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RISE NETWORK ARCHITECTURES AND DEPLOYMENT STRATEGIES ANALYSIS: FINAL RESULTS

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Abstract

In this deliverable, we report on the final results within the RISE-6G project related to reconfigurable intelligent surfaces empowered (RISE) network architectures and deployment strategies analysis, shedding the light on architectural interfaces and corresponding taxonomy.

Keywords

Beyond-5G; 6G; Reconfigurable Intelligent Surface*; Network architecture; Deployment strategy; Communications; Localization; Sensing; Energy efficiency; Electromagnetic field exposure; Secrecy*

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List of Acronyms

2D	Two Dimensional
3D	Three Dimensional
3GPP	The 3rd Generation Partnership Project
AMF	Access and Mobility management Function
AN	Artificial Noise
AOD	Angle of Departure
AP	Access Point
BER	Bit Error Rate
BF	BeamForming
BS	Base Station
CC	Control Channel
CE	Channel Estimation
CN	Core Network
CP	Control Plane
CSI	Channel State Information
CU	Central Unit
D2D	Device-to-Device
DL	Downlink
DU	Distributed Unit
EE	Energy Efficiency
EMF	ElectroMagnetic Field
EMFE	EMF Exposure
EMFEU	EMFE Utility
ES	Edge Server
FF	Far-Field
FWA	Fixed Wireless Access
HAP	High Altitude Platform
I/O	Input/Output
IAB	Integrated Access and Backhaul
KPI	Key-Performance Indicator
LMF	Location Management Function
LoS	Line-of-Sight
L&S	Localization and Sensing
MEC	Mobile Edge Computing
MIMO	Multiple Inputs Multiple Outputs
MISO	Multiple Inputs Single Output
NF	Near-Field
NLoS	Non-Line-of-Sight
NR	New Radio
O-FH	Open Fronthaul
O-RAN	Open RAN
OFDM	Orthogonal Frequency Division Multiplexing
RAN	Radio Access Network
RF	Radio Frequency
RIC	RAN Intelligent Controller
RIS	Reconfigurable Intelligent Surface
RISA	RIS Actuator
RISC	RIS Controller
RISE	RIS Empowered
RISO	RIS Orchestrator

RIS-x	RIS-aided/assisted/augmented/based/boosted/empowered/enabled categories
RSS(I)	Received Signal Strength (Indicator)
RTT	Round-Trip Time
RU	Remote Unit
Rx	Receiver
SLAM	Simultaneous Localization And Mapping
SMSE	Sum Mean Squared Error
SNR	Signal to Noise Ratio
SSE	Secrecy Spectral Efficiency
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
UP	User Plane
WP	Work Package

1 Introduction

RISE-6G as one of the pioneers of the novel technology reconfigurable intelligent surfaces (RIS), has the aim at identifying and building the first version of a suitable network architecture with corresponding deployment strategies. This is used to exploit this emerging technology in the proposed scenarios, considering relevant metrics and key performance indicators (KPIs) defined in [RISE6G_D23] and [RISE6G_D24], respectively.

Depending on scenarios and application needs, flexible RIS devices will need to be organised in a network in which they can be adaptively (re-)configured and orchestrated based on real-time/predicted network dynamics so that optimized network architectures and deployment strategies can lead to enhanced targeted KPIs.

In this deliverable, we report on the final results obtained within the RISE-6G project related to RIS Empowered (RISE) network architectures and deployment strategies analysis. The work builds on the final deliverables within the technical work packages, namely WP4 on “RIS for Enhanced Connectivity and Reliability”, WP5 on “RIS for Enhanced Localisation and Sensing”, and WP6 “RIS for Enhanced Sustainability and Security”, [RISE6G_D44], [RISE6G_D54] and [RISE6G_D64], respectively (some material from these deliverables is summarized here for the convenience of the reader). This deliverable also serves as a point of collection and harmonisation of all contributions within RISE-6G towards the proposed RISE network architecture.

The outline of the deliverable is as follows.

In Chapter 2, first we present our novel architecture framework for RIS, with a harmonization of concepts and vocabulary, novel logical elements definitions, RIS hardware taxonomy and RIS control Taxonomy.

In Chapter 3, we summarize the network architecture requirements from technical WP4, WP5 and WP6, each one exploiting RIS for a different usage.

Finally, in Chapter 4 we derive two RISE-6G network architecture proposals: an Open architecture with potential extensions within Open-RAN (O-RAN), a 3rd Generation Partnership Project (3GPP) integrated Access and Backhaul based architecture. We also relate our work to the ongoing 6G architectural work, and the work made by the ETSI ISG RIS. We finally provide some thoughts on deployment strategies.

2 RISE-6G Network Architecture Framework for RIS

This section delves into a pioneering RIS architecture meticulously crafted within the RISE-6G project. RIS, with its ability to intelligently manipulate electromagnetic waves, emerges as a cornerstone in overcoming the challenges posed by traditional wireless networks. The integration of RIS into the B5G/6G landscape ushers in a new era of efficiency, reliability, and unprecedented data rates. As we navigate through the intricacies of this novel architecture, we will unravel the key design principles, technical intricacies, and transformative potential that the RISE-6G network architecture for RIS holds. This architectural paradigm shift not only addresses existing communication bottlenecks but also charts a course for the seamless convergence of technology and connectivity in the 6G era. Prepare to embark on a journey through the innovative corridors of the RISE-6G project, where the marriage of Reconfigurable Intelligent Surfaces and cutting-edge network architecture sets the stage for a future where connectivity knows no bounds.

2.1.1 Novel logical elements in the network

The new network node introduced by RISE-6G is the *Reconfigurable Intelligent Surface* (RIS), which can have different impacts on the network that embeds it. In general, across the whole project, different envisioned solutions where RIS devices are used can be categorised as follows:

- RIS-*aided/assisted/augmented/based/boosted/empowered* solutions where at least one RIS allows to obtain (appropriately defined) improved system performance metrics;
- RIS-*enabled* solutions where certain services/performance cannot be obtained without at least one RIS.

In this deliverable, unless necessary to refer to a very specific category (in which case it will be made explicitly clear), **RIS-*x*** expression will be used for concepts that apply to different categories.

The definition of “architecture” in this deliverable is hereafter provided: a set of logical blocks that interact with each other in a network in order to provide users with the expected service(s)/KPIs.

In the logical architecture of an RIS-x system defined within the RISE-6G project proposed in section 3.4 au-dessous, the following functional elements are defined as a harmonized view of similar concepts already used in the analysis performed by the technical WPs:

- ***RIS (device)*** – A **RIS device** can be based on the reflect-array or meta-material technology that is directly controlled by an associated RIS actuator with an expected time granularity between nanoseconds and 10 ms.
- The ***RIS Actuator (RISA)*** is the element in charge of actuating the logical commands received by the RISC, i.e., of translating them into physical configurations to be applied to the RIS device. In particular, such configurations might be envisioned as phase shifts or ad-hoc meta-material state changes. In addition, the RISA can provide feedback or limited sensing input when considering different RIS devices. The RISA is controlled by the RISC with an action time granularity *between microseconds and 20 ms*.
  - ***Separated RIS Actuator (RISA)*** In some scenarios, the RIS actuator may be a different entity. In such a case, we envision a resulting new RIS device which implements an RIS function and it is directly controlled by the RIS controller (RISC) (unless it is directly connected to an enB/gnB as shown in Figure 2-1).
  - ***Embedded RIS Actuator (RISA):*** **RIS function**. In some implementations, the RIS actuator may be embedded into the RIS device. In such a case, we envision a resulting new RIS device which implements an **RIS function** and it is directly

controlled by the RIS controller (RISC) (unless it is directly connected to an enB/gnB).

- ***RIS controller (RISC)*** – It is the controller associated to an RISA (in the case where the RISE device is separated from the RISA) or an RIS function (in the case where the RISA is embedded into the RIS device). It is responsible for generating the logical commands associated to the switching operations between the configurations/states of the RIS elements (e.g., predefined phase shifts). RISCs may have different levels of complexity and capabilities and they can embed third-party apps to implement smart algorithms. An RISC may either receive orders from other elements in the network, in which case it simply acts as an interface that configures the RIS elements (through the RISA, if it exists) based on external explicit instructions (Controlled RIS – see Figure 2-3), or it may operate on its own (Autonomous RIS – see Figure 2-3). **Finally, the RIS controller (or RIS Control functions) may be split between the RIS device and other nodes in the network**. The expected action time granularity is between 20 ms and 100 ms.
- ***RIS orchestrator (RISO)*** – It is placed on a higher (hierarchical) layer and it orchestrates multiple RISCs. Its action time granularity is expected to be between 100 ms and a few seconds.

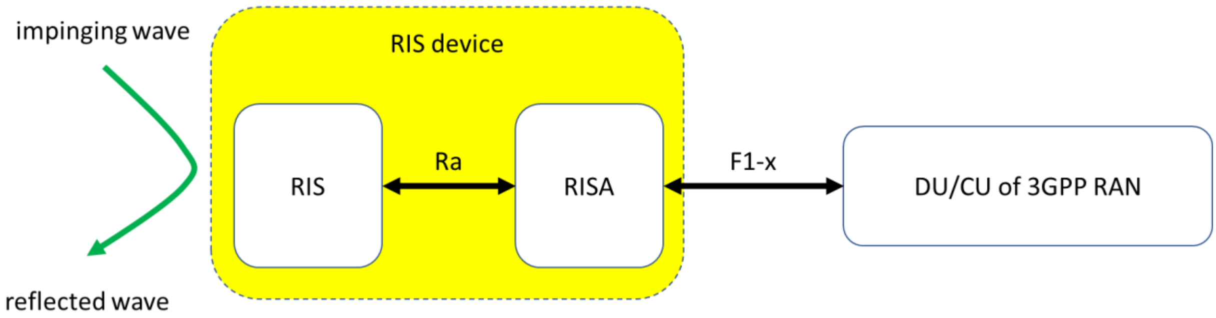


Figure 2-1 – Example of a logical architecture where the RIS and the RISA are co-located within the same physical RIS device which is interfaced with the CU/DU 3GPP-compliant RAN.

2.1.2 RIS hardware taxonomy

Since the term RIS comes with many distinct hardware implementations with different capabilities, it is worth recalling here the RIS definitions and taxonomy derived from the documents written in the technical WPs (e.g. see [RISE6G_D41], section 1.3), which is done in the following tables. Note that while the term metasurface may be used interchangeably with the term RIS, it may represent an RIS realized with metamaterials that would implement a continuous programmable surface.

Table 1 summarizes **RIS hardware (HW) categories** depending on the RIS capabilities of operation. It is assumed that every HW category has a modem for receiving (mandatorily) and transmitting (optionally) L1/L2 control signalling (either wireless or wired type) and might be able to send ACK/NACK.

Table 1 – RIS hardware category taxonomy.

Hardware category	General definition	Capabilities
nearly-passive	No RF chains, only ultra-low-power elements to change the reflection states.	Changing the reflection state of RIS elements. Can receive scheduling orders, Reflective Beam Indexes.
quasi-active or hybrid	Up to *N* receiving RF chains are included in the RIS, where *N* Is the number of RIS elements.	Changing the reflection state of RIS elements (like nearly-passive RIS); it has also sensing capabilities and can use its receiving RF chain(s) to collect measurements (in time-orthogonal manner with reflection or simultaneously); depending on its baseband functionalities, embedded computational/storage capabilities, as well as target application(s), it can also locally perform additional processing tasks such as radio parameters estimation (e.g., AoA), localization (e.g., of transmitted UEs or scatterers), channel estimation, received signal averaging (e.g., for radio cartography), etc. It might be able to send large L1/2 signalling (e.g., information regarding the reflected beam currently in use), or even sensing-oriented data (typically estimated channel parameters, estimated locations, collected or processed samples of received radio signals).
active	Up to *N* RF receiving and transmitting chains are included in the RIS, where *N* is the number of RIS elements.	Beyond the capabilities of the quasi-active/hybrid category, it can also perform reflection amplification or transmit its own signals.

2.1.3 RIS Control Taxonomy

Table 2 summarizes the different **Control Channel (CC) options** used to control the RIS, depending on how the control of the RIS is split between the RIS device itself and an external entity.

Table 2 – Control Channel taxonomy.

Implicit CC		There is no dedicated CC or signal over which explicit instructions are sent to the RISC (but the synchronization signal). As such, all decisions wrt. RIS(A) operations must be made locally by the RISC; however, these decisions can be based on other received and interpreted signals (e.g. pilot symbols, user equipment (UE) scheduling information) which implicitly (indirectly) control the behavior of the RIS.
Explicit CC	Out-of-band	Any communication channel, either wireless or wired, that does not consume resources from the primary communication channel that is influenced by the RIS; examples include: wired channel, wireless channel in a different frequency band, free-space optical, etc. This allows for simpler CC design, but at the cost of possibly lower spectral efficiency.
	In-band	The CC employs resources overlapping RIS operational spectrum resources, so it does influence the operation of the RIS. This implies a more complex CC design, but with possibly higher spectral efficiency.

Table 3 provides a classification of **RIS operational modes**.

Table 3 – RIS operational modes.

Totally Controlled RIS	**Partially Controlled RIS**	**Totally Autonomous RIS**
RIS operations are controlled by an **external entity** providing the main computational processing, and informing the RISC functions through the explicit CC.	RIS operations are in part controlled by **an external entity** and by the RIS device itself.	RIS operations are defined by the RISC on its own, **without involving any external entity**, even though an explicit CC may be present for communicating synchronization or feedback information.

Figure 2-2 enriches the example of Figure 2-1 with different CC options summarised in Table 2 which are either implicit (a), explicit and in-band (b), explicit and out-of-band (c). Interfaces names derive from the RISE-6G network architecture proposal of section 4.

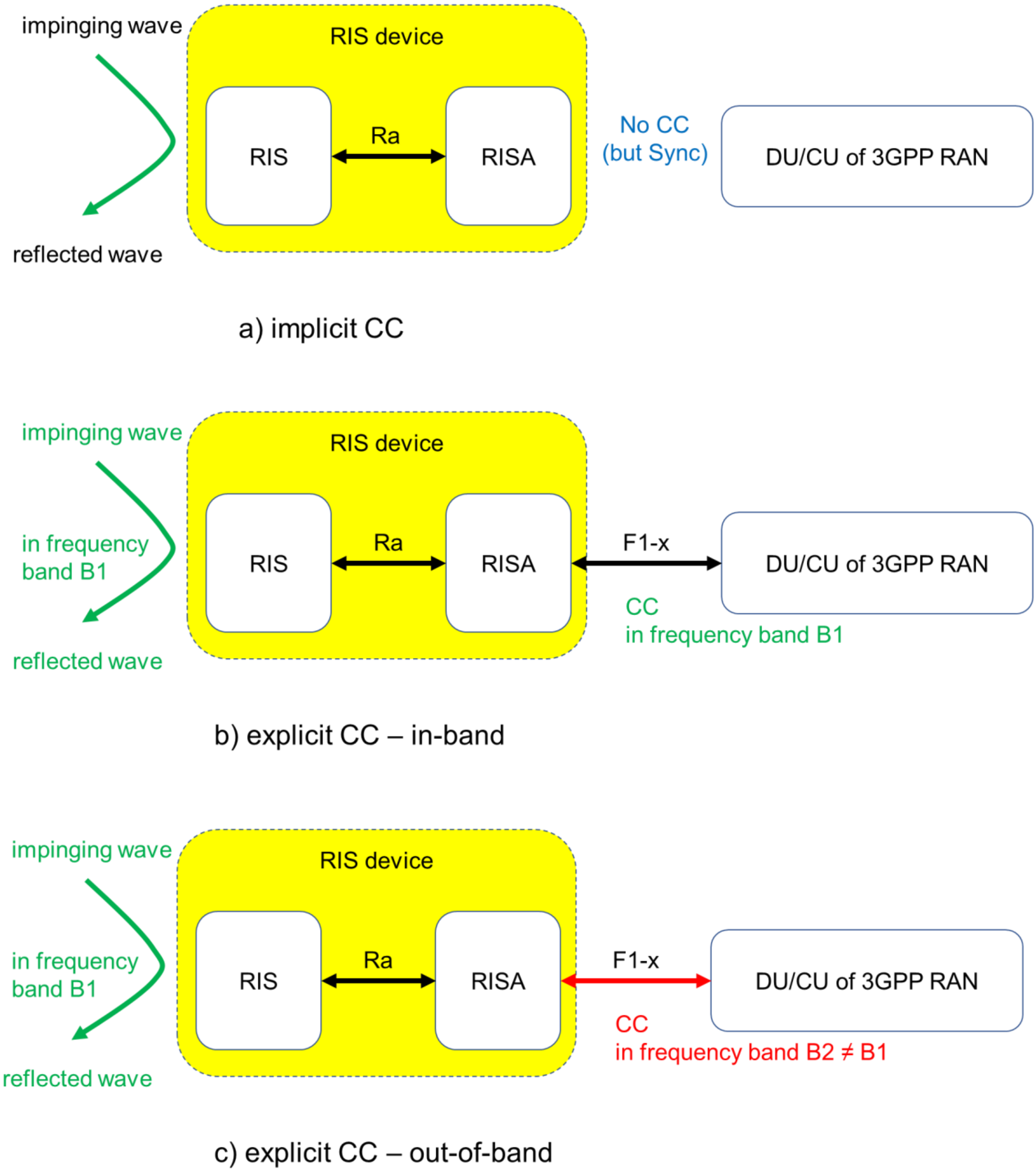


Figure 2-2 – Illustrating different CC options in one example of a logical architecture.

Figure 2-3 provides high-level examples of the RIS operational modes as reported in Table 3.

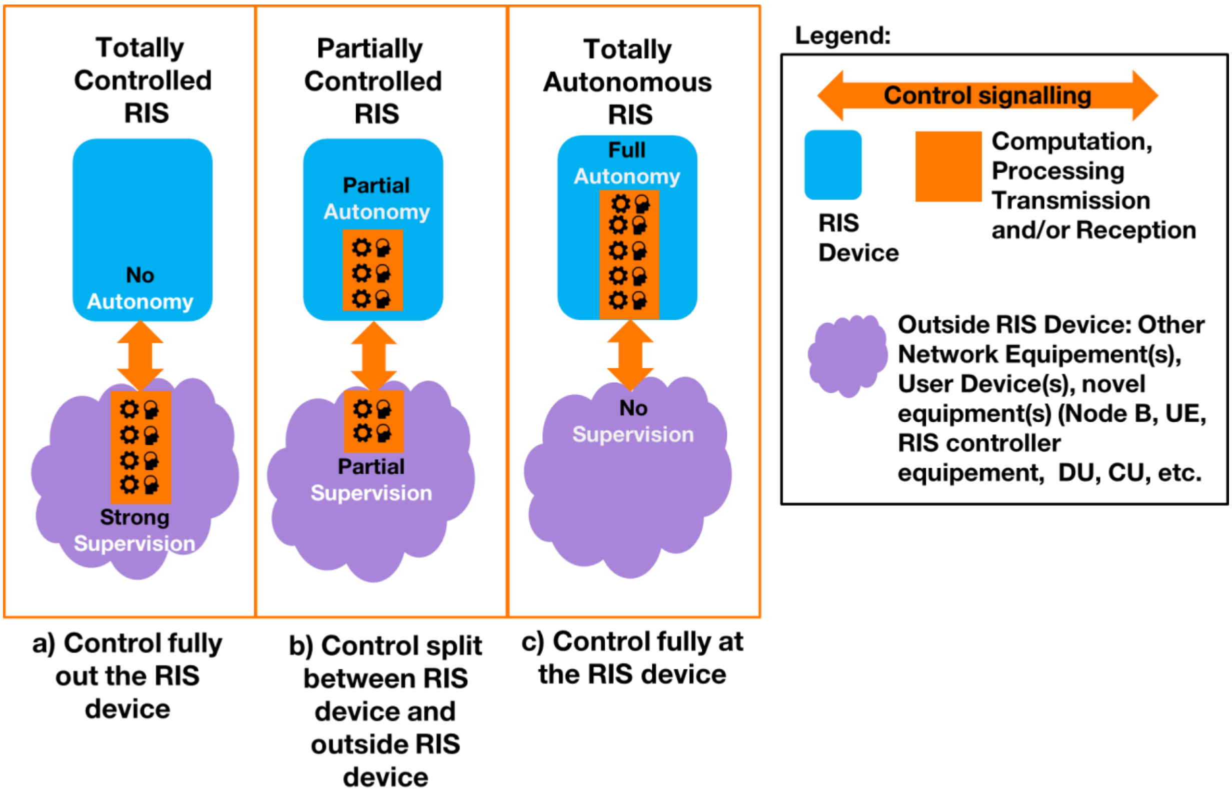


Figure 2-3 – The control of the reconfiguration of the RIS device is split between the RIS device and an entity out of it, for three different categories of splits.

Figure 2-4 provides more detailed example of the totally controlled RIS device presented in case a) of Figure 2-3.

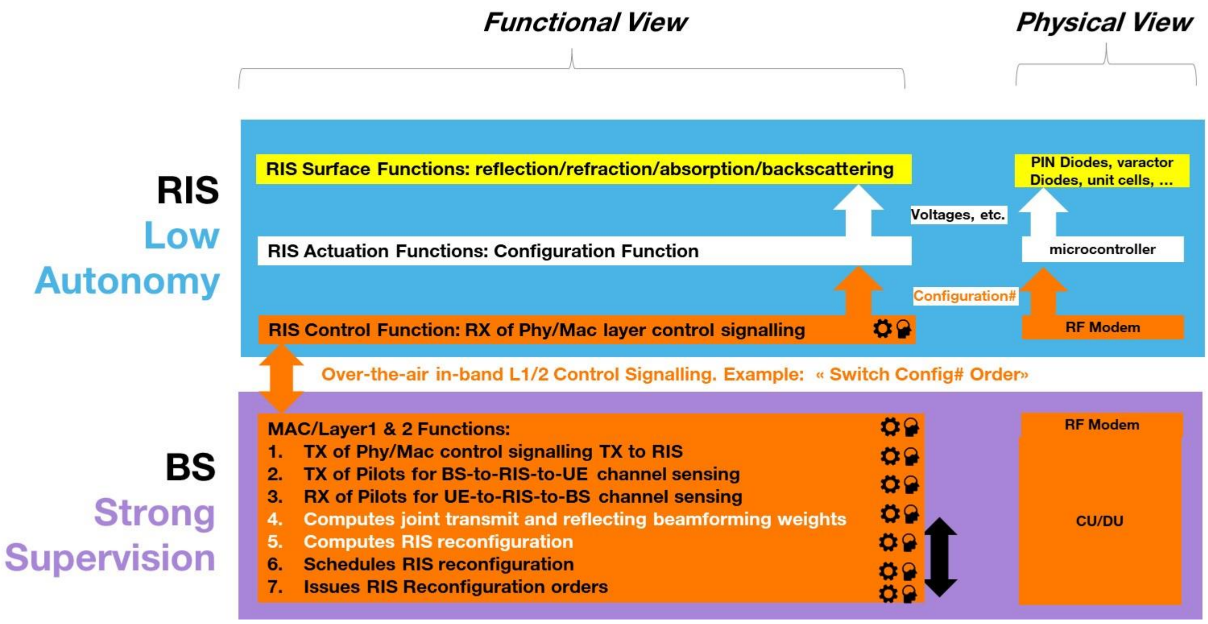


Figure 2-4 – Example of case a) split of the control of the RIS reconfiguration of Figure 2-3.

Figure 2-5 provides more detailed example of the totally autonomous RIS device sketched in case c) of Figure 2-3.

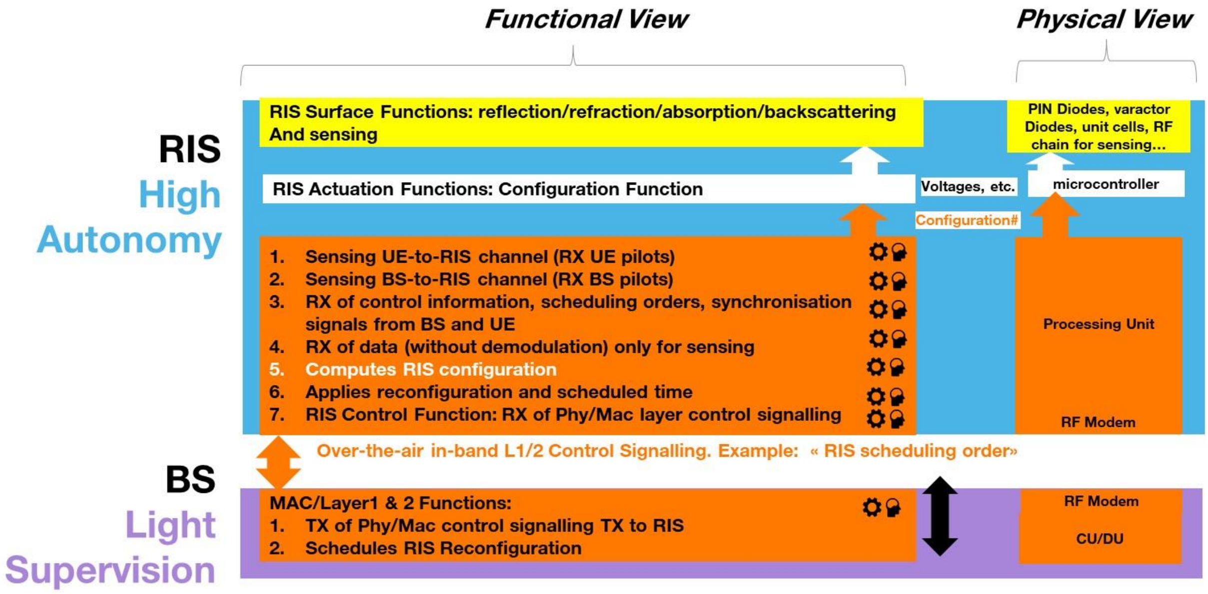


Figure 2-5 – Example of case c) split of the control of the RIS reconfiguration of Figure 2-3.

3 RISE-6G Network architecture requirements per RIS usage

RISE-6G technical WPs (i.e., WP4, WP5 and WP6) have investigated the requirements on an RIS-based network architecture from their specific points of view associated to the usage of the RIS for:

- enhanced/enabled connectivity and reliability (WP4);
- enhanced/enabled localisation and sensing (WP5);
- enhanced/enabled sustainability and security (WP6).

The results of their analyses can be found in the corresponding deliverables, namely [RISE6G_D43], [RISE6G_D53] and [RISE6G_D63], which are summarised in the following sub-sections of this section for easier reference.

3.1 RIS for Enhanced/Enabled Connectivity and Reliability

3.1.1 General Requirements

WP4 contributed to the main architectural characteristics of a RIS-based network for RIS-x scenarios related to connectivity and reliability listed in Table 4 (which is derived from Table 5 of [RISE6G_D43]).

It is worth being remarked that, in this context, we refer to contributions that exploit the knowledge of the statistical CSI (i.e., the statistics of the long-fading term of the CSI) indicated with the term *statistical* in the *Timeline* column of the table.

Table 4 – RISE-6G contributions to main architectural characteristics for RIS-x scenarios related to connectivity and reliability.

Contrib.	# BS	#RIS	#UE	RIS mobility	Freq. band	RIS HW [NP] Nearly-Passive [QA] Quasi-Active	RIS operation [A] Autonomous [C] Controlled	RIS CC	UE mobility	Timeline	[RISE6G_D43] relevant section
6.2	Multiple	Multiple	One	No	Sub-6GHz	NP	C	Explicit, out-of-band	No	Offline	**Erreur ! Source du renvoi introuvable.**
6.3	One	One	Multiple	No	mmWave	NP	C	Explicit, out-of-band	No	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.4	One	One	Multiple	Yes	Sub-6GHz	NP	C	Explicit, out-of-band	Yes	Statistical	**Erreur ! Source du renvoi introuvable.**
6.5	One	One	Multiple	No	Any	NP	C	Explicit, in-band and out-of-band	No	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.6	One	Multiple	Multiple	No	Any	NP	C	Explicit, out-of-band	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.7	One	One	Multiple	No	Any	NP	C	Explicit, in-band and out-of-band	No	Within channel coherence	**Erreur ! Source du renvoi introuvable.**

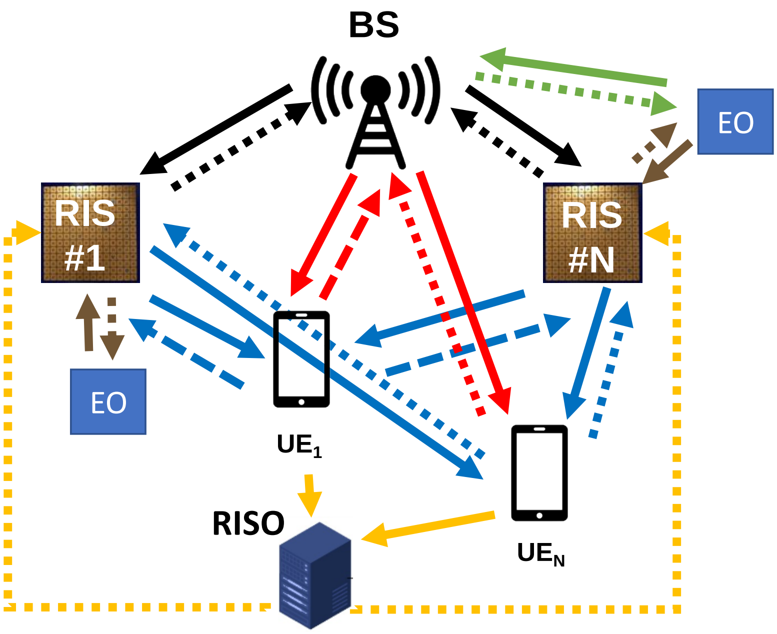
6.8	One	One	Multiple	No	Any	NP	C	Explicit, out-of-band	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.9	One	Multiple	Multiple	No	Sub-6GHz	NP	C	Explicit, in-band and out-of-band	Yes	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.10	One	One	Multiple	No	Any	QA	A	Implicit	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.11	One	Multiple/One	Multiple/One	No	Any	NP	C	Explicit out-of-band / Implicit	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.12	One	Multiple/One	One	No	Any	NP	C	Explicit out-of-band	No	Slower than channel coherence	**Erreur ! Source du renvoi introuvable.**
6.13	One	One	Multiple	No	Any	QA	C	Explicit out-of-band	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**
6.14	One	One	One	No	Sub-6GHz	NP	C	Implicit	No	Statistical	**Erreur ! Source du renvoi introuvable.**
6.15	One	One	Multiple	No	Any	NP	A	Implicit	Low mobility	Within channel coherence	**Erreur ! Source du renvoi introuvable.**

In general, envisioned scenarios may still be realized using the proposed RISE-6G architecture of section 4 that implements ad-hoc reference points[1] among relevant build blocks. However, specific functions can be further implemented (into, e.g., RISA and/or RISC) according to the expected action time granularity.

[1] In an architecture, *reference point* is commonly used to name the point of a building block which gets connected to the corresponding one(s) of other building blocks.

3.1.2 Requirements in terms of interfaces

In **Erreur ! Source du renvoi introuvable.** all considered interfaces and connections between the various entities in the network for the reported contributions of Table 4 are summarised.



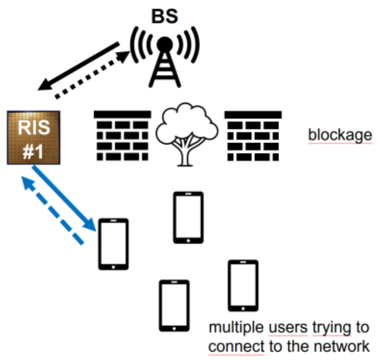
Arrow	interface	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10	6.11	6.12	6.13	6.14	6.15
	BS-to-RIS	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	RIS-to-BS			X	X		X	X			X		X		
	BS-to-UE	X	X	X	X	X	X		X	X	X	X	X	X	X
	UE-to-BS				X		X		X	X	X				X
	RIS-to-UE	X	X	X		X		X	X	X	X	X	X	X	X
	UE-to-RIS				X		X	X	X	X	X		X		X
	UE-to-RISO	X	X			X								X	
	RISO-to-RIS	X	X			X			X						
	EO-to-BS			X											
	BS-to-EO			X											
	EO-to-RIS			X											
	RIS-to-EO			X											

Figure 3-1: Summary of communication interfaces related to contributions of Table 4.

3.1.3 Requirements in terms of data/control time flows and signalling

The data-flow diagrams for the RIS-x systems operations have been provided by WP4 in [RISE6G_D43] as examples on how the data and control are exchanged. Here, we report the data flow and devices involved for access, CSI acquisition, optimization of RIS configuration, PHY-layer orchestration in presence of autonomous quasi-active (hybrid) RIS, and MEC, which represent the main scenarios of application. The other data-flow diagram can be found in Section 6 of [RISE6G_D43].

- **UE access procedure [Contrib. 6.8, RISE6G_D43]** in presence of RIS can exploit the spatial diversity of the latter to improve admission probability. A scenario with a single RIS is presented in Figure 3-2; a possible data frame for the use of RIS on random access is given in Figure 3-3, where the RIS changes configuration on a slot basis during learning and access phases. A further acknowledgement phase can be considered afterward to notify the UEs their access/successful transmission (see Section 6.8 [RISE6G_D4.3]). Finally, a data frame for merging scheduled and random access for static and mobile UEs in presence of multiple RIS is given in Figure 3-4.



Arrows	Used Interface	Nature of transactions (and order in messages sequence)
	BS-to-RIS	1) Channel Oracle: the BS sends pilots towards the UEs while the RIS changes its configuration on a slot basis
	RIS-to-UEs	1) Channel Oracle: The UE receives the pilot whose channel is subject to the environment changes imposed by the current configuration. The UE learns a model that tells him/her how its channel varies with respect to the configurations.
	UE-to-RIS	2) Access: The UE choose 1 or more slots to attempt access based on an access policy. The access policy is based on the information learned via the channel oracle. If two or more Ues try to access the same slot, there is a collision.
	RIS-to-BS	2) Access: The BS decodes the received packets/access requests and can make use of techniques to reduce the number of collisions, such as, the employment of a SIC receiver.

Figure 3-2 - Example of scenario of deployment for random access in RIS-aided communication (Section 6.8 in [RISE6G_D43]).

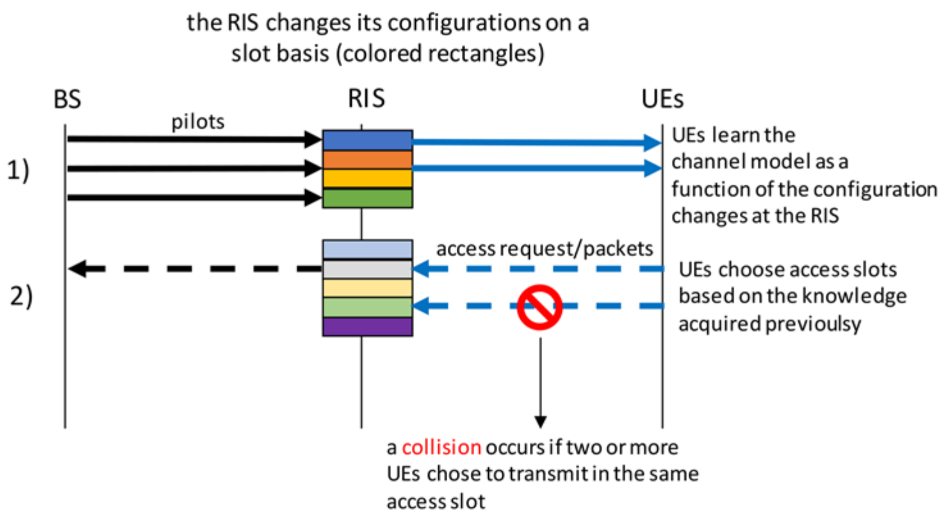


Figure 3-3 - Data-flow diagram for UE random access protocol (Section 6.8 [RISE6G_D43]).

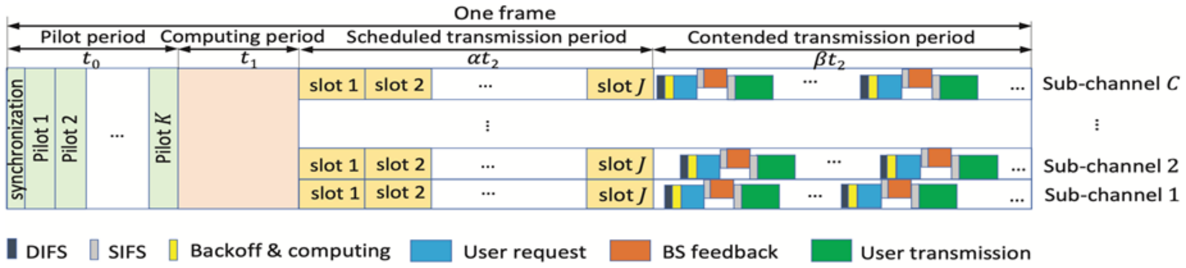
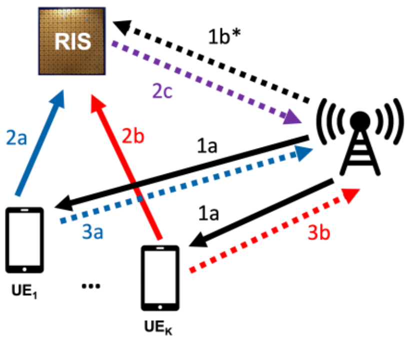


Figure 3-4 – Frame structure of multiple access protocol for static and mobile UEs with multiple RIS (Section 6.9 [RISE6G_D43]).

- **Multi-user channel estimation framework when an RIS is involved [Contrib. 6.5, RISE6G_D43]** (see Figure 3-5 and Figure 3-6). An uplink scenario is considered, where the UEs transmit orthogonal pilots while the surface changes its configuration at every pilot transmission to allow for the estimation of the cascaded channel. Two control protocols can be applied: in the first case, the RIS is notified that the estimation process starts, and from this point onwards it changes its configuration in a pre-specified manner (it has the benefit of minimal control overhead, but it requires synchronization); in the second protocol, for every pilot exchange, the sending node transmits a control signal to the surface instructing it to change its configuration, and then pilot is transmitted (the number of control signals is larger, but no synchronization is required, if the receiving end is aware of the order of the selected configurations).



Arrow	Interface	Use
	BS-to-UEs	1a) BS signals Ues for CE start
	BS-to-RIS	1b*) BS signals RIS for CE start
	UE_1-to-RIS	2a) UE_1 sends orthogonal pilots
	UE_K-to-RIS	2b) UE_2 sends orthogonal pilots
	RIS-to-BS (reflected)	2c) UE_1 sends orthogonal pilots to BS
	UE_1-to-BS	3a) UE_1 sends orthogonal pilots to BS
	UE_K-to-BS	3b) UE_K sends orthogonal pilots to BS

Figure 3-5 - General deployment and signal diagram for CE with a reflecting RIS (Section 6.5 of [RISE6G_D43]).

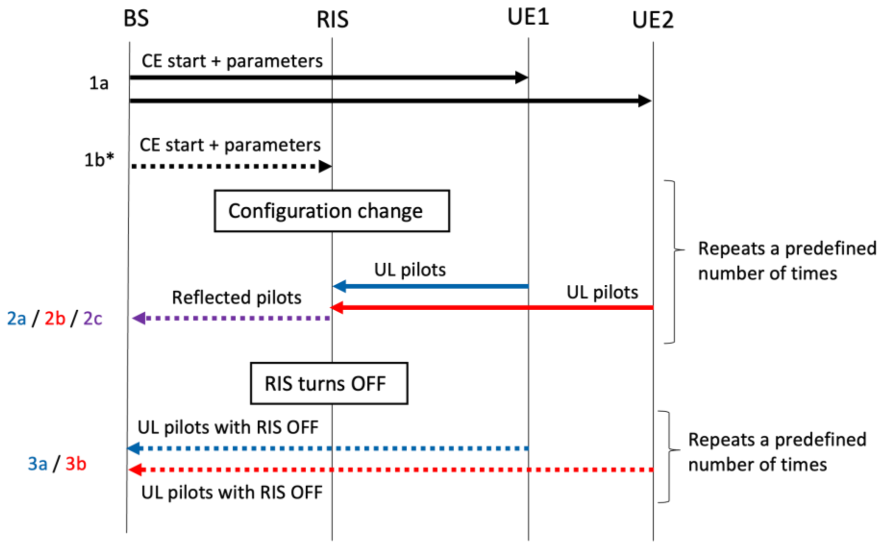


Figure 3-6 - Time diagram of the signalling process of the general CE framework with reflecting RISs. (Section 6.5 of [RISE6G_D43]).

- **Centralised multi-UE multi-RIS optimization for controlled RIS [Contrib. 6.6, RISE6G_D43].** The scenario of the CSI acquisition and RIS configuration optimization in a multi-UE and multi-RIS environment is given in Figure 3-7. Based on the consideration on the channel estimation, the time diagram is given in Figure 3-8, where the control signaling to communicate the optimized configuration to the RISs is considered.

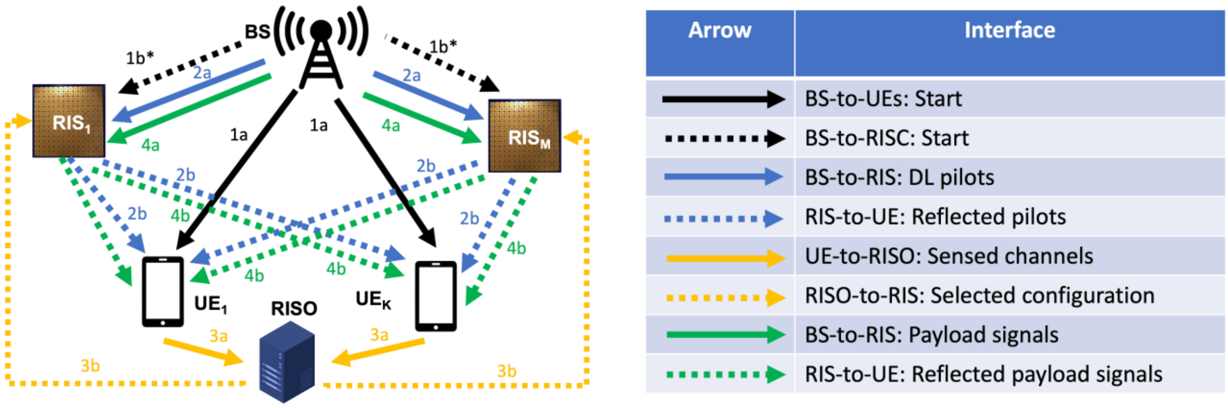


Figure 3-7 - System and signal model of the centralised RIS orchestration scheme (section 6.6 [RISE6G_D43]).

- **Autonomous RIS protocol [Contrib. 6.10, RISE6G_D43].** In presence of autonomous RIS (see scenario in Figure 3-10), the explicit exchange of information between BS and RIS is not needed, due to the latter usually having sensing capabilities providing information for self-optimizing its own configuration. However, an orchestration framework is required, whose time and data frame diagrams are given in Figure 3-9.
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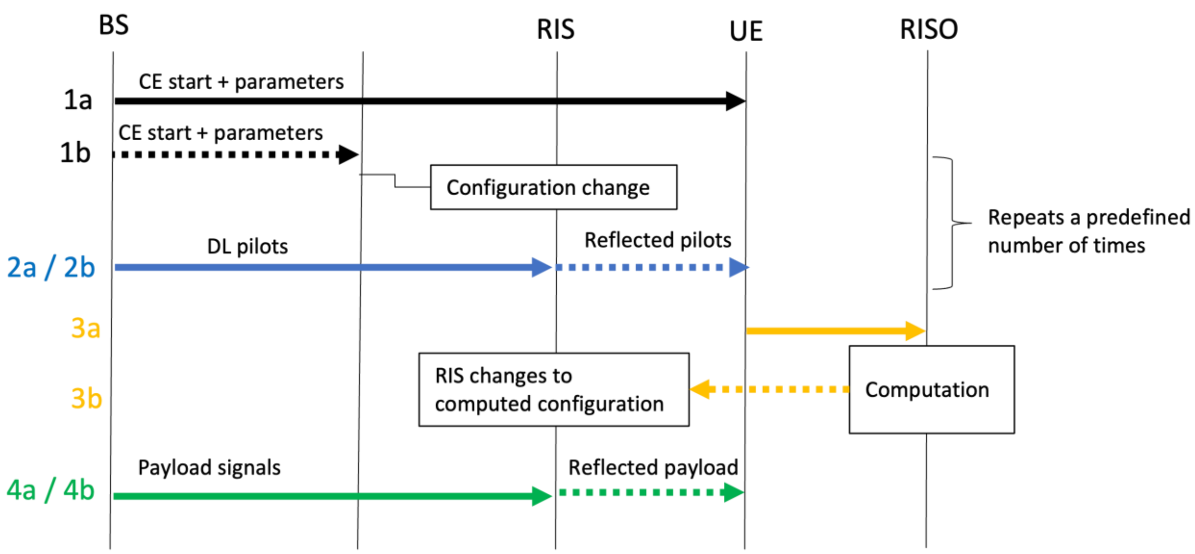
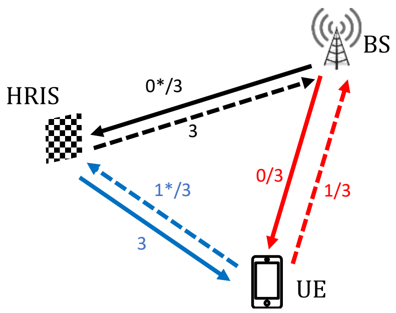


Figure 3-8 - Time diagram of the centralised RIS optimisation architecture within a channel coherence time (section 6.6 [RISE6G_D43]).



Arrows	Used Interface	Nature of transactions (and order in messages sequence)
	BS-to-RIS	0*) HRIS passively senses the broadcast channel to acquire frame level sync and BS-HRIS CSI
	RIS-to-BS	3) UL data transmission
	BS-to-UE	0) Synchronization signal through broadcast channel 3) DL data transmission
	UE-to-BS	1) UL Pilot transmission 3) UL data transmission
	UE-to-RIS	1*) HRIS passively senses pilot transmission to acquire UE-HRIS CSI
	RIS-to-UE	3) DL data transmission

Figure 3-10 - Scenario of autonomous RIS orchestration (Section 6.10 [RISE6G_D43]).

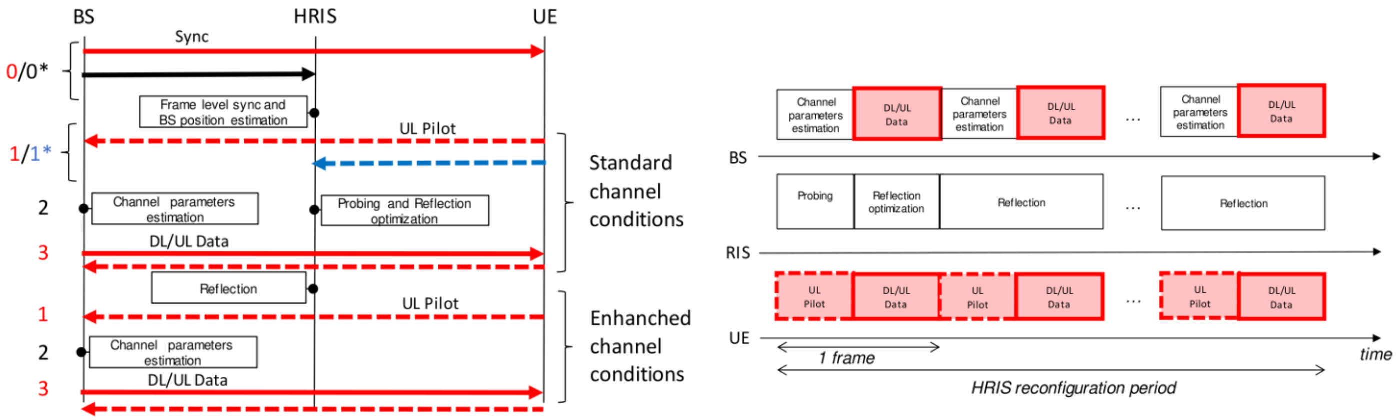


Figure 3-9 - Time and frame diagram for autonomous RIS orchestration (Section 6.10 [RISE6G_D43]).

- **MEC empowered by RISs [Contrib. 6.11, RISE6G_D43]** (see Figure 3-11, where all required exchange of information among the main actors, UEs, RIS, AP, and the ES, is detailed). There are three separate phases: access, CSI estimation and resource optimization, computation offloading.

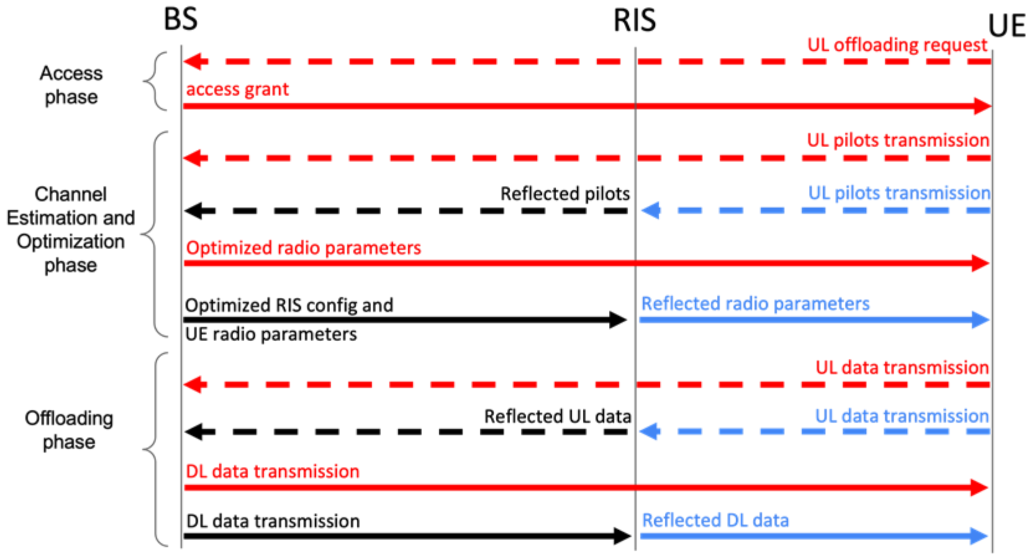


Figure 3-11 – Data-flow diagram for RIS-empowered MEC (Section 6.11 of [RISE6G_D43]).

3.2 RIS for Enhanced/Enabled Localisation and Sensing

3.2.1 General Requirements

A RIS-x localisation architecture must support i) the collection of location-dependent radio measurements at the BS and/or UE, ii) the application of specific RIS configurations during measurements collection, as well as iii) the synchronisation of the latter with the transmission of pilots by the BS or UE. Localisation algorithms also require knowledge of (or even control over) the RIS configurations utilised while collecting measurements, as well as the measurements themselves (as inputs to the solvers of the location estimation problem). These algorithms can run either at the RIS controller or at the measurement point, whereas other choices for computation execution would require both the RIS configuration and measurements as inputs (thus, necessitating extra information transfer).

In comparison, sensing-oriented architectures must also support the collection of measurements in RIS-centric systems. Like in most of the sensing approaches put forward in [RISE6G_D53], this can be performed directly by the RIS itself, either in sampled or sampled and pre-processed baseband format. If observations at the BS are relevant for sensing, they should also be supported by the architecture. In sensing approaches, the data flow is usually one way, from UE to the network side (typically leveraging UL signals). The network side then collects the information with the endpoint being at the physical RIS. The necessary signalling includes only the RIS configuration and related timing control.

From a localisation and sensing standpoint, the relationship between the deployed physical entities and the logical components/functions of the architecture is strongly impacted by a priori application requirements, as well as by the computational complexity affordable at each of these physical entities (typically, at the RIS device).

The different components of the RISE-6G architecture indeed operate at different time scales, so that they have a close relation to the localisation/sensing *latency*. The latency itself is upper bounded due to the mobility and the accuracy requirement. Roughly speaking, an accuracy requirement of E meters and a mobility of V meter/second has a tolerable latency of around $0.1E/V$ seconds. The latency is distinct from the refresh period, which may be of the order of tens of ms to several seconds, depending on the available external sensors and fusion mechanisms. With these considerations in mind, the following applies (see also Figure 3-12):

- A localization refresh period on the order of 100 ms is usually suitable to most mobility regimes (typically, like GPS readings every 100 ms).
- Once requested, the overall localisation process should be sufficiently timely to avoid that the UE has travelled a too large distance during acquisition. In practice, localization shall hence be typically completed within 10 ms, which supports cm-level accuracy at low velocities (< 1 m/s, e.g., indoors) and m-level accuracies at high mobility (around 10 m/s, e.g., outdoors).
- In scenarios requiring more than one RIS, the RISO serves (more or less) as a scheduler, which oversees orchestrating all the beam operations of different RISs involved in localisation and sensing. Typically, every 100 ms, RISO then selects and triggers clusters of RISs that must perform their tasks within 10 ms (e.g., beam scanning).
- In terms of logical RIS control, these high-level tasks may be split into more elementary tasks (e.g., beam selection in a pre-defined localisation-optimal sequence), which are performed by the RIS controller that is either co-located with the BS (on the network side), or hosted at the physical RIS device, depending on the computational capabilities of the latter. Finally, the most elementary operations (i.e., that with finest time

granularity) are carried out at the RIS device level through its RIS actuator (e.g., loading of the requested RIS configuration).

- To produce one single location estimate, the RIS configuration needs to be changed depending on the kind of processing:
  - ***In non-coherent processing***, the RISs generate directional beams, which can be used to derive AoA or AoD (e.g., based on signal strength) and ToA (based on the strongest beam). The plurality of RIS beams should be generated within the latency budget. For instance, if 2 RISs cooperate to localise a user, and each RIS uses 20 beams, then the beams should be changed every 250 µs, given a latency budget of 10 ms.
  - ***In coherent processing***, the RIS update period depends mostly on the channel coherence time and hence on operating frequency, since phase-coherent integration and processing is performed. At a carrier frequency of 3 GHz and a velocity of 1 m/s, the coherence time is approximately 100 ms, while at 30 GHz, the coherence time drops to 10 ms. All RIS configurations must hence be executed within this coherence time.

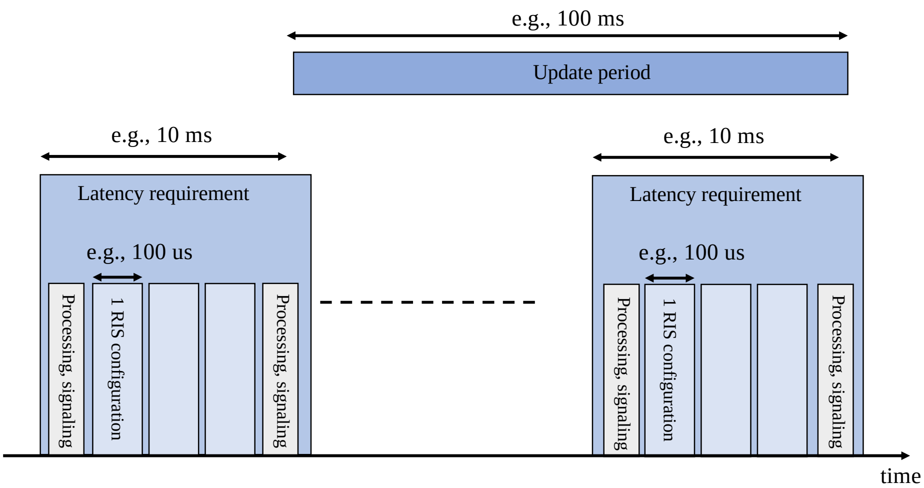


Figure 3-12: Localisation and sensing time scales [RISE6G_D53].

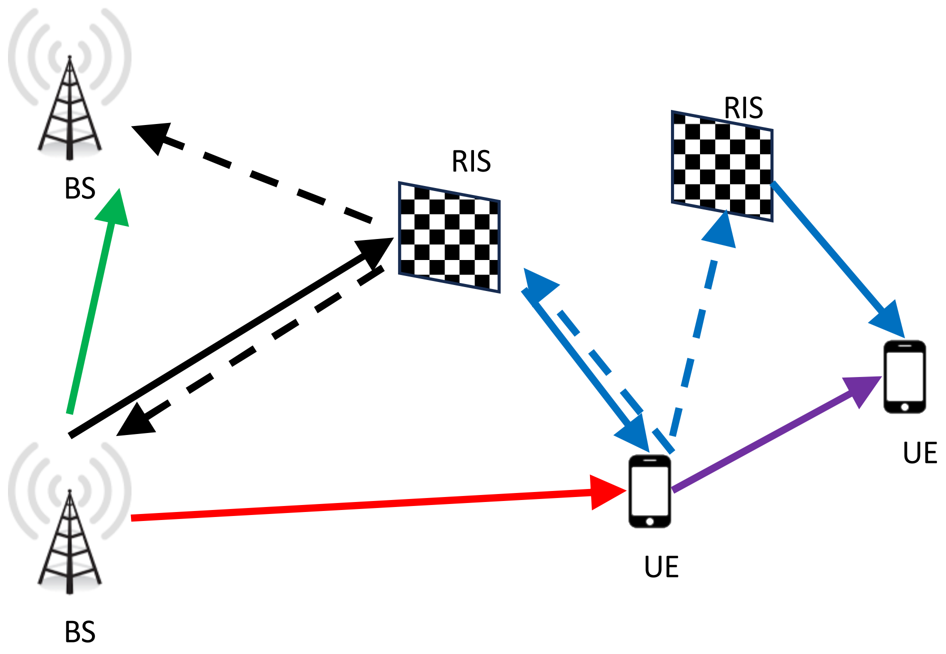
3.2.2 Requirements in terms of interfaces

Erreur ! Source du renvoi introuvable. Table 5 summarizes the main proposals from RISE-6G WP5 for localisation and sensing described in details in [RISE6G_D53], while focusing on physical architecture and deployment, control (at beam or unit cell levels) and signalling aspects. Moreover, in Figure 3-13 all considered interfaces and connections between various entities in the network for the reported contributions are summarized.

Table 5 – Overview of the architecture proposals for localisation and sensing (columns with the same colour rely on a similar physical deployment, while symbol "*" in the "Architecture" rows denote the physical entities to be located) [RISE6G_D53].

WP5 Contributions	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Physical Architecture										
Nr BS	1	≥2 (2D) ≥3 (3D)	0	0	1	1	0	0	1	1

Nr RIS	1 (LOS), ≥2 (NLOS)	1*	1 (RTT and AOD) 3-4 (RTT only)	1	1	1	≥3	1	≥2 (NLOS)	1
Nr UEs	1*	0	1*	≥2*	1*	1*	1*	1*	1*	≥1*
UE Mobility	Static	Mobile	Static	Static	Static	Static	Static	Static	Static	Static
RIS Type	Reflect. (Passive)	Reflect. (Passive)	Reflect. (Passive)	Reflect. (Passive)	Reflect. (Passive)	Reflect. (Passive)	Receiv. (Hybrid)	Receiv. (Hybrid)	Reflect. (Passive)	Receiv.
Nr non-connected targets	0	0	0 for localisation, ≥1* for mapping	0	0	0	0	0	0	≥1*
Localization functionality placement	At UE (or BS)	At BS	At UE	At UE	At UE (or BS)	At UE (or BS)	At RISC	At RISC	At BS (also RISC)	At RISC
Setup										
Indoor/outdoor	Indoor (short range)	Outdoor (multi-BS)	Indoor or outdoor	Indoor or outdoor (e.g., V2V)	Indoor (short range)	Indoor (short range)	Indoor	Indoor	Indoor or outdoor	Indoor or outdoor
2D/3D	3D	2D/3D	3D	3D	3D	3D	3D	3D	3D	2D
Frequency Band	Preferably mmWave	Any	Preferably mmWave or even sub-THz	mmWave	Preferably mmWave	Preferably mmWave	Any	Any	Any	Any
Near field/far field	FF	NF/FF	FF	FF	NF/FF	NF/FF	FF	FF	FF	NF/FF
LOS/NLOS/ Both	LOS	BS-BS LOS (+RIS-reflected paths)	LOS (+ NLOS for mapping)	UE-UE LOS (+RIS-reflected paths)	LOS/ NLOS	NLOS	LOS/ NLOS	LOS	NLOS	LOS
Hardware considerations	None	None	Full-Duplex UE needed	None	Large surface	Large surface + Lookup tables of element-wise reflection coefficient needed	None	Partially connected RIS (with several RF chains)	None	Large surface
Data flow & Signalling										
Uplink/ Downlink	UL or DL	DL and UL	UL	UL	DL	DL	UL	UL	UL	UL
Measurement type	AOD and Delay in LOS WB (or several AODs in NB and/or in NLOS)	Delays (+ optional AOAs/AODs if TxBSs and RXBSs have multiple antennas)	RTT and RIS AOD	Delays (+ optional AOAs/AODs)	Position directly from IQ samples	Position directly from IQ samples	AOD at each RIS	Several AODs at the RIS	AOAs from RIS-reflected paths	Radio map (Matched filter output)
RIS configuration strategy	Arbitrary or location-based / Several profiles needed	Random / Several profiles needed	Arbitrary or location-based / Several profiles needed	Arbitrary or location-based / Several profiles needed	Location-based / Several profiles needed	Location-based / Several profiles needed	Arbitrary / Several profiles needed	Arbitrary / Several profiles needed	Random / Several profiles needed	Arbitrary
Who collects measurements	UE (DL) or BS (UL)	BS	UE	UE	UE	UE	RIS	RIS	BS	RIS
Narrowband/wideband	WB or NB	WB	WB	WB	WB or NB	WB or NB	NB	NB	NB	NB
Relevant section (on [RISE6G_D53])	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	4.11



Arrow	Interface	1	2	3	4	5	6	7	8	9	10
	BS-to-RIS	X	X			X	X			X	
	RIS-to-BS		X			X	X			X	X
	BS-to-UE	X									X
	UE-to-BS	X									X
	RIS-to-UE	X		X	X	X	X			X	
	UE-to-RIS			X	X	X	X	X	X	X	X
	BS-to-BS		X								
	UE-to-UE				X						

Figure 3-13: Physical architecture requirements in terms of control signalling for all the proposed localisation and sensing schemes [RISE6G_D53].

3.2.3 Requirements in terms of data/control time flows and signalling

As in communication contexts, the incorporation of RIS for localisation and sensing purposes naturally introduces additional signalling overhead. Most notably, as already mentioned above, signalling is for instance required for conveying the minimal control information to the RIS so that it can adjust its element-wise phase configurations or beams at specific times and accordingly, enable localisation or even locally/timely boost performance. Synchronization signals and procedures are hence required so as to align in time these RIS configurations with the transmitted pilot signals and, in some of the investigated settings, to facilitate the exchange of localisation/sensing data with the network. Finally, certain localisation and sensing algorithms call for more specific signals to initiate, terminate or acknowledge the exchange between BS, RIS and UE.

In [RISE6G_D53], multiple data/control-flow and signalling diagrams have already been provided, corresponding to the various RISE-x localisation and sensing proposals listed in d**Erreur ! Source du renvoi introuvable.**ifferent message sequence charts may correspond to distinct underlying physical architectures. Hereafter, we focus on three main signalling schemes (out of ten), as representative variants involving conventional network entities (i.e., excluding BS-free and UE-free settings, which may be somehow too specific with respect to the architecture harmonization targeted herein), namely:

- Single-BS UE localisation with one reflective RIS (See Figure 3-14);
- Single-BS NLoS UE localisation with several reflective RISs (See Figure 3-15);
- Simultaneous localisation of connected UEs and mapping of passive objects with one sensing RIS (See Figure 3-16).

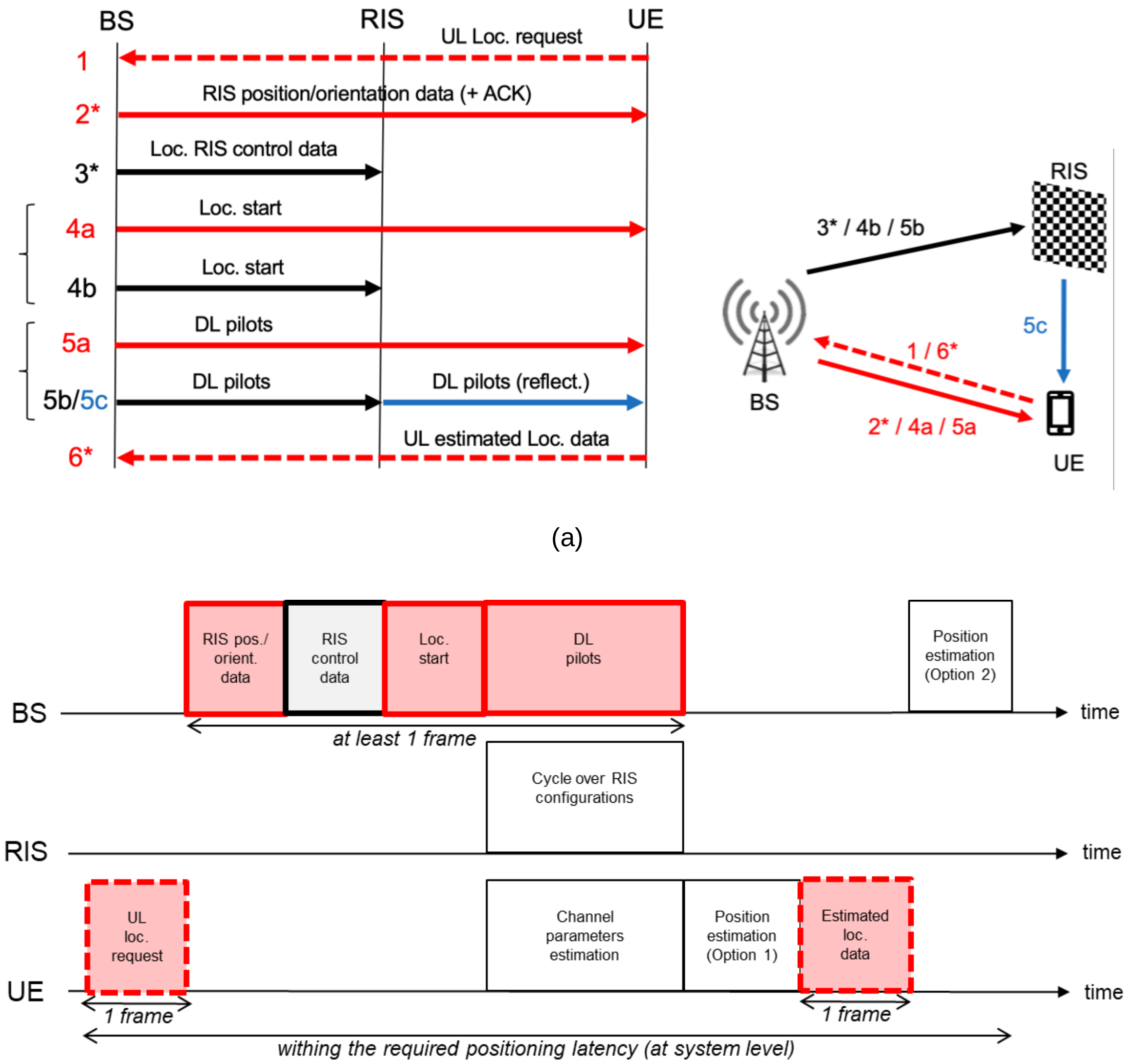
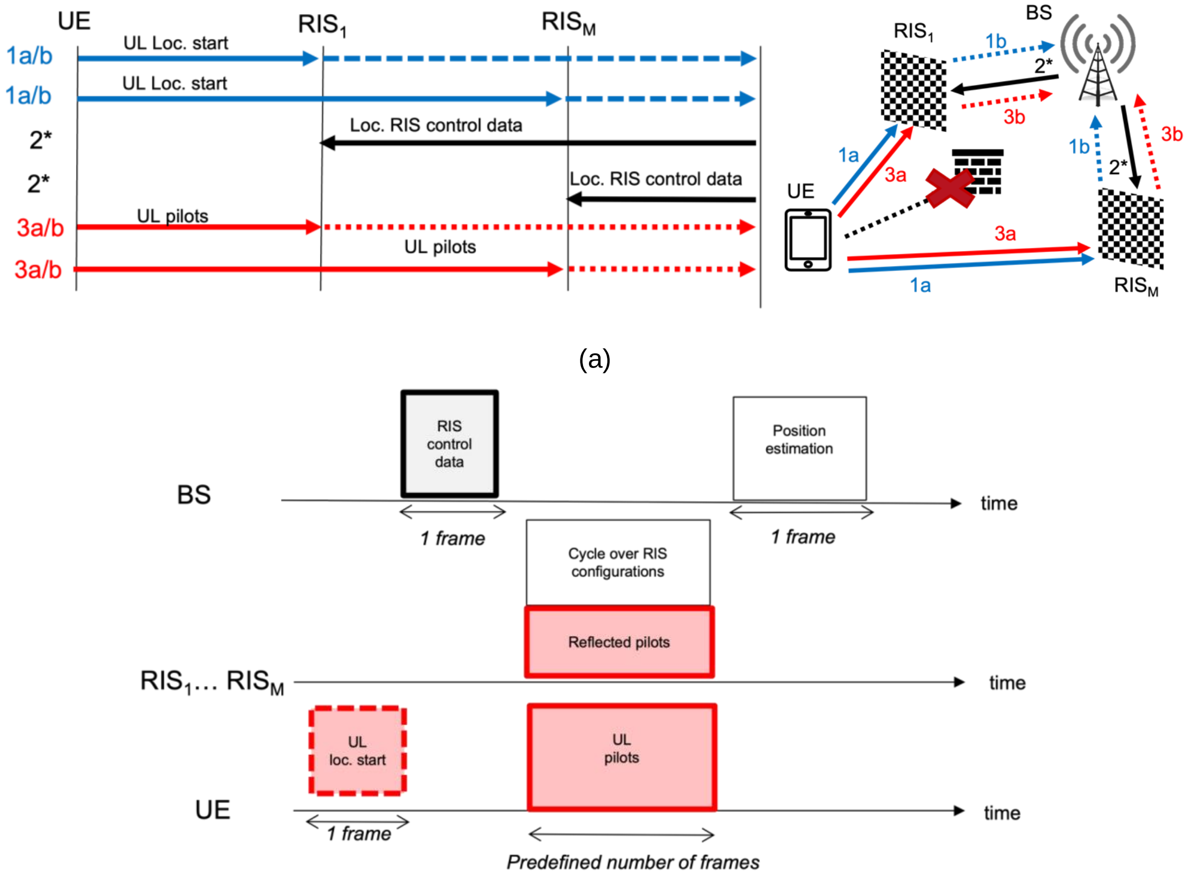
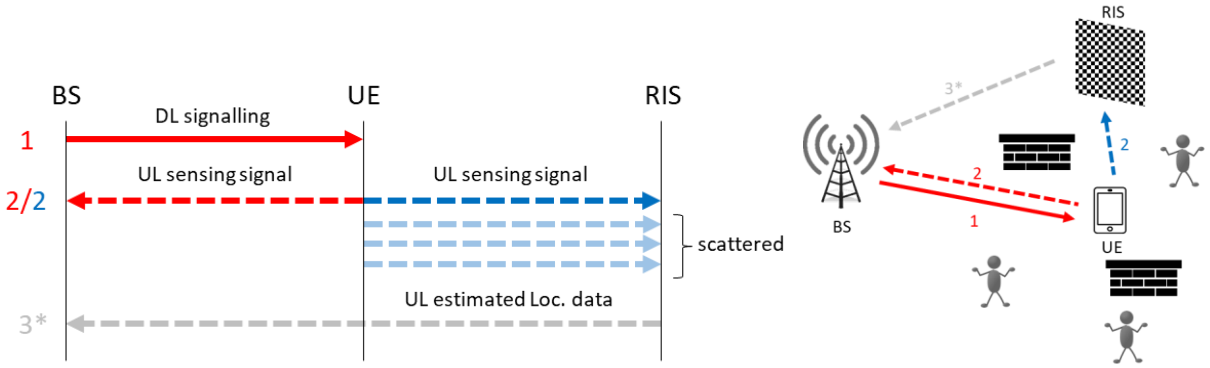


Figure 3-14 – Messages sequence chart (a) and time diagram (b) for single-BS UE localisation with one reflective RIS (contribution C1, C5 and C6 of [RISE6G_D53]).

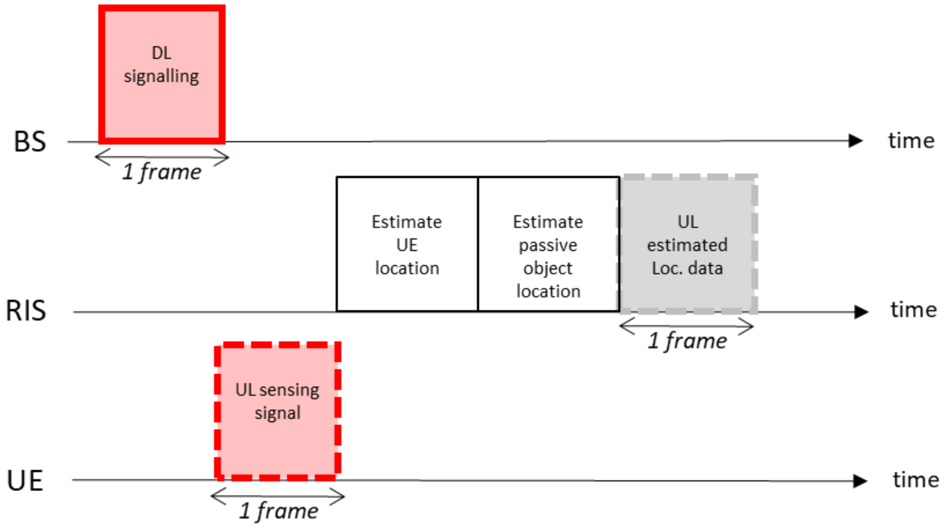


(b)

Figure 3-15 – Messages sequence chart (a) and time diagram (b) for single-BS NLoS UE localisation with several reflective RISs (contribution C9 of [RISE6G_D53]).



(a)



(b)

Figure 3-16 – Messages sequence chart (a) and time diagram (b) for localisation of both active and passive UEs with one sensing RIS (contribution C10 of [RISE6G_D53]).

3.3 RIS for Enhanced/Enabled Security and Sustainability

3.3.1 General Requirements

WP6 concentrated on the role of the RIS devices to boost the following metrics defined in [RISE6G_D24] within "boosted" areas identified in deployment scenarios listed in [RISE6G_D23]:

- Energy-Efficiency (EE),
- Electromagnetic Field Exposure Utility (EMFEU),
- Secrecy Spectral Efficiency (SSE).

Recall that the EMFEU and the SSE metrics are based on the concepts of *Intended* and *Non-Intended* users which are illustrated in Figure 3-17 (extracted from [RISE6G_D63]) with one example where a RIS-x network emits radio waves with the *Intended* user as a target, in the presence of four *Non-Intended* entities:

1. a *Non-Intended User* who uses his/her UE (connected to the network) to *eavesdrop*; the network uses the connection with the *eavesdropper* to avoid eavesdropping, and thus the eavesdropper *unintentionally* helps the network;
2. a *Non-Intended User* who is *exposed* to the radio waves emitted by the RIS-x network, and who uses his/her UE (connected to the network) to help *intentionally*, the network to reduce their exposure;
3. a *Non-Intended* person, who is *exposed* to the radio waves emitted by the RIS-x network but it is *not* helping the network to reduce his/her exposure;
4. a *Non-Intended* person, who uses a device (which is not connected to the network) to *eavesdrop*, *without* helping the network to prevent him/her from eavesdropping.

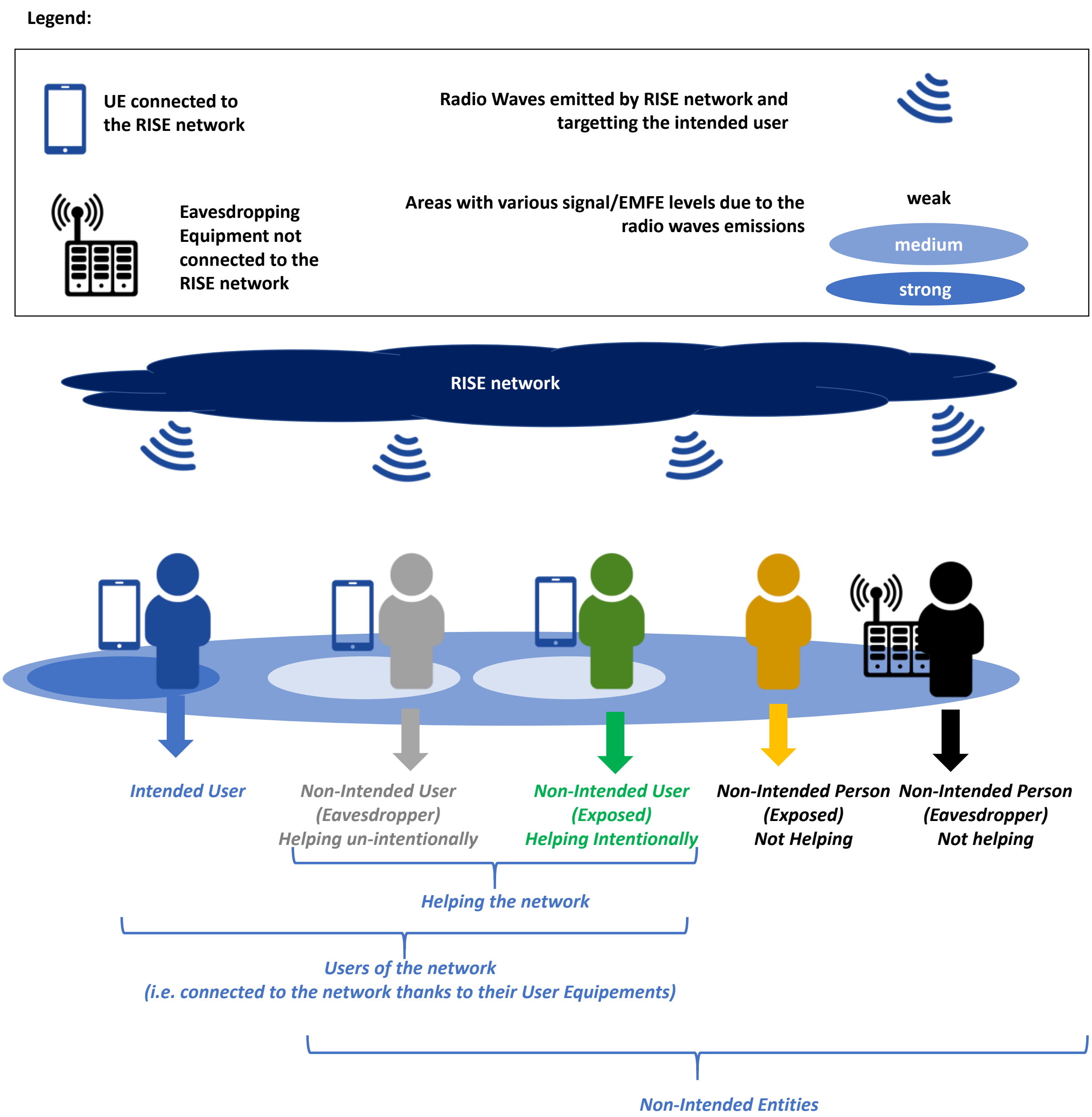


Figure 3-17 – Example where the RIS-x network emits radio waves with the *Intended* User as a target, in the presence of four different types of *Non-Intended* entities (extracted from [RISE6G_D61]).

In the context described in Figure 3-17,

- boosting the EMFEU consists in boosting the ratio of the received spectral efficiency at the Intended user over the exposure of the (most exposed) user; when the most exposed user is different from the Intended user (i.e. it is the Non-Intended user), *inter-EMFEU* is considered; when the user is exposing his/herself with his/her own data flow, *self-EMFEU* is considered (in this case the intended user and the Non-Intended user are the same user);

- similarly, boosting the SSE consists in boosting the difference between the received spectral efficiency at the Intended user and the spectral efficiency attained by the eavesdropping Non-Intended user.

3.3.2 Requirements in terms of interfaces

In this section, we provide some recommendations regarding architecture and control signalling based on the analysis detailed in sections 2, 3 and 4 of D6.3 with reference to all the Technical Components (TCs) analysed by WP6 which are sketched in Figure 3-18 and listed in Table 6.

Note that, while a reference to the corresponding section of D6.3 is given for every TC of Table 6, TC#12 is described in D6.4. However, it is listed here as well to show that I-EMFEU in UL was also considered in the project. Table 7, TC#12 is described in D6.4 [RISE6G_D64]. However, it is listed here as well to show that I-EMFEU in UL was also considered in the project.

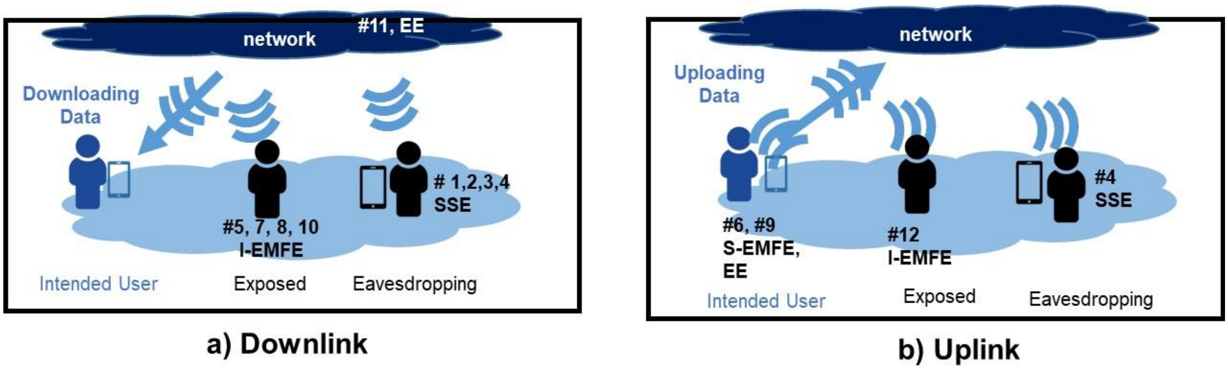


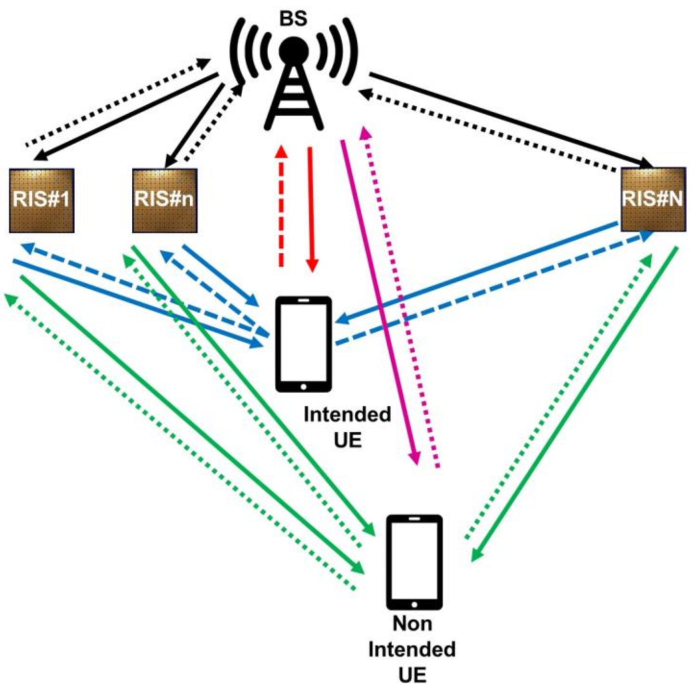
Figure 3-18 – All studied TCs in a glimpse (TC numbers refer to Table 6).

Table 6 – Considered schemes with corresponding objectives and deployment scenarios.

TC#	Name	Section In D6.3	Objective	Frequency
1	SSE with Full CSI knowledge	2.2.1	SSE, EE	Agnostic
2	SSE with Partial CSI knowledge	2.2.2	SSE, EE	Agnostic
3	On Maximizing the Sum Secret Key Rate for Reconfigurable Intelligent Surface-Assisted Multiuser Systems	2.2.3	SSE, EE	Agnostic
4	Spatial SSE	2.2.4	SSE, EE	Agnostic
5	RIS-aided EMF-Aware Downlink BF for sub-6 GHz	3.2.1	I-EMFEU, EE	Sub-6 GHz.
6	Energy Efficiency Optimisation of Reconfigurable Intelligent Surfaces with Electromagnetic Field Exposure / Global Reflection / Active element Constraints, at mmWaves	3.2.2	S-EMFEU, EE	mmWaves
7	Low sum EMFE of multiple radio access networks in strong visibility, without coordination, at mmWaves	3.2.3	I-EMFEU, EE	mmWaves

8	EMFE Avoidance thanks to Non-Intended User Equipment and RIS-aided BF, at mmWaves	3.2.4	I-EMFEU, EE	mmWaves
9	Creating and Operating Areas With a reduced S-EMFE Thanks to RIS-aided received BF	3.2.5	S-EMFEU, EE	Sub-6 GHz.
10	EMF Exposure Mitigation in RIS-Assisted Multi-Beam Communications	3.2.6	I-EMFEU, EE	mmWaves
11	Energy efficiency maximisation of MMIMO communications with dynamic metasurface antennas	4.2.1	EE	mmWaves
12	Blue Communications for Edge Computing: the Reconfigurable Intelligent Surfaces Opportunity [ACS22]	see D6.4	S-EMFEU	mmWaves

The figure below summarises the architecture requirements for each scheme in terms of over-the-air in-band interfaces needed for control signalling.



Legend

	Arrow	interface	1	2	3	4	5	6	7	8	9	10	11
		BS-to-RIS	X	X	X	X	X	X	X	X	X	X	X
		RIS –to-BS	X	X		X	X	X		X		X	X
Intended UE		BS-to-UE	X	X	X	X	X	X	X	X	X	X	X
		UE-to-BS	X	X	X		X	X	X	X	X	X	X
		RIS-to-UE	X			X		X		X		X	X
		UE-to-RIS			X		X	X		X	X	X	X
Non-Intended UE		BS-to-UE	X	X		X	X			X			
		UE-to-BS	X	X			X			X			
		RIS-to-UE				X	X						
		UE-to-RIS					X						

Figure 3-19 – Architecture requirements for all SSE- and EMFEU-oriented schemes, in terms of control signalling (see Figure 3-18).

All proposed schemes rely on a hybrid RIS which can switch between different modes including at least a reflecting mode and a receiving mode and, for some schemes, a transmitting mode and a transparent mode.

3.3.3 Requirements in terms of data/control time flows and signalling

So far, the interfaces between the critical blocks of the RIS-x architectures for EMFEU and SSE have been mainly assessed from a data/control flow and signalling standpoint [RISE6G_D63]. Hence the different message sequence charts given below for some of the TCs listed in Table 6 (see Figure 3-20 to Figure 3-25) correspond to the different architecture variants enabling EMFEU and SSE boosting, where, along the different arrows, one can retrieve the information transiting between the blocks in an abstract high-level representation. Table 7 corresponds to the different architecture variants enabling EMFEU and SSE boosting, where, along the different arrows, one can retrieve the information transiting between the blocks in an abstract high-level representation.

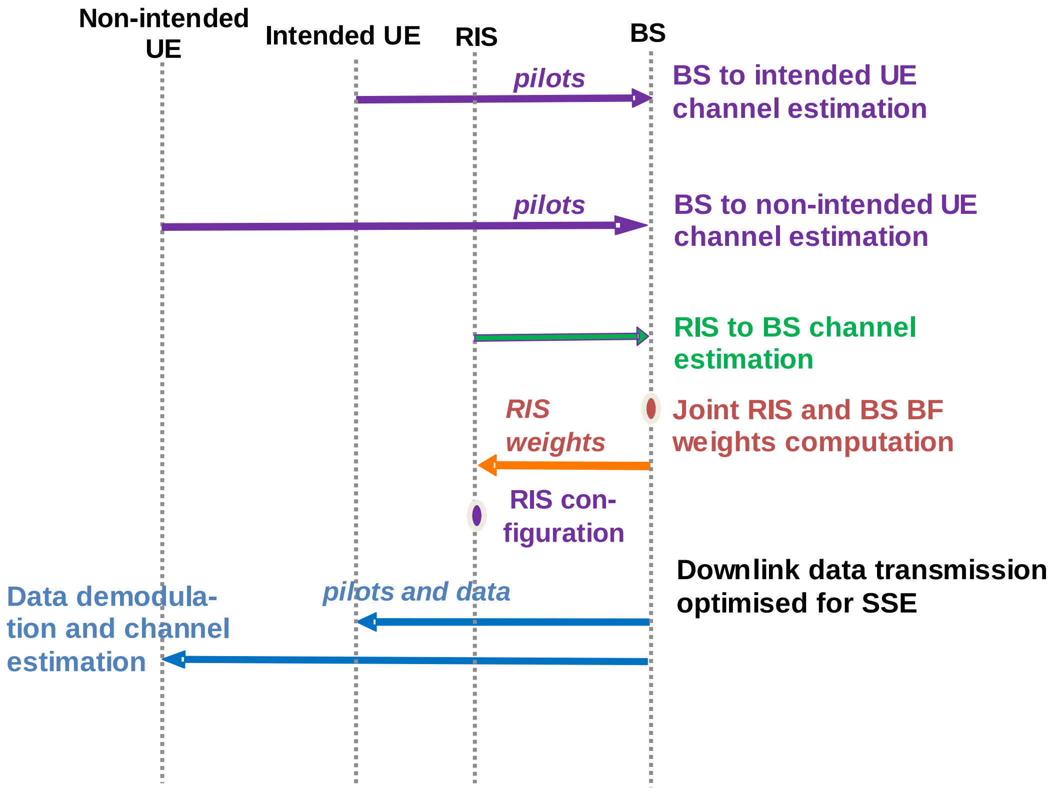


Figure 3-20 – Data flow and control signalling for the spatial focusing scheme (Scheme #4).

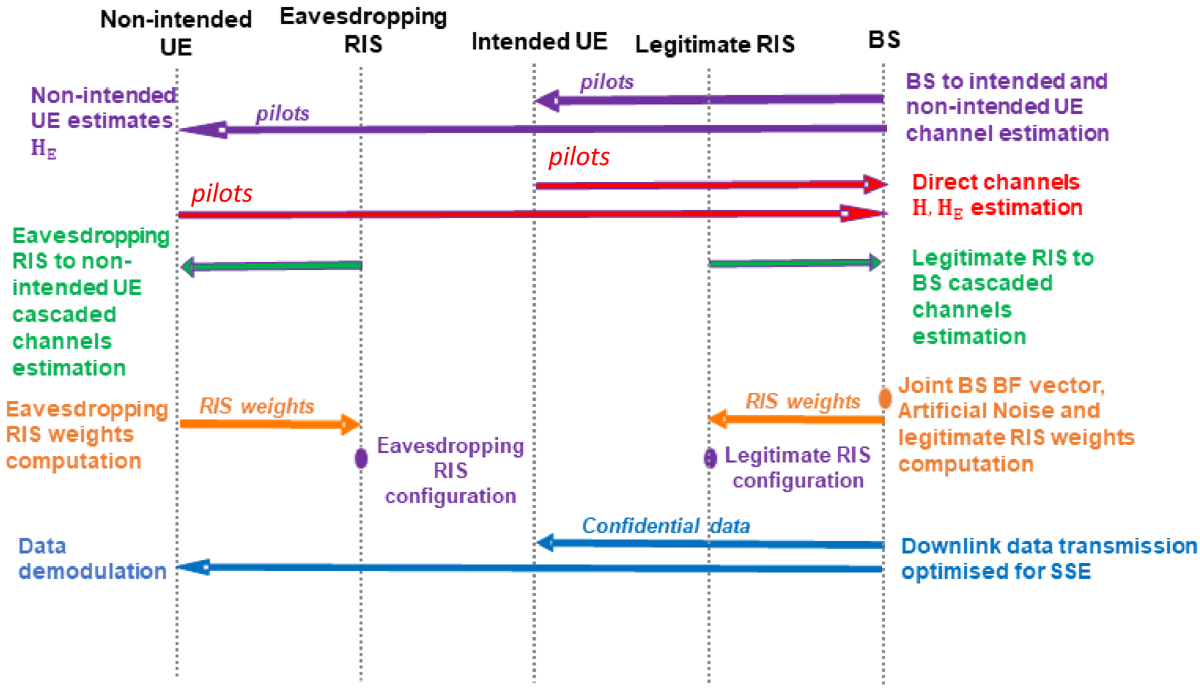


Figure 3-21 – Data flow and control signalling for the secrecy spectral efficiency scheme with full CSI (Scheme #1).

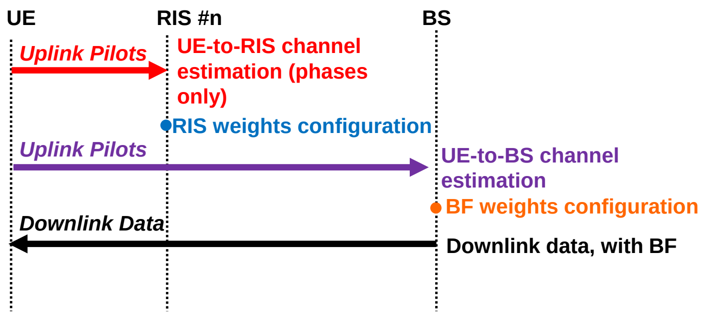


Figure 3-22 – Data and control flows, all RISs #n (n=1 to N) doing the same thing simultaneously (Scheme #5).

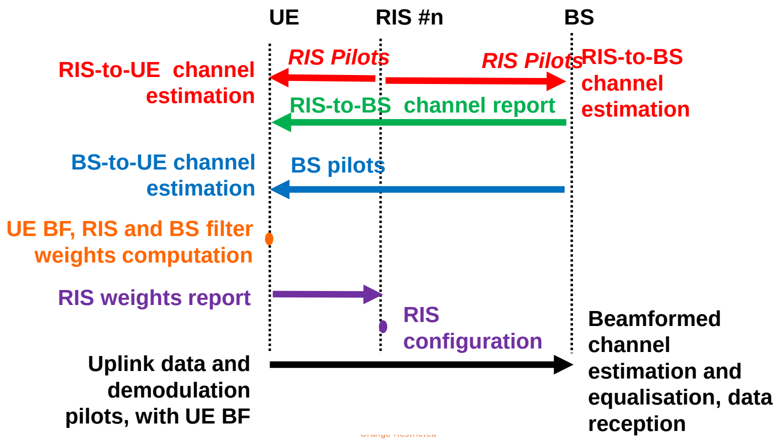


Figure 3-23 – Data and control flows, with RIS channels estimation, in sequence for RIS #n, n=1 at N (Scheme #6).

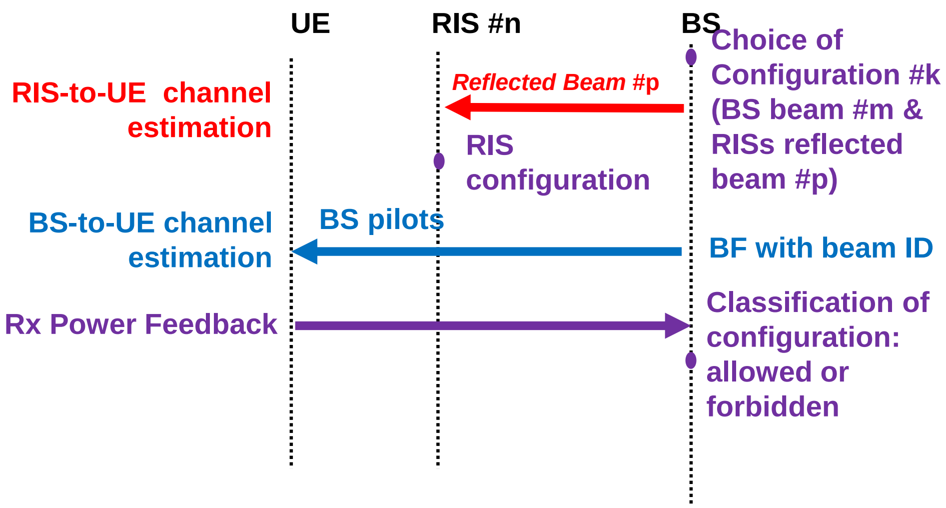


Figure 3-24 – Data and control flows, with all RISs #n=1 to N, doing the same thing simultaneously (Scheme #7).

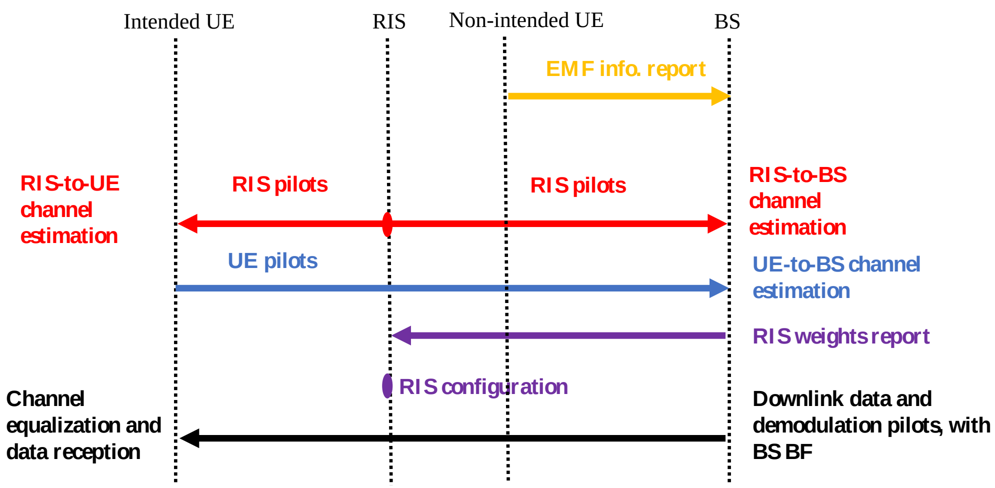


Figure 3-25 – Data and control flows (Scheme #8).

These time diagrams and flowcharts for the considered schemes for SSE and EMFEU improvements show that the full protocol (including control signalling and data transmission) is designed to be preferably performed within the channel coherence time. Therefore, in most cases, proposed schemes apply to low mobility or steady UEs.

3.4 Future outlook

After having analysed the proposed schemes described in previous sections, it was found that the majority of them need an architecture where the deployed RIS(s) are able to exchange control signalling and/or pilot sequences with the BS and the UEs within the coherence time of the channel, i.e. before the propagation environment varies.

- Therefore, in most cases, the RIS device with an embedded RISA (RIS function) may be the most suitable option.
- Also, in most cases, the control of the RIS is split between the RIS device itself, the BS(s) and the UEs.

One solution would be to consider an RIS as a slave node of a BS, and act as an UL or DL relay node between the BS and the intended UE. Such relay nodes already exist in current standards [TS123501]. Compared to a standard relay node, in all TCs (apart from TC#11) the RIS has the following new property: it can reflect the BS and/or the UE waves transporting their own data. Regarding the other exiting properties of the relay nodes, the RIS may potentially be less sophisticated (i.e. with less computing and signal processing capabilities).

- Another solution would be to consider an RIS as a distributed passive antenna of a BS.

4 RISE-6G network architecture proposals

When grappling with established network architectures, the RISE-6G architecture proposals outlined in the current section unveil a transformative approach to interface seamlessly. Such proposals represent a paradigm shift in how Reconfigurable Intelligent Surfaces (RIS) are integrated into the communication landscape, offering novel methods to control RIS deployment and establish direct interactions with Radio Access Network (RAN) elements. This not only facilitates control but also enables the exchange of critical messages with pertinent RISE-6G architectural blocks.

The visionary architectural propositions of the RISE-6G project reconfigure the conventional understanding of network dynamics. One key proposal revolves around the intelligent interfacing of RIS within existing networks, ensuring a harmonious coexistence and collaboration between RISE-6G elements and established network infrastructure. This dynamic integration is engineered to empower RAN elements, allowing them unprecedented control over RIS deployment. Furthermore, the RISE-6G architecture envisions a direct line of communication between RAN elements and specific RISE-6G architectural blocks.

This interaction paves the way for a symbiotic relationship, wherein RAN elements can seamlessly coordinate and exchange vital information with the intricacies of the RISE-6G framework. Such communication pathways serve as the backbone for optimizing network performance, enabling real-time adjustments, and harnessing the full potential of RIS technology. In essence, the RISE-6G architectural proposals transcend mere theoretical constructs; they represent a tangible blueprint for an evolved communication infrastructure. By fostering dynamic interfaces and direct linkages, the RISE-6G project pioneers a future where the coalescence of RIS and RAN elements defines a new era of efficiency, adaptability, and unparalleled connectivity in the B5G/6G landscape.

4.1 Open-radio access network (O-RAN)-based architecture proposal

Figure 4-1 sketches RISE-6G network architecture proposal **with open interfaces to the RIS device,** where RIS(A), RISC and RISO functional elements defined in section 2.1.1 with their own time granularities are placed and connected to each other. Localization-boosted areas are there only as an example, but other RIS-x use cases could apply as well.

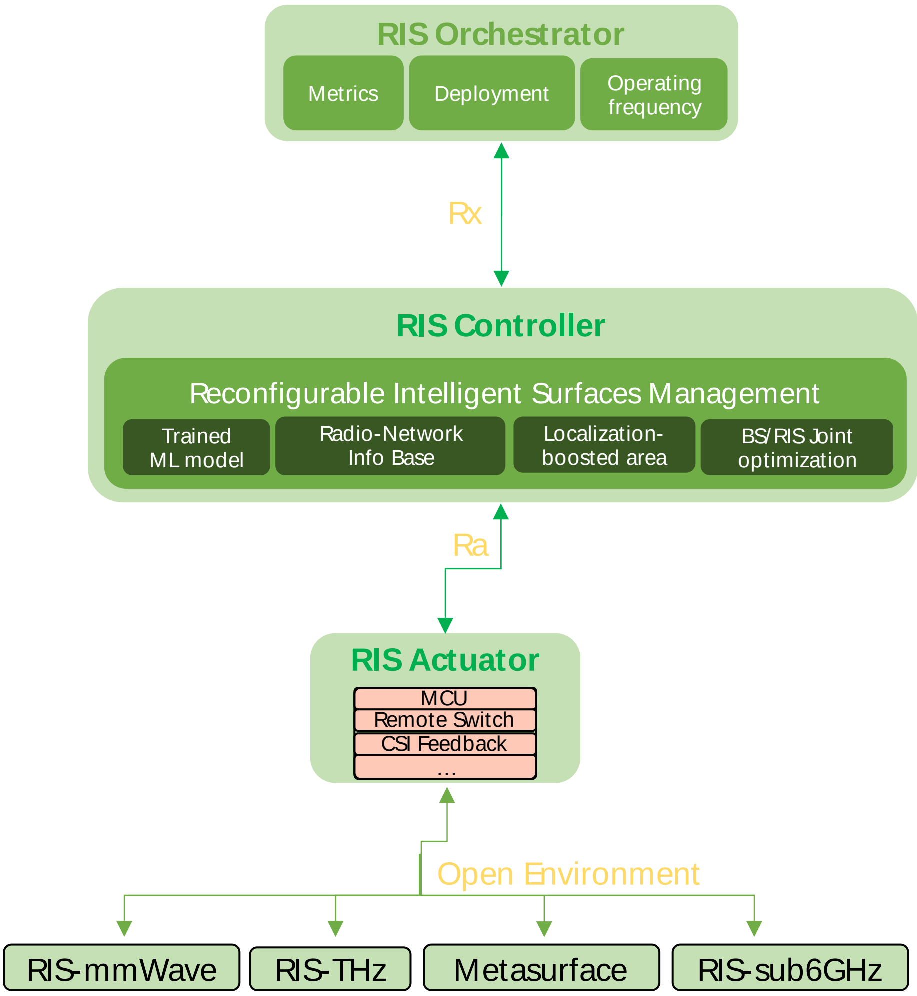


Figure 4-1 - RISE-6G network architecture proposal.

As it can be seen in Figure 4-1 , there is no one-to-one correspondence between RIS and RISA as it could be expected. Such architectural choice relies on the need to take into account that different RIS types might involve a number of RISA embedded functions (for instance, CSI Feedback can be provided only for Hybrid-RIS, ect.).

The open environment of Figure 4-1 is a class of protocols that can be implemented to include different types of RIS as described in section 2. However, it might be challenging defining a common baseline that aligns all basic functionalities of different types of RISs.

In Figure 4-2 main O-RAN functional blocks show how the RAN functional split is applied according to 3GPP. 3GPP-compliant interfaces are highlighted in blue colour whereas O-RAN interfaces are represented in red text. Each RAN element, namely eNB or gNB according to the 3GPP jargon, can be split into a Centralized Unit (CU), a Distributed Unit (DU) and a Remote

Unit (RU), including different ISO/OSI stack layers. Specifically, the very low physical layer functions are left to the RU that represents the RF device and shall be placed at the remote cell site. DU functions can be placed on an edge cloud with very-high-capacity connection to assist and support real-time operations between RLC/MAC layers and the physical layers. CU functions can also be placed on edge clouds and shall be split into control plane (CP) and user plane (UP) functions. CUs and DUs are connected through the F1 interface (F1-c and F1-u for control plane and user plane respectively). Finally, DUs are connected to RUs via the open fronthaul (O-FH) protocol that includes four different planes: user (U-) and control (C-) planes to transport physical layer and control commands, synchronization plane (S-plane) to manage synchronization among DUs and Rus, and management plane (M-plane) to configure RU features.

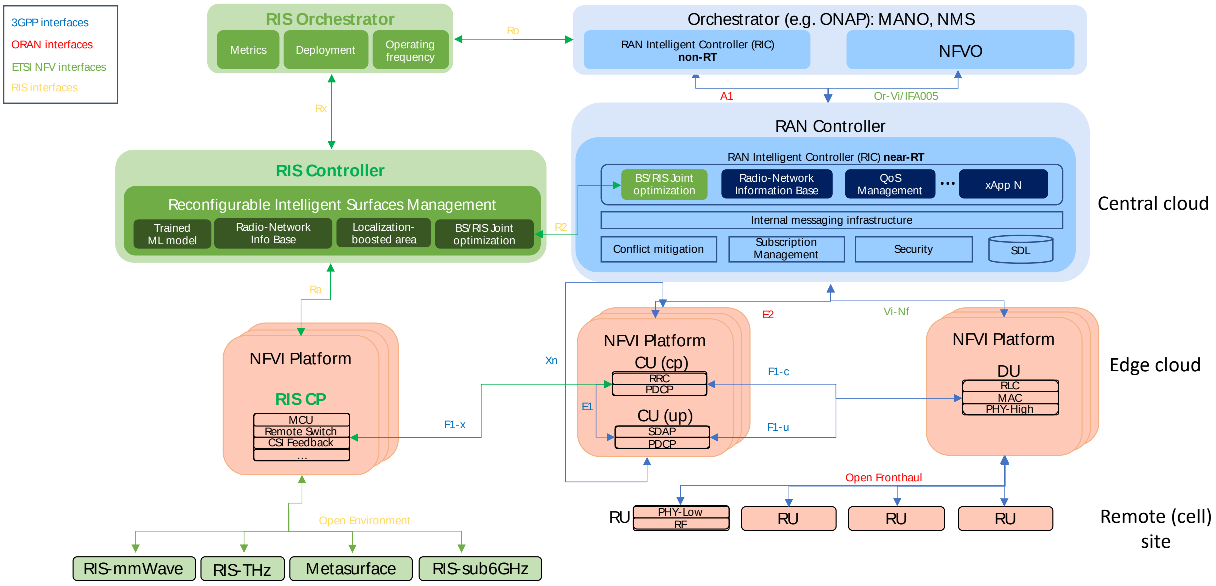


Figure 4-2 – Relevant interfaces between RISE-6G architecture and O-RAN/3GPP/ETSI network architectures.

The O-RAN Alliance has introduced a new entity, namely the near-RealTime (near-RT) RAN Intelligent Controller (RIC), that automatically interacts with the CU functions through the E2 interface. Such RAN controller can integrate third-party applications, called xApps that will control specific RAN functions. Finally, the O-RAN Alliance also introduced the non-RealTime (non-RT) RIC that can exchange messages with the near-RT RIC using the A1 interface.

When the RISE-6G architecture is in place, all functions that are included in the RISA, RISC and RISO can be virtualized, abstracted and deployed into edge or central clouds while physical devices (RF) shall be placed on site. The RISA can directly operate physical devices, such as Metasurfaces/RIS, at different operating frequency through the general interface called Open Environment that would implement different planes based on the type of RIS we consider, e.g., nearly-passive RIS, hybrid RIS, holographic RIS and so on. The RISC will trigger configurations and get specific feedbacks (according to the type of RIS considered) from RISA through Ra interface. RISO can control multiple RISC through Rx interfaces.

The RISE-6G architecture may directly interact with the above-mentioned network architecture by means of novel interfaces, namely F1-x, R2 and Ro. Specifically, two use-cases can be envisioned.

- **RIS device is directly connected to enB/gnB** to optimize transmitter beamforming parameters and RIS configurations. In this case, the CU C-plane can trigger specific RIS configuration to the RISA within few ms. This is relevant when the RIS deployment is under the network operator control.

- **RIS device is connected to the management of the eNB/gNB** in a master/slave or peer-to-peer fashion. In this case, RISA and RIS device can only be configured by the RISC. However, the RISC directly interacts with the near-RT RIC by means of a dedicated xApp that will have its counterpart in the RISC. This case would include self-contained and independent RIS deployments.

4.2 3GPP Integrated Access and Backhaul (IAB)-based architecture

Based on the analysis conducted in Sections 3 and 4, one can propose several architecture candidates to introduce RISs in the 3GPP.

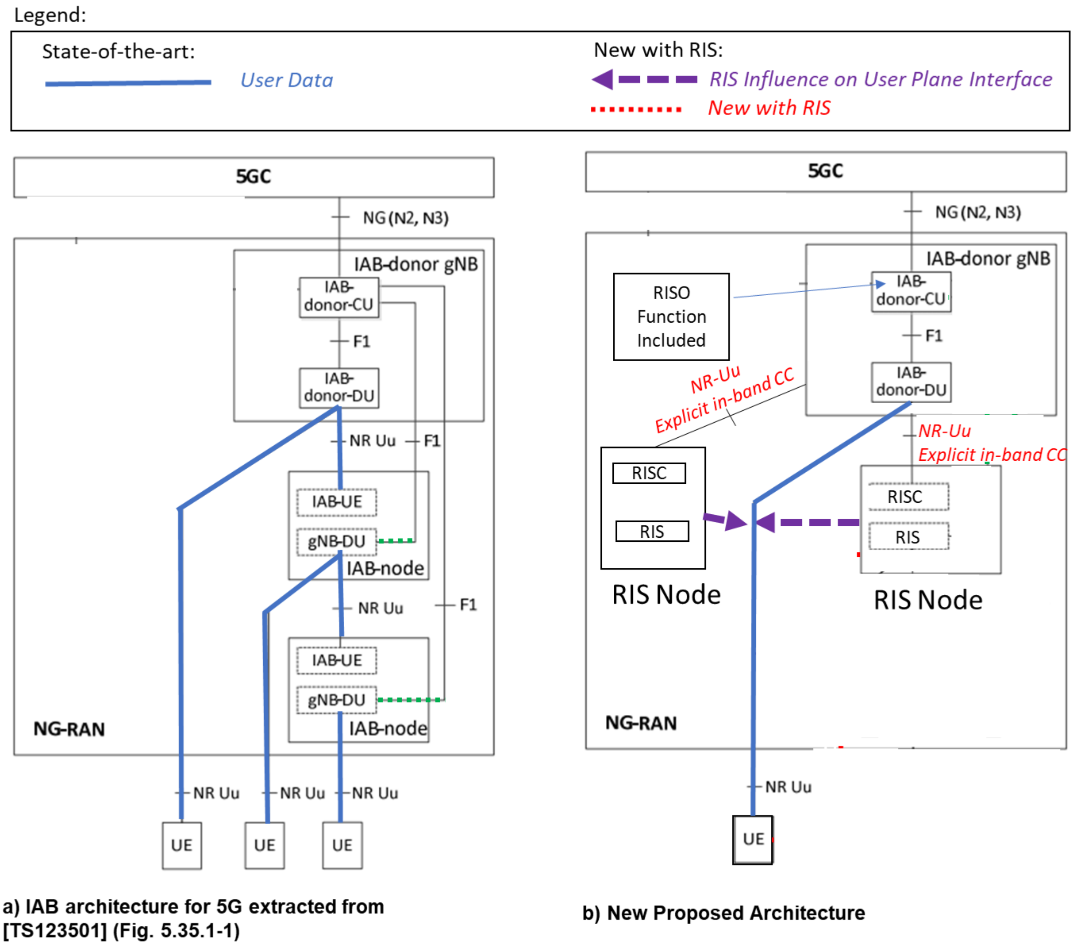


Figure 4-3 – Proposed architecture, with RISA and RISC functions co-located in RIS node, using explicit in-band CC on NR-Uu interface to gNB (hosting the RISO function).

RIS helping Location Management Function (LMF)

Based on our analysis of the various proposed schemes for localisation and sensing, we propose several new architectures, based on 3GPP and illustrated in Figure 4-3.

RIS as a passive relay

Based on our analysis of the various proposed schemes (for EMFEU and SSE boosting for instance), among others we envision an architecture, where RIS(s) are slave nodes of a BS, and act as UL or DL relay nodes between the BS and the intended UE. Such relay nodes already exist in current standards [TS123501] and the corresponding architecture is called Integrated Access and Backhaul (IAB). Compared to a standard relay node the RIS has the following new property: it can reflect the BS waves or UE waves transporting their data. Regarding the other exiting properties of relay nodes, the RIS may potentially be less sophisticated (with less computing and signal processing capabilities).

Figure 4-3 shows the state-of-the-art 3GPP IAB for 5G, and the new proposed architecture with RIS as a nearly-passive relay. As traditional IAB-nodes (relays) they are controlled through the F1 interface. However, they need a new interface (which we call F2) to be controlled by the UE, and also, they do not have any user plane interface with the UE. Instead, they have an “influence” on the base station (gNB) – UE User Plane interface (the so-called NR-Uu interface).

4.3 Relation to 6G architectural work

Hexa-X/ Hexa-X-II projects [Hexa-X], [Hexa-X-II] have been/ is investigating technology enablers and architectural components for 6G. Research on these architectural components aims at supporting the architectural transformation needed for 6G, with three main directions: 6G architecture should enable intelligent networks, flexible networks, and efficient networks.

Another main research direction, named “Flexible networks”, targets global service coverage, with efficient integration of different types of networks. Mesh, relaying and D2D are therefore part of the solutions considered and explored, and multi-hop / mesh networks will be part of the 6G “network of networks”.

Since RISs can be seen as passive relay nodes and these nodes should be managed in the architecture as multi-hop / mesh networks, the work in RISE-6G could fit into the 6G architectural work developed in Hexa-X/ Hexa-X-II.

4.4 Relation to ETSI ISG RIS

[ETSI002] lists many examples of architectures for particular use cases and deployment scenarios. In these examples, the RIS is integrated in the wireless network. In most reported cases, the RISA is embedded in the RIS device, and RIS control functions are split between the RIS device, BS, UE and LMF. Hence, similar conclusions as in Section 3 are driven.

4.5 Further thoughts: Deployment strategies from a technical perspective

Very first results on RIS deployment strategies can be derived especially from the activities performed within WP4 and they are summarized in what follows.

The location of the RISs determines how they should be physically interconnected with the rest of the network and what is their optimal configuration at a given time instant, so RISs require ad-hoc design, deployment, and management operations to be fully exploited.

Furthermore, while RISs properly steer the reflected beams towards specific directions, interference is also focused onto unwanted areas, if not properly managed. This issue exacerbates the overall deployment complexity calling for advanced optimisation techniques to strike the optimal trade-off between RISs density and the corresponding spurious detrimental interference.

RIS deployment strategies will have to face a situation which is intrinsically critical: on one hand, optimal RISs deployment requires a-priori information on the applied RISs configurations, on the other hand, the optimal RISs configurations can be obtained only upon fixing the BSs and RISs positions. To overcome this issue and to make the analysis tractable, simplistic assumptions on agnostic RISs optimisation can be done, however a full exploitation of the RISs capability to improve network performance requires advanced modelling and optimization. A valuable example is provided in the contribution #D-4 described in [RISE6G_D54].

The deployment problem is tightly coupled with the RIS application scenario. The following list collects a few interesting ones derived from D2.3.

- Active beamforming via an antenna array at the transmitter side and passive beamforming in the channel via RIS can complement each other and provide even larger gains when they both are jointly optimised.
- RISs can be integrated in the wireless networks in a nomadic way, i.e. by mounting them on-board moving objects such as UAVs, HAP, FWA, or even cars/public transport. UAVs have attracted considerable interest owing to their agile deployments and the ability to establish a LoS link towards ground users thereby acting as flying access points, which can avoid obstacles impairing the overall communication quality. In this context, RISs may be mounted as substitutes to bulky active components such as conventional BSs.
- MEC-enabled networks allow UEs to offload computational tasks to nearby processing units or Edge Servers (ESs), typically placed close to Access Points (APs), in order to run the computation on the UEs' behalf. In this context, a strong performance boost can be achieved empowering MEC with RISs, with the aim of increasing uplink and downlink capacities, and to counteract channel blocking effects in the case of directive mmWave communications. In such a dynamic context, the available resources (i.e., radio, RISs, computation, etc.) must be properly managed to provide the UEs with a satisfactory Quality of Service and the ES can also represents the central unit that performs online resource optimisation and RIS control.

5 Conclusions

In this deliverable, we have reported on the final results within the RISE-6G project related to RISE network architectures and deployment strategies analysis.

In particular, in the Introduction, we have proposed a harmonization of concepts highlighting the need to make a distinction between different categories of solutions, which rely on the RIS technology.

In Chapter 2, we introduced our innovative architectural framework for RIS, featuring an overarching conceptual framework, novel definitions of logical elements, a taxonomy for RIS hardware, and a taxonomy for RIS control.

Chapter 3 provides a summary of the network architecture requirements outlined in technical WP4, WP5, and WP6. Each of these technical work packages explores the utilization of RIS for different purposes.

In the concluding Chapter 4, we present two proposed RISE-6G network architectures: an open architecture with potential extensions within Open-RAN (O-RAN) and a 3rd Generation Partnership Project (3GPP) integrated Access and Backhaul based architecture. Our discussion also establishes connections between our work and the ongoing 6G architectural initiatives, as well as the efforts of the ETSI ISG RIS. Lastly, we offer insights into deployment strategies.

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