Document Number: H2020-ICT-52/RISE-6G/D6.1

Project Name:
Reconfigurable **I**ntelligent **S**ustainable **E**nvironments for **6G** Wireless Networks
(RISE-6G)

Deliverable D6.1

Network architectures & deployment strategies with RIS for enhanced EE, EMFEU, and SSE (Intermediary Specifications)

Date of delivery:	13/05/2022	Version:	1.0
Start date of Project:	01/01/2021	Duration:	36 months

Deliverable D6.1

Network architectures & deployment strategies with RIS for enhanced EE, EMFEU, and SSE (Intermediary Specifications)

Project Number:	101017011
Project Name:	**R**econfigurable **I**ntelligent **S**ustainable **E**nvironments for **6G** Wireless Networks

Document Number:	H2020-ICT-52/RISE-6G/D6.1
Document Title:	Network architectures & deployment strategies with RIS for enhanced EE, EMFEU, and SSE (Intermediary Specifications)
Editors:	K. D. Katsanos and G. C. Alexandropoulos (NKUA).
Authors:	D.-T. Phan-Huy (ORA), M. Di Renzo (CNRS), H. Guo, T. Svensson (CHAL), and Petar Popovski (AAU).
Dissemination Level:	PU
Contractual Date of Delivery:	13/05/2022
Security:	Public
Status:	Final
Version:	1.0
File Name:	RISE-6G_WP6_D6.1_V1.0.docx

Abstract

This deliverable provides the results of the RISE-6G proposals on architectures, control, signalling, and data flow related to work package 6 “RIS for Enhanced Sustainability and Security”, as well as initial performance evaluations of these proposals.

Keywords

Beyond-5G, 6G, RIS, Security, Sustainability, Energy Efficiency, EMF exposure.

Contents

List of Figures

List of Tables

List of Acronyms

2D	Two-dimensional
AN	Artificial noise
AP	Access Point
BF	Beamforming
BS	Base station
CN	Core network
CSI	Channel state information
DL	Downlink
EE	Energy efficiency
EMF	Electromagnetic field
EMFE	Electromagnetic field exposure
EMFEU	EMFE Utility
FDD	Frequency division duplex
I	Intended
LOS	Line-of-sight
MIMO	Multiple-input multiple-output
mmWave	Millimeter wave
mMIMO	Massive MIMO
MISO	Multiple-input Single-output
MRT	Maximum ratio transmission
NI	Non-intended
NLOS	Non-light-of-sight
RAN	Radio access network
RIS	Reconfigurable intelligent surface
RISE	RIS-empowered
RX	Receiver
SSE	Secrecy spectral efficiency
SNR	Signal-to-noise ratio
TDD	Time division duplex
UE	User equipment
UL	Uplink

1 Introduction

RISE-6G is a 5G-PPP project funded by the European Commission under the H2020 framework. The project's vision hinges on the latest advances on reconfigurable intelligent surfaces (RISs) technology for radio wave propagation control, with the aim of improving this technology, and conceiving sustainable, programmable, and goal-oriented wireless environments. The main objectives of RISE-6G are: (i) the definition of novel architectures and control strategies incorporating multiple RISs; (ii) the study of the fundamental limits of the RIS technology based on realistic and validated radio wave propagation models; (iii) the design, by three different workpackages (WPs), of algorithmic frameworks based on RIS-empowered smart wireless environments providing enhanced connectivity and reliability (WP4), enhanced localisation accuracy (WP5), and enhanced sustainability and security (WP6); (iv) the prototyping of the proposed innovation via two complementary trials with verticals. Deployment scenarios and use cases are defined by WP2.

Within RISE-6G, WP6 proposes innovative PHY-MAC technical enablers to improve the sustainability and security of wireless networks. More precisely, WP6 proposes solutions to boost the performance of wireless networks in terms of energy-efficiency (EE), electromagnetic-field exposure (EMFE) utility (EMFEU), and secrecy spectral efficiency (SSE) metrics, as defined in Deliverable D2.4. WP6 aims at improving these metrics focusing on spatially localised areas. Such performance "boosted areas" have been defined in Deliverable D2.3 and identified for various deployment scenarios and use cases listed in the same deliverable. It is expected that the EE, EMFEU, and SSE metrics require specific and novel network architectures & deployment strategies with RISs, as well as novel assessment methods of their consideration.

Since the RISE-6G project targets very different objectives in WP4, WP5, and WP6, the following two-step approach has been chosen, to derive architecture and control signalling requirements:

- During step 1: each WP derives its initial views on requirements on architecture and signalling, based on the WP very specific objectives and the WP's list of technical contributions and innovations; the results of these independent works are reported in deliverables D4.1, D5.1, and in the current Deliverable D6.1, separately.
- During step 2: WP2 uses D4.1, D5.1, and D6.1 as inputs to build a common framework for architecture and control signalling that will be described in the upcoming Deliverable D2.5.

As a consequence, concepts and terminology regarding architecture and control signalling may slightly differ in the deliverables D4.1, D5.1, and D6.1. However, every concept is clearly defined inside each deliverable. Common concepts and terminology will be defined in D2.5, to be used afterwards during the project.

This current deliverable provides the intermediate results from WP6, on network architectures and deployment strategies with RIS to boost the EMFEU and SSE metrics defined in Deliverable D2.4, for the use cases listed in D2.3. The impact of the presented solutions for RIS-enabled/-boosted EMFEU and SSE on the EE performance metric is also discussed; explicit solutions for RIS-enabled/-boosted EE will be present in the upcoming Deliverable D6.2. The deliverable lists several architectural options, RIS control strategies, as well as related data flows and control signalling, all derived from various technical contributions and innovations proposed within WP6.

To summarise, the following concepts apply to both EMFEU- and SSE-boosted networks and guide the way we design our solutions:

- Radio waves are *desirable* at the position of an *intended* entity (device, user, person, or object), because this entity is receiving data from the network or is sensed by the network;
- Radio waves are *undesirable* at the position of a *non-intended* entity (device, user, person, or object) which can be either an *exposed* entity with undesirable EMFE or an *eavesdropper* to whom signal reception is undesirable;

- A *non-intended* entity (device, user, person, or object) can be either *not helping* or *helping* the network to boost the EMFEU or the SSE;
- In the case of EMFEU, the *helping non-intended* entity can help *intentionally* by participating to the protocol reducing the EMFE; and
- In the case of SSE, the *non-intended* entity is always helping in a *non-intentional* manner. The network simply exploits an existing connection between the *non-intended* entity and itself.

Also, in this deliverable, the impact of the designed schemes on the EE metric is discussed.

Time diagrams and flowcharts for the considered schemes for SSE and EMFEU improvements present the designed protocols (including control signalling and data transmission), which are mainly devised to perform within the channel coherence time. Therefore, in most cases, the proposed schemes apply to low mobility or static UEs.

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

Based on our analysis of the various proposed schemes, we recommend 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. Compared to a standard relay node, the RIS has the following new property: it can reflect the BS's or UE waves forwarding their data. Regarding the other existing properties of relay nodes, the RIS may potentially be less sophisticated (with less computing and signal processing capabilities).

1.1 Deliverable objectives & methodology

This document provides the intermediate view and results from WP6, on network architectures, deployment strategies and control signalling with RIS for enhanced EE, EMFEU and SSE metrics defined in Deliverable D2.4, for the use cases and deployment scenarios listed in D2.3.

The current deliverable follows a bottom-up approach:

- First of all, the various PHY-MAC solutions or innovations proposed by WP6 to boost SSE or EMFEU are all briefly described and analysed, in terms of deployment, architecture and control signalling requirements. Hence, for each proposed scheme, separately, one option of architecture and control signalling is derived. In addition, for each scheme, the impact on the EE metric is briefly analysed. Note that detailed description of the proposed schemes and their performance is not in the scope of this current deliverable. They will be provided in the upcoming Deliverable D6.2.
- Then, all requirements from all proposed schemes are gathered into a single set of requirements.

Each of the proposed schemes aimed at boosting EMFEU, is based on general principles explained hereafter. First of all, the control of EMFE towards humans, other living beings as well as certain objects that should have a limited EMFE needs to be reflected in specific protocol operations that take place in a RIS-aided communication system. In general, the communication system needs to differentiate between spatial points where the radiation is *desirable* and *undesirable*, respectively. The spatial points with *desirable* radiation are the ones occupied by an *intended* entity: an *intended* receiver (for instance hold by an *intended user* of the communication link) that will receive the radio waves, an *intended* object or person that needs to be illuminated by radio waves to be sensed by the network. Hence, radio waves are *desirable* at the position of *intended* receivers, *intended* users and *intended* sensed humans or objects. At the spatial points with *undesirable* radiation, the EMFE needs to be kept below a certain value. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) [ICNIRP] provides recommendation regarding such threshold, based on the analysis of scientific studies. However, it can happen that some countries or cities adopt more constraining limits than the ICNIRP guidelines [GSMA]. Also, some use cases presented in D2.3 and D2.4 propose to provide "EMFEU boosted areas" as a service, for instance, in a Train Station. Therefore, the threshold can be set arbitrarily low, either by a city, a country, or a building owner. Note that according to the local regulation, the threshold usually has to be ensured in a statistical sense (for instance on average and during a given pre-defined period) [TFC+17][DTT16][XZY+19][PCE+18][C+19][CZA21]. The spatial points with *undesirable* radiation are the ones occupied by a *non-intended exposed* entity: a *non-intended exposed* user (a user of the communication network having subscribed to a low EMFE service), a *non-intended exposed* person or object. There are two main ways in which the communication system can detect and control *undesirable* EMFE at the *non-intended exposed* entity (user, person or object), depending on the level of participation of *non-intended exposed* entity to the communication system protocol:

- The *non-intended exposed* entity is *not helping:* In this case the *non-intended* entity does not provide information about its positioning or status of EMFE, such that the communication system needs to infer it based on its own sensing capabilities, or by interfacing to application programming interface (APIs) and systems that can provide such information. For example, there could be a different system that measures room occupancy and based on that information the communication system can adjust the calculation of the induced EMFE.
- The *non-intended exposed* entity is *intentionally helping:* This is the case in which the *non-intended exposed* entity explicitly provides information to the communication system to assist the control of EMFE. For example, the device associated with a *non-intended exposed* user can use some of its signalling messages to indicate the level of EMFE or, simply, to make itself known to the communication system in order to force it to limit the EMFE at that spatial location. Such active methods for EMFE control may require dedicated protocol messages that can initiate certain action, such as change of the RIS pattern or decrease of the transmit power.

Our proposed design solutions for boosted SSE are based upon the same general principles as for EMFEU boosting. Indeed, an *eavesdropper* is similar to a *non-intended exposed* user. Again, there are two main ways in which the communication system can detect and control *undesirable* signal at the *eavesdropper*, depending on the level of participation of the *eavesdropper* to the communication system protocol:

- The *eavesdropper* is *not helping:* In this case the *eavesdropper* does not provide information about its positioning or status of received signal, such that, as for the exposed user, the communication system needs to infer it based on its own sensing capabilities. In the worst case, i.e. without any knowledge regarding the eavesdropper, the network would simply try to reduce the level of signal in general; note that such eavesdropper is sophisticated.
- The *eavesdropper* is *non-intentionally helping:* This is the case in which the *eavesdropper* is itself a User Equipment (UE), such as a smartphone, connected to the communication network. In this case, like any UE connected to the network, the eavesdropper exchanges data, control signals and pilots with the network. However, contrary to a normal UE, the eavesdropper tries to demodulate messages sent over radio resources allocated to another user equipment. To avoid such type of eavesdropping, the network could use pilot, control and data signals circulating between itself and the eavesdropper. In this case, the eavesdropper *non-intentionally helps* the network to improve its SSE; note that such eavesdropper is less complex as it is very close to a standard commercial device.

Figure 1-1 below illustrates the aforementioned concepts with one example where a 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 his/her exposition;

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 exposition;
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.

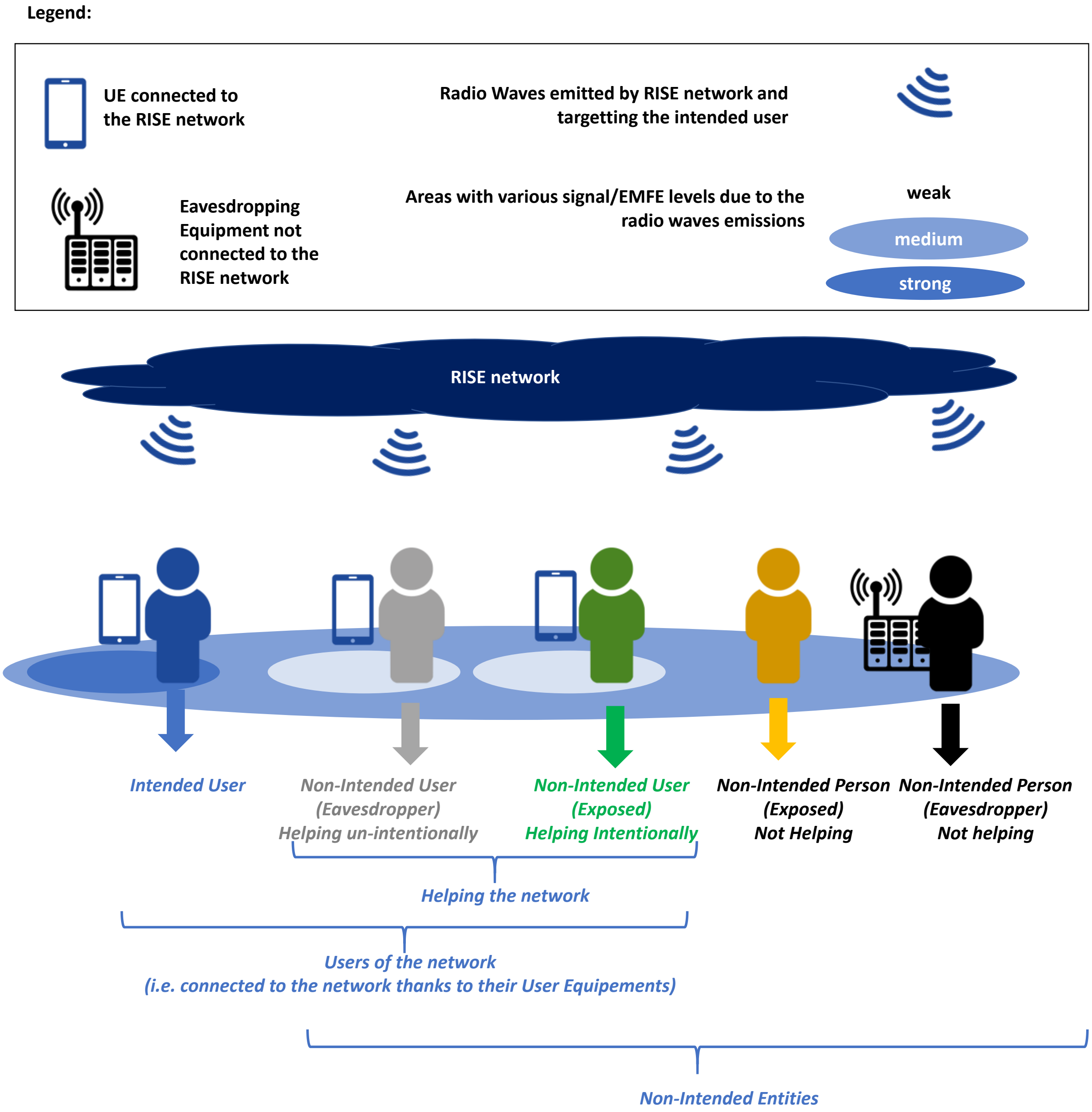


Figure 1-1 – Example where the RISE network emits radio waves with the Intended User as a target, in the presence of four different types of Non-Intended entities.

Finally, this deliverable focuses on the main signalling aspects of layers 1 and 2 in the 5G protocol stack to support EMFEU and SSE boosting during data transmission. Therefore, it is not an exhaustive analysis of all aspects of control signalling (i.e., the 5G layer 3 signalling, random access, mobility, etc. are not treated).

1.2 Deliverable structure

The deliverable is organised as follows:

- In Section 2, we briefly present Spectral Security Efficient schemes proposed in the project, and for each scheme, separately, we analyse the requirements in terms of network architecture and control signalling; the impact on the EE metric is studied;
- In section 3, we briefly present EMFE Utility schemes proposed in the project, and for each scheme, separately, we analyse the requirements in terms of network architecture and control signalling; the impact on the EE metric is studied;
- Section 4 summarizes our recommendation regarding network architecture and control signalling for enhanced sustainability and security;
- Section 5 concludes this deliverable.

2 Secured RISE networks

In this section, we briefly present Spectral Security Efficient schemes proposed in the project. For each scheme, separately, we derive the requirements in terms of network architecture and control. Such SSE oriented schemes are presented in Section 2.2 and try to maximise the SSE metric, whose definition is recalled in Section 2.1.

2.1 SSE metric

The SSE metric has been defined in Deliverable D2.4. We recall hereafter its definition.

The ***secrecy spectral efficiency*** (SSE) metric is defined as the difference between the intended receiving UE (RX)'s rate R_I, referring to the legitimate link, and the non-intended RX's rate R_{NI}, referring to the link between the legitimate transmitter and the eavesdropper. When this difference results in a negative number, it means that no security is guaranteed, and the SSE is defined as zero.

Putting all above together, the mathematical definition of SSE is given by

$$\boldsymbol{SSE} = \mathbf{max}\,(\mathbf{0}, \boldsymbol{R_I} - \boldsymbol{R_{NI}}) \quad (\mathbf{bits/s/Hz})$$

where $R_I = \log_2(1 + SNR_I)$ and $R_{NI} = \log_2(1 + SNR_{NI})$ with SNR_l being defined as in sub-section 2.1 of D2.4, while SNR_{NI} is defined in a similar way by considering the BS to the non-intended UE direct channel $\mathbf{g}_d$ and the RIS to the non-intended UE channel $\mathbf{g}$.

Note that, in these definitions, the waves impinging on non-intended users fall into the category of *undesirable* waves, whereas the waves impinging on intended users, can be seen as *desirable*, as defined in Section 1.1.

2.2 SSE-oriented architecture and control signalling requirements

In this section, we derive the requirements in terms of network architecture and control signalling to support Spectral Security Efficient schemes proposed in the project. For each scheme, we provide:

- The objective of the scheme and the deployment scenario.
- The Architecture Requirements (i.e., which nodes must be connected).
- Data Flow and Control Signalling Requirements (i.e., a protocol description).

The detailed specification of the proposed schemes and initial performance results are not in the scope of this deliverable; they will be provided in the future D6.2 deliverable.

2.2.1 Spatial Focusing

Objective & Deployment Scenario

To investigate the spatial locality of the SSE improvement, a scenario with an *M*-antenna BS is considered which attempts to transmit secret single stream data to the single-antenna receiver (RX) (an intended UE), where the single-antenna eavesdropping RX, also connected to the network (a non-intended UE), is present at the system. To further safeguard the legitimate system, an RIS is also employed under the control of the BS that designs both the precoding vector $\mathbf{w}$ and the passive beamforming diagonal matrix $\mathbf{\Phi}$.

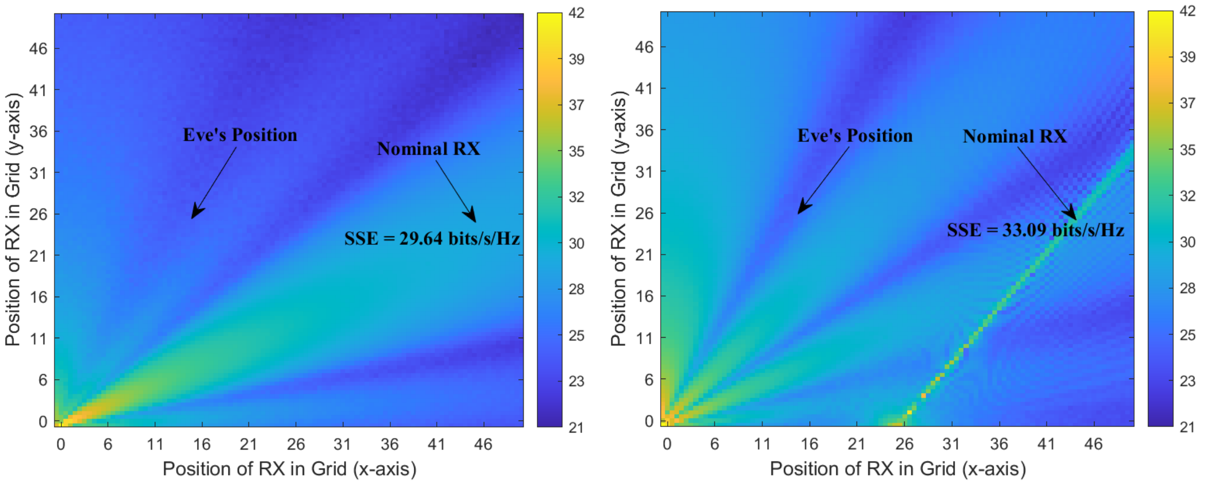


Figure 2-1 – SSE values on a 2-dimensional (2D) grid (as a function of the intended RX position) with the presence of an eavesdropper (Eve). (Left) without the presence of a RIS. (Right) with a RIS placed at [0, 25].

In Figure 2-1, the 2D grids of the SSE, as a function of the position of the intended RX (i.e. the intended UE), are depicted in the case of the absence (on the left) and the presence (on the right) of an RIS with 100 unit elements. The eavesdropping non-intended RX (i.e., the non-intended UE) position is at the point [10.5 m, 20.5 m] from the BS which is placed at the origin. Also, the nominal position of the intended RX is at [40.5 m, 20.5 m]. When a non-intended RX is present even closer to the BS than the intended RX, it is observed that the presence of an RIS boosts the whole area with higher SSE values. Interestingly, a strong beam pattern is observed in the direction which connects the RIS with intended RX.

Architecture requirements

The proposed scheme has the following minimum architecture requirements (captured in Figure 2-2): a multi-antenna BS is serving a single antenna intended UE at a time, through a bi-directional time division duplex (TDD) air interface, with the help of one RIS node, in the presence of a single-antenna non-intended UE. The BS BF weights and RIS's reflected BF weights are optimised in terms of SSE for a single couple of intended UE and non-intended UE, at a time. Channel reciprocity is exploited to acquire full channel state information (CSI).

The RIS node is assumed to be hybrid [AV20], [ASA+21], [AAN+21]: it can switch between a transmission mode, a reception mode and a reflecting mode.

The RIS node is connected to the BS as follows:

- The RIS listens to the BS's synchronisation signals to be aware of the transmitted frame structure, and to be able to apply the protocol described in the next sub-section.
- The RIS sends pilot signals to the BS, in order for the BS to estimate the channels between the two nodes (channel reciprocity in TDD mode is exploited).
- Then, it receives the configured weights from the BS.

In addition, we consider the special case where the non-intended UE is connected to the BS as described below:

- The non-intended UE sends pilots to the BS to support its own connection to the network.
- The BS listens to the non-intended UE pilots and estimates the channel state information.

The above process is similar for the case of the communication between the BS and the intended UE. Also, the non-intended UE tries to eavesdrop the confidential intended UE data signals and the BS is aware of this situation and considers it as a potential eavesdropper, trying to reduce the signal towards this non-intended UE. Note that in this case, the non-intended UE is unintentionally helping the network to prevent it from eavesdropping (as described in Section 1.1).

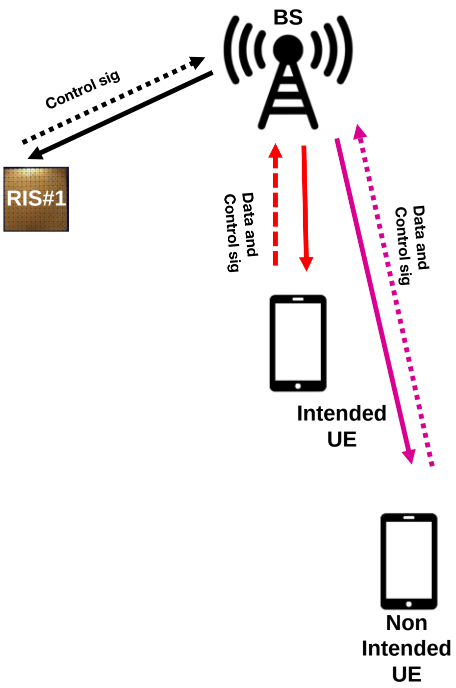


Figure 2-2 Architecture requirements for spatial focusing scheme.

Data Flow and Control Signalling Requirements

For the above scheme, the requirements for data flow and control signalling are given sequentially (as a protocol description) and then illustrated in Figure 2-3:

1. The intended and non-intended UEs send pilot signals to the BS, for the intended UE-to-BS channel and the non-intended UE-to-BS channel estimations. During this step, the RIS's weights are in a reference state known at the BS.
2. Then, the RIS sends pilots to estimate the RIS-to-BS channel. Then, the BS deduces the direct UE-to-BS channel and the non-intended UE-to-BS channel (by withdrawing from the estimated channels at step 1, the estimated channel of step 2, assuming a cascaded channel model).
3. Next, the BS jointly computes the RIS and BF weights, optimised for SSE.
4. Then, the RIS configuration is sent to the RIS by the BS.
5. The RIS's controller configures the RIS according to the received configuration.

Finally, the BS transmits data with BF weights optimised for SSE. Both UEs receive the data and demodulate them either successfully in the case of the intended UE, or unsuccessfully in the case of the non-intended UE.

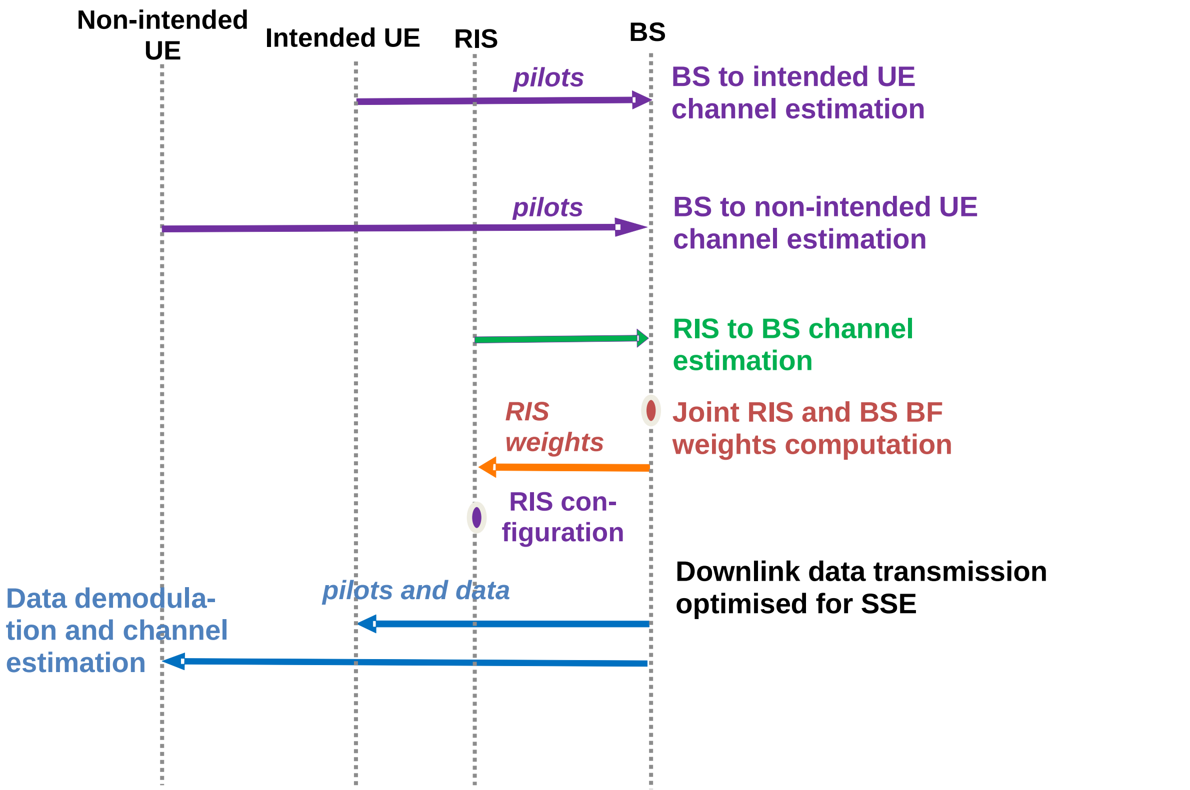


Figure 2-3 Data flow and control signalling for the spatial focusing scheme.

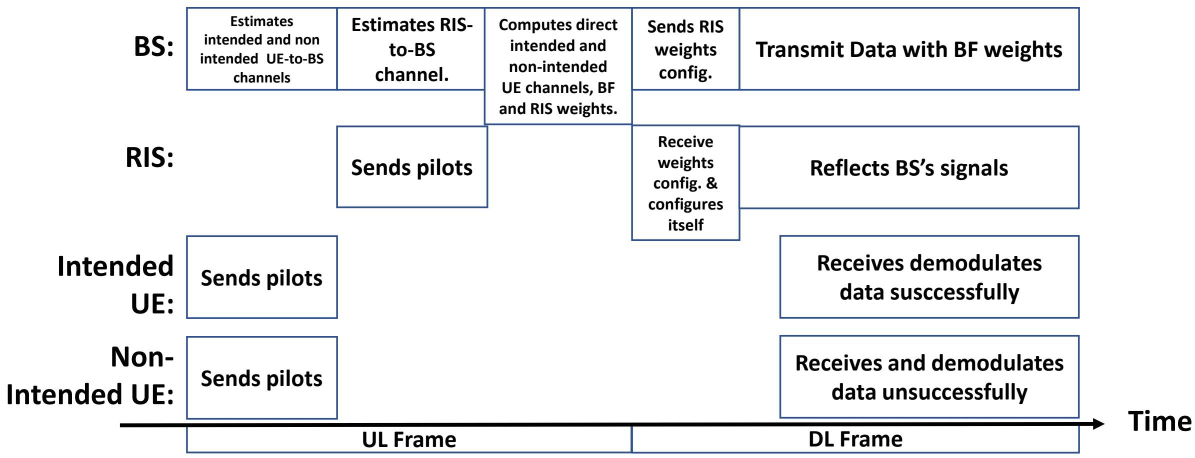


Figure 2-4 Time diagram for the spatial focusing scheme.

Energy Efficiency

Thanks to the proposed spatial focusing scheme, the intended UE will experience better performance in terms of energy efficiency due to the presence of the RIS, especially when it is located at the line connecting the RIS with the nominal intended UE's position, according to Figure 2-1.

2.2.2 SSE with Full CSI knowledge

Objective & Deployment Scenario

The considered secrecy-oriented system [AKW+21], illustrated in Figure 2-5, comprising three multi-antenna nodes (an intended RX UE, a non-intended eavesdropping UE, and a BS) and two multi-element RISs, one serving the non-intended RX UE (eavesdropper E) and the other the intended RX UE (legitimate BS-RX link). The two UEs are connected to the BS. The BS is assumed to be unaware of the existence of the malicious RIS and the same is assumed for E regarding the legitimate RIS. TDD air interface is assumed. Channel reciprocity can be exploited to acquire full CSI. Finally, it is assumed that there is no propagation path between the BS and the intended UE passing by the malicious RIS, and there is no propagation path between the BS and the non-intended UE passing by the legitimate RIS.

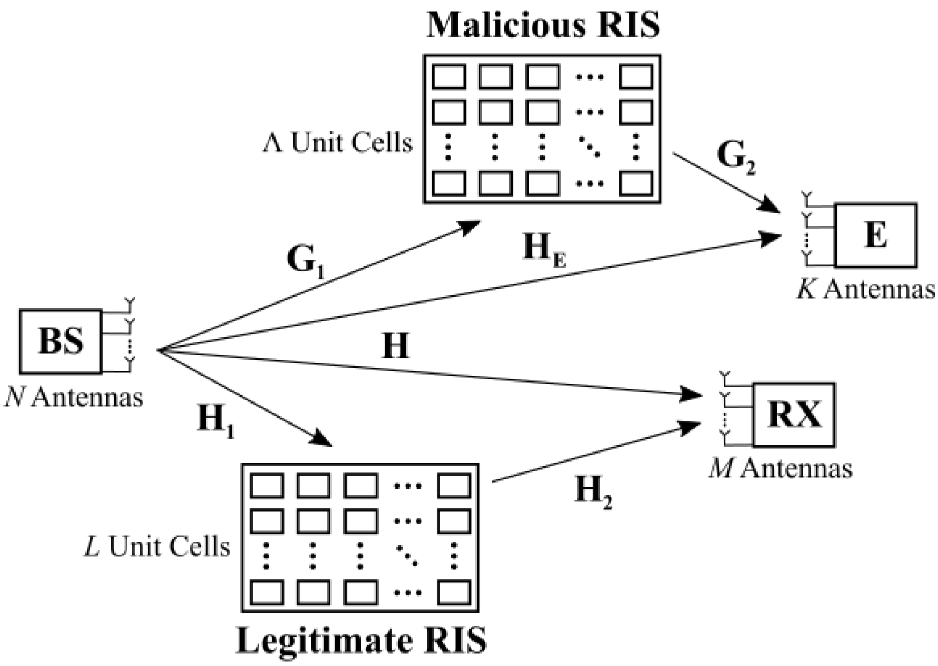


Figure 2-5 Considered deployment scenario for the secrecy spectral efficiency with full CSI knowledge.

Architecture requirements

For the above model illustrated in Figure 2-5, the following architecture requirements are assumed: we consider full CSI knowledge for both legitimate and eavesdropping sides, regarding the channels that each side needs to possess in order to design its free parameters, such as RIS configuration, beamforming vectors/matrices and receive combiners. We assume that the BS acquires the channel matrices $\mathbf{H}$, $\mathbf{H}_1$ and $\mathbf{H}_2$, while it is also assumed that the BS and the non-intended UE cooperate to estimate the BS-to-non-intended UE channel $\mathbf{H}_{\mathrm{E}}$ based on the following channel estimation scheme: BS transmits pilot signals to non-intended UE that estimates $\mathbf{H}_{\mathrm{E}}$ and then feeds this estimation back to BS. This cooperation may apply to the case where the non-intended UE plays the dual role of an intended receiver and of an eavesdropper. BS is unaware of the existence of the malicious RIS; hence, it has no knowledge on the BS-to-malicious RIS channel $\mathbf{G}_1$ and the malicious RIS-to-non-intended UE channel $\mathbf{G}_2$. However, the latter two channels are assumed available at the eavesdropping side.

The RIS nodes are assumed to be hybrid [ASA+21] and able to switch between several modes: transmission mode, reflection mode and transparent mode (where they are transparent to impinging waves). Note that such transparent mode could be obtained for instance by loading the unit cells with a switchable impedance very far from the adapted impedance for the carrier frequency of interest.

Data Flow and Control Signalling Requirements

For the described scheme above, the necessary protocol and the associated requirements for control signalling are summarised below:

1. The BS sends pilots in the downlink (DL) and the UEs estimate $(\mathbf{H}, \mathbf{H}_{\mathrm{E}})$. During this step, the two RISs are assumed to be in a "transparent state", for instance, their unit cells are loaded with large impedances (close to an open circuit).
2. The UEs send pilots in the uplink (UL) and the BS estimates $(\mathbf{H}, \mathbf{H}_{\mathrm{E}})$. During this step, the two RISs are assumed to be in a "transparent state", for instance, their unit cells are loaded with large impedances (close to an open circuit).
3. Next, the BS turns on the legitimate RIS, to estimate the cascaded channel, that is, $\mathbf{H}_1$ and $\mathbf{H}_2$. In parallel, the eavesdropper E turns on the malicious RIS and estimates the cascaded channels of the malicious RIS ($\mathbf{G}_1$ and $\mathbf{G}_2$).
4. The BS computes the weights for the BS BF and for the legitimate RIS, optimised for SSE, only based on the knowledge of $\mathbf{H}, \mathbf{H}_{\mathrm{E}}$, $\mathbf{H}_1$ and $\mathbf{H}_2$. In parallel, the eavesdropper E compute the RIS weights for the malicious RIS only based on the knowledge of $\mathbf{H}_{\mathrm{E}}$, $\mathbf{G}_1$ and $\mathbf{G}_2$.
5. The BS sends the weights to the legitimate RIS. In parallel, the eavesdropper E sends the weights to the malicious RIS.
6. The legitimate RIS configures itself according to the received weights. In parallel, the malicious RIS configures itself according to the received weights.
7. The BS sends confidential data using the BF weights. Hopefully, the intended UE receives and demodulates the data successfully, and the non-intended UE demodulates it unsuccessfully.

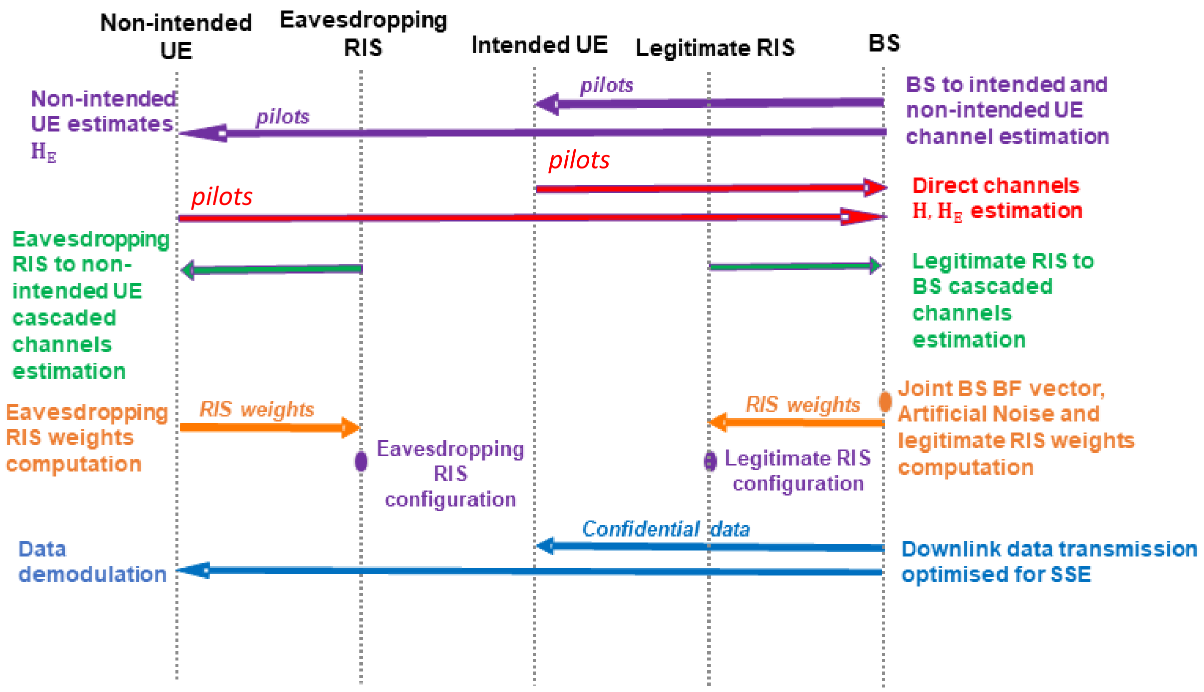


Figure 2-6 Data flow and control signalling for the secrecy spectral efficiency scheme with full CSI.

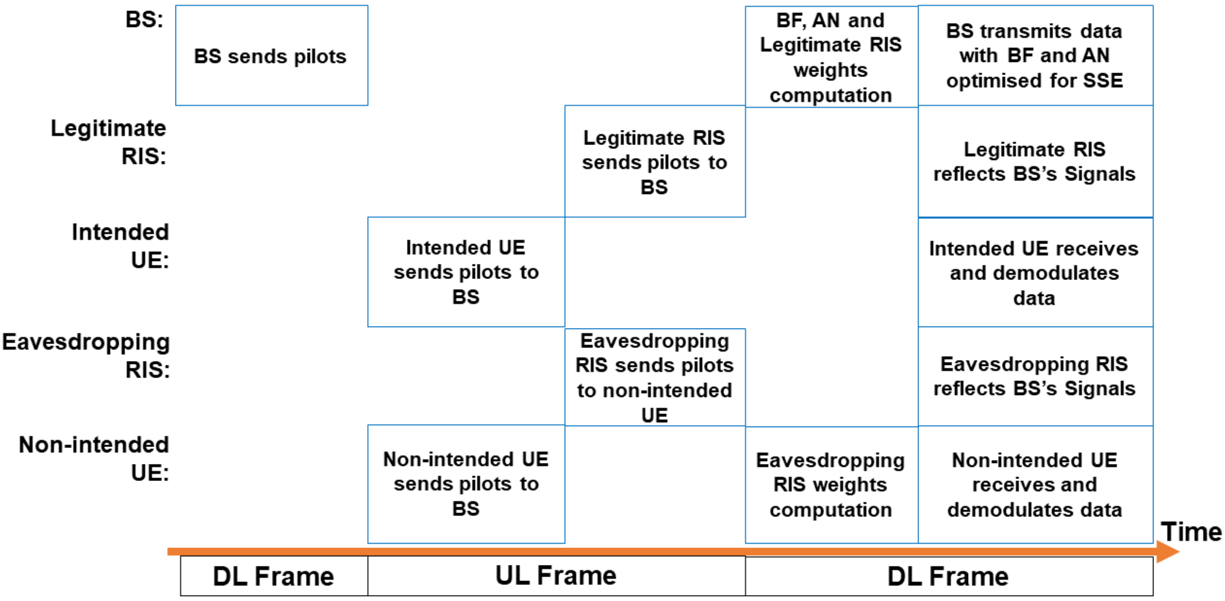


Figure 2-7 Time diagram for the secrecy spectral efficiency scheme with perfect CSI.

Energy Efficiency

Thanks to the proposed SSE scheme, the intended UE will experience higher rates due to the presence of the legitimate RIS, even when the malicious RIS has five times more unit elements than it, according to the results in [AKW+21].

3 EMFE Utility RISE networks

In this section, we derive the requirements in terms of network architecture and control signalling to support EMFE Useful schemes proposed in the project. Such EMFE Utility (EMFEU) oriented schemes are presented in Section 3.2 and try to maximise the EMFEU metric, which definition is recalled in Section 3.1.

Note that the detailed description of the schemes and their performance is not in the scope of this deliverable. They will be provided in the upcoming D6.2 deliverable.

3.1 EMFEU metric

The EMFEU metric has been defined in Deliverable D2.4 Section 2.10. We recall its definition hereafter.

In addition to the DL case, we also consider the UL case.

We first consider as a target service, a DL data communication towards an intended UE. We also consider a non-intended user (or person or object) who is potentially exposed to the EMF generated by this link. For this target service, we propose the following definition of the ***inter EMFEU***:

$$\boldsymbol{EMFEU_{inter} = R^{DL}/X^{NI}},$$

where R^{DL} is data rate that is delivered to the intended UE and X^{NI} is the EMF which the non-intended user (or person or object) is exposed to. In the case we are considering multiple non-intended users (or persons or objects), X^{NI} is the EMF of the most exposed one.

As a target service, we then consider an UL data communication issued by an intended UE. In this case, the intended UE is also the exposed one. For this target service, we propose the following definition of the **self EMFEU**:

$$EMFEU_{self} = R^{UL}/X^{I},$$

where R^{UL} is data rate that is transmitted by the intended UE and X^{I} is the EMF which the intended user (we recall that the intended user "uses" the intended UE) is exposed to. This refers to the user own radiation, which should be a very local phenomenon. A RIS can help boosting the self EMFEU through improving the link's quality, thus, allowing the UE to achieve the same rate with a lower transmit power and a lower self EMFE.

Note that, in these definitions, the waves impinging on non-intended users fall into the category of *undesirable* waves, whereas the waves impinging on intended users can be seen as *desirable*, as defined in Section 1.1.

3.2 EMFE-oriented architecture and control signalling requirements

In this section, we derive the requirements in terms of network architecture and control signalling to support EMFE Useful schemes proposed in the project. For each scheme, we provide:

- The objective of the scheme and the deployment scenario.
- The Architecture Requirements (which nodes must be connected).
- The Data Flow and Control Signalling Requirements (a protocol description).

The detailed specification of the proposed schemes and initial performance results are not in the scope of this deliverable; they will be provided in the future D6.2 deliverable.

3.2.1 RIS-aided EMF-Aware BF

Objective & Deployment Scenario

A macro-cell deployment of massive MIMO BSs operating with a sub-6GHz carrier frequency is considered. As illustrated in Figure 3-1, we consider both outdoor-to-outdoor and outdoor-to-indoor environments. The following type of propagation is considered: multiple scatterers, multiple RISs, both LOS and NLOS. RISs and scatterers are in far field of target UE and BS. Slow moving or steady UEs only are considered. TDD mode is assumed. Channel reciprocity can be exploited to acquire full CSI.
RIS-aided EMF-Aware beamforming schemes [APV21] [APV+22-1] [APV+22-2] are proposed with the following objectives: to deliver DL data from the BS to the UE with maximum received power at the target UE, whilst complying with the EMFE regulation.

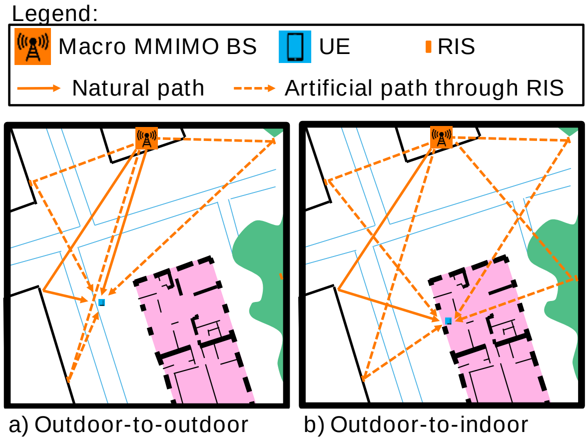


Figure 3-1 Considered deployment scenarios.

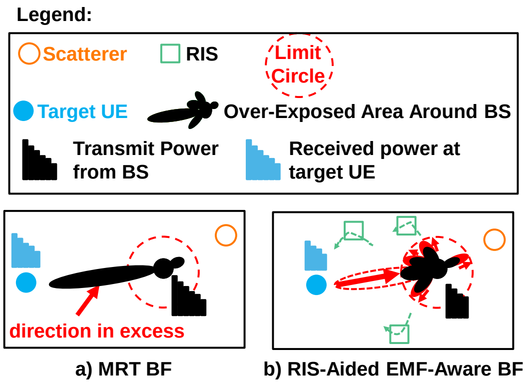


Figure 3-2 RIS aided EMF-Aware BF principle.

The principle of the proposed technical solutions is summarised hereafter. It addresses a drawback of M-MIMO maximum ratio transmission (MRT) BF (which exploits the channel reciprocity in TDD systems), which yields the creation of undesired high exposure regions (over-exposed area in terms of EMFE) in the vicinity of the antenna, as illustrated in Figure 3-2 a). Such over-exposed area is concentrated in few directions (around the antenna) corresponding to the best propagation paths between the antenna and the receiver. Various novel electromagnetic field aware beamforming schemes are proposed that: (i) spread the beamforming radiation pattern in the angular domain by adding to the 'natural' propagation paths some 'artificial' propagation paths thanks to RISs; (ii) truncate the pattern in strong directions; (iii) boost the pattern in weak directions. Such proposed novel schemes maximize the received power at the target, without violating the exposure constraint.

This scheme therefore boosts the *inter EMFEU* metric. However, as non-intended UEs, persons and objects are *not helping* the network to avoid exposing them, this scheme only reduces the global level *undesirable* radiations.

Note that the detailed description of this scheme and its performance is not in the scope of this deliverable. It will be provided in the upcoming D6.2 deliverable.

Architecture requirements

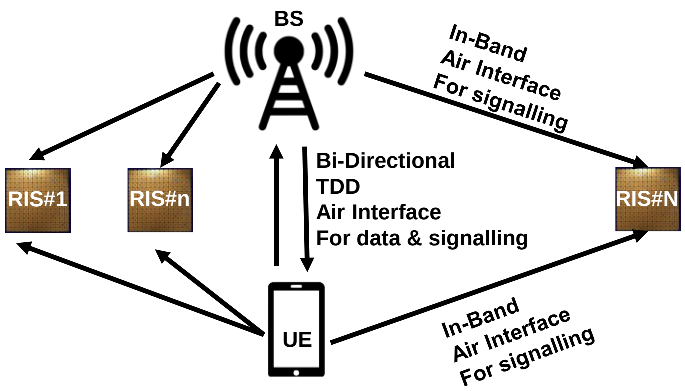


Figure 3-3 Architecture requirements, with RIS #n, n=1 to N.

The proposed schemes have the following minimum architecture requirements (captured in Figure 3-3: a single BS is serving a single UE at a time, through a bi-directional TDD air interface, with the help of one or several RIS nodes. The BS BF weights and RISs reflected BF weights are optimised for a single UE at a time.

Although a RIS node is mute, it is connected to the BS and the UE as follows:

- it listens to the BS synchronisation signals to remain synchronised with the BS, to be aware of the frame structure, and be able to apply the protocol described further down.
- it listens to the UE uplink pilots.

Hence, the RIS node is assumed to be hybrid: it can switch between a reception mode and a reflecting mode.

Data Flow and Control Signalling Requirements

The proposed schemes have the following minimum requirements (captured in Figure 3-4 and Figure 3-5) in terms of protocol and control signalling:

1. the UE sends pilots in the uplink, each RIS senses the phases of the propagation channel between the UE and its unit cells;
2. then, based on the knowledge of these phases, each RIS computes its weights to "turn itself electronically" towards the target UE, and "freezes".

3. The UE sends pilots in the uplink again, to allow the BS to sense the UE-to-BS channel under the influence of RISs.
4. Then, based on the knowledge of the channel, the BS computes the BF weights
5. Finally, the BS sends data to the UE, using BF.

Steps 1 to 3 are re-iterated to take into account changes in the propagation environment. However, the UE is supposed to be steady or slowly moving, and to the most frequent occurrence of steps 1 to 3 is once per UL frame (as illustrated in Figure 3-5).

Note that in this scheme, the *non-intended* UE is not helping as it is not participating to the protocol.

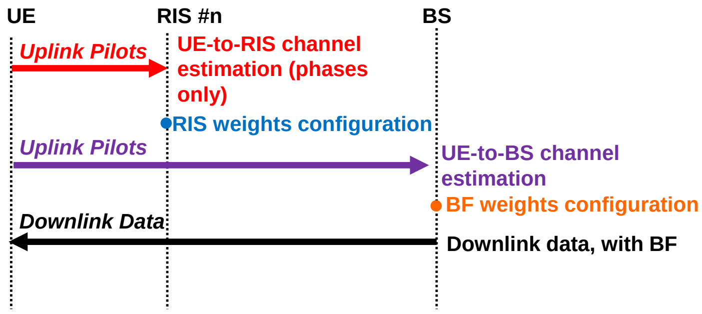


Figure 3-4 Data and control flows, all RISs #n (n=1 to N) doing the same thing simultaneously.

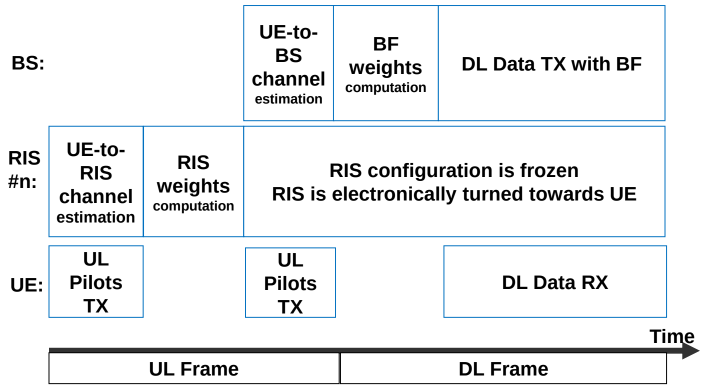


Figure 3-5 Time diagram, all RISs #n (n=1 to N) doing the same thing simultaneously.

Energy Efficiency

[APV21] shows that using truncation only already improves the attained received power at the UE, whilst meeting the EMFE constrain. Hence the EMFE Utility is boosted. [APV+22-1] shows that boosting in addition to truncation, further improves the attained received power at the UE, whilst meeting the EMFE constrain, but at the expense of a large amount of energy spending. Hence, in this case, the EMFE Utility is further boosted, at the expense of an EE degradation. [APV+22-2] is similar to [APV+22-1]. It is therefore up to the network operator to choose the trade-off between EMFEU and EE and select the right technique to attain this trade-off.

3.2.2 Energy Efficiency Optimisation of Reconfigurable Intelligent Surfaces with Electromagnetic Field Exposure Constraints

Objective & Deployment Scenario

An indoor deployment of small cell BSs or APs operating with a sub-6GHz carrier frequency is considered. As illustrated in Figure 3-6, we consider indoor-to-indoor environments. We consider the following type of propagation: multiple scatterers, multiple RISs and only NLOS. RISs and scatterers are in far field of target UE and BS. Slow moving or steady UEs only are considered. TDD mode is assumed, where full channel state information can be obtained thanks to channel reciprocity.
As illustrated in Figure 3-6, joint RIS and BF EMFE aware schemes [ZR22] are proposed with the following objectives: to deliver uplink data from the UE to the BS with maximum EE under EMFE constrain.

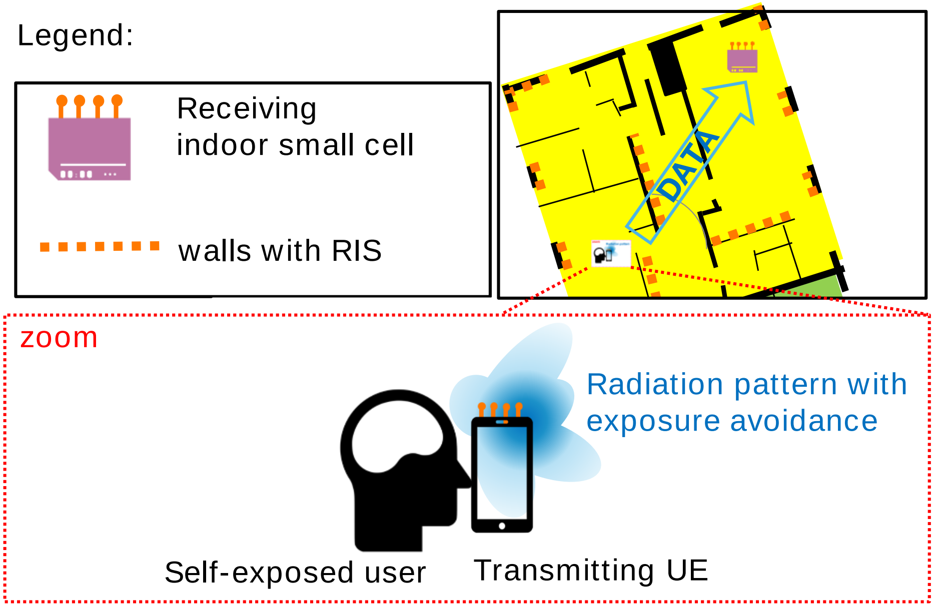


Figure 3-6 Considered deployment scenarios.

The principle of the proposed technical solutions in [ZR22] is summarised hereafter. The problem of energy efficiency maximisation in a RIS-based communication link, subject to not only the conventional maximum power constraints, but also additional constraints on the maximum exposure to electromagnetic radiations of the end-users is considered.
This scheme therefore boosts the *self EMFEU* metric. In this particular case, the UE *helps* the network to reduce the exposition.

Note that the detailed description of this scheme and its performance is not in the scope of this deliverable. It will be provided in the upcoming D6.2 deliverable.

Architecture requirements

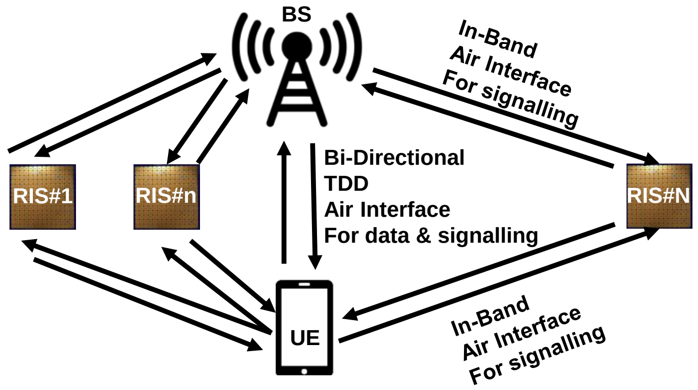


Figure 3-7 Architecture requirements.

The proposed schemes have the following minimum architecture requirements (captured in Figure 3-7): a single BS is serving a single UE at a time, through a bi-directional TDD air interface, with the help of one or several RIS nodes. The BS BF weights, the UE filter and RISs reflected BF weights are optimised for a single UE at a time.

The RIS node can listen and talk, and it is connected to the BS and the UE as follows:

- it listens to the BS synchronisation signals to remain synchronised with the BS, to be aware of the frame structure, and be able to apply the protocol described further down;
- it sends pilots to the BS;
- it sends pilots the UE;
- it listens to the UE message signalling the RIS weights to be applied.

Hence, the RIS node is assumed to be hybrid: it can switch between a transmission mode, a reception mode and a reflecting mode.

Data Flow and Control Signalling Requirements

The proposed schemes have the following minimum requirements (captured in Figure 3-8 and Figure 3-9) in terms of protocol and control signalling:

1. Each RIS #n (n=1 to N), in sequence, sends pilots to allow the UE and the BS to measure the RIS-to-UE and the RIS-to-BS channels.
2. The BS reports the RIS-to-BS channels, for each RIS, to the UE;
3. The BS sends pilots to the UE to allow the UE to measure the BS-to-UE channel (for this stage, the RIS are assumed to be frozen in a known configuration, so that the UE can withdraw from the BS-to-UE the 'artificial' part of the channel with RIS influence, and extract the 'natural' part only);
4. Based on all aforementioned channel measurements, the UE computes the UE BF weights, the BS filter weights and the RIS weights;
5. The UE sends to each RIS, its individual weights;
6. Each RIS configures its weights according to the received control message from the UE;
7. The UE sends data with demodulation pilots to the BS

8. The BS measures the channel, equalizes it (after having determined the BS filter) and received the data.

Step 1 requires the introduction of a ‘RIS frame’ during which the BS and the UE are mute.
Steps 1 to 5 are re-iterated to take into account changes in the propagation environment. However, the UE is supposed to be steady or slowly moving, and to the most frequent occurrence of steps 1 to 3 is once per overall (RIS, DL and UL) frame (as illustrated in Figure 3-9).

Note that in this scheme, the non-intended UE is helping as it is participating to the protocol.

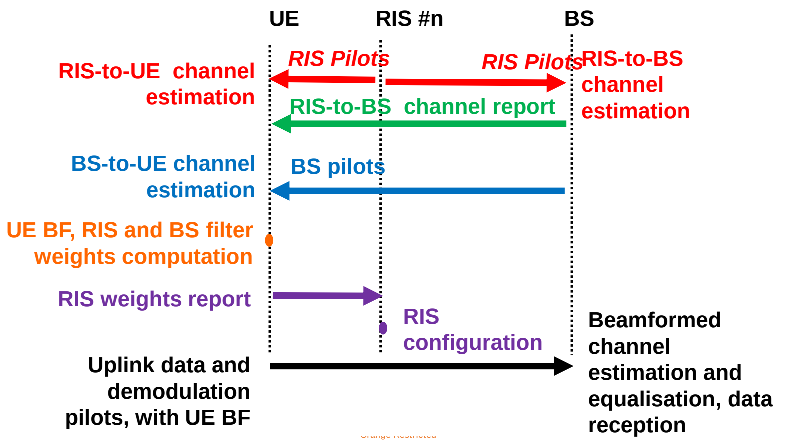


Figure 3-8 Data and control flows, with RIS channels estimation, in sequence for RIS #n, n=1 at N.

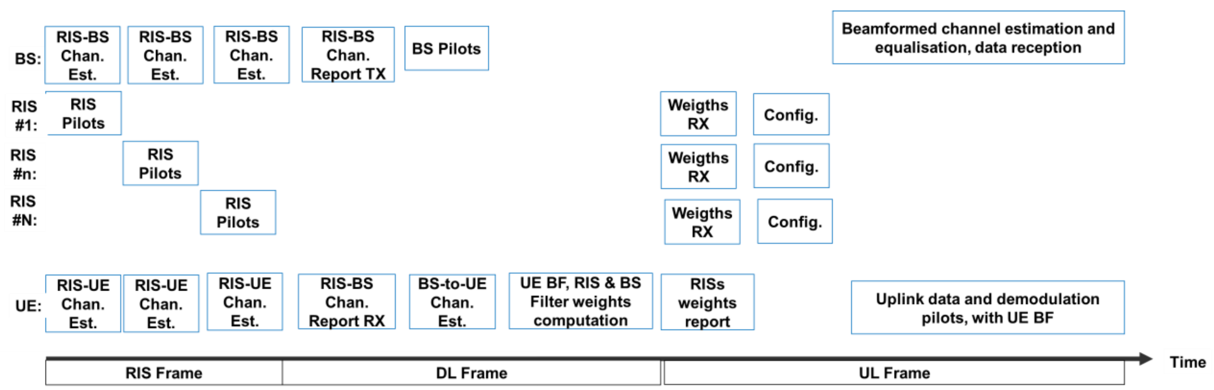


Figure 3-9 Time diagram, with RIS channels estimation, in sequence for RIS #n, n=1 at N.

Energy Efficiency

[ZRV22] aims at maximizing the EE. Two low-complexity algorithms are developed that jointly optimize the RIS phase shifts, the transmit beamforming, the linear receive filter, and the transmit power. One algorithm can be applied to the general system setups but does not guarantee global optimality. The second algorithm is provably optimal in a notable special case. The numerical results show that RIS-based communications can ensure high energy efficiency while fulfilling users’ exposure constraints to radio frequency emissions.

3.2.3 Low sum EMFE of multiple radio access networks in strong visibility, without coordination

Objective & Deployment Scenario

A deployment of small cell BSs or Aps operating with a mmWave carrier frequency is considered. As illustrated in Figure 3-10, we consider indoor-to-indoor environments. We consider the following type of propagation: multiple scatterers, multiple RISs and LOS dominant propagation. RISs and scatterers are in far field of target UE and BS. No constrain on the mobility of UEs is considered. As illustrated in Figure 3-10, at least two operators O1" and "O2" are considered, each with its own RIS, BS, radio access network (RAN) and core network (CN) equipments.
As illustrated in Figure 3-10, a joint RIS and BF EMFE aware scheme is proposed with the following objective: each operator should avoid exposing a common target "low EMFE area" that is in strong visibility of the BSs.

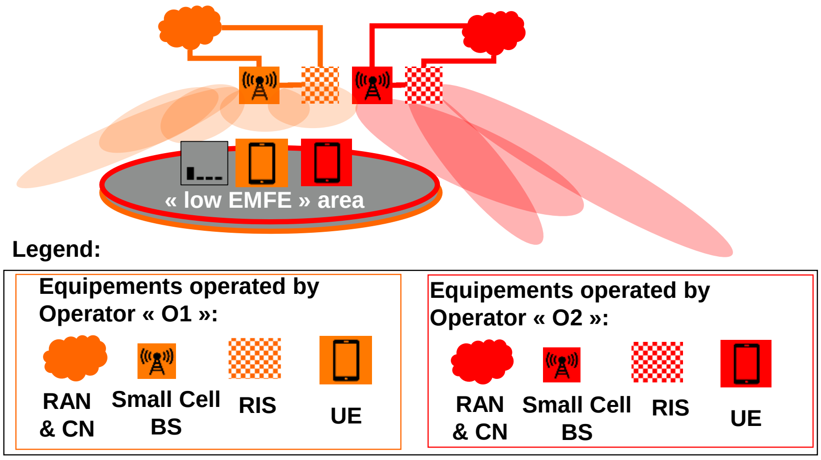


Figure 3-10 Considered deployment scenarios.

The principle of the proposed technical solution requires some field measurements by "O1" and some static optimisation of the BS and the RIS.
More precisely, a measurement UE is used to scan the "low EMFE" area, manually (by an employee of "O1" for instance) while the BS and the RISs of "O1" are performing transmitted beam sweeping, and reflected beam sweeping, respectively. The BS of "O1" determines the list of "forbidden couples of beams and reflected beams" that expose the "low EMFE" area above a pre-defined threshold and stores them. The complementary list of couples of beams and reflected beams therefore gathers the "allowed couples of beams and reflected beams".
Then, when the network is operated it only uses allowed couples of beams and reflected beams.
The same principle applies to operator "O2".
This is expected to provide a "low EMFE area" without live coordination between operators O1" and "O2".
However, it is operationally expensive as it requires some field measurements and sub-optimal since it is not dynamically adapted. Some pre-optimisation using ray-tracing simulation tools can reduce the time spent in field measurements.
Note that the detailed description of this scheme and its performance is not in the scope of this deliverable. It will be provided in the upcoming D6.2 deliverable.

This scheme therefore boosts the inter EMFEU metric.

Architecture requirements

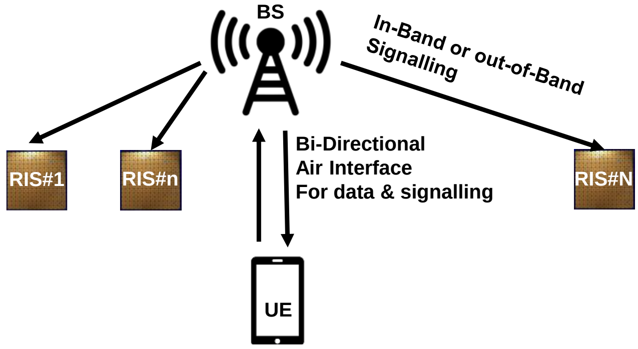


Figure 3-11 Architecture requirements.

The proposed scheme has the following minimum architecture requirements (captured in Figure 3-11) : a single BS is serving a single "measurement UE" at a time, through a bi-directional TDD or FDD air interface, with the help of one or several RIS nodes.

The RIS node can listen to the BS as follows:

- it listens to the BS synchronisation signals to remain synchronised with the BS, to be aware of the frame structure, and be able to apply the protocol described further down;
- it listens to the BS message signalling the RIS weights to be applied.

Hence, the RIS node is assumed to be hybrid: it can switch between a reception mode and a reflecting mode.

Data Flow and Control Signalling Requirements

The proposed schemes have the following minimum requirements (captured in Figure 3-12 and Figure 3-13) in terms of protocol and control signalling:

1. the BS choses a configuration (a reflected beam ID for each RIS, and a beam ID for the BS itself).
2. The BS signals the configuration to all RISs;
3. Each RIS configures its reflected beam according to the signalled configuration;
4. The BS configures its beam according to the chosen configuration;
5. The BS sends pilots using the chosen beam and the UE measures the BS-to-UE channel for the given configuration;
6. The UE feeds back to the BS the received power;
7. The BS classifies the tested configuration as "forbidden" or "allowed" depending on whether it exceeds or not a given threshold.

Steps 1 to 7 are iterated for all configurations. If the BS does not receive any feedback during step 6, it considers that the propagation is so poor that the configuration can be classified as "allowed".

Note that in this scheme, the non-intended UE is not helping as it is not participating to the protocol. However, a testing UE is *helping* before the network is used by the non-intended user.

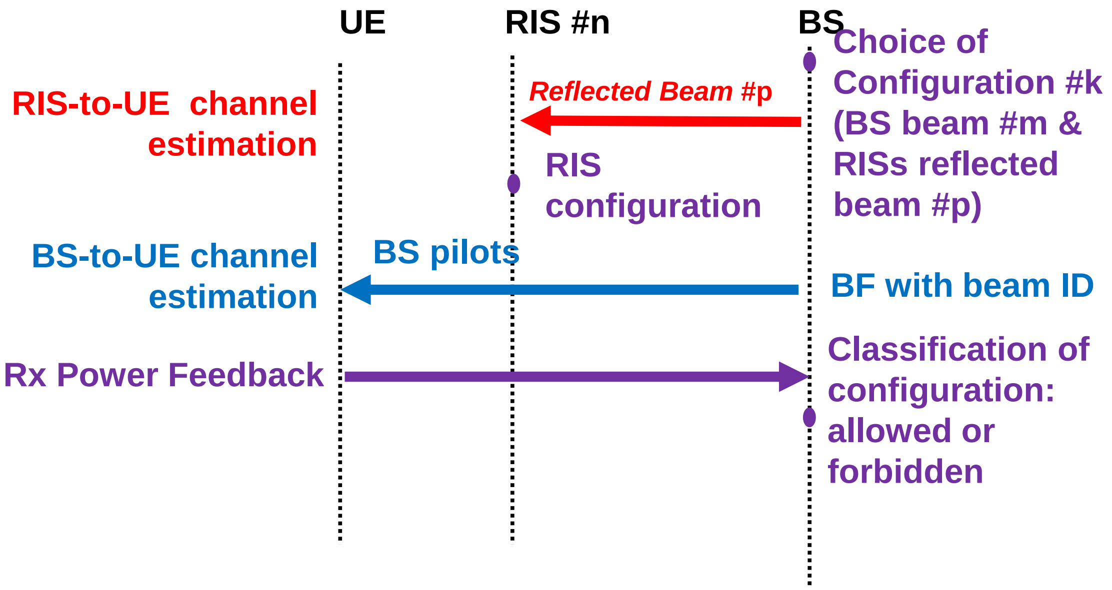


Figure 3-12 Data and control flows, with all RISs #n=1 to N, doing the same thing simultaneously.

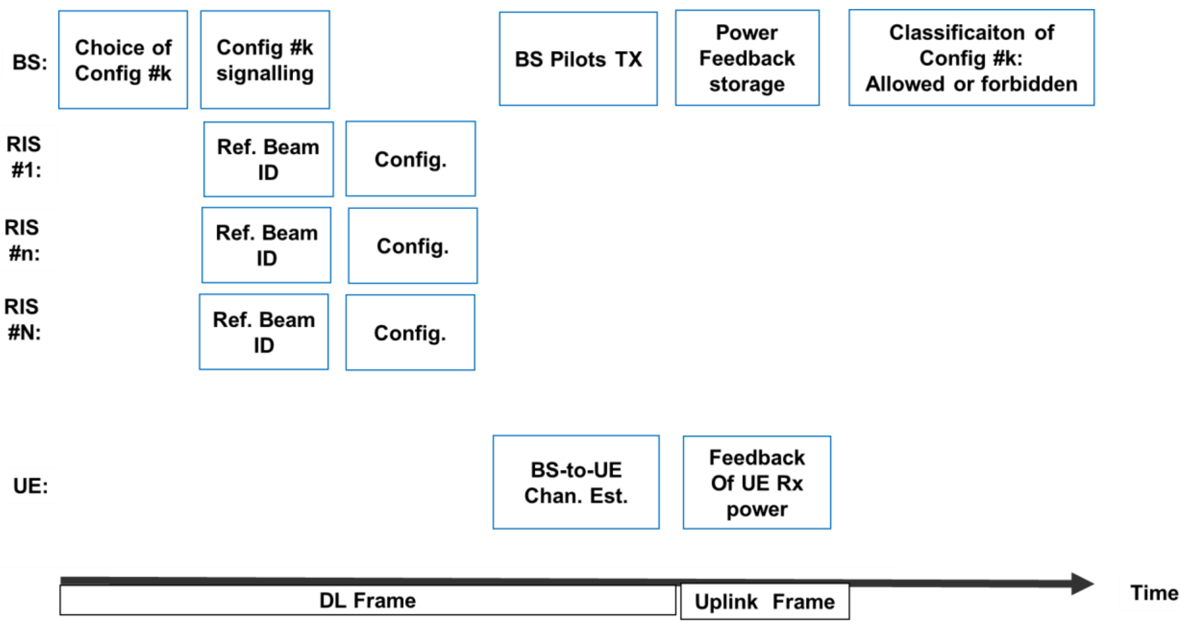


Figure 3-13 Time diagram, with all RISs #n=1 to N, doing the same thing simultaneously.

Energy Efficiency

Such scheme is sub-optimum as it is based on field measurements and then the use of a static list of allowed and forbidden beams. The energy efficiency is expected to be very degraded compared to a scheme without this static list constraint.

3.2.4 Joint RIS and DL BS BF under EMF exposure constraint

Objectives and deployment scenarios

We consider a small cell outdoor BS/AP operating with mmWave carrier frequencies. As illustrated in Figure 3-14, the following type of propagation is considered: geometry-based channel with multiple scatterers and one RISs. RISs and scatterers are assumed to be in the far field of target UEs and the BS. Time Division Duplex (TDD) mode is assumed, where full channel state information can be obtained from channel reciprocity.

As illustrated in Figure 3-14, we jointly optimize the RIS and the BS BF for the intended user, given that a non-intended user is between the BS to the intended user, and it has some EMF constraints. Targeting on minimizing the transmit power at the BS to satisfy the SNR requirement of the intended user, we propose a closed-loop scheme with the direct link being considered, in order to fully explore the potential of RIS-assisted systems with EMF constraints.

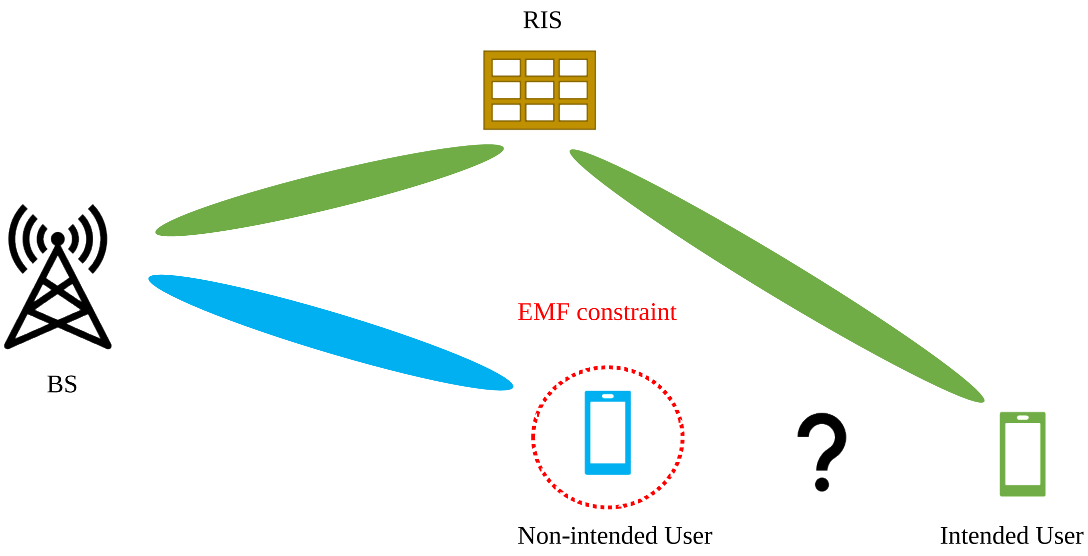


Figure 3-14 Considered deployment scenarios.

The principle and objective of the proposed technical solution is summarised here after:

We jointly optimize the BF weights for BS and RIS in a DL transmit system, targeting on minimizing the transmit power at the BS. Here, the direct link between the BS to the intended user is “blocked” by a non-intended user with EMF constraints. With, e.g., different level of EMF requirements, channel models, user’s location uncertainties, there are potentials to utilize the direct link to further reduce the transmit power at the BS based on the EMF exposure level feedback from the non-intended user. This scheme is therefore boosting the inter EMFEU metric.

Note that the detailed description of this scheme and its performance is not in the scope of this deliverable. It will be provided in the upcoming D6.2 deliverable.

Architecture requirements

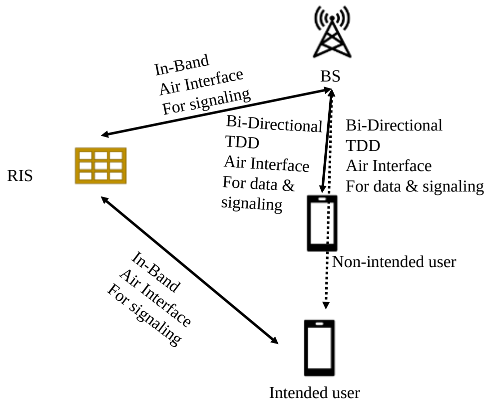


Figure 3-15 Architecture requirements.

The proposed scheme has the following minimum architecture requirements (captured in Figure 3-15) : A single BS is serving a single intended UE at a time, through a bi-directional TDD air interface, with the help of one RIS node and potentially the direct link. The BS BF weights, the UE equalizer and RISs reflected BF weights are optimised for the intended UE at a time. Channel reciprocity can be exploited to acquire full CSI.

The RIS node can listen and talk, and it is connected to the BS and the UE as follows:

- it listens to the BS synchronisation signals to remain synchronised with the BS, to be aware of the frame structure, and be able to apply the protocol described further down;
- it sends pilots to the BS;
- it sends pilots to the UE;
- it listens to the UE message signalling the RIS weights to be applied.

Hence, the RIS node is assumed to be hybrid: it can switch between a reception mode and a reflecting mode.

Data Flow and Control Signalling Requirements

The proposed schemes have the following minimum requirements (captured in Figure 3-16 and Figure 3-17) in terms of protocol and control signalling:

1. Non-intended user sends EMF-related information, e.g., location, object size, to the BS.
2. The RIS sends pilots to allow the intended UE and the BS to measure the RIS-to-UE and the RIS-to-BS channels.
3. The UE reports the RIS-to-UE channels to the BS.
4. The UE sends pilots to the BS to allow the BS to measure the UE-to-BS channel (for this stage, the RIS are assumed to be frozen in a known configuration, so that the BS can withdraw from the BS-to-UE the ‘artificial’ part of the channel with RIS influence, and extract the ‘natural’ part only).
5. Based on all aforementioned channel measurements, the BS computes the BS BF weights, the UE filter weights and the RIS weights.
6. The BS sends to the RIS with its weights.
7. The RIS configures its weights according to the received control message from the BS.
8. The BS sends data with demodulation pilots to the UE.

9. The UE measures the channel, equalizes it (after having determined the BS filter) and received the data.

Step 1 requires information from the non-intended UE, and such information could be used by power minimisation at the BS. Step 2 requires the introduction of a 'RIS frame' during which the BS and the UE are on mute. Steps 2 to 6 are re-iterated to take into account changes in the propagation environment.

Note that in this scheme, the non-intended user is *helping* as it is participating to the protocol.

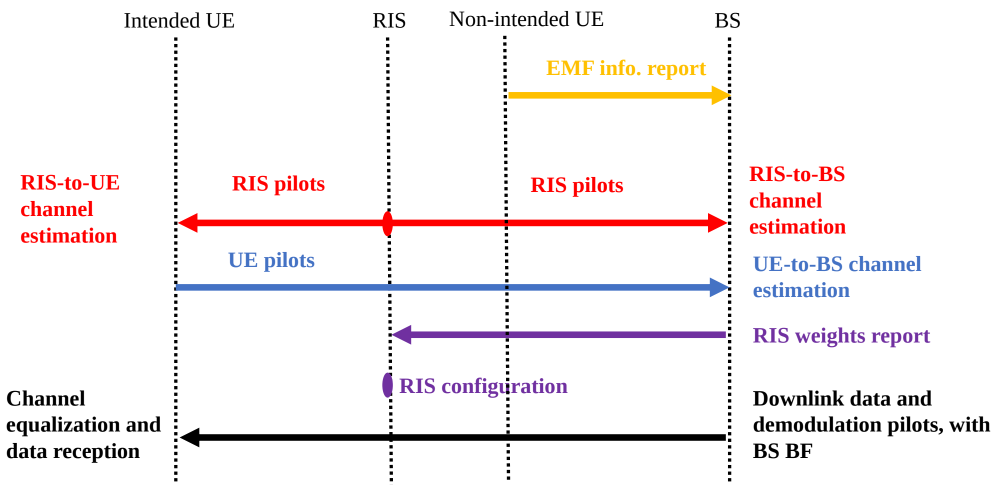


Figure 3-16 Data and control flows.

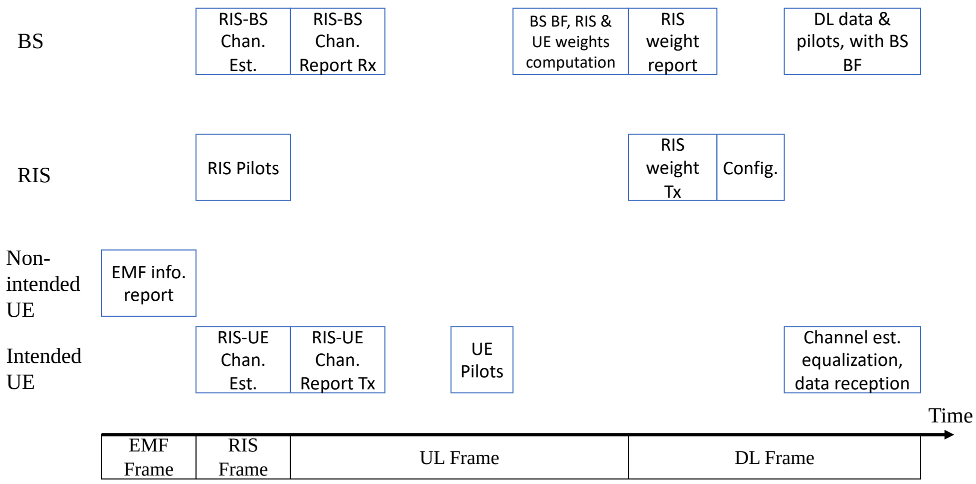


Figure 3-17 Time diagram.

Energy Efficiency

The proposed RIS-assisted beamforming scheme targets on better energy efficiency when serving the intended user, while satisfying the EMF requirements for the non-intended user.

4 Architecture and control signalling recommendations

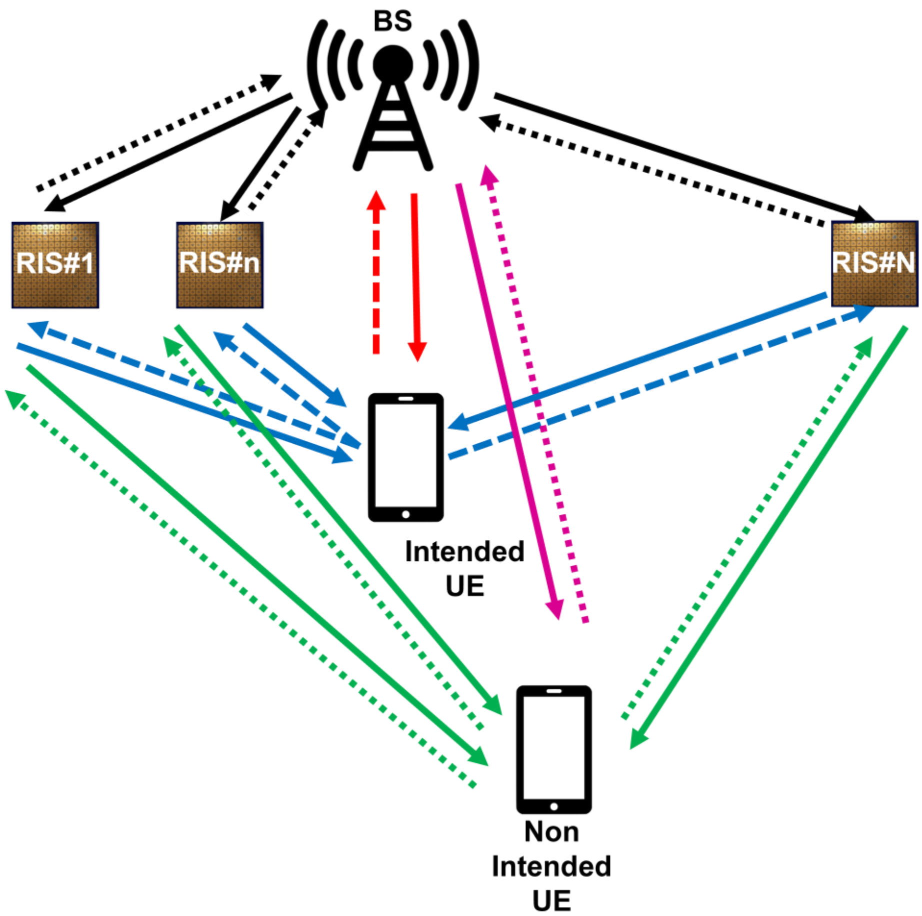
In this section, we provide some recommendations regarding architecture and control signalling based on the analysis in Sections 2 and 3.

The table below lists the considered schemes with their objectives and deployment scenarios.

Table 1 Considered schemes with corresponding objectives and deployment scenarios.

#	Name	sub-section	Objective (metric to be improved)	Deployment Scenario
1	Spatial Focusing	2.2.1	Secrecy Rate	DL MISO BF, indoor/outdoor sub-6 GHz.
2	SSE with Full CSI knowledge	2.2.2	Secrecy Spectral Efficiency	DL MIMO BF and AN, indoor/outdoor sub-6 GHz.
3	RIS-aided EMF-Aware BF	3.2.1	$EMFEU_{inter}$	DL M-MIMO BF outdoor-to-outdoor et outdoor-to-indoor, sub-6 GHz.
4	Energy Efficiency Optimisation of Reconfigurable Intelligent Surfaces with Electromagnetic Field Exposure Constraints	3.2.2	$EMFEU_{self}$	UL MIMO BF indoor-to-outdoor et outdoor-to-indoor, sub-6 GHz.
5	Low sum EMFE of multiple radio access networks in strong visibility, without coordination	3.2.3	$EMFEU_{inter}$	DL M-MIMO BF indoor-to-indoor mm-waves, multiple uncoordinated operators.
6	Joint RIS and DL BS BF under EMF exposure constrain	3.2.4	$EMFEU_{inter}$	DL M-MIMO BF indoor-to-indoor mm-waves, multiple uncoordinated operators.

The figure below summarizes the architecture requirements for each scheme in terms of control signalling (note that the malicious RIS of scheme #1 is not illustrated).



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*
Intended UE		UE-to-BS		X	X	X*		
Intended UE		RIS-to-UE	X	X		X		
Intended UE		UE-to-RIS			X	X		X
Non-Intended UE		BS-to-UE	X	X			X*	X
Non-Intended UE		UE-to-BS		X			X	
Non-Intended UE		RIS-to-UE	X	X				
Non-Intended UE		UE-to-RIS		X				

Figure 4-1 Architecture Requirements for all SSE and EMFEU oriented schemes, in terms of control signalling and data (* means that data is transmitted over the air-interface in addition to control signalling).

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, the proposed schemes apply to low mobility or steady UEs.

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

Based on our analysis of the various proposed schemes, we recommend an architecture, where RIS(s) are slaves 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]. 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).

5 Conclusions

This document provides the intermediate results from WP6 network architectures & deployment strategies with RIS to boost the EE, EMFEU and SSE metrics defined in Deliverable D2.4, for the use cases listed in D2.3. The deliverable lists several architectural options, RIS control strategies, as well as related data flows and control signalling, all derived from various technical contributions and innovations proposed within WP6.

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

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

Based on our analysis of the various proposed schemes, we recommend an architecture, where RIS(s) are slaves 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. 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 existing properties of relay nodes, the RIS may potentially be less sophisticated (with less computing and signal processing capabilities).

References

[AAN+21]	I. Alamzadeh, G. C. Alexandropoulos, N. Shlezinger, and M. F. Imani, “A reconfigurable intelligent surface with integrated sensing capability,” *Nature Scientific Reports*, vol. 11, no. 20737, pp. 1–10, Oct. 2021.
[AKW+21]	G. C. Alexandropoulos, K. Katsanos, M. Wen, and D. B. da Costa, “Safeguarding MIMO communications with reconfigurable metasurfaces and artificial noise,” in *Proc. IEEE International Conference on Communications*, Montreal, Canada, 14–18 June 2021, pp. 1–6.
[APV21]	N. Awarkeh, D. -T. Phan-Huy and R. Visoz, “Electro-Magnetic field (EMF) aware beamforming assisted by reconfigurable intelligent surfaces,” 2021 IEEE 22nd International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), 2021, pp. 541-545.
[APV+22-1]	N. Awarkeh, D.-T. Phan-Huy, R. Visoz, M. di Renzo “A novel RIS-Aided EMF-Aware beamforming using directional spreading, Truncation and Boosting,” accepted to EuCNC 2022.
[APV+22-2]	N. Awarkeh, D.-T. Phan-Huy, M. di Renzo “A novel RIS-Aided EMF exposure aware Approach using an angularly equalized virtual propagation channel,” accepted to EuCNC 2022.
[ASA+21]	G. C. Alexandropoulos, N. Shlezinger, I. Alamzadeh, M. F. Imani, H. Zhang, and Y. C. Eldar, “Hybrid reconfigurable intelligent metasurfaces: Enabling simultaneous tunable reflections and sensing for 6G wireless communications,” available at: https://arxiv.org/abs/2104.04690, 2021.
[AV20]	G. C. Alexandropoulos and E. Vlachos, “A hardware architecture for reconfigurable intelligent surfaces with minimal active elements for explicit channel estimation,” in *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing*, Barcelona, Spain, 4-8 May 2020, pp. 9175-9179.
[D2.3]	RISE-6G Deliverable D2.3 “Reference system, scenarios and use cases analysis: final results”, Feb. 2022.
[D2.4]	RISE-6G Deliverable D2.4 “Metrics and KPIs for RISE wireless systems analysis: final results”, Feb. 2022.
[D4.1]	RISE-6G Deliverable D4.1 “Deployment and control strategies of RIS based connectivity (Intermediary Specifications)”, 30th April 2022.
[D5.1]	RISE-6G Deliverable D5.1 “Control for RIS-based localisation and sensing (Intermediary Specifications)”, 30th April 2022.
[ZR22]	A. Zappone and M. di Renzo “Energy efficiency optimization of reconfigurable intelligent surfaces with electromagnetic field exposure constraints”, submitted to SPL 2022, available at: https://arxiv.org/abs/2104.06283.
[INCIRP]	ICNIRP
[TFC+17]	B. Thors, A. Furuskär, D. Colombi, and C. Tornevik “Time-Averaged realistic maximum power levels for the assessment of radio frequency exposure for 5G radio base stations using massive MIMO,” *IEEE Access*, vol. 5, pp. 19711-19719, Sept. 2017.
[DTT16]	E. Degirmenci, B. Thors, and C. Tornevik, “Assessment of compliance with RF EMF exposure limits: Approximate methods for radio base station products utilizing array antennas with beam-forming capabilities,” IEEE Transactions on Electromagnetic Compatibility, vol. 58, no. 4, pp. 1110-1117, August 2016.
[XZY+19]	B. Xu, K. Zhao, Z. Ying, D. Sjöberg, W. He and S. He, “Analysis of impacts of expected RF EMF exposure restrictions on peak EIRP of 5G user equipment at 28 GHz and 39 GHz Bands,” IEEE Access, vol. 7, pp. 20996-21005, February 2019.

[PCE+18]	S. Persia, C. Carciofi, S. D'Elia and R. Suman, “EMF evaluations for future networks based on massive MIMO,” Int'l Symp. on Personal, Indoor and Mobile Radio Comm. (PIMRC), pp. 1197-1202, Sept. 2018.
[C+19]	D. Colombi et al., “Assessment of actual maximum RF EMF exposure from radio base stations with massive MIMO antennas,” PIERS-Spring, pp. 570-577, June 2019.
[CZA21]	L. Chiaraviglio, A. Elzanaty and M. -S. Alouini “Health risks associated with 5G exposure: A view from the communications engineering perspective,” in IEEE Open Journal of the Communications Society, vol. 2, pp. 2131-2179, 2021.
[GSMA]	“Arbitrary radio frequency exposure limits: Impact on 4G network deployment. Case Studies. Brussels, Italy, Lithuania, Paris and Poland” Available at: https://www.gsma.com/publicpolicy/wp-content/uploads/2014/03/Arbitrary-Radio-Frequencyexposure-limits_Impact-on-4G-networks-deployment_WEB.pdf
[TS123501]	TS 123 501 - V15.3.0 - 5G; System Architecture for the 5G System (3GPP TS 23.501 version 15.3.0 Release 15) (etsi.org)) Available at: https://www.etsi.org/deliver/etsi_ts/123500_123599/123501/15.03.00_60/ts_123501v150300p.pdf