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RISE NETWORK ARCHITECTURES AND DEPLOYMENT STRATEGIES ANALYSIS: FIRST RESULTS

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Abstract

In this deliverable, we report on the first results within the RISE-6G project related to reconfigurable intelligent surfaces empowered (RISE) network architectures and deployment strategies analysis.

Keywords

*Beyond-5G; 6G; R*econfigurable 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

One of the tasks in RISE-6G is to identify the most suitable network architectures and deployment strategies for exploiting the Reconfigurable Intelligent Surface (RIS) technology in the scenarios, and under the 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. The goal is to identify optimized network architectures and deployment strategies that would lead to enhancement of the targeted KPIs.

In this deliverable we report on the first results within the RISE-6G project related to RIS Empowered (RISE) network architectures and deployment strategies analysis. The work builds on the initial deliverables within the technical work packages WP4 “RIS for Enhanced Connectivity and Reliability”, WP5 “RIS for Enhanced Localisation and Sensing”, and WP6 “RIS for Enhanced Sustainability and Security”, [RISE6G_D41], [RISE6G_D51] and [RISE6G_D61], respectively. To this end, some material from these deliverables is summarized here to show the current basis for the work towards RISE network architectures and deployment strategies analysis, and for the convenience of the reader. I.e., this deliverable also serves as a point of collection and harmonisation of all contributions towards the proposed RISE network architecture so far within RISE-6G. The presented results are first results, and more mature and refined results will be reported in deliverable D2.6 by the end of the project.

The outline of the deliverable is as follows.

In chapter 1, we proceed with proposing a harmonization of concepts and vocabulary, based on the work within WP4-6.

In chapter 2, we proceed with proposing a common RIS taxonomy and description of RIS features.

In chapter 3, we summarize the network architecture requirements from technical WP4-6.

In chapter 4 we propose an initial RISE-6G network architecture and briefly discuss some identified open issues on logical nodes and interfaces.

In chapter 5 we provide an initial discussion related to deployment strategies from a technical perspective.

Finally, in chapter 6 we discuss the proposed RISE-6G network architecture and its relation to existing architectures and potential extensions within Open-RAN (O-RAN), the 3rd Generation Partnership Project (3GPP), and also in relation to 6G architectural work.

1.1 Harmonization of concepts and vocabulary

The new element RISE-6G is focused on 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 performances;
- RIS-*enabled* solutions where certain services/performances 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 used explicitly), **RIS-*x*** expression will be used for concepts that apply to different categories.

The definition of “architecture” in this deliverable is as follows. A number of logical elements which 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 4.3 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 and to be adopted by the whole project from now on:

- ***RIS (device)***: is the RIS device that can be based on reflect-array or meta-material technology that is directly controlled by an associated RIS actuator with an expected time granularity between 100 microseconds and 10 ms. In some scenarios, the RIS actuator may be embedded into the RIS device. In such a case, we envision a resulting new RIS device directly controlled by the RIS controller (RISC) function.
- ***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 RIS actuator 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 1 and 20 ms.
- ***RIS controller (RISC)***: the controller associated to an RIS actuator or an RIS function. 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 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 based on external explicit instructions (Controlled RIS), or it may operate on its own (Autonomous RIS). The expected action time granularity is between 20 ms and 100 ms.
- ***RIS orchestrator (RISO)***: the orchestrator is placed on a higher (hierarchical) layer and it orchestrates multiple RISCs. Action time granularity is expected to be between 100 ms and a few seconds.

Figure 1-1 illustrates an example of an RIS logical architecture, where a RIS and the associated RISC are co-located within the same physical RIS device and interfaced with the CU/DU 3GPP-compliant RAN. Interfaces names derive from the RISE-6G network architecture proposal of section 4.3.

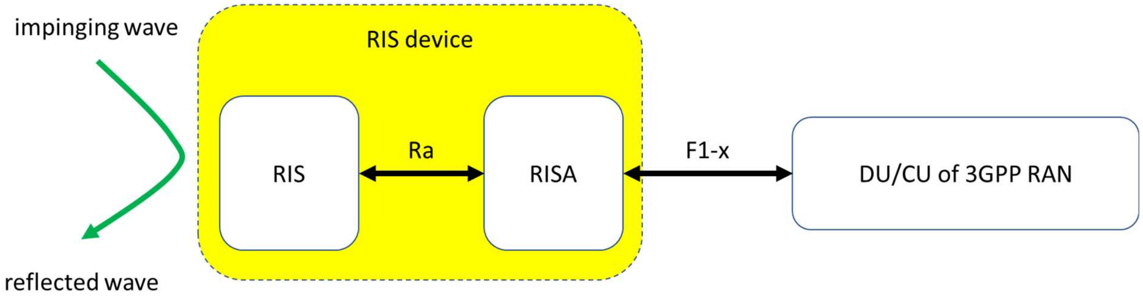


Figure 1-1 – Example of logical architecture where the RISA/RISC/RISO concepts are used.

2 RIS taxonomy and features

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 the different RIS hardware categories depending on the RIS capabilities of operation.

Table 1 – 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.
hybrid	No RF chains, limited sensing capabilities.	Changing the reflection state of RIS elements (like nearly-passive RIS) but with an additional limited sensing capabilities to detect (Tx/Rx) signal Angle-of-Arrival. This might be used for self-configuration and extended to many different use cases.
quasi-active	RF receiving chains are included in the RIS.	Changing the reflection state of RIS elements; it can also collect measurements in baseband for performing sensing/parameters estimation (in time-orthogonal manner with reflection or simultaneously); it can also have processing capabilities to perform localization, channel estimation, etc.
active	RF transmitting chains are included in the RIS.	Changing the reflection state of its elements; it can also perform reflection amplification or transmit its own signals.

Table 2 summarizes the different Control Channel (CC) options used to control the RIS operation.

Table 2 – Control Channel taxonomy.

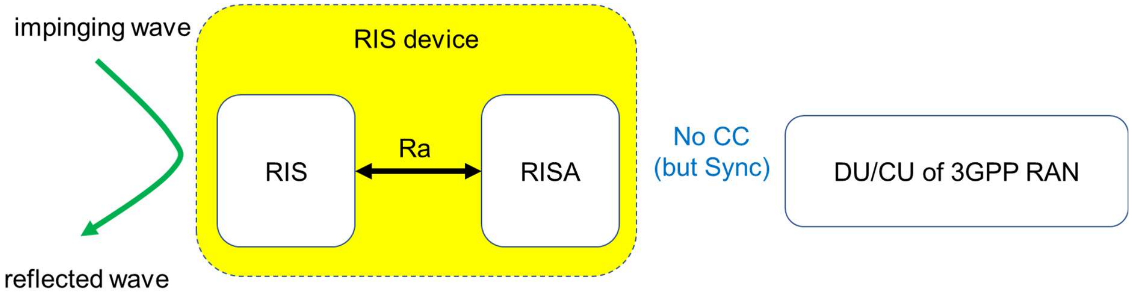
Implicit CC		There is no dedicated CC or signal over which explicit instructions are sent to the RISC (but the synchronization signal). As such, all decisions wrt. RIS(A) operations must be made locally by the RISC; however, these decisions can be based on other received and interpreted signals (e.g. 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 the RIS operational modes.

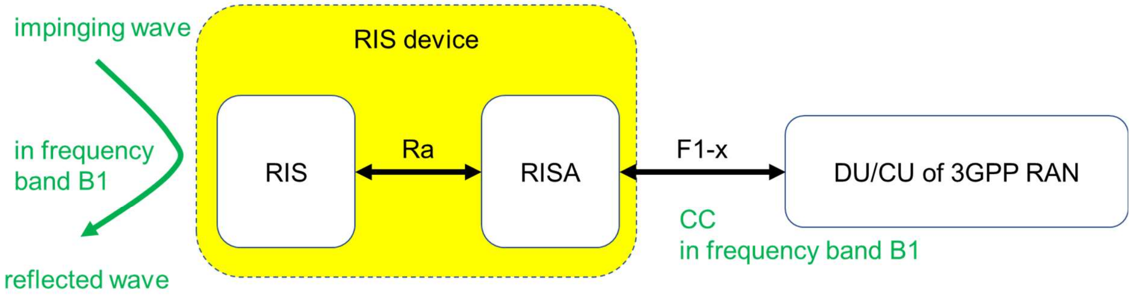
Table 3 – Operational mode taxonomy.

Controlled RIS	**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 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.

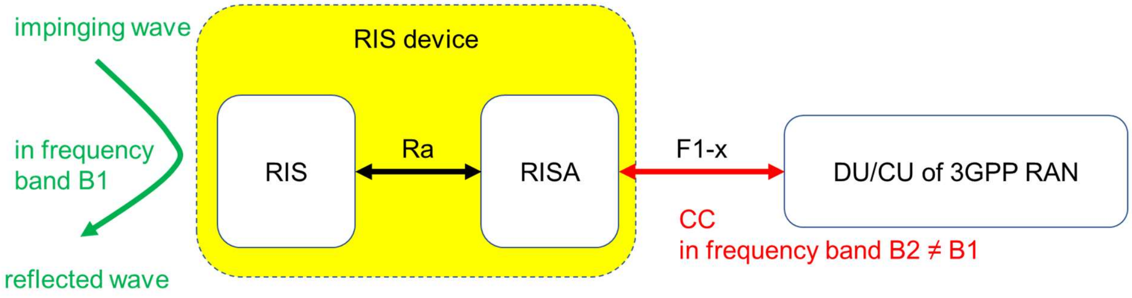
Figure 2-1 au-dessous illustrates an example of an RIS logical architecture, where a RIS function and the associated RIS Controller might be co-located in the same physical RIS device (hence the dashed lines around RIS and RISC elements) and interfaced with the CU/DU 3GPP RAN, and the CC is either implicit (a), explicit and in-band (b), explicit and out-of-band (c). Interfaces names derive from the RISE-6G network architecture proposal of section 4.3.



a) implicit CC



b) explicit CC – in-band



c) explicit CC – out-of-band

Figure 2-1 – Illustrating CCs in one example of logical architecture.

3 Network architecture requirements from technical WPs

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. The results of their analyses can be found in the corresponding deliverables, namely [RISE6G_D41], [RISE6G_D51] and [RISE6G_D61], which are summarised in this section for easier reference.

3.1 WP4 requirements

WP4 contributed to the main architectural characteristics defined for a few scenarios in the area of RIS-x connectivity. They are listed in Table 4 au-dessous (derived from Table 4 of [RISE6G_D41]).

Table 4 – RISE-6G contributions to main architectural characteristics for a few RIS-x scenarios.

Architectural characteristic	Scenario A-0 RIS-aware indoor network planning	Scenario A-1 RIS-enabled beamforming for IoT massive access	Scenario A-2 RIS-empowered UAV communications for robust and reliable air-to-ground networks	Scenario A-3 A self-configuring RIS solution towards 6G	Scenario A-4 RIS-empowered Mobile Edge Computing
# of BS	multiple	1	1	1	1
# of RIS	multiple	1	1	1	multiple/single
# of UEs	1	multiple	multiple	multiple	multiple
UE mobility	static	static	static	static	static/slow mobility
RIS mobility	static	static	mobile	static	static
Frequency band	any	any	any	any	any/high frequency bands
LoS/NLoS	LoS	Both	LoS	LoS	both
KPI	max min SNR	SMSE	max min SNR	sum-rate	energy, latency

In general, envisioned scenarios may still be realized using the proposed RISE-6G architecture of section 4.3 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.

3.2 WP5 requirements

From the localisation and sensing perspective, an RIS can be considered as part of the infrastructure (in which case the RIS location and orientation needs to be known), or as part of a user device (in which case the RIS location and orientation is to be estimated). A variety of novel architectures are thus possible, reducing the reliance on BSs, and in extreme cases not requiring any BSs.

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[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.

The basic functionality of the RIS is to enable accurate delay or angle information for localisation of connected users or a rich set of signals for sensing passive users. Obtaining this information requires fine RIS control, as well as novel signalling (including for synchronisation).

In contrast to communication, positioning and sensing typically require a plurality of RIS configurations, based on pilots. Pilot sequences can enable integration of observations over time and thus achieve high SNR. On the other hand, since localisation is time sensitive (under UE mobility), pilot transmissions are limited to a few tens of milliseconds. Combined, this means that the architecture should support quickly varying RIS configurations (ideally at an OFMD symbol or slot level).

In terms of signalling overhead, the level of autonomy of the individual RIS controller plays an important role. Typically, an RIS controller with significant computational and storage capacities could locally determine optimized RIS configurations or store mappings from user location to several codebooks. A low-complexity RIS controller is limited by a smaller set of feasible configurations, a subset of which must be selected externally (e.g., by the RIS orchestrator).

As suggested in [RISE6G_D51], from a pure localisation and sensing standpoint, the minimal RISE-6G architecture should support:

- Dynamically changing RIS configurations during the positioning process, with sufficient update rate.
- Synchronisation between the RIS and the UE, BS.
- Directional RIS configurations with variable beamwidth and precisely known main lobe directions.

But depending on the targeted localisation or sensing functionality, more specific requirements can be expressed, as follows:

- A **localisation-oriented architecture** must support the collection of radio measurements at the BSs and/or at the UE, RIS configuration during the measurements, as well as synchronisation of these with the transmission of pilots by the BS or UE. Localisation algorithms typically will require knowledge of (or also control over) the RIS configurations utilised during the measurement, as well as the measurements. Therefore, the localisation algorithms can be envisioned to be performed in either the RIS controller or the measurement point (i.e., BS or UE), whereas other choices for computation execution require both the RIS configuration and measurements as inputs (e.g., in a distant server).
- A **sensing-oriented architecture** must support the collection of radio measurements in an RIS-based system. This may be, as in some of the contributions reported in [RISE6G_D51], directly from the RIS itself (i.e., whenever put in receive mode), either in sampled or sampled and pre-processed baseband format. If observations at the BS are relevant for sensing, they should be also supported by the architecture (e.g., interpreting uplink (UL) channel variations under various reflective RIS configurations, similarly to a passive radar approach). In most of these sensing approaches, the data flow is one way, from the UE to the network side. The network side collects the information with the endpoint being at the RIS or RIS controller. The necessary signalling includes only the RIS configuration and related timing control.

3.3 WP6 requirements

WP6 concentrated on the role of 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 3-1 (extracted from [RISE6G_D61]) with one example where an RISE 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 RISE 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 RISE network but 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.

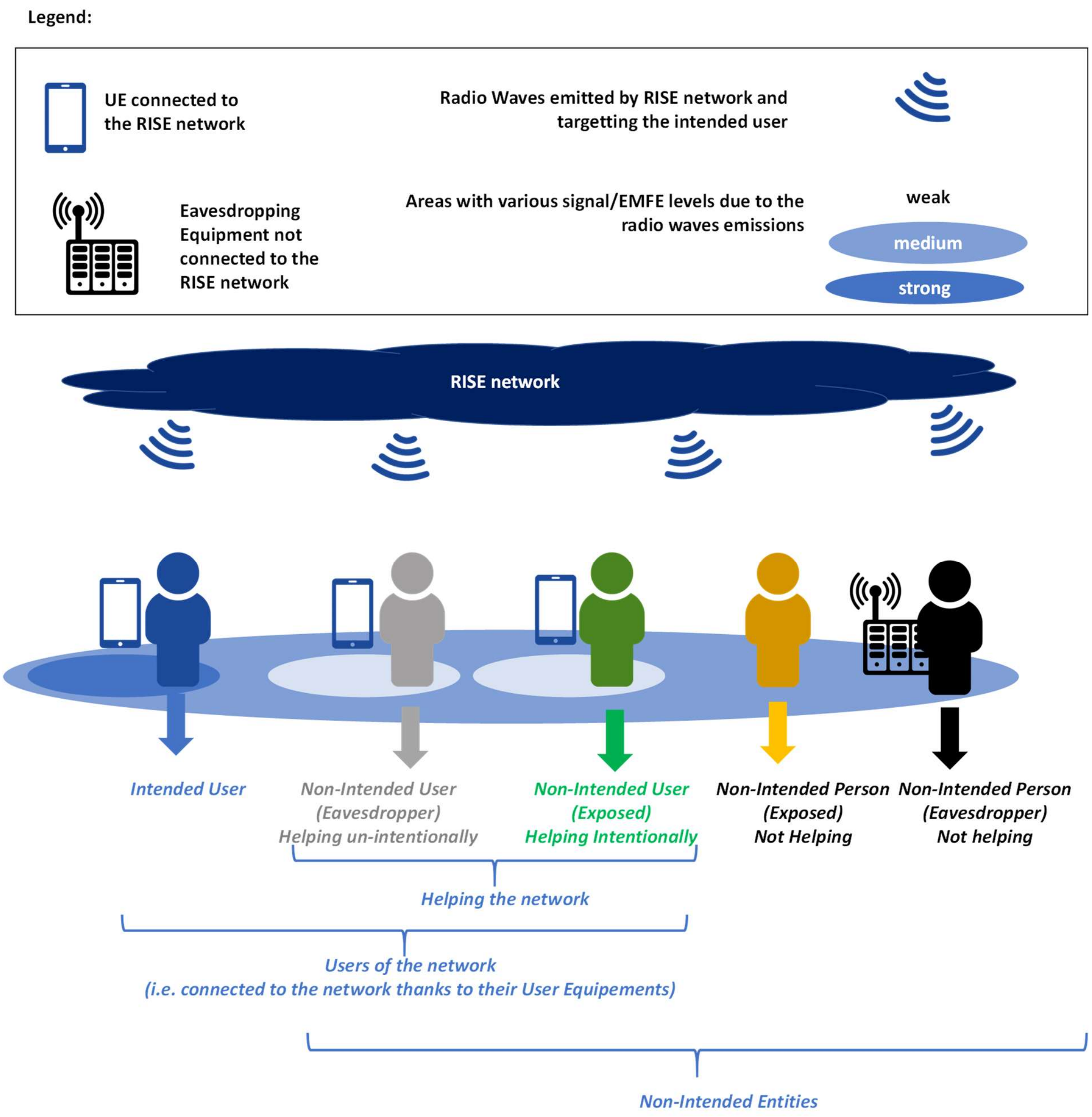


Figure 3-1 – Example where the RISE network emits radio waves with the Intended User as a target, in the presence of four different types of Non-Intended entities (extracted from [RISE6G_D61]).

In the context described in Figure 3-1,

- boosting the EMFEU consists in boosting the ratio of the received spectral efficiency at the Intended user over the exposure of the (most exposed) non-intended user; when the Non-Intended user is different from the 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.

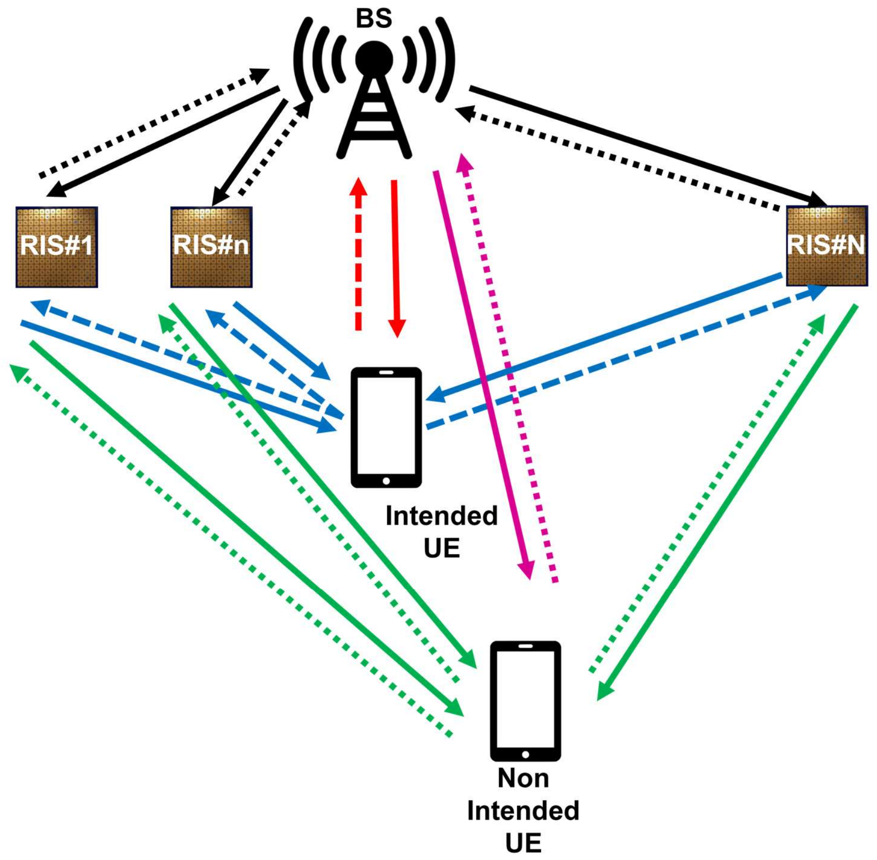
Table 5 au-dessous lists the schemes analysed and detailed in [RISE6G_D61], with the associated objectives (i.e. metrics to be improved) and deployment scenarios.

Table 5 – Considered schemes with corresponding objectives and deployment scenarios.

#	Name	Objective	Deployment scenario
1	Spatial Focusing	Secrecy Rate	DL MISO BF, indoor/outdoor sub-6 GHz
2	SSE with Full CSI knowledge	SSE	DL MIMO BF and AN, indoor/outdoor sub-6 GHz
3	RIS-aided EMF-Aware BF	inter-EMFEU	DL M-MIMO BF outdoor-to-outdoor and outdoor-to-indoor, sub-6 GHz
4	EE Optimisation of RIS with EMFE constraints	self-EMFEU	UL MIMO BF indoor-to-outdoor and outdoor-to-indoor, sub-6 GHz
5	Low sum EMFE of multiple RANs in strong visibility, without coordination	inter-EMFEU	DL M-MIMO BF indoor-to-indoor mm-waves, multiple uncoordinated operators
6	Joint RIS and DL BS BF under EMFE constrain	inter-EMFEU	DL M-MIMO BF indoor-to-indoor mm-waves, multiple uncoordinated operators

Based on the analysis of the schemes summarised in Table 5 au-dessus, WP6 recommends an architecture where RIS(s) devices are slave nodes of a BS (i.e. they are completely controlled by a BS), and act as UL or downlink (DL) passive relay nodes between the BS and the intended UE with the new property that an RIS can reflect the BS waves or the UE waves transporting their data (even though in general an RIS may potentially have less computing and signal processing capabilities).

WP6 also makes recommendations for architecture requirements in terms of control signalling for each scheme listed in Table 5 (note that the malicious RIS of scheme #1 is not illustrated). They are summarized in Figure 3-2, where RIS nodes are RIS devices, hosting both RIS and RISC functions, and the RISC function makes use of explicit in-band CC to communicate with the BS and/or the UEs.



Legend

	Arrow	interface	scheme					
			1	2	3	4	5	6
	←	BS-to-RIS	X	X	X	X	X	X
	⇠	RIS –to-BS	X	X		X		
Intended UE	→	BS-to-UE	X	X	X*	X		X*
	⇢	UE-to-BS		X	X	X*		
	→	RIS-to-UE	X	X		X		
	⇢	UE-to-RIS			X	X		X
Non-Intended UE	→	BS-to-UE	X	X			X*	X
	⇢	UE-to-BS		X			X	
	→	RIS-to-UE	X	X				
	⇢	UE-to-RIS		X				

Figure 3-2 – Architecture requirements for all SSE- and EMFEU-oriented schemes, in terms of control signalling and data (* means that data is transmitted on the over-the-air interface in addition to control signalling).

4 RISE-6G network architecture

4.1 Network architecture proposals from technical WPs

The integration of RIS as a new element into the network infrastructure requires defining both the roles of the RIS, as well as the protocols between the RIS and the rest of the system [DZD+20]. The new resulting RIS-x architecture must consider that the RIS is intended to be a multi-purpose element, used for (not limited to) communication, sensing and positioning purposes.

The architecture embedding RIS devices is thus envisioned to include the following new components:

- **RIS(A), RISC, RISO functional elements** defined in section 0;
- a dedicated **control channel (CC)**.

However, such proposed architectural solution only considers RAN-related functions leaving open core-domain interfaces. For specific scenarios, it might be convenient to introduce additional functional blocks that directly talk to existing core domain functions.

4.1.1 Localization and sensing network architecture proposal

As reference, in a general 5G localisation context (i.e., regardless of RIS considerations), **[DSM+21]**, the Location Management Function (LMF) is central into the architecture, as it configures the UE using the long-term evolution (LTE) positioning protocol and must coordinate with the BS. Accordingly, a typical positioning procedure involves additional control overhead, via the Access and Mobility management Function (AMF), between the LMF, the BSs, and the UE, as shown in Figure 4-1.

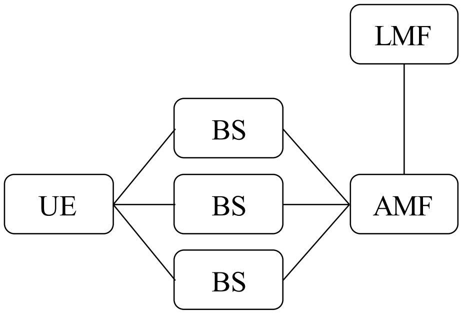


Figure 4-1 – Schematic of 5G positioning architecture[2], based on [DSM+21], supporting both UL and DL measurements.

Beyond, just like in a more general RIS-based communication context, the new RIS-augmented architectures envisioned to support, enable and/or optimize localization and sensing functionalities, must include the necessary components to configure and operate the RIS, namely the RIS orchestrator and the RIS controller. The RIS phase configuration indeed controls the physical radio observations that positioning is based on, and thereby any positioning strategy either requires the explicit control of the RIS configuration or must operate with the knowledge of the RIS configuration in use.

The architecture variants in Figure 4-2 implement the requirements for RISE-6G localisation and sensing oriented architectures, whose main parameters and deployment settings are listed

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[2] It is worth recalling that BS and UE are part of the RAN, while both LMF and AMF are part the CN.

in Table 6 (derived from of Table 4-1 of [RISE6G_D51]), with a relatively simple cooperation between the RIS controller and the AMF in all cases where the RIS is not operated autonomously. The latter architectures are expected to be directly applicable in a single operator case, but they need further analysis in a multi-operator case.

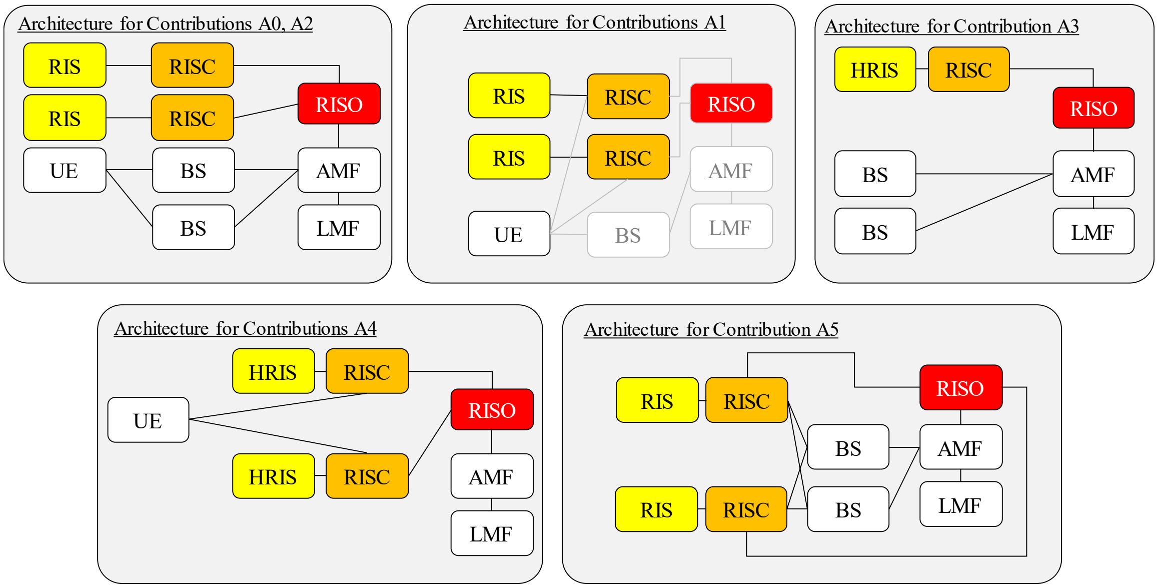

Figure 4-2 – Block diagrams of the RISE-6G localization- and sensing oriented architectures[2] [RISE6G_D51].

Table 6 – Main parameters and deployment settings of the RISE-6G L&S-oriented architectures.

Architectural characteristic	**Scenario A-0: RIS-enabled UE localisation with access points**	**Scenario A-1: RIS-enabled localisation without access points**	**Scenario A-2: RIS-enabled localisation without delay-based measurements**	**Scenario A-3: Receiving RIS to detect passive users**	**Scenario A-4: Sensing-RIS-enabled UE localisation without any access points**	**Scenario A-5: Mobile RIS localisation**
# of BS	1	0	1	1	0	at least 3
# of RIS	1	1 for RTT and AOD, 3-4 for RTT only	2	1	3	1
# of UE	1	1	1	Multiple	1	N/A
UE Mobility	static	static	static	static	static	mobile
RIS Type	passive	passive	passive	receiving	receiving or hybrid	reflecting
Localisation functionality placement	at UE or at BS	at UE	at UE	at RIS	at RISC	at BS
Nr Operators	1	1	1	1	1	1
Setup						
Indoor/outdoor/UAV	indoor (short range)	indoor (short range)	indoor (short range)	indoor	indoor	outdoor
2D/3D	3D	3D	3D	3D	3D	3D
Frequency Band	mmWave	mmWave, subTHz	any	sub-6 GHz	any	any
NF/FF	NF under LoS blockage.	FF	FF	NF	FF	FF
LoS/NLoS/Both	LoS and NLoS	LoS and NLoS	LoS	LoS and NLoS	LoS and NLoS	LoS and NLoS
Imperfections or other hardware considerations	none	full-duplex UE needed	none	none	none	none

Data flow and signalling						
Uplink/Downlink	UL or DL	UL	DL	UL	UL	DL
Measurement type	angle and delay in FF position in NF	RTT and AOD	AOD	RSS at RIS	AOD at RIS	delay
RIS configuration strategy	arbitrary or location-based, several profiles needed	arbitrary or location-based, several profiles needed	arbitrary or location-based, several profiles needed	arbitrary phase, quantized phase, finite codebook	arbitrary, several profiles needed	random
Who collects measurements	UE or BS	UE	UE	RIS	RIS	BSs
Synchronisation	us-level	us-level	us-level	Phase	us-level	us-level
Narrowband/wideband	wideband[3].	multi-carrier	single-carrier	narrowband	narrowband	wideband

4.1.2 RIS-enabled architectures from state of the art

Beyond, other higher-level visions have also been put forward in the literature regarding RIS-enabled architectures for localisation and sensing (e.g., **[WHD+20]**). As an illustration, Figure 4-3 shows a simplified block diagram, along with the corresponding signalling flowchart, for an RIS-aided downlink localization and mapping system. In this example, the a-priori user location information is used to determine which RIS to activate and how to optimally set its phases. The downlink pilot signal, reflected by the RIS, is then optimized given the current UE and environmental conditions, and it is used by the UE to estimate the channel parameters. These channel parameters are fed to the simultaneous localisation and mapping (SLAM) algorithm, which determines the UE location and the local map. Maps from different UEs can then be fused to provide global situational awareness.

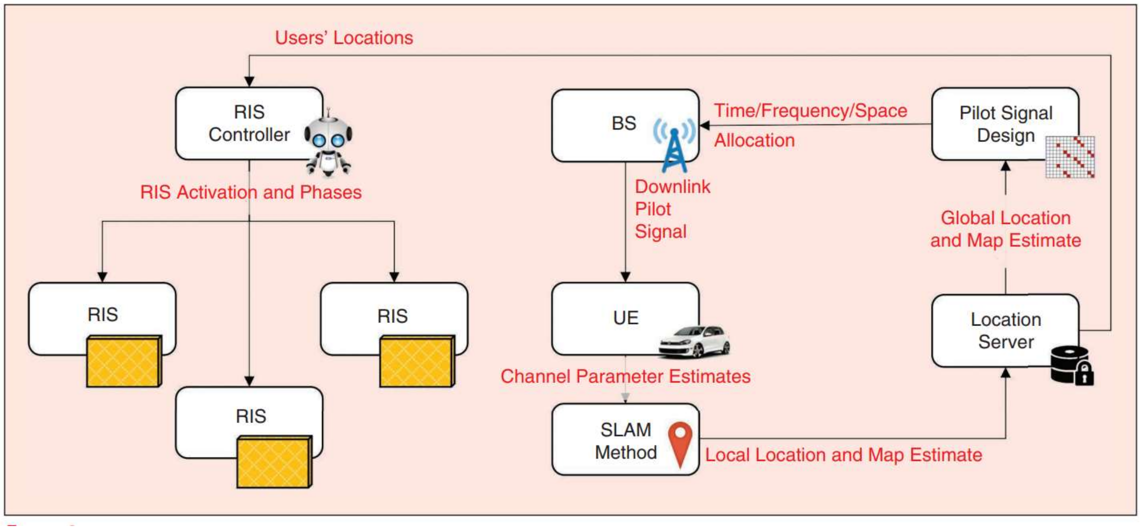

Figure 4-3 – Example of block diagram and signalling flowchart for downlink localization and mapping within a RIS-enabled network architecture [WHD+20].

4.2 Data/control flow and signalling proposals from technical WPs

So far interfaces between the critical blocks of the RIS-x architectures have been mainly assessed by technical WPs (see [RISE6G_D41], [RISE6G_D51], [RISE6G_D61]) from a data/control flow and signalling standpoint. That is a basis for the project's future activity, where a more rigorous way of describing the interfaces will be provided (for instance, for each identified

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[3] In NF narrowband is sufficient.

"arrow" in the sketches, the corresponding I/O (kind of info, format, unit, communication protocol, etc.) could be detailed).

4.2.1 WP4 data/control flow and signalling proposals

The following data-flow diagrams for the operations of access, CE, and MEC of RIS-x systems have been provided by WP4 in [RISE6G_D41] as examples on how the data and control are exchanged for very different operations.

- **UE initial access procedure** (without considering the DL feedback for scheduling the user, which is left to future activities) of Figure **4-4** which involves the operation of the main actors BS, RIS and UEs. Here, *S* is used to represent the number of configuration profiles available at the RIS provided by the BS, hence, the scenario corresponds to the BS-side control.

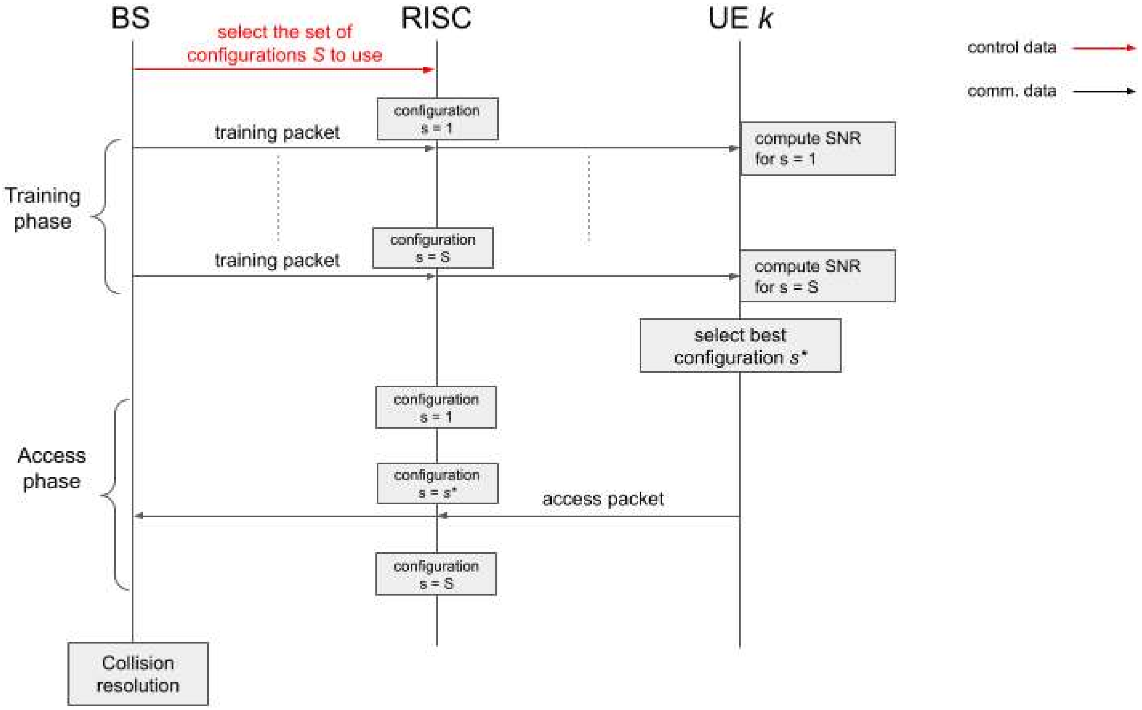

Figure 4-4 **– Data-flow diagram for UE initial access protocol (contribution #B-0 of [RISE6G_D41]).**

- **Standard channel estimation process when an RIS is involved** (see Figure **4-5**). An uplink scenario is performed where 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).

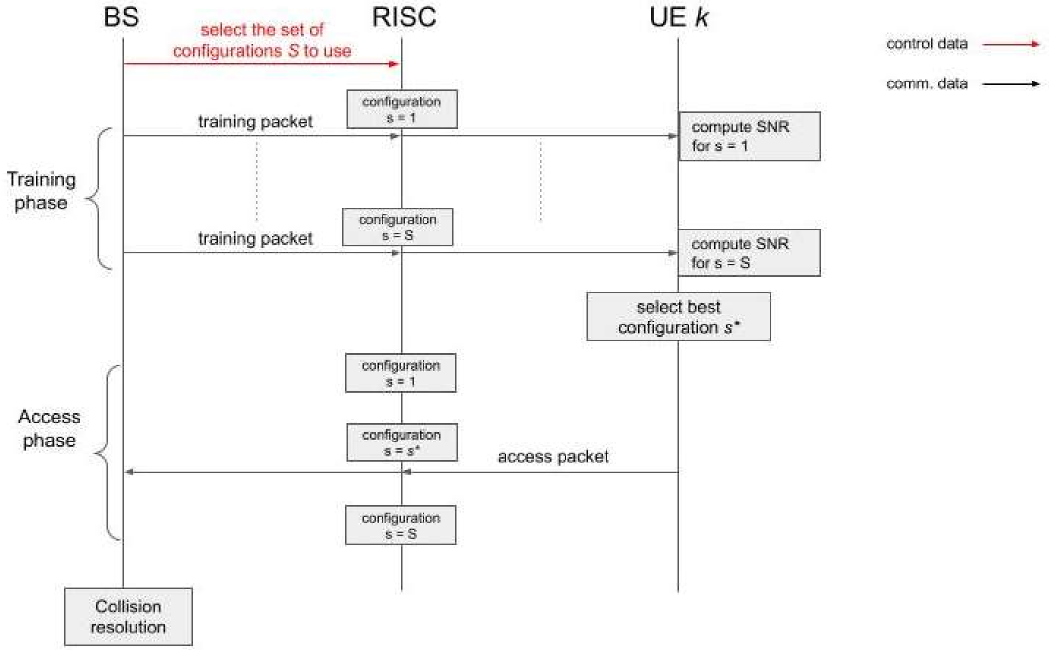

Figure 4-5 **– Uplink channel estimation process in RIS-empowered environments (contributions #B-1 and #B-2 of [RISE6G_D41]).**

- **MEC empowered by RISs** (see Figure 4-6, 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.

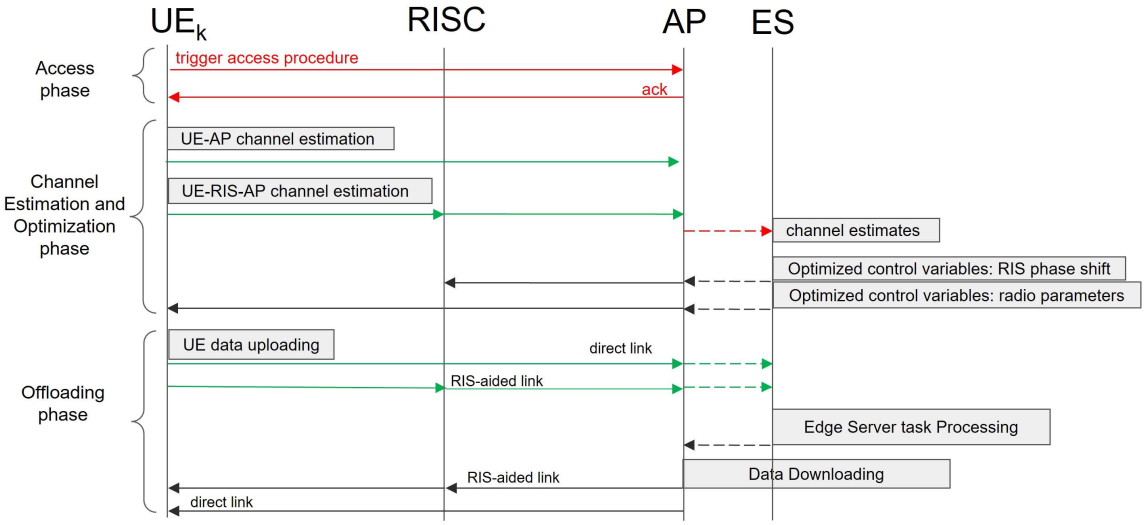

Figure 4-6 – Data-flow diagram for RIS-empowered MEC (contribution #A-4 of [RISE6G_D41]).

4.2.2 WP5 data/control flow and signalling proposals

The following data/control-flow and signalling diagrams for localisation and sensing in RIS-x systems have been provided in [RISE6G_D51]. Different message sequence charts correspond to different architecture variants enabling the investigated localisation and sensing functionalities. Along different arrows, information transiting between blocks in an abstract high-level representation can be retrieved.

- **UE localisation from a single BS, aided by one reflecting RIS** (contribution A-0 of [RISE6G_D51]) or **RIS-Enabled localisation without delay-based measurements** (contribution A-2 of [RISE6G_D51]), by extending to several RIS operating in parallel (Figure 4-7). In some cases, RIS configurations depend on the current knowledge of the UE position. Note that the position estimation does not necessarily need to be performed at the UE side, and that this flow can also be done in the UL.

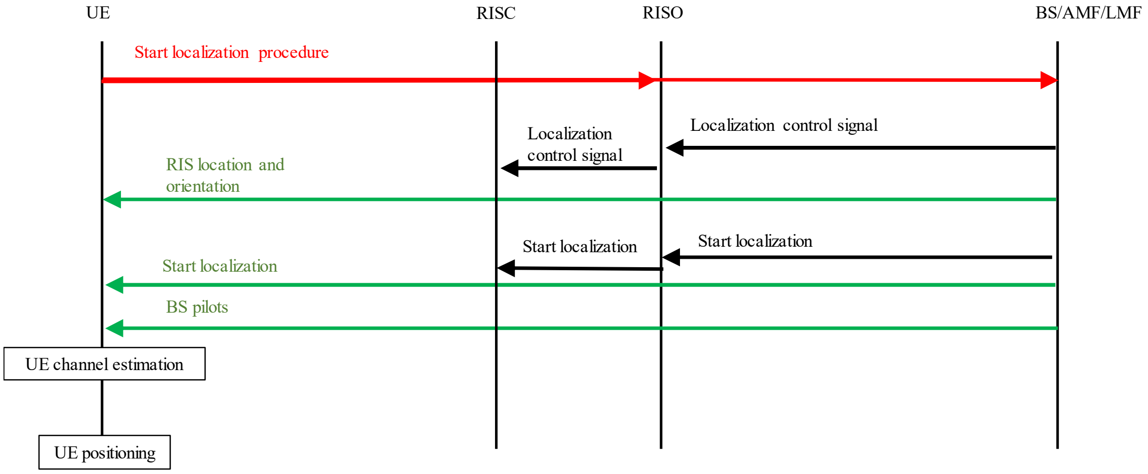

Figure 4-7 – Data and control flow for UE localization from a single BS, aided by a reflecting RIS, or RIS-enabled localization with no delay measurements.

- **UE localisation without BS** (contribution #A-1 of [RISE6G_D51]) of Figure 4-8. The UE can communicate the control signals directly with the RIS control unit.

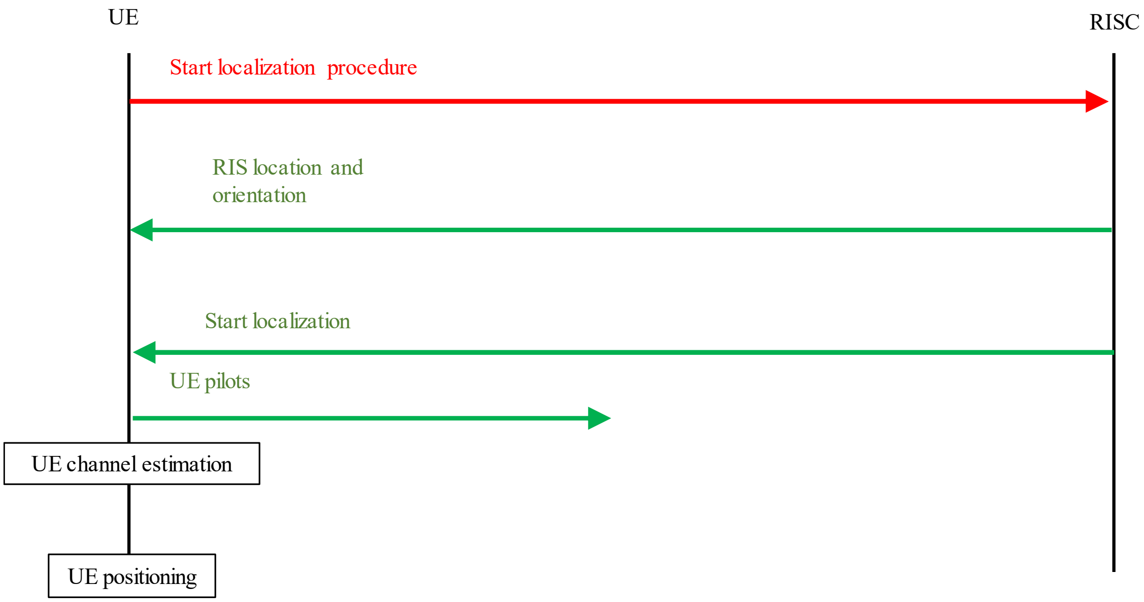

Figure 4-8 – Data and control flow for UE localization without BS.

- **UE localisation with multiple sensing RISs but without BS** (contribution #A-4 of [RISE6G_D51]) of Figure 4-9.

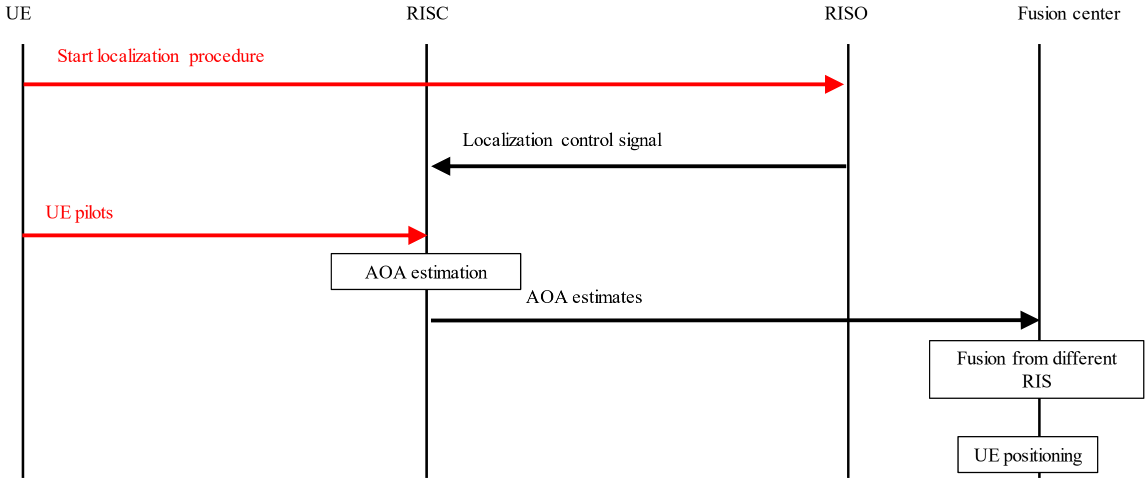

Figure 4-9 – Data and control flow for UE localization with multiple sensing RISs but without BS.

- **Semi-passive localisation of RIS-enabled EUs** (contribution #A-3 of [RISE6G_D51]) of Figure 4-10. Note that the computation of the final position requires the fusion of information from all receiving BSs.

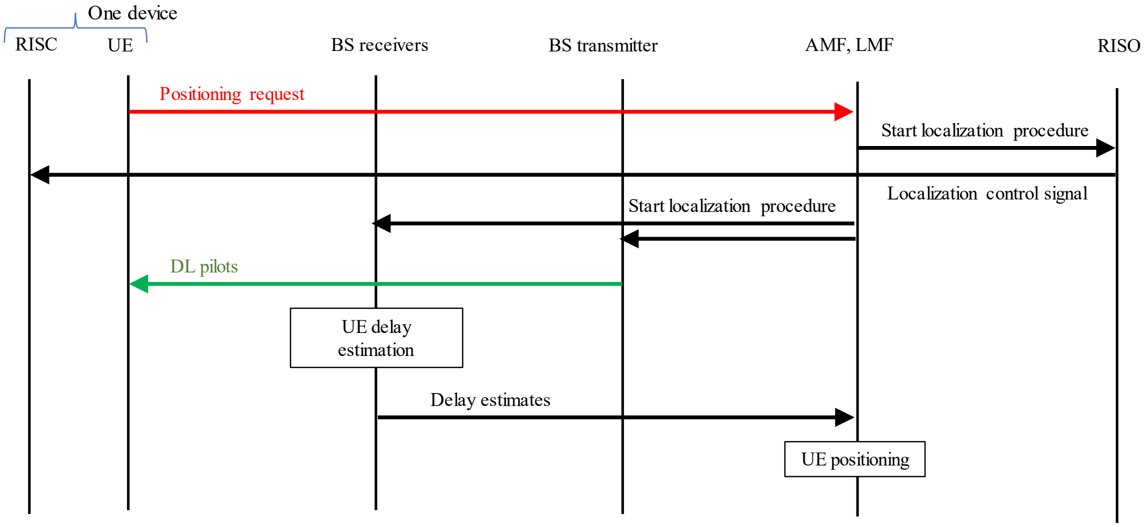

Figure 4-10 – Data and control flow for the localization of RIS-enabled UEs.

4.2.3 WP6 data/control flow and signalling proposals

So far, the interfaces between the critical blocks of the RIS-augmented architectures for EMFEU and SSE have been mainly assessed from a data/control flow and signalling standpoint [RISE6G_D61]. Hence the different message sequence charts below, from Figure 4-11 to Figure 4-16, correspond to the different architecture variants enabling EMFEU and SSE boosting. Along the different arrows, one can retrieve the information transiting between the blocks in an abstract high-level representation for each scheme listed in Table 5.

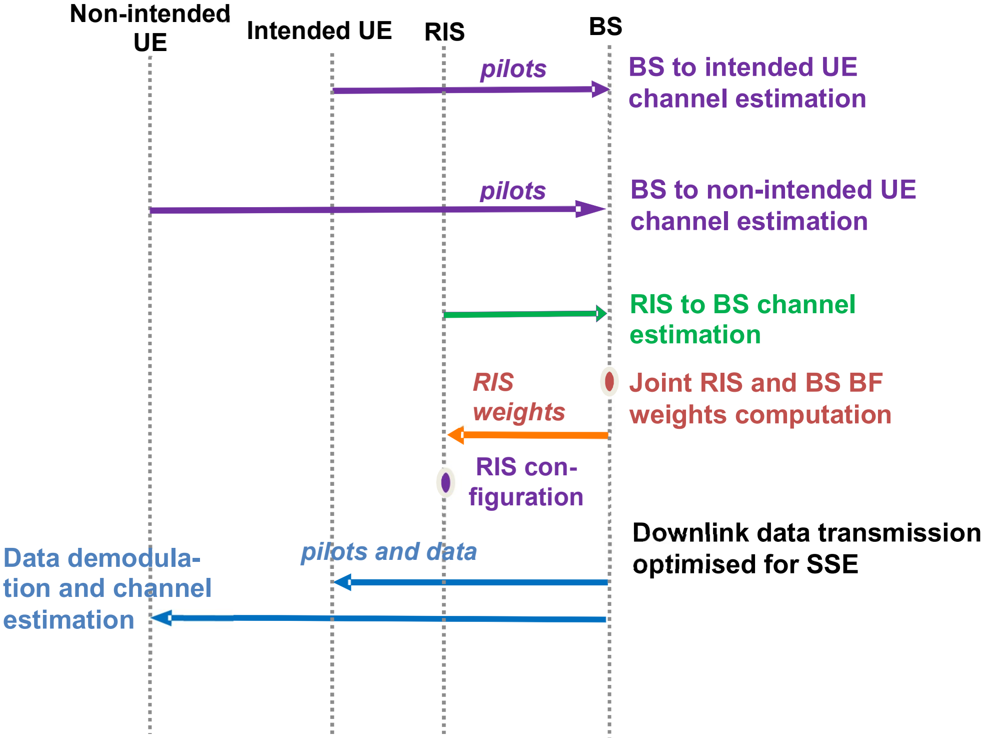

Figure 4-11 – Data flow and control signalling for the spatial focusing scheme (Scheme #1).

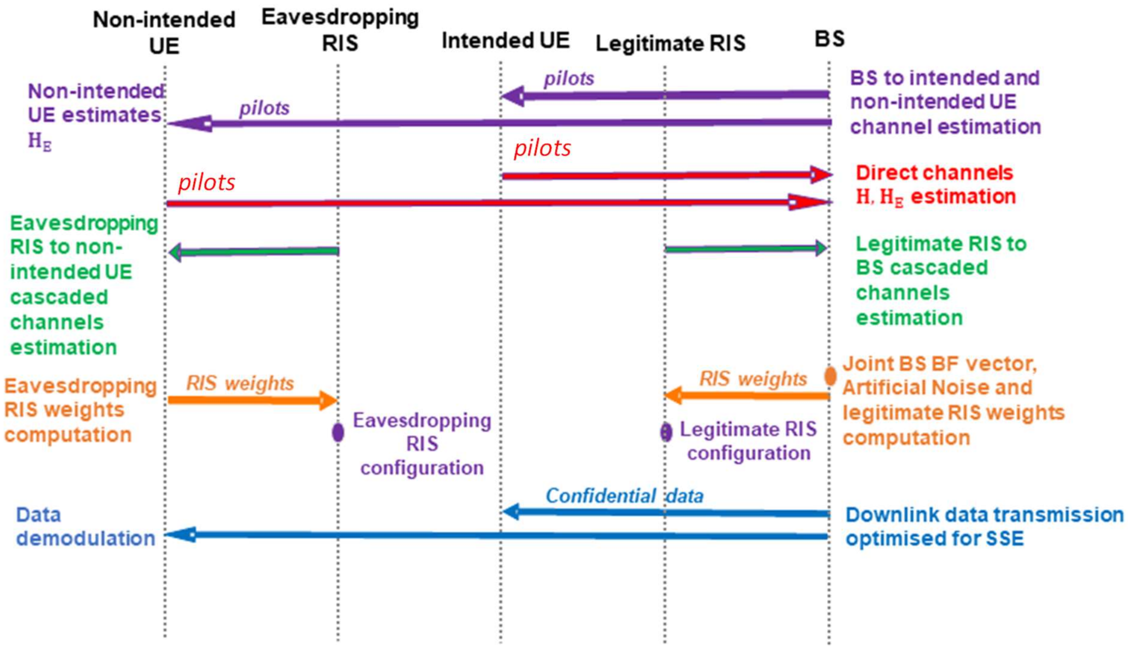

Figure 4-12 – Data flow and control signalling for the secrecy spectral efficiency scheme with full CSI (Scheme #2).

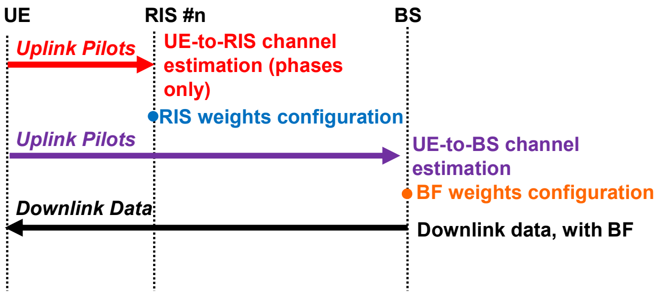

Figure 4-13 – Data and control flows, all RISs #n (n=1 to N) doing the same thing simultaneously (Scheme #3).

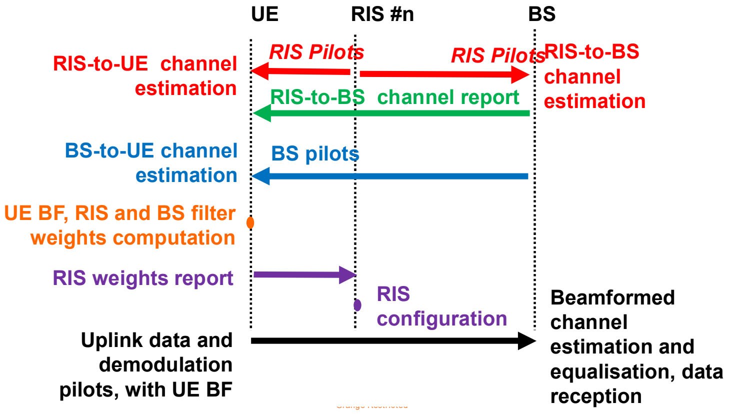

Figure 4-14 – Data and control flows, with RIS channels estimation, in sequence for RIS #n, n=1 at N (Scheme #4).

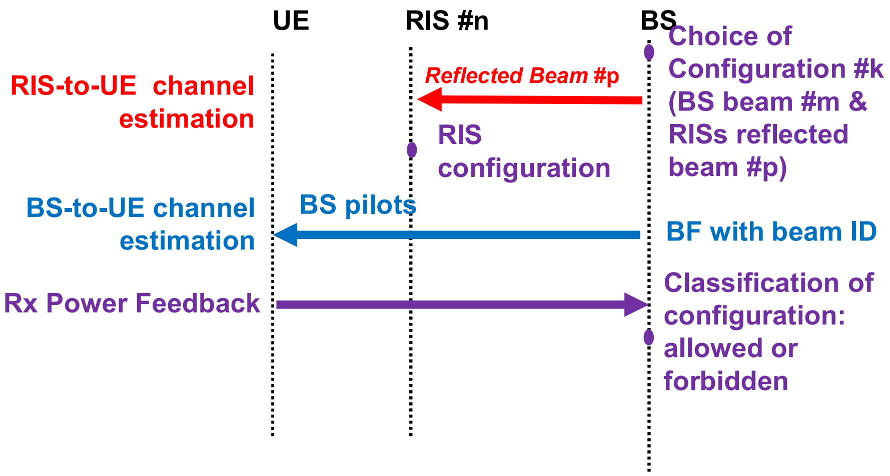

Figure 4-15 – Data and control flows, with all RISs #n=1 to N, doing the same thing simultaneously (Scheme #5).

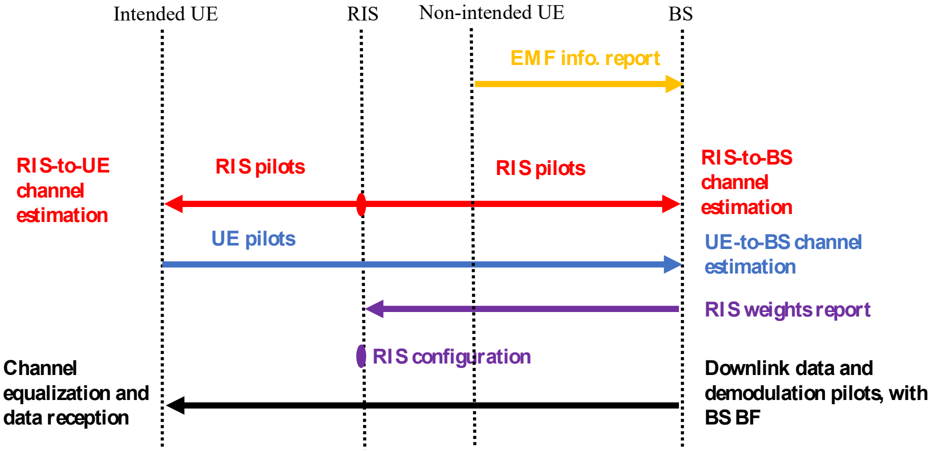

Figure 4-16 – Data and control flows (Scheme #6).

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.

4.3 RISE-6G network architecture proposal

Figure 4-17 sketches current RISE-6G network architecture proposal where RIS(A), RISC and RISO functional elements defined in section 0 are placed and connected. Localization-boosted areas are there only as an example, but other RIS-x use cases could apply as well.

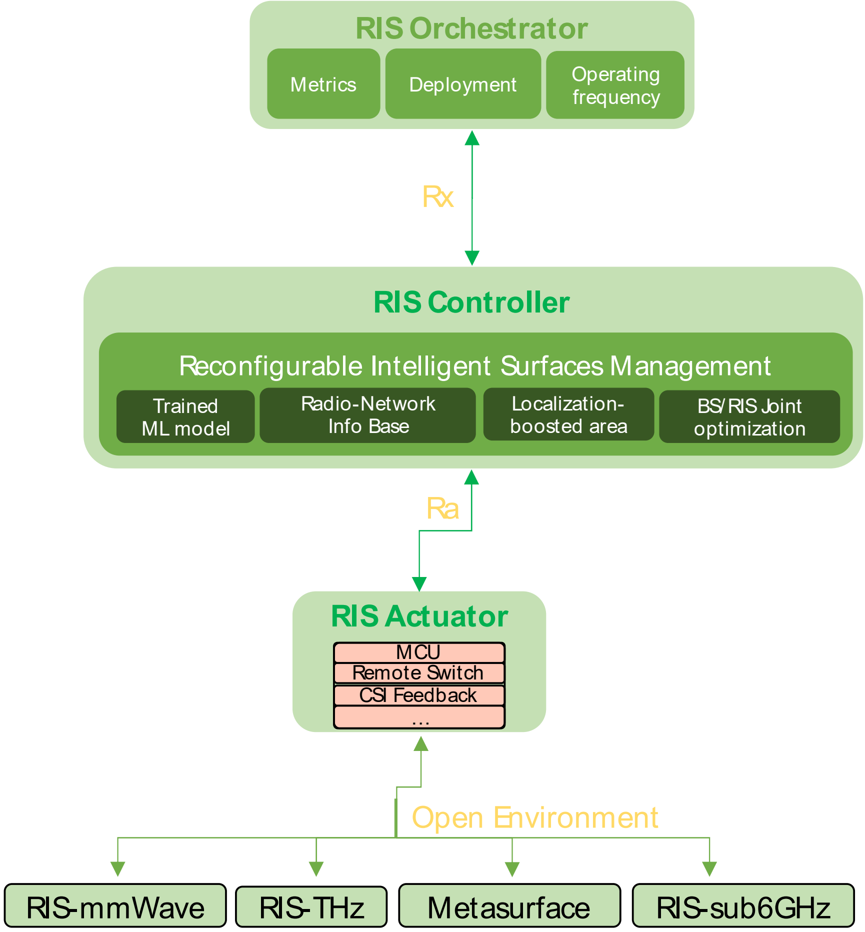

Figure 4-17 – RISE-6G network architecture proposal

As it can be seen in Figure 4-17, 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 4-17 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. The RISE-6G project is currently investigating available overarching options to provide a concrete and solid solution to be detailed in D2.6.

A further proposal for applying the network architecture of Figure 4-17 to current O-RAN architecture can be found in section 6.1 au-dessous.

5 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.

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.

6 Relation to existing architectures and potential extensions

6.1 Open-RAN (O-RAN)

When dealing with existing network architectures, the RISE-6G architecture proposal described in Figure 4-17 can be properly interfaced to provide novel means to control the RIS deployment and a direct interaction with RAN elements, so that they can control or exchange messages with relevant RISE-6G architectural blocks.

In Figure 6-1 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.

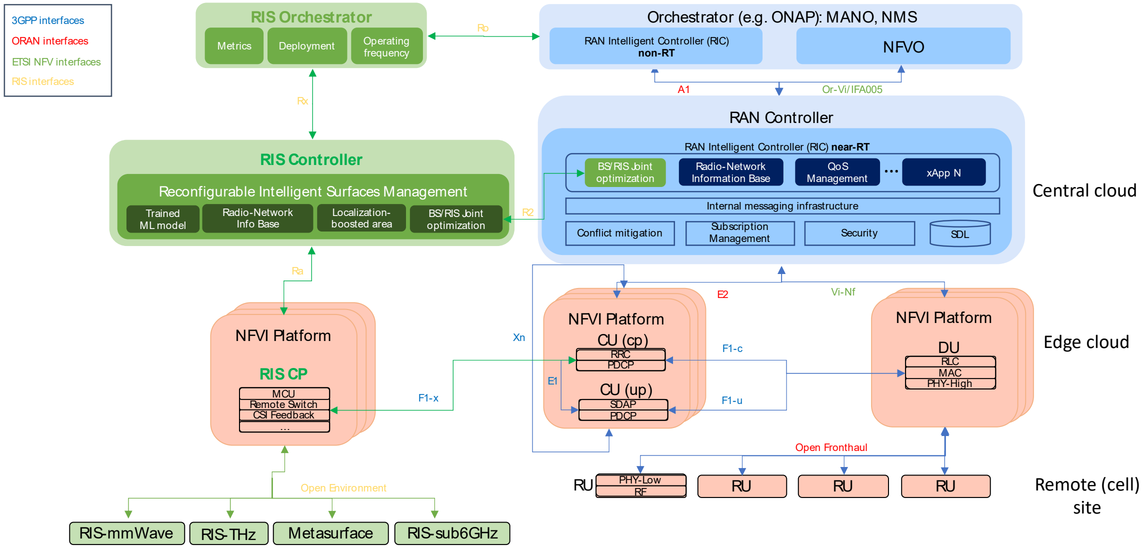

Figure 6-1 – Relevant interfaces between RISE-6G architecture and O-RAN/3GPP/ETSI network architectures.

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[4].

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.

6.2 3GPP

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

RIS helping 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 4-2.

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 6-2 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).

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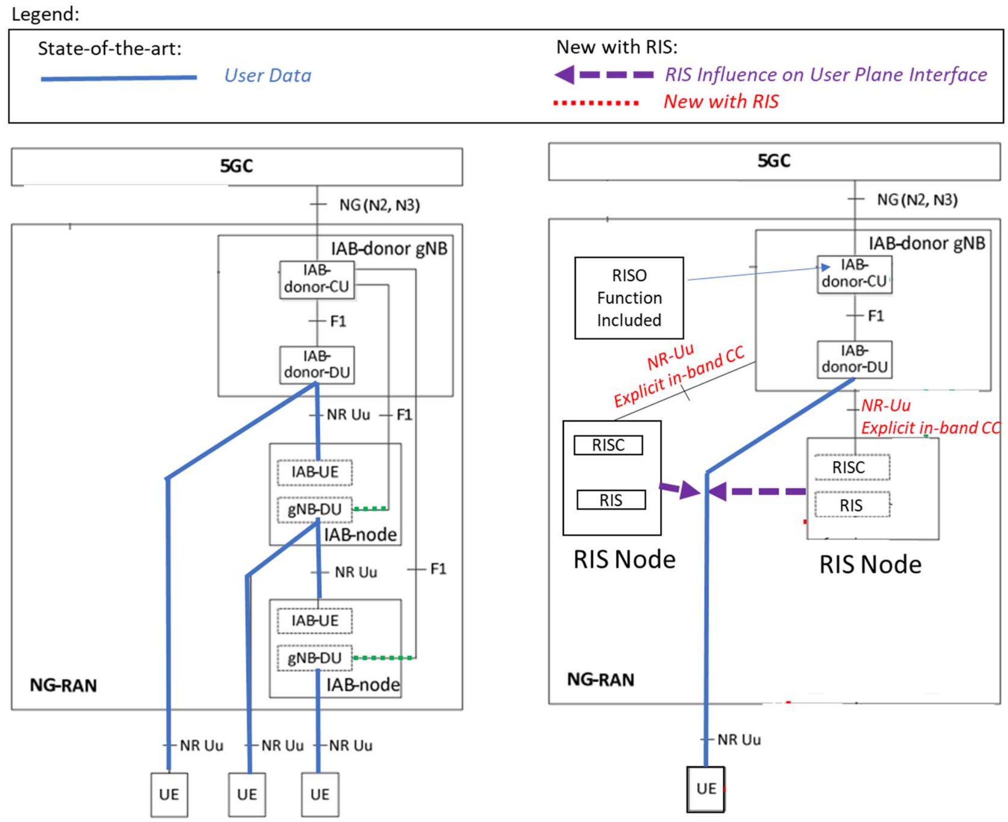
[4] Further details about RISE-6G interfaces (Ra, Rx, Open Environment) will be provided in the document D2.6.



a) IAB architecture for 5G extracted from [TS123501] (Fig. 5.35.1-1)

b) New Proposed Architecture

Figure 6-2 – 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).

6.3 Relation to 6G architectural work

Hexa-X project [Hexa-X] 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.

7 Conclusions

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

In Chapter 1, we proposed a harmonization of concepts and vocabulary. In particular, we highlighted a need to make a distinction between different categories of solutions which rely on the RIS technology. Furthermore, we introduced four logical network nodes: RIS (device), RIS actuator, RIS controller, and RIS orchestrator.

In Chapter 2, we summarized and proposed to adopt the RIS taxonomy and features characterization based on the work in [RISE6G_D41] for use in all further work within RISE-6G.

In Chapter 3, we summarized the network architecture requirements from technical WP4-6. In particular, it is shown that there are some key differences in the network architecture requirements.

In Chapter 4, we proposed an initial RISE-6G network architecture and briefly discussed some identified open issues on logical nodes and interfaces. In particular, we highlighted that it might be challenging to define a common baseline that aligns all basic functionalities of different types of RISs. Further work on this will be performed towards D2.6.

In Chapter 5, we provided an initial discussion related to deployment strategies from a technical perspective that also will be further detailed in the work towards D2.6. In particular, we highlighted that the deployment problem is tightly coupled with the RIS application scenario.

Finally, in Chapter 6 we discussed the proposed RISE-6G network architecture and its relation to existing architectures and potential extensions within O-RAN, 3GPP, and also in relation to 6G architectural work. Further work on monitoring these external activities will also be performed as input for the work towards D2.6.

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