shorter periodicity. For another scenario where the RIS is deployed on the windows of high speed trains to serve passengers in the seat, the RIS-BS channel is dynamic and the RIS-UE channel is semi-static. In this case, how to perform channel measurement for the RIS-BS channel becomes a main challenge. For the scenario where the RIS is deployed on the unmanned aerial vehicles and can be moving, the RIS-BS channel and RIS-UE channel are both dynamic. As a result, the coherence time of both channels is short and channel measurement for the RIS-BS channel and RIS-UE channel should be done in a short periodicity.

Further, channel measurements and feedback may also depend on the properties/features of RIS. For example, if RIS is not capable of performing channel measurement, optimizing and configuring RIS coefficients to aid the communication may rely on measuring and feeding back the cascaded channel (BS-RIS and RIS-UE) using reference signals transmitted from BS or UE. By tuning the reflection coefficients of RIS elements during the measurement, e.g. by switching between different reference signal beams reflected in different directions, the best beam to serve the UE can be selected; furthermore, the separation between the individual RIS channels can be achieved via signal processing at the controlling node as discussed in ETSI GR RIS 003 [i.6]. The other aspect needs to be considered is when the direct channel between BS and UE is present. One way of separating the RIS channels from the direct can be achieved with the help of RIS ON/OFF control information described in clause 7.2.1. This can enable measuring only the direct channel during OFF states of RIS, so that it is subtracted from RIS channels. On the other hand, when RIS is capable of performing the channel measurements and feedback, or the capability of RIS for configuring phase-shift and/or amplification gain per element-wise, sub-surface-wise or as a complete RIS configuration, can be taken into account. In case where RIS is capable of performing channel measurements, it may simplify the process of performing measurements to obtain individual/separated channels i.e. BS-RIS and RIS-UE channels and can be beneficial in dynamic scenarios. Obtaining end-to end cascaded channel measurements may be challenging in certain scenarios.

The channel measurement and feedback overhead may vary based on the set configuration, such as RIS being configured to measure and report element-wise, sub-surface based, or complete channel-state-information. For example, the sub-surface based configuration can be suitable for dynamic scenarios with mobile BS and/or UE, to enable reduced overhead and low-latency channel measurements and feedback.

7.4 Potential specification impact

Compared with the legacy communication system, the RIS-integrated network includes the RIS to assist the communication between the BSs and UEs. Based on the above description and analysis, the control information is required to control the RIS's operation, and these control information can be transmitted from the BS/UE to the RIS through the air interface. In this way, it may have additional enhancement on the current signalling structure, e.g. a new configuration to configure the control information may be needed, a new or enhanced signalling structure to carry the configured control information can be considered in the present document. Besides, the different channel measurement mechanism can be considered for the RIS-BS and RIS-UE channel, which may also require additional specification support.

8 Conclusion and recommendation

The present document summarizes the views of ETSI ISG RIS on the technological challenges to deploying RIS entities, the potential impacts on architecture, framework and the required interfaces of RIS-integrated networks, and potential specification impacts to support RIS as a new network node. The contents can serve as a reference point for relevant specifications and standards to study and model RIS-integrated systems.

History

Document history		
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