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Reference system, scenarios and use cases analysis: first results

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Abstract

In this deliverable we analyse and discuss relevant RIS-based reference scenarios shedding the light on technical challenges and potential achievable performances. In addition, we detail use cases that will be explored within the project timeframe and expected field-trials demonstrations.

Keywords

Beyond-5G; 6G; RIS; Scenarios; Use-cases; Localization; Connectivity

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List of Acronyms

5G-NR	5th Generation - New Radio
BS	Base Station
CAPEX	CAPital EXpenditure
DL	Downlink
DL-DoD	Downlink Direction of Departure
DL-TDoA	Downlink Time Difference of Arrival
DoA	Direction of Arrival
DoD	Direction of Departure
EM	Electromagnetic
GDoP	Geometric Dilution of Precision
KPI	Key-Performance Indicator
LB-AoI	Localization Boosted - Area of Influence
LE-AoI	Localization Enabled - Area of Influence
LoS	Line-of-Sight
MIMO	Multiple Inputs Multiple Outputs
NVAA	Non-Value-Added Activities
OPEX	OPerating EXpenditure
RF	Radio Frequency
R-RIS	Reflective RIS
RT-RIS	Reflective-transmission RIS
RIS	Reconfigurable Intelligent Surface
RSSI	Received Signal Strength Indicator
RTT	Round Trip Time
RT-ToF	Round Trip – Time of Flight
Rx	Receiver
SISO	Single Input Single Output
SLAM	Simultaneous Localization and Mapping
TDoA	Time Difference of Arrival
ToA	Time of Arrival
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
UE	User
UTDoA	Uplink Time Difference of Arrival
UL	Uplink
UL-DoA	Uplink Direction of Arrival
UL-TDoA	Uplink Time Difference of Arrival

1 Introduction

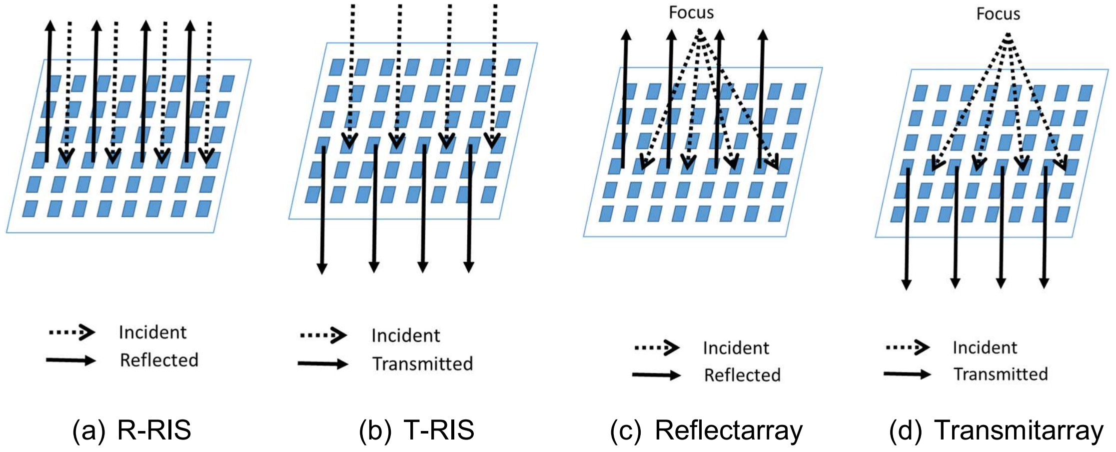
RIS technology represents a turning-point in the next-generation wireless network design. Given the multitude of envisioned business opportunities and corresponding scenarios and use-cases, we have generally carried out a preliminary analysis to highlight the motivation behind such novel framework while shedding the light on technological requirements and feasibility study. A detailed characterization of relevant RIS-based scenarios helps to deeply understand the potential of such a novel research field with corresponding advantages and limitations. In addition, a set of use-cases is identified and some of those are mentioned in the field-trial demonstrations, which will be realized within the project timeframe.

1.1 Deliverable objectives, structure

The general objective of this deliverable is to investigate high relevance Beyond-5G (B5G) scenarios and use cases where RIS technology can be successfully exploited while making the difference delivering advanced services.
Scenario are divided into the following categories.
Enhanced connectivity and reliability scenarios. Wireless network QoE/QoS might below expectation, therefore RIS technology can enable coverage extension in both outdoor (dense and dynamic NLOS urban environments) and indoor (lack of coverage mainly due to large metallic objects and/or people) environments will be beneficial, implemented in the form of regulation-friendly solutions in line with EMFE limits;
Enhanced localisation and sensing scenarios. RIS technology is expected to enable advanced sensing and localisation techniques for environment mapping, motion detection, opportunistic channel sounding, and passive radar capabilities applied to industrial (e.g. smart factory), high user-density (e.g. train stations), indoor (e.g. augmented/mixed reality) environments.
Enhanced sustainability and security scenarios: RISE networks are expected to enable the reduction of the energy spent to radiate the mobile signal, so as to improve EE, EMFEE and SSE due to highly directive and location-dependent communications; a first, already identified use case is a “train station”. An orchestrated network of RIS devices can be optimally configured here to target the minimum energy necessary to provide advanced services at the QoE/QoS expected by users.
In general, for each category in this deliverable we identify the reference scenario, we describe situations and conditions that might require the fully exploitation of the RIS technology and we showcase an exemplary application of RIS technology in such a given scenario.

1.2 Definitions

Reconfigurable intelligent surfaces (RISs) are surfaces composed of a discrete set of antenna elements following the generalised Snell’s law, and can be seen as **reflective or transmissive electromagnetic surfaces** as a function of the selected operation mode. Specifically, **a reflective surface (R-RIS)** operates as an electromagnetic mirror, where an incident electromagnetic wave is reflected towards the desired direction, typically anomalous in the sense that this direction is non-specular, with specific radiation and polarisation characteristics. On the other hand, a **transmissive RIS (T-RIS)** operates as a lens or a frequency selective surface, where the incident field is manipulated (by filtering, polarisation, beam splitting, etc.) and/or phase shifted, and re-radiated so as to control the refraction of plane impinging waves. Although RISs have great potential to implement advanced electromagnetic wave manipulations, only simple functionalities, such as electronic beam-steering and multi-beam scattering, have been demonstrated in the literature. Recently, some investigators have touched upon the possibility of deflecting the beam to achieve **simultaneous reflective-transmission RIS (RT-RIS)** [WDB18].



(a) R-RIS (b) T-RIS (c) Reflectarray (d) Transmitarray

Figure 1.1 – RIS taxonomy

Several different antenna technologies (e.g., [GTB16], [SN17]) can be considered as RIS hardware technologies, including **reflectarrays** [HPC14], **transmitarrays** (e.g., [DCD20], [DCS20], [RVC19]), as well as smart, programmable or software-defined metasurfaces (e.g., [BMM20], [YCY16], [TBM14], [ZZZ10], and [DGL20]).

When the elements have both size and spacing **lower than 1/10th** of the communication operation wavelength, RISs are also **defined as metasurfaces** [GTB16]. Metasurfaces are artificial materials able to manipulate electromagnetic waves, in a way that cannot be performed in homogeneous materials. Simple functionalities enabled by metasurfaces include anomalous reflections or transmissions. Achieving **perfect** anomalous reflection and refraction is possible if metasurfaces are bianisotropic with weak spatial dispersion [AAT16]. Spatially dispersive metasurfaces are realized as artificial sheets, which are typically composed of metallic patches or dielectric engravings in planar or multi-layer configurations within subwavelength thickness. The interaction with electric and/or magnetic fields, is typically provided by resonant effects controlled by the geometry of the unit cells and their distribution, enabling antenna performance enhancement (beamshaping), flat lens, artificial magnetic conductors, cloaking, absorbers and scattering reduction. In particular, the introduction of programmable metasurfaces could realize intelligent environments---giving birth to the novel concept of Environment as a Service (ENVaaS)---where such metamaterials act as smart reflectors to enhance coverage and open new technical and business opportunities for beyond-5G (and 6G) networks.

Compared to classical phased arrays, which require phase-shifters and power amplifiers, RISs are generally passive radiative architectures integrating switches, RF-MEMS, p-i-n diodes, varactors, and/or liquid crystals, to control electronically the local surface phase-shift and/or impedance characteristics. So according to the technology of the unit cell (UC) we can distinguish **between active RIS**, where the reflected signal is amplified by an active element in UC, and **passive RIS,** where the UC is realized with low loss reactive components that are used to implement a prescribed phase shift, either continuous or quantized, resulting in low-energy device.

Figure 1.2 – Typical RIS passive architecture: T-RIS/Transmitarray (a), R-RIS/Reflectarray (b)

Finally, as for relays we can also distinguish different operating modes: **Regenerative RIS** that decode, regenerate and retransmit a copy of the original signal; **Non-Regenerative RIS** that act as analog repeaters by retransmitting the signal they receive (in some cases amplified through beamfoming techniques or active elements). A receiving RIS (RX-RIS) enables measurement collection at its site, through a single or few Receive (RX) Radio-Frequency (RF) chains attached to all or a subset of the its unit elements [AV20]. A hybrid surface (H-RIS) combines two of the above-mentioned modes, being able to reflect the impinging signal and simultaneously sense/measure a part of it [ASA21], [ZSA21].

In this context, RISE-6G investigate RIS over a wide span: suggested prototypes are mainly with UCs separation of half-wavelength. However, different studies include metasurfaces, e.g., dipole-based metasurfaces that considered to address the theoretical performance evaluation of RIS assisted wireless systems when the RIS is based on metasurface structures, i.e., including mutual coupling between subwavelength UCs. Prototypes of T-RIS, R-RIS and simultaneous RT-RIS are addressed theoretically and experimentally. From the technology point of view mainly passive RIS based on p-i-n diodes, RF-MEMS and varactors are addressed below 40 GHz. Above these frequencies, active UCs are considered too.

1.3 How RIS is expected to overcome weaknesses and limitations

Limited capacity in conventional outdoor network scenarios, extremely-high CAPEX and OPEX for installing, configuring and maintaining new points-of-access while actuating network densification and poor localization performance in kitting operations foster looking for novel and advanced wireless technologies, such as RIS. The envisioned paradigm enables performance-boosted wireless connectivity as multiple RISs can be easily deployed outdoors, in indoor hot spots, and in public **highly frequented areas**, such as metro/train stations, airports, and shopping malls), in indoor residential scenarios to boost both indoor and outdoor-to-indoor wireless communications, as well as in vertical scenarios, such as Industry 4.0-related environments as well as V2X applications). In particular, such revolutionary context will adopt nearly passive and low-cost network infrastructures rather than deploying additional active points-of-access thereby resulting in avoidance and alleviation of several network installation and maintenance issues. Substantial gains are therefore expected in terms of

- minimization of cost and effort for installation and maintenance;
- delay minimization due to the avoidance of long site-negotiation process;

- reduced energy consumption for operating the dense network of cell-free as compared with conventional transceivers and relays;

State-of-the-art and planned contributions of RIS design and fabrication [HFL19] witness that RIS might be lightweight and aesthetically transparent devices, deployed very close to the customers and, in some cases, able to provide them ad-hoc means to proactively configure it to deliver tailored services. This unique feature will allow consideration of a plethora of existing power-plugs in urban areas as RIS-coated network nodes, such as glass-made building facades, billboards, publicity displays, walls with plugs near seated customers in coffee shops, offices or waiting rooms.

1.4 RIS-Enabled scenarios and use cases: preliminary analysis

To better understand the opportunities enabled by the novel RIS technology, hereafter we provide a detailed list of potential reference scenarios and future use-cases that might be employed to facilitate proper performance metrics.
In particular, we list in Table 1.1 and Table 1.2 currently selected scenarios and use cases respectively as a preliminary analysis of the research activity within the RISE-6G project, while providing in the following sections a detailed description of each referenced entry.

Reference scenario
Scenario 1 - Unambiguous localization under favourable problem geometry with a minimal number of active Base Stations (incl. single-BS)
Scenario 2 - Non Line-of-Sight mitigation for better service coverage and continuity in far-field conditions
Scenario 3 - Non Line-of-Sight mitigation for better service coverage and continuity in near-field conditions
Scenario 4 - On-demand multi-user and multi-accuracy service provision
Scenario 5 - Opportunistic detection/sensing of passive objects through multi-link radio activity monitoring
RIS-assisted search-and-rescue operations in emergency scenarios via UAVs
Scenario 7 - Localization without base stations using multiple RIS
Scenario 8 - Radar localization/detection of passive target(s)
Scenario 9 - RIS-aided radio environment mapping for fingerprinting localization
Scenario 10 - RIS lens
Scenario 11 - Radar localization/detection of passive target(s)
Scenario 12 – EMFE-enabled

Table 1.1 – RIS-based scenarios.

Use case
Factory plant use cases
UAV localization and navigation
AGV localization and navigation
Kitting process monitoring

Component position in container
Collaborative manufacturing (synchronous moving)
Container contents monitoring
Human-robot interaction and hazards
Monitoring of assembly steps by human operators
Monitoring of ergonomic load of production operators
Identification of hazards in internal logistics
Identification of logistic systems loading status
Remote Human-robot interaction and robot control
Railway station use cases
Coverage difficulties or network extension (B2C/B2B)
EMF protection for workers or specific public (B2C/B2B)
Dedicated download areas (B2C)
EMF protection for private areas (B2B)
Travelers flow modelisation (B2B)
People geolocation system (B2B/B2C)
Isolated agents' detection at night (B2B)

Table 1.2 – RIS-based use cases.

2 Enhanced connectivity and reliability

Conventional network scenarios impose communication performance to be achieved via uncontrolled wireless medium. However, this might result in resource inefficiency and huge complexity. Conversely, the envisioned smart radio environment built upon RISs will enable the granting of highly localized quality of experience and specific service types to the end users. Such pioneering network paradigm aims at going **one step** beyond the classical 5G use cases, which require that the network is tuned to one of the available service modes in an orthogonally isolated manner, offering non-focalized areas of harmonized and balanced performance: We can go one step beyond by proposing performance-boosted areas as dynamically designed regions that can be highly localized, offering customized high-resolution manipulation of radio wave propagation to meet selected KPIs.

2.1 Conventional scenarios (i.e., with non-RIS systems)

In this subsection, we analyze conventional sub-scenarios (as a non-RIS baseline). In Figure 2.1, we describe the conventional coverage problem. The BS, equipped with multiple antennas, communicates with a UE, either being a single- or multi-antenna one. When the UE moves in an area behind a wall, the signal from the BS is blocked or strongly attenuated. In this area, proper coverage cannot be ensured.

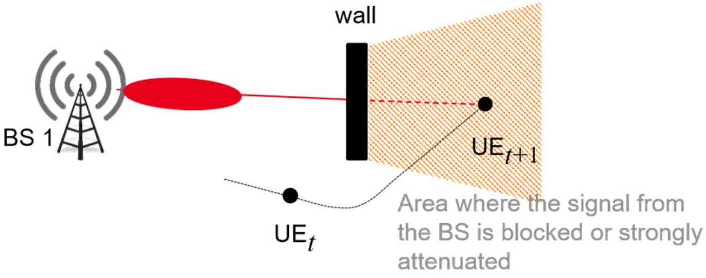
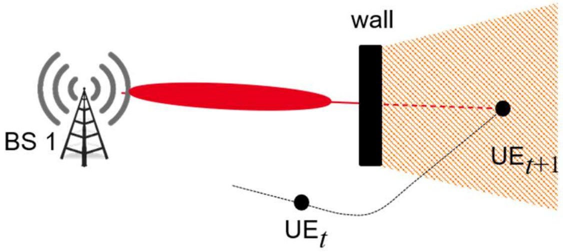
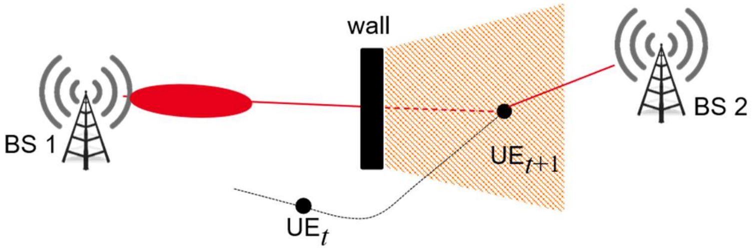


Figure 2.1 – Conventional systems for connectivity and reliability.

In Figure 2.2, we describe state-of-the-art solutions to the coverage problem. In Figure 2.2 (a), the BS is equipped with a much larger number of antennas compared to the case in Figure 2.1, so that the signal received by the UE in the blockage area gets amplified. In Figure 2.2 (b), the solution is based on network densification, where a new BS is added to cover the area, which previously had a weak coverage. The disadvantage of those solutions is that they might result in high costs, as the BS should be upgraded with new hardware or a new BS should be installed.



(a) The BS is upgraded with an increased number of antennas



(b) Network densification: add a BS in relevant location

Figure 2.2 – State-of-the-art solutions to the coverage problem.

2.2 Technical challenges in RIS-enabled reference scenarios

For the conventional system settings and strategies identified in Section 2.1, based on a qualitative analysis of both localization feasibility (incl. possibly high-level identifiability considerations) and expected performance, we determine *where* and *how* RISs could improve connectivity in conventional systems. In all cases described, we consider that the RIS is in reflecting operating mode, as defined in Section 1.2. The RIS can optionally also receive signals to, for instance, perform in-band channel estimation or localization.

For enhanced connectivity and reliability, the following problems will be considered:

- **Channel Estimation:**
  - ***With RIS(s) in reflective mode;*** measurements: received BS pilot signals at UE(s) (downlink) or received UE(s) pilot signals at BS (uplink).
  - ***With RIS(s) capable of receiving/sensing;*** measurements: received BS and UE(s) pilot signals at the RIS(s) (for RIS(s) with RX RF chains), the latter plus received BS pilot signals at the UE(s) (downlink), or the latter plus received UE(s) pilot signals at the BS(s) (uplink).

- **Design of RIS(s)' phase configuration(s):**
  - ***For low latency and accurate channel estimation.***
  - ***For connectivity and reliability optimization;*** measurements: CSI collection at a central controller or a MEC server (wired or wireless connections with the involved nodes).

We next present all considered scenarios, focusing on the downlink case as an example; the uplink case can be readily extended following the same approach.

2.2.1 Connectivity and reliability boosted by a single RIS

In this scenario, illustrated in Figure 2.3, there exist(s) direct link(s) between the multi-antenna BS and the single- or multi-antenna UE(s). Connectivity is further boosted via a single or multiple RISs. The phase profile(s) of the RIS(s) can be optimized for desired connectivity and reliability levels. We will consider 3D deployment of the network nodes, as well as line-of-sight and multipath channels.

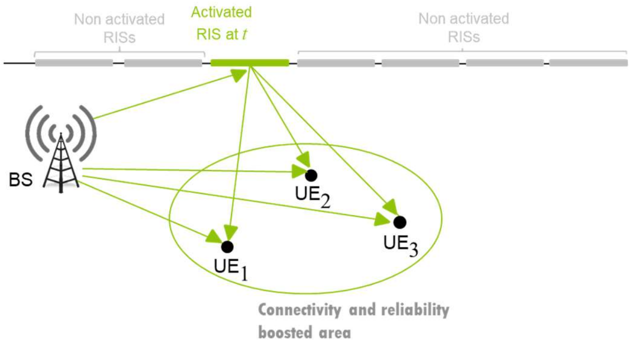


Figure 2.3 – RIS-aided downlink or uplink wireless communication systems, where connectivity and reliability are enabled by RISs.

2.2.2 Connectivity and reliability *boosted* by individually controlled multiple RISs

In this scenario, illustrated in Figure 2.4, multiple BSs aim to boost connectivity and reliability with their respective UEs. The deployed RISs are assigned to pairs of BS-UE, and each pair is capable to control and optimize the phase profile of its individual RIS(s). We therefore consider 3D deployment of the network nodes, as well as line-of-sight and multipath channels.

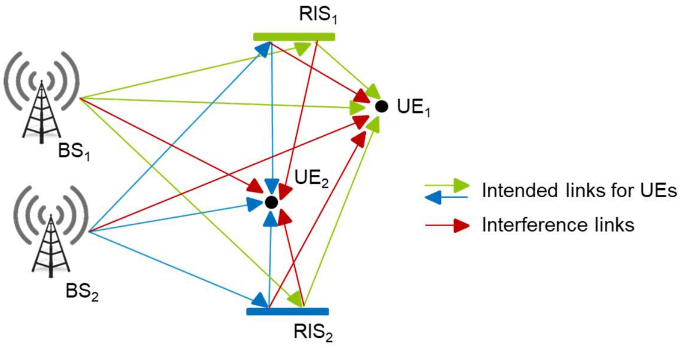


Figure 2.4 – RIS-aided downlink wireless communication systems of multiple transmit-receive pairs, where the RISs can be controlled individually by each pair.

2.2.3 Connection reliability *enabled* by multiple RISs

In this scenario, illustrated in Figure 2.5 – R, the direct link(s) between the multi-antenna BS and the single- or multi-antenna UE(s) is(are) blocked, and connectivity is enabled via a single or multiple RISs. The phase profile(s) of the RIS(s) can be optimized for desired connectivity and reliability levels. Similar to scenario 1, we will consider 3D deployment of the network nodes, as well as line-of-sight and multipath channels.

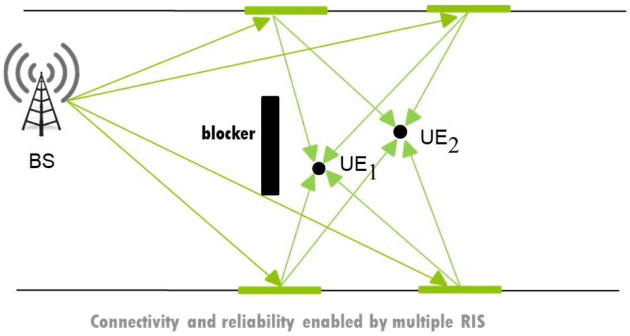


Figure 2.5 – RIS-aided systems where connectivity is enabled by multiple RISs.

2.2.4 Connectivity and reliability *boosted* by a single multi-tenant RIS

For this scenario, we consider pairs of BS-UE(s) and a single RIS. The RIS is now considered as a shared resource, dynamically controlled by the infrastructure commonly accessed by the BS-UE(s) pairs. The phase profile of the RIS can be commonly optimized by the BSs to serve their UE(s) simultaneously, as shown in Figure 2.6. Alternatively, the control of the RIS may be time-shared among the BS-UE(s) pairs. Note that, the control channel envisioned by this scenario will be thoroughly investigated in future activities, out of the scope of this deliverable at the moment.

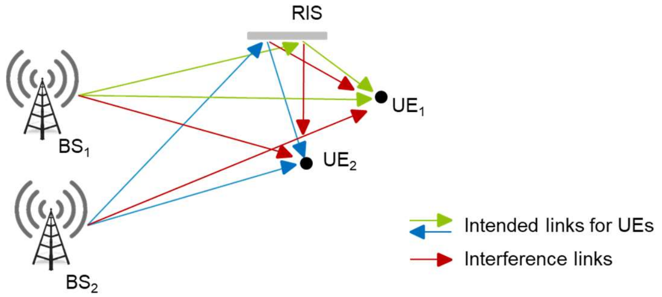


Figure 2.6 – A multi-tenancy scenario with pairs or BS-UE(s) and a shared RIS that is optimized to simultaneously boost communication of different BS-UE pairs.

A special case of this scenario is the one which considers a setup where the communication is enabled by multiple cellular BSs, each one serving a distinct set of UEs. When the UE(s) move across the cell boundaries of two or more BSs, they might change their serving BS(s) frequently (i.e., yielding frequent handovers). Shared RISs between the two or more BSs can be placed in the cell boundaries in order to dynamically extend the coverage of the serving BSs (i.e., reducing the number of handovers).

2.2.5 Mobile edge computing as key-enabler in RIS-empowered scenarios

With the advent of beyond 5G networks, mobile communication systems are evolving from a pure communication framework to enablers of a plethora of new services (verticals), such as Industry 4.0, Internet of Things (IoT) and autonomous driving. These new services present very diverse requirements, and they generally involve massive data processing within low end-to-end delays. In this context, a key-enabler is Mobile Edge Computing (or Multi-Access Edge Computing, namely MEC), whose aim is to move cloud functionalities (e.g., computing and storage resources) at the edge of the wireless network to avoid the relatively long and highly variable delays necessary to reach centralized clouds. MEC-enabled networks allow User Equipments (UEs) to offload computational tasks to nearby processing units or Edge Servers (ESs), typically placed close to Access Points (APs), to run the computation on the UEs' behalf. However, moving toward millimeter wave (mmWave) communications (and beyond), poor channel conditions due to mobility, dynamicity of the environment and blocking events, might severely hinder the performance of MEC systems. In this context, a strong performance boost can be achieved with the advent of RISs, which enable programmability and adaptivity of the wireless propagation environment, dynamically creating service boosted areas where energy efficiency, latency, and reliability can be traded to meet momentary and location-dependent requirements of MEC systems.

An exemplary scenario of such kind is depicted in Figure 2.7 where 2 edge devices (that can be considered as generic UEs), a BS equipped with an edge server (ES), and 2 available RISs are considered. The edge devices aim to run sophisticated applications by offloading computations to the edge server, exploiting the wireless communication link with the BS. Under the assumption that the direct link between the users and the BS can be possibly impaired by the presence of obstacles, which attenuate or eventually block the communication, as qualitatively shown in Figure 2.7, the presence of the RISs helps in counteracting this detrimental effect by allowing alternative communication paths between the UEs and the BS in both uplink and downlink directions. Time is divided in slots indexed by t. Then, at each time slot, new offloading requests are generated by the UEs, and are handled through a dynamic queueing system that accounts for both communication (both uplink and downlink) and processing delays. In this scenario, the goal is to jointly optimize communication (e.g., powers, rates, and RIS phase shifts) and computation resources (e.g., CPU frequencies) to enable energy-efficient edge computing with low-latency and high-accuracy requirements.

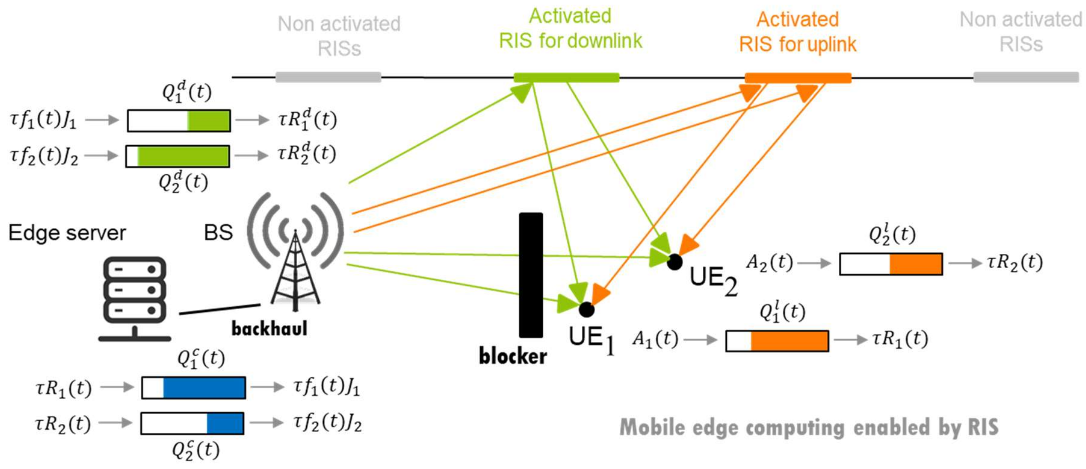
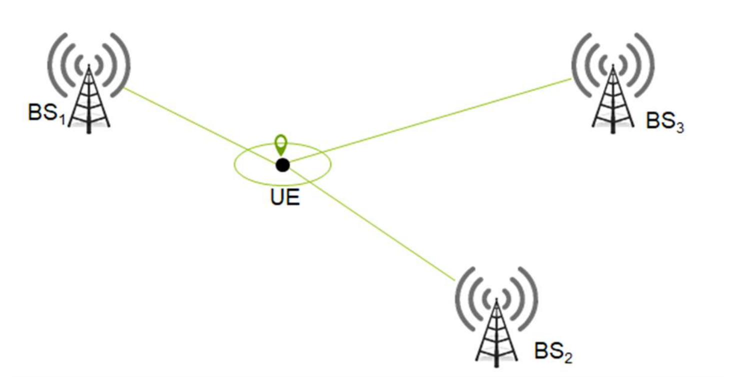


Figure 2.7 – RIS-empowered mobile edge computing systems.

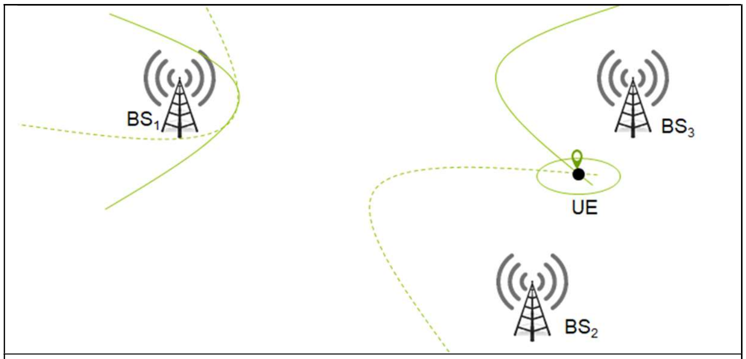
3 Enhanced localization and sensing scenarios

3.1 Conventional scenarios (i.e., with non-RIS systems)

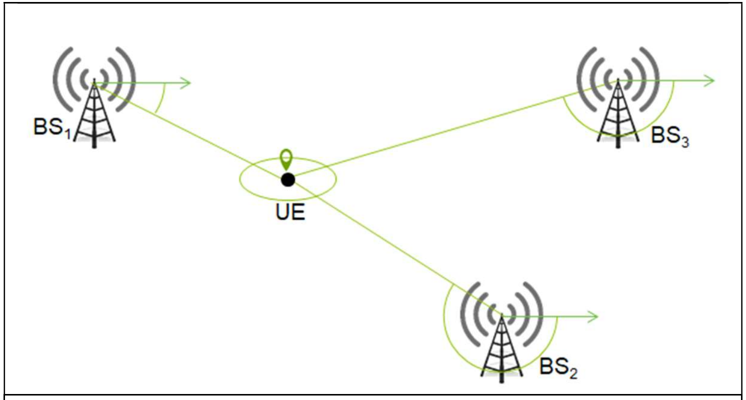
Conventional localization systems are visually summarized in Figure 3.1 and they can be differentiated depending on the applied positioning approaches listed in Table 3.1 where their prerequisites (in terms of the used radio metrics, synchronization requirements, UL/DL transactions, minimum number of deployed BSs, …) and their representation in existing/pending standard releases or mobile communication system generations (4G, 5G...) are presented [PRL+17, KSH+19].



Conventional localization systems for settings 1-2 of Table 3.1 *(i.e., trilateration / circular positioning)*



Conventional localization systems for settings 3-4 of Table 3.1 *(i.e., trilateration / circular positioning)*



Conventional localization systems for settings 5-6 of Table 3.1 *(triangulation positioning)*

Figure 3.1 – Conventional localization systems.

Setting	Measurement	Uplink or Downlink	Synchronization requirements	Maturity
1	RSSI, Cell-ID, fingerprinting	UL and/or UL indifferently	None (all except but minimum synchronization level required to establish the communication)	2G (fingerprinting in 4G)
2	RT-ToF based on delay/ToA for peer-to-peer ranging (also called multi-RTT for positioning)	Both UL & DL	Both BS and UE (a priori asynchronous at the beginning of the localization procedure) need to apply multi-way peer-to-peer ranging transactions to solve timing offset (and possibly compensate relative clock drifts)	5G NR

3	TDOA based on delays/ToAs at Rx BSs (also called UTDoA or UL-TDoA)	UL only	Synchronous BSs (in Rx)	3G
4	OTDOA based on delays/ToAs at Rx UE (also called DL-TDoA)	DL only	Synchronous BSs (in Tx)	3G
5	DoA at Rx BS (also called UL-DoA)	UL only	None (all except but minimum synchronization level required to establish the communication)	5G NR
6	DoD from Tx BS + RSSI at Rx UE (& fingerprinting with an a priori database of learnt RSSI signatures under different TX beams) (also called DL-DoD)	DL (+ UL retransmission of DL RSSI)	None (all except but minimum synchronization level required to establish the communication)	5G NR

Table 3.1 – Conventional localization approaches.

In all cases listed in Table 3.1 measurements are used to solve a non-linear optimization problem. The quality of the positioning depends on the quality of the measurements, as well as on the relative locations of the base stations.

3.2 RIS-Enabled scenarios

For the conventional localization system settings and strategies identified in section 3.1, based on a qualitative analysis of both localization feasibility (incl. possibly high-level identifiability considerations) and expected performance, we determine *where* and *how* RISs could assist or boost conventional localization solutions. These benefits can take various forms, depending on the RIS operating mode (i.e., reflect., refract., transmit., relay, … - see section 1.2). They can be also classified in terms of:

- **Enabled localization**: making localization feasible again, whenever the conventional system fails, thus providing improved service continuity, coverage, resilience.
- **Boosted localization**: improving timely and/or locally the localization performance (in terms of accuracy, latency, etc.), while relying on the same amount of radio resources (i.e., number of active devices, spectrum, etc.) as in conventional systems. This leads to improved performance limits and tunable performance.
- **Low-profile localization**: achieving a priori localization performance targets, while requiring much lower resource in comparison with the conventional system (performance is also related to sustainability, power consumption, deployment costs).

Note that a particular RIS usage (e.g., a given couple {RIS operating mode, RIS physical deployment}) may enable to cover several of the previous benefits at a time.

In the following sub-sections 12 generic scenarios where RIS provide performance benefits for localization are defined only as examples (refer to the technical literature for a more comprehensive overview [KKS20,AKK20,KKD21]) and can be related to the above-given classification as follows:

Scenario	1	2	3	4	5	6	7	8	9	10	11
RIS-enabled loc.	X	X	X		X	X	X	X		X	X
RIS-boosted loc.				X	X			X	X		X
RIS-aided low-profile loc.				X			X			X	

Table 3.2 – RIS-Enabled scenarios.

3.2.1 RIS in reflection mode

Scenario 1 - Unambiguous localization under favourable problem geometry with a minimal number of active Base Stations (incl. single-BS)

In this scenario, the conventional infrastructure is insufficient to provide a location estimate (typically within all the conventional settings 1 to 5 above). The RIS enables localization [KKS20]. Beyond localization feasibility considerations, even if just one single RIS reflection is needed in addition to the direct path in this scenario, the selection of the most relevant RIS to be controlled (typically in terms of phase profiles) in a multi-RIS deployment setting can also contribute to improve performance (typically through the control of Geometric Dilution of Precision (GDoP)).

- **Settings:** single-antenna BS, single-antenna UE, planar RIS
- **Signal measurements:** ToA as measured by the BS, ToA as measured by RIS, DoD as measured by RIS
- **Unknowns to be solved for:** 3D UE location, 1D UE clock bias
- **Knowns:** BS location, RIS location and orientation, transmitted signal, sequence of RIS phase configurations
- **RIS requirements:** known location and orientation, variable RIS phase configurations, zero-sum RIS phase configurations. RIS synchronized to BS.

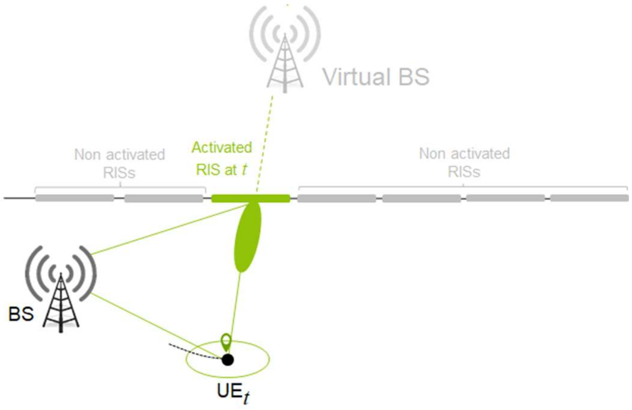


Figure 3.2. Scenario 1 example

Scenario 2 - Non Line-of-Sight mitigation for better service coverage and continuity in far-field conditions

Just like in the previous scenario, conventional non-RIS systems would be insufficient to provide a location estimate (within approaches 1 to 5 in the table above) whenever the minimum number of BSs (anchors) in visibility (i.e., a number required to ensure unambiguous localization) is not fulfilled, while the 2D user location can be estimated via narrow-band signals received from two RISs in the absence of Direct Path (even with one single BS in non-visibility, as shown in the

Figure below), given that the two resulting reflected paths are properly resolved on the Rx side. The user and the BS are assumed to be in the far-field of the RISs.

- **Settings:** a single-antenna BS, a single-antenna UE, two planar RIS
- **Signal measurements:** DoD from both RISs
- **Unknowns to be solved for:** 3D UE location
- **Knowns:** BS location, RIS location and orientation, transmitted signal, sequence of RISs phase configurations
- **RIS requirements:** known location and orientation, variable RIS phase configurations, orthogonal RIS phase configurations. RIS synchronized to BS.

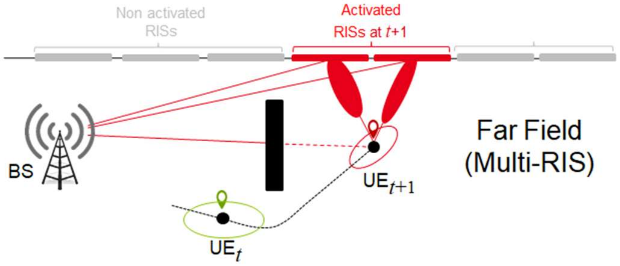


Figure 3.3 Scenario 2 example

Scenario 3 - Non Line-of-Sight mitigation for better service coverage and continuity in near-field conditions

In this scenario again, the user location can be estimated via the signal received from one RIS in the absence of Direct Path (even with one single BS in non-visibility, as shown in the Figure below), but the user is now assumed to be in the near-field of the RIS. Typically, this allows to exploit signal wavefront curvature for direct positioning [AKK20,RDK21], unlike in far field where one would for instance need to estimate separately the direction of departure from the RIS and the time of arrival of the RIS-reflected path to estimate the UE position.

- **Settings:** a single-antenna BS, a single-antenna UE, planar RIS
- **Signal measurements:** user position is solved from the received signal directly
- **Unknowns to be solved for:** 3D UE location
- **Knowns:** BS location, RIS location and orientation, transmitted signal, sequence of RISs phase configurations
- **RIS requirements:** known location and orientation, variable RIS phase configurations, RIS synchronized to BS.

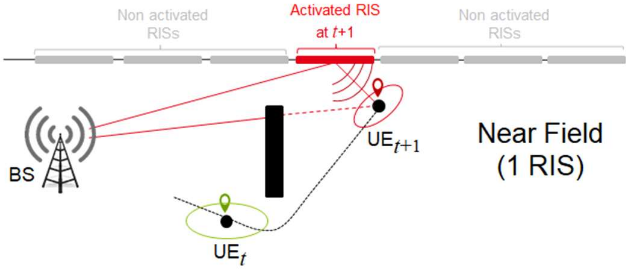


Figure 3.4 Scenario 3 example

Scenario 4 - On-demand multi-user and multi-accuracy service provision

In a multi-user context, a conventional multi-BS localization infrastructure would require allocating a larger amount of radio resource (e.g., in terms of time, frequency, power…) or even a larger number of BS (i.e., > 3 in 2D) to meet the a priori localization requirements of most-demanding UEs, with no possibility to finely control the dilution of precision, and hence, to guarantee an arbitrary (e.g., constant) level of accuracy over the scene, the latter being totally bounded by the "static" deployment of those active BSs.

On the contrary, the deployment (and the selective control) of multiple RISs makes possible (i) the (on-demand) provision of various classes of localization services to different users sharing the same physical environment, depending on the needs they express locally/temporarily, while (ii) spatially controlling both the localization accuracy and the geometric dilution of precision in the different dimensions (i.e., both the sizes and orientations of the location uncertainty ellipses in the figure shown below) [WD20]. This allows meeting more easily a priori fairness criteria, while limiting to the strict minimum the amount of required resource for active transmissions (again, in terms of time, frequency/bandwidth, power). For this purpose, in combination with the conventional resource allocation strategies cited above, RISs provide one more degree of freedom, by offering the possibility to dedicate to specific users a subset of the deployed RISs, or even sub-areas of these RIS…

This would be particularly relevant in challenging application environments such as smart factories, where various levels of authorization and/or safety must be guaranteed depending on the specific zone occupied by operators, robots or mobile assets, under fast changing and heavily obstructed radio conditions (See e.g., typical factory use cases).

- **Settings:** single-antenna BSs, single-antenna UE, multiple planar RISs
- **Signal measurements:**
  - DL only: ToA of DP, ToA of RIS-reflected path and DoD from RIS (at each UE).
  - DL & UL: ToA of DP and ToA of RIS-reflected path (at each UE); ToA of DP, ToA of RIS-reflected path (at each BS).
- **Unknowns to be solved for:**
  - DL only: 3D UE location, 1D UE clock bias
  - DL & UL: 3D UE location
  - **Knowns:** BS location, RISs locations and orientations, transmitted signals, sequences of RISs phase configurations
  - **RIS requirements:** known location and orientation, variable phase configurations, synchronization to BSs.

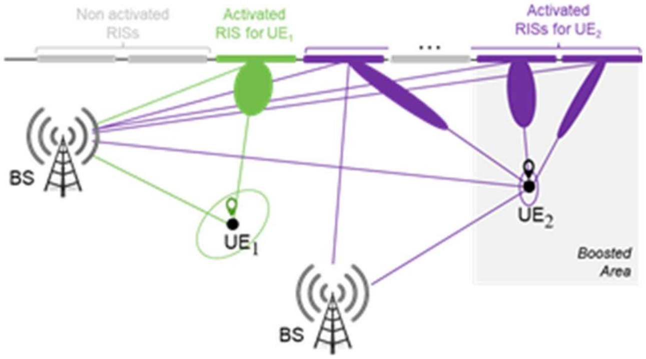


Figure 3.5 Scenario 4 example

Scenario 5 - Opportunistic detection/sensing of passive objects through multi-link radio activity monitoring

In this multi-RIS scenario, the idea is to enable the opportunistic detection of both static and mobile passive objects, by monitoring the time evolution of multipath profiles over a communication link between the BS and one or several UE(s) (DL and/or UL).

Given that adequate channel estimation and data association algorithms are developed, extending the concept of passive (multi-static) radar, the observed space-time correlations, the sudden appearance/disappearance and/or the power fluctuation/stability of resolved RIS-reflected multipath components over both time and RIS operations can typically be exploited to indicate the presence, the position/attitude and even possibly the mobility pattern, of such passive objects in the environment.

In comparison with more classical non-RIS passive radar approaches, which aim at sensing and classifying physical activity based on standard range-Doppler analysis (e.g, [LPW+19]), the dynamic and selective control of RISs (i.e., changing over time both the RISs to be controlled and their phase profiles, as illustrated in the Figure below) is expected to improve multipath diversity and provide richer location-dependent “geometric” information (while operating at higher frequency, e.g. at mmWave frequencies) to improve the performance in terms of detection, activity classification and/or even location estimation.

In terms of the unknowns to be solved, several options are hence possible, depending on whether the UE location is a priori known (e.g., resulting from a preliminary localization phase) or not. In case the locations of both the UE(s) and passive objects must be jointly determined from scratch, one can hence leverage and extend to the RIS context existing Simultaneous Localization and Mapping (SLAM) approaches (e.g., mmWave SLAM in [KDU20, MWB18]). In this case, extensions to multi-user cooperative radio monitoring (i.e., in both cooperative and non-cooperative modes) are also envisaged.

However, in highly reverberant environments that can create ultra-dense multipath echoes, in irregular propagation environments with complex scattering effects and/or whenever the transmitted signals can occupy only relatively narrow bandwidths (say, in comparison with e.g., that in the mmWave domain, where up to several GHz are typically available), multipath resolution is usually very challenging. Accordingly, the parametric localization approaches devised above, which estimate location variables based on a priori “geometric” signal models (i.e., models aiming at establishing a deterministic link between Rx radio signals and location information), become less efficient and even hardly practical. In such operating conditions, alternative fingerprinting techniques may be applied instead for localizing passive objects. Multiple RISs can then be used to leverage so-called configurational diversity through wavefront shaping, even with single-antenna single-frequency measurements (e.g., [HIF18,H20]).

- **Settings:** single-antenna or multi-antenna BSs, single-antenna or multi-antenna UE, multiple planar RISs
- **Signal measurements:**
    - DL or UL indifferently: Time series of multipath channel estimates, i.e., ToAs, gains and possibly AoAs (optional, in case of multi-antenna BS) of all resolved

  - multipath components (including DP -if only present-, RIS-reflected paths and scattering paths created by objects);
- **Unknowns to be solved for:**
  - Option 1: Presence, attitude, mobility and/or 3D locations of passive objects only (given the location(s) of UE(s))
  - Option 2: 3D locations of both UE and passive objects (~SLAM)
- **Knowns:** BS location, RISs locations and orientations, transmitted signals, sequences of RISs phase configurations, UE(s') location(s) (Optional)
- **RIS requirements:** known location and orientation, variable phase configurations, synchronization to BSs.

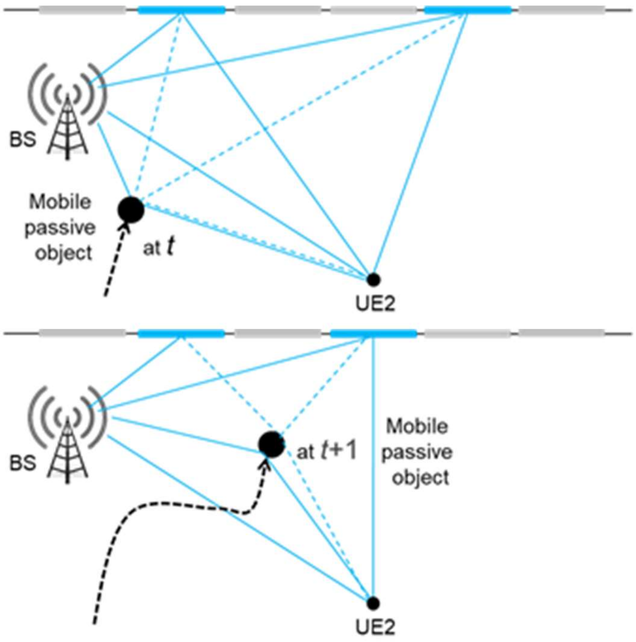


Figure 3.6 Scenario 5 example (at different time instants)

Scenario 6 - RIS-assisted search-and-rescue operations in emergency scenarios via UAVs

The usage of UAVs in emergency situations may help but it still needs to cope with specific technical challenges when it comes to victims' localization. While UAVs may directly implement classical cellular-based localization techniques, such techniques are developed for static anchor points, such as base stations, thereby missing new opportunities introduced by their motion capabilities [ASP21]. RISs may support and overcome the shadowing effect induced by rubble in such scenarios by building ad-hoc controllable propagation conditions for the cellular signals employed in the measurement process.

Specifically, by means of RIS we can circumvent LoS blockage but more sophisticated approaches are possible. Due to the wavefront curvature in the near-field of a large RIS, it is possible to accurately determine unknown clock biases by combining Phase-of-Arrival (PoA) and Time-of-Arrival (ToA) information. In harsh environments such as indoor industry 4.0 scenarios, RISs can maintain consistent multipath thereby allowing dynamically accounting for object movements.

In addition, lightweight and low-complex RISs may be exploited to cope with the impelling energy-consumption issue of UAVs to be used to bring connectivity capabilities to hard-to-reach locations, as shown in Figure 3.7. RIS can be automatically controlled to focus the incoming signal towards specific locations while assisting victim localization process by means of RISs installed on the wall/window glass. This would significantly help first responder teams in emergency situations, when for e.g. the smog may impair the normal visibility inside the building [MDSP21].

- **Settings:** UAV provided with a single RIS; single ground BS (or van equipped with a portable BS).
- **Signal measurements:**

  Incoming signal (from the UAV) at each ground user (UE).
- **Unknowns to be solved for:**
  - Location of the UAV, perturbation of the position;
  - Location of the ground UE (i.e., victims).
- **Knowns:** Ground BS location, very large area wherein UEs (i.e., victims) are located.
- **RIS requirements:** Variable phase configurations, wireless control channel, limited power consumption (on in reflection mode).

Figure 3.7 UAV-equipped RIS assisting search-and-rescue operations in emergency scenarios

3.2.2 RIS in Receive Mode

In this subsection, scenarios including RISs, each equipped with a single or few Receive (Rx) Radio Frequency (RF) chains (that are much fewer than the total number of each RIS's unit elements), will be presented. A typical receive RF chain attached to all (the single-Rx-RF RIS case) or a subset (the multi-Rx-RF RIS case) of an RIS's elements consists of a low-noise amplifier, a mixer for signal down-conversion to baseband, and an analog-to-digital converter. The Rx RF chains at an RIS enable measurements' collection at its site, which can be used for channel estimation, localization, and sensing of passive objects (radio mapping).

Scenario 7 - Localization without base stations using multiple RIS

In this scenario, illustrated in Figure 3.8, AoA estimations obtained at multiple RISs, having the architecture of [AV20], are combined to produce the estimation of the UE(s) location(s).

- **Settings:** 3D deployment, single- or multi-antenna UE(s), multiple RISs.
- **Measurements:** Received signal at each RIS via its phase profile configuration (analog combining reception).
- **Unknowns to be solved for:** 3D locations of the UE(s).
- **Knowns:** RISs' locations and orientations, pilot signals.
- **RIS and system requirements:** Variable RIS phase configurations, computing capability for AoA estimation at each RIS, collection of all AoA estimations at a central controller (wired or wireless) that combines them for location(s) estimation.

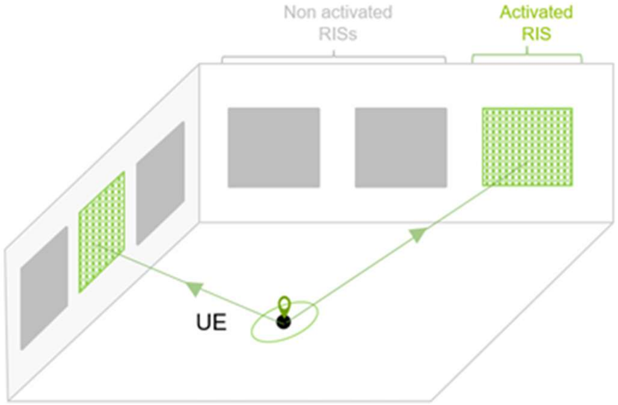


Figure 3.8 Scenario 7 example

Scenario 8 - Radar localization/detection of passive target(s)

In this scenario, illustrated in Figure 3.9, a radar is assisted by multiple RISs, having the architecture of [AV20], to localize/detect static or moving target(s). In the recent relevant literature, authors have explored applying RISs in Radar systems in order to perform user localization [ZHZ20], enable localization for users in NLOS areas [AMR21] and enhance the target detection problem performance [LDF21], [LLF21], [JRZ21], [BGL21]. The novelty of Scenario 8 is found in the receiving RISs being deployed (in comparison with the passive RISs in the literature only being able to reflect), giving the system the capability to localize users as well as the radar itself.

- **Settings:** 3D deployment, full-duplex MIMO transceiver (radar), passive target(s), line-of-sight or multipath channels, multiple RISs.
- **Measurements:** Received signal at each RIS via its phase profile configuration (analog combining reception), received signal at the multi-antenna Rx of the radar, narrowband or wideband.
- **Unknowns to be solved for:** Detection or 3D location(s) of static or moving target(s), 3D location of the radar.
- **Knowns:** RISs' locations and orientations, pilot signals.
- **RIS and system requirements:** Variable RIS phase configurations, computing capability for features' estimation/detection at each RIS, collection of the latter at the radar (wired or wireless) that combines them for the location(s) estimation of static or moving target(s).

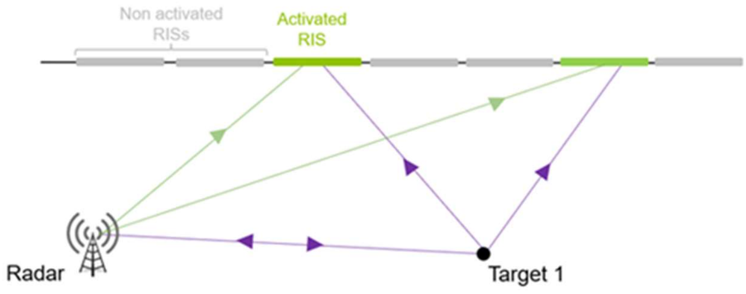


Figure 3.9 Scenario 8 example

Scenario 9 - RIS-aided radio environment mapping for fingerprinting localization

In this scenario, a set of active/hybrid RISs enables the cartography of the EM power spatial density in a specific area of interest.

From a localization standpoint, the ability to build reliable and “complete” RF maps is of paramount importance to fingerprinting-based positioning approaches, where one first needs to “learn” in-site radio signatures in known UE locations (offline). The latter are collected to form a prior database, which is subsequently used for comparison with current radio measurements to determine the unknown UE location (online). In practical cases however, only sparse and spatially non-uniform measurements are usually collected on the field to build and calibrate those prior RF map.

In comparison with classical non-RIS approaches (typically, conventional fingerprinting setting 1 above, assuming RSSI measurements with respect to several BSs), the use of Rx RISs at a few strategic locations for offline RF cartography could contribute to accentuate the location-dependent features of the radio signatures stored in the database. Ultimately, the learnt RF maps are also expected to be more suitable to fingerprinting needs to boost localization performances. This could be done for instance by introducing more diversity in the collected radio fingerprints, over dedicated time-varying sequences of Rx RIS phase profiles. Dually, the use of RISs should also enable to reduce the minimum amount of field measurements required for RF map calibration (in terms of both time and space). This kind of RIS usage, along with their actual benefits, are however still quite exploratory and would necessitate deeper investigations.

- **Settings:** multiple BSs, multiple active RISs
- **Signal measurements:** EM field intensity at RIS locations
- **Unknowns to be solved for:** EM field intensity over a set of discrete positions where we do not have direct access to RISs measurements
- **Knowns:** BS location, RIS location and orientation, sequence of RIS phase configurations
- **RIS requirements:** RIS must be endowed with RF receiver chains on some elements to measure the local EM field intensity

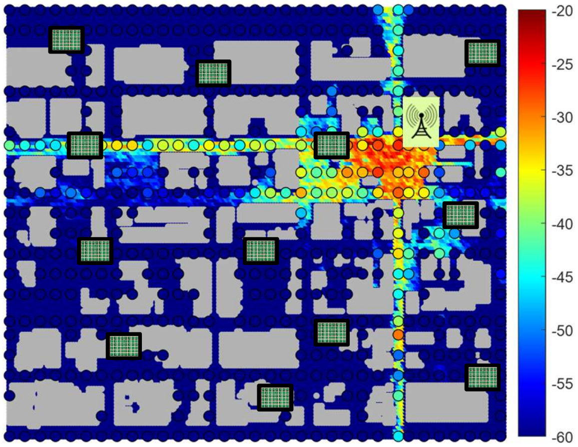


Figure 3.10 Scenario 9 example.

3.2.3 RIS in Transmit Mode

Scenario 10 - RIS lens

In this scenario, the RIS is placed in front of a single-antenna transmitter. The user position is estimated at the user side via the narrow-band received signal.

- **Settings:** 3D deployment, single-antenna user(s), single-antenna transmitter and planar RIS at the transmitter.
- **Measurements:** Received narrow-band signal at UE.
- **Unknowns to be solved for:** 3D locations of the UE(s).
- **Knowns:** RISs' locations and orientations, transmit-antenna location, pilot signals, RIS phase profiles.
- **RIS and system requirements:** known location and orientation, variable RIS phase configurations.

3.2.4 RIS in Hybrid Mode

Scenario 11 - Radar localization/detection of passive target(s)

In this scenario, illustrated in Figure 3.11, a radar is assisted by multiple RISs, having the architecture of [ASA21], in order to localize/detect static or moving target(s). In the recent relevant literature, authors have explored applying RISs in Radar systems in order to perform user localization [ZHZ20], enable localization for users in NLOS areas [AMR21], and enhance the target detection problem performance [LDF21], [LLF21], [JRZ21], [BGL21]. The novelty Scenario 8 is found in the hybrid RISs' architecture being deployed, which simultaneously receive and reflect (in comparison with the passive RISs in the literature only being able to reflect), giving the system the capability to localize users as well as the radar itself.

- **Settings:** 3D deployment, full-duplex MIMO transceiver (radar), passive target(s), line-of-sight or multipath channels, multiple RISs.
- **Measurements:** Received signal at each RIS via its phase profile configuration (analog combining reception), received signal (reflections from the target(s) and the RISs) at the multi-antenna RX of the radar, narrowband or wideband.
- **Unknowns to be solved for:** Detection or 3D locations of static or moving target(s), 3D location of the radar.
- **Knowns:** RISs' locations and orientations, pilot signals.

- **RIS and system requirements:** Variable RIS phase configurations, computing capability for features' estimation/detection at each RIS, collection of the latter at the radar (wired or wireless) that combines them for the location(s) estimation of static or moving target(s).

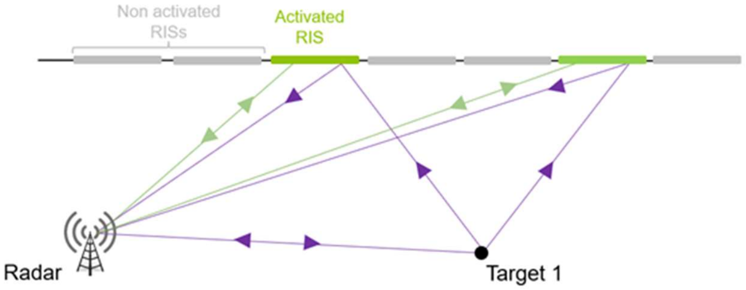


Figure 3.11 Scenario 11 example

4 Enhanced sustainability and security scenarios

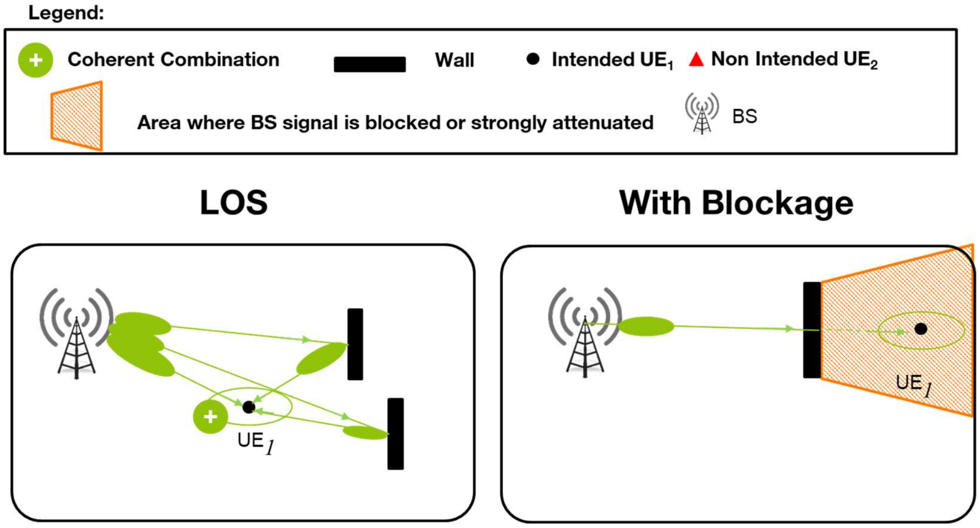
Somehow it is the coverage problem again described in Section 2 but with specific emphasis on getting the best performances of the communication system in terms of Energy Efficiency (EE) / Electromagnetic Field exposure Efficiency (EMFEE) / Secrecy Spectral Efficiency (SSE).

4.1 Conventional scenarios (i.e., with non-RIS systems)

In this section, we draw a first and non-exhaustive list of baseline scenarios without RIS, where we believe that the deployment of RIS(s) for EE/EMFEE/SSE would be meaningful for their capability to overcome current limitations due to the propagation channel.

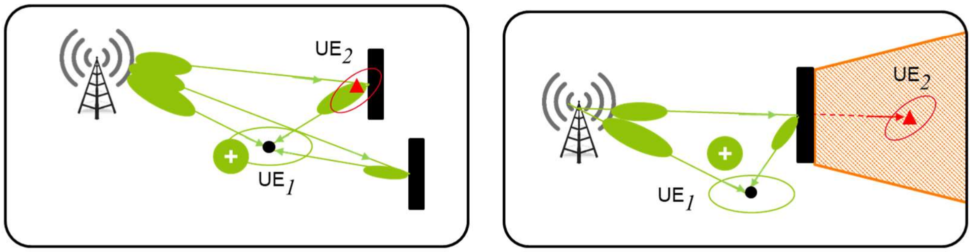
In Figure 4.1-a), we describe the conventional solution to provide an energy efficient radio link from a BS to an intended UE. In this solution, the BS uses beamforming to maximise the received power at the target UE, under a limited transmit power constrain. However, the power received at the UE is limited by the number of propagation paths between the BS and the considered UE. The smaller is this number the weaker is the signal received at the target UE.

In Figure 4.1-b), we illustrate the conventional solution to provide a secured link to an intended UE in the presence of an eavesdropping non-intended UE. Again, the BS performs beamforming to deliver the target received power at the intended user, with a minimum of transmit power. With such approach the received power at the non-intended user (whatever its location) is reduced compared to the case without beamforming. However, the contrast between the received power at the target UE and the received power at the non-intended UE is limited by the number of propagation paths. The smaller is this number of paths the weaker is this contrast. In the worst case scenario, the non-intended UE can even be on one of these propagation paths. As illustrated in Figure 4.1-a) andFigure 4.1-b), the aforementioned limitations due to lack of multipath in the propagation channel, are observed both in the cases where the link between the BS and the target UE is in line-of-sight (LOS) or blocked by an obstacle.



Limitation: UE$_1$ received power is limited by the propagation channel

a) Beamforming for energy efficient link provision

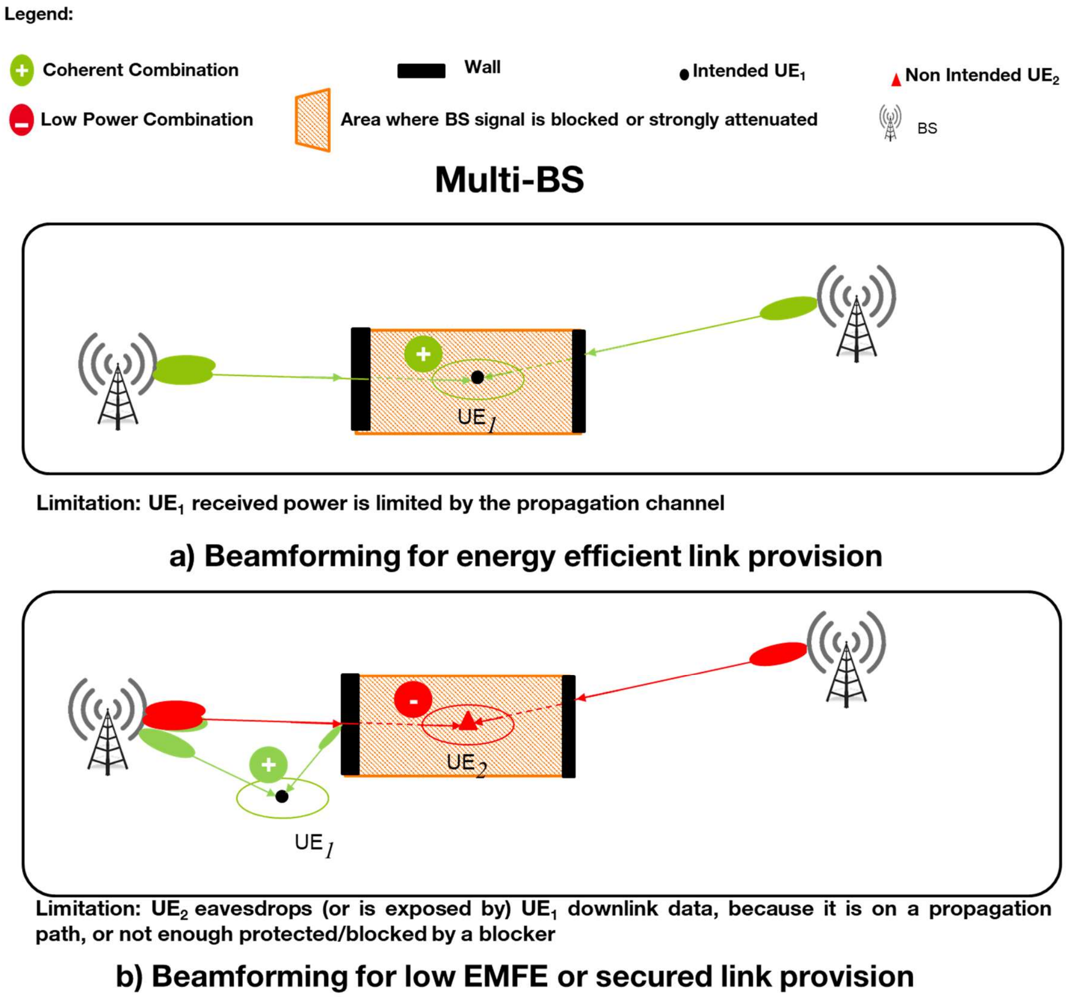


Limitation: UE$_2$ eavesdrops (or is exposed by) UE$_1$ downlink data, because it is on a propagation path, or not enough protected by a blocker

b) Beamforming for low EMFE or secured link provision

Figure 4.1: Example of conventional single-BS systems based on beamforming for coping with EE, SSE and EMFEE requirements

Previously described scenarios can be generalized to multi-BS scenarios, where several synchronized and coordinated BSs perform joint beamforming, as in the examples illustrated in Figure 4.2.



Limitation: UE$_1$ received power is limited by the propagation channel

a) Beamforming for energy efficient link provision

Limitation: UE$_2$ eavesdrops (or is exposed by) UE$_1$ downlink data, because it is on a propagation path, or not enough protected/blocked by a blocker

b) Beamforming for low EMFE or secured link provision

Figure 4.2: Example of conventional multi-BS systems based on beamforming for coping with EE, SSE and EMFEE requirements

Note that similar scenarios for uplink can be derived with receive BF instead of transmit BF. The main difference will be that the EE will be improved at the UE side instead of the BS side.

4.2 Scenario 12 – EMFE-enabled

In this section, we reuse the baseline scenarios without RIS, defined in previous section, and deploy one or several RIS(s).

More precisely, in Figure 4.3-a), we illustrate examples of single-BS scenarios with RIS, where downlink transmit beamforming (BF) is used to optimize the EE of the link between the BS and the target UE, by exploiting the artificial shaping of the propagation channel thanks to RIS(s).In Figure 4.3-a), the potential advantages brought by RIS to boost the received power at the target UE is illustrated for three types of propagation scenarios:

- the BS-to-intended UE link is in LOS: in this case, the RIS artificially adds a propagation path to the channel, this path coherently combining with other “natural” paths to boost the received power at the target UE;

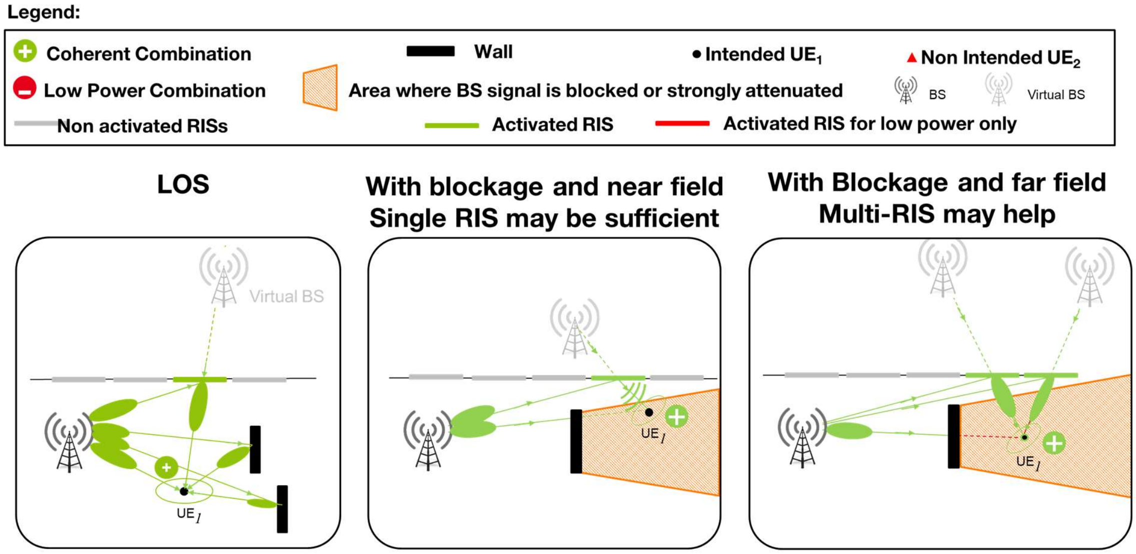
- the BS-to-intended UE link is blocked by an obstacle and the intended UE is in near field of a RIS: in this case, the RIS artificially creates the main and strongest propagation path, to enable the target UE to receive power from the BS;
- the BS-to-intended UE link is blocked by an obstacle and the intended UE is in far field of a RIS: this case is similar to the previous case, except that several RIS(es) may be useful to focus the energy towards the target UE.

In Figure 4.3-b), we illustrate examples of single-BS scenarios with RIS, where downlink transmit beamforming (BF) is used to optimize boost the received power at the target intended UE, and reduce the received power at the non-intended UE by exploiting the artificial shaping of the propagation channel thanks to RIS(s). When the non-intended UE is an exposed UE, the obtained link is a low EMF link, whereas when the non-intended UE is an eavesdropper, the obtained link is a secured link. In Figure 4.3-b), the advantages brought by RIS to reduce the received power at the non-intended UE (whether it is an eavesdropper or an exposed UE) compared to the received power at the target UE are illustrated for three types of propagation scenarios:

- the BS-to-intended UE link is in LOS: in this case, the RIS artificially adds propagation paths to the channel, these paths coherently combining with other “natural” paths to boost the received power at the target UE, and un-coherently combining with other “natural” paths to reduce the received power at the non-intended UE;
- the BS-to-intended UE link is blocked by an obstacle and the intended UE is in near field of a RIS: in this case, the RIS artificially adds an a propagation path to the existing “natural” paths, to reduce the received power at the non-intended UE;
- the BS to intended UE link is blocked by an obstacle and the intended UE is in far field of a RIS: this case is similar to the previous case, except that several RIS(es) may be useful to reduce the energy at the non-intended UE.

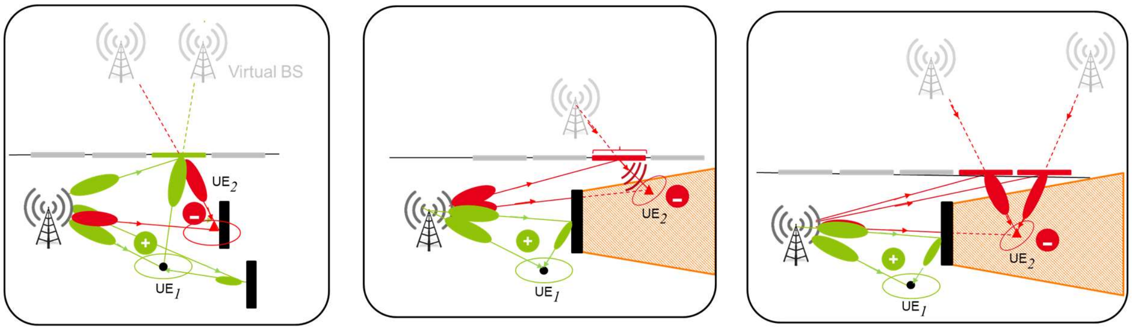
Note that similar scenarios for uplink can be derived with receive BF instead of transmit BF. The main difference will be that the EE will be improved at the UE side instead of the BS side.
Note that, in these scenarios, we assume that:

- RIS can optionally also receive signals, for instance, to perform in-band channel estimation.
- RIS can optionally use a positioning system, as described in section 3, even to localize non-intended users.



Expected enhancement: UE$_1$ receives better signal for the same transmit downlink power because UE$_1$ is now on a location where propagation has been strengthened artificially thanks to RIS(s)

a) RIS-enhanced Beamforming for energy efficient link provision

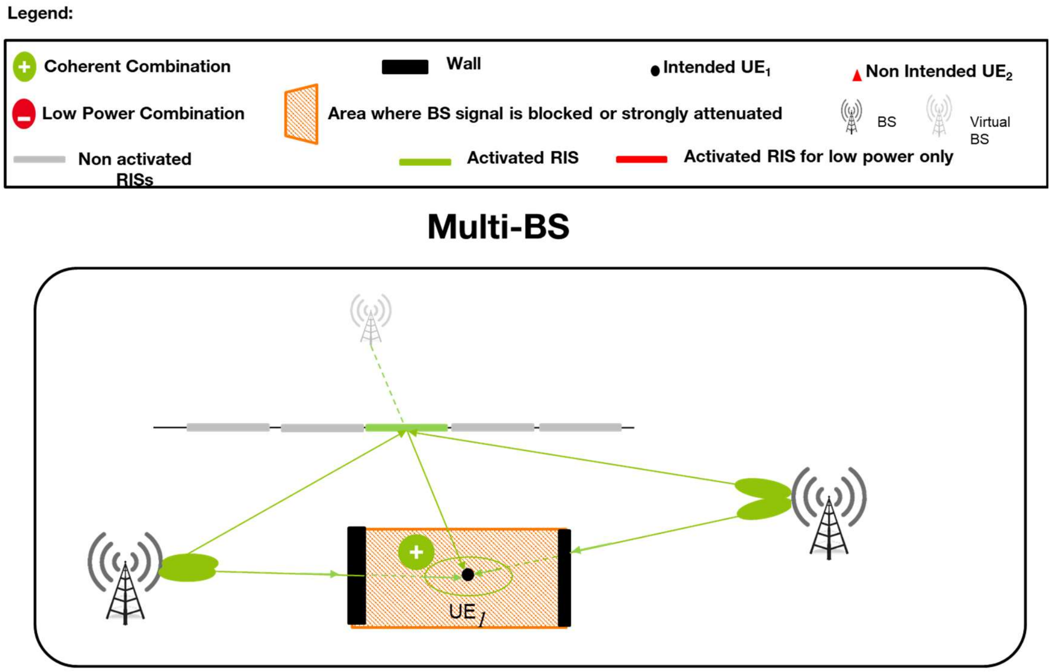


Expected enhancement : UE$_2$ eavesdrops less (or is less exposed by) UE$_1$ downlink data because UE$_2$ is now on a location where propagation has been weakened artificially thanks to RIS(s)

b) RIS-enhanced low EMFE or secured link provision

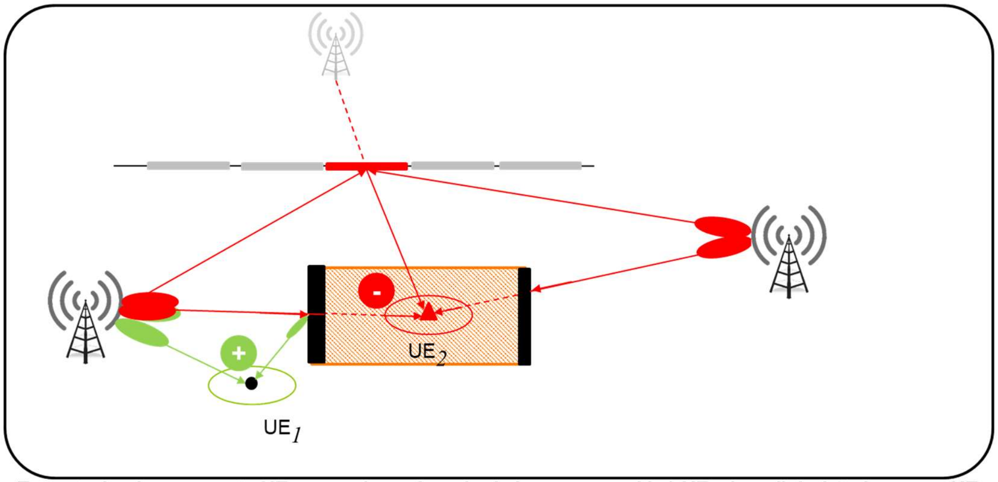
Figure 4.3: Example of RIS-enhanced single-BS systems based on beamforming for EE, SSE and EMFEE provision

Previously described scenarios can be generalized to multi-BS scenarios, where several synchronized and coordinated BSs perform joint beamforming, as in the example illustrated in Figure 4.4.



Expected enhancement: UE_1 receives better signal for the same transmit downlink power because UE_1 is now on a location where propagation has been strengthened artificially thanks to RIS(s)

a) RIS-enhanced Beamforming for energy efficient link provision



Expected enhancement : UE_2 eavesdrops less (or is less exposed by) UE_1 downlink data because UE_2 is now on a location where propagation has been weakened artificially thanks to RIS(s)

b) RIS-enhanced low EMFE or secured link provision

Figure 4.4: Example of RIS-enhanced multi-BS systems based on beamforming for EE, SSE and EMFEE provision

5 Real applications in field-trials

The following sub-sections describe the potential use cases identified by the two end-users of the project: CRF, representing the Automotive Group Stellantis, and SNCF, for the railway sector. As the project is still in an early phase, the end-users have assessed numerous applications of the project outputs to their processes, to provide the technical partners in the project with insights on all relevant applications, informal requirements and help in focusing further developments. These use cases will be streamlined in a second step, to define the final use cases to be addressed in the project demonstrators.

5.1 Factory plant use cases

5.1.1 UAV localization and navigation

Figure 5-1 – Indoor/ outdoor express delivery with UAVs.

Description: The case study considers the application of a drone in the production plant[1] for the following purposes, as shown in the figure above:

- Rapid material delivery: the fast transportation of components when a material shortage at the lineside leads to an emergency, which could produce a production line stop. This occurrence would produce a very high cost and so has to be avoided. Therefore, the drone, from the plant warehouse, is loaded with the requested component(s), and then it moves directly to the right station of the production line performing the delivery.
- Warehouse monitoring, where the drone is used, coupled with a camera, for the detection of the different component amounts inside the warehouse.

To perform autonomous flight missions, a common solution is represented by the use of different markers positioned on the selected path and recognized by the drone vision system allowing the movement along the path. In the new solution, the marker system is substituted by the RIS installation (whether onboard or out of the drone), which is able to help capturing, with a very high frequency, the position of the drone. The latter is then communicated to the drone software, enabling the travel along the desired path.

Actors and enablers: The actors involved in the case study are the (fleet of) drones used with the related infrastructure which can comprehend the on-board component plus different elaboration stations. The communication to the drone is performed thanks to an internal wi-fi network.

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[1] Note that specific flight could be mixed outdoors and indoors.

Issues: drone control and difficulties to guarantee a high level of stability and precision during the flight without the input coming from the drone camera; frequency of update of the map (>10Hz).

Business value: The new configuration can bring better control of the trajectories during the flight mission execution, improving the efficiencies in terms of energy consumption and the reliability on the mission execution time, allowing to optimize the number of drones in the fleet. Safety can be increased as the UAV avoids any physical interference with the infrastructure and avoids the areas where humans are located.

Business KPIs: cycle time, energy consumption per distance unit, fleet capex.

5.1.2 AGV localization and navigation

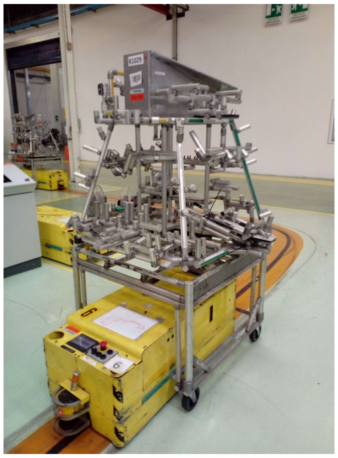


Figure 5-2 – AVG transporting an empty kit holder (magnetic spot navigation).

Description: The AGV navigation inside its operative area is one of the most important factors that determines the success of such typologies of implementation. The use case considers the use of RIS elements in order to capture the position of AGVs that has the task of composing a kit in a supermarket area inside the plant which has to be then sent to the production line for the assembly operations, as shown in the figure above. The data collected are then retrieved by the AGV navigation module so as to be able to move precisely inside the supermarket area.

Actors and enablers: The use case perimeter comprehends: the AGV fleet, including the different software components like the aforementioned navigation module or that for the mission planning and scheduling; RIS on the AGV or on the infrastructure; different plant production management software, in order to allow the alignment with the other related plant processes.
Issues: The exact detection of the position of the AGV, considering the complicated shapes that such an object could have, could present several challenges. The frequency of refresh for the mapping should be high (>5Hz).

Business value: the objective of the new implementation is to increase the precision in the identification of the position of the different AGVs used in a supermarket for the kit composition, to permit an improvement in their path definition and coordination, guaranteeing at the same time a more reduced error in the reach of a goal position.

Business KPIs: distance (meters) per mission, AGV fleet dimension, goal position average error.

5.1.3 Kitting process monitoring

Figure 5-3 – Kit area.

Description: The use case considers the application of RIS components inside a supermarket area used for the kit preparation to be sent to the assembly line, as shown in the figure above.. The objective is the monitoring of the different elements of the area dedicated to the container management and preparation for the picking by the assigned actor by means of advanced localization and tracking RIS-based solutions. The area map can be updated every time a modification occurs in the real scenario. These data are then used by the various actors involved in the operations related to the supermarket area.

Actors and enablers: A supermarket area is generally composed of different structures (e.g. gravity racks) able to host the component containers and ease their handling and management and the picking operations. They are arranged in order to define a path which permits to the dedicated actors (e.g. AGV with robotic arms) to compose the kit optimizing the distance covered.

Issues: The huge amount of data coming from the fine mapping performed by the RIS application, considering the high rate of update, could be difficult to manage by the software system of the different production actors involved in the kit composition.

Business value: The opportunity of a map instantaneously updated allows to optimize the mission schedule for the solutions employed for the kit composition, considering the different component variants which can bring to different possible paths, the travelling time during a single mission and to reduce picking errors, in particular due to the distance of the AGV from the target objects.

Business KPIs: cycle time, resource saturation, average distance error with respect to picked object and container.

5.1.4 Component position in container

Figure 5-4 – Component in plastic containers.

Description: The identification of the component position inside the containers is one of the key aspects in the automation of the kit composition operation through the use of a solution which considers an AGV with a robotic arm installed. In this case study the RIS elements contribute to this task, helping in determining both the localization of the different components present in the container and their alignment, as shown in the figure above, and then communicate the information to the AGV system allowing the movement elaboration by the robotic arm.

Actors and enablers: full container, in which the components can be arranged with different possible configurations, on the basis of the presence of separators which help to maintain a more predictable position; RIS positioned in the container or outside; AGV system mobile base.

Issues: The identification of a component inside the container (and the distance to the other components) has to reach a sufficient degree of precision to allow the robotic arm to perform the picking operation.

Business value: In order to identify the component position characteristics, traditional applications of this kind of solution need to install a vision system on every AGV system, which would be eliminated with the RIS-supported system. Besides, the identification time could be reduced, with benefits on the duration of the entire picking operation.

Business KPIs: Average picking time, % of the picking operation failed, capex on AGVs.

5.1.5 Collaborative manufacturing (synchronous moving)

Description: The use of AGVs for assembly operations on the production line is spreading in the automotive industry. In this application, we use the same AGV as in the use cases above, composed of a mobile base with an integrated robot arm. The AGV has a synchronous movement with respect to the car body, proceeding at constant speed, on which are assembled the components. The most relevant aspect is constituted by the need to avoid speed delta between the line and the AGV in order not to hinder the precision of the robotic arm movement and eventually damage the components or car body. The novel RIS technology will support high-accuracy in tracking and tracing operations.

Actors and enablers: The AGV path is basically defined by a forward path, which follows the production line performing the assembly operations, and a return path which allows the AGV to get back to the beginning of the assembly line. The RIS application has the main objective, during the forward path, to enable the detection of the AGV and car body position and allow their alignment.

Issues: the precision and frequency of updating of the map are critical, to enable a precise alignment between the AGV and the car body for the entire duration of the assembly cycle, guaranteeing a sufficient robustness level to the application.

Business value: The use of the RIS will increase the solution applicability, reliability and flexibility, avoiding the cost increase due to the introduction of additional vision elements and extending the range of application.

Business KPIs: % of damaged components per car body, cycle time, number of additional possible applications

5.1.6 Container contents monitoring

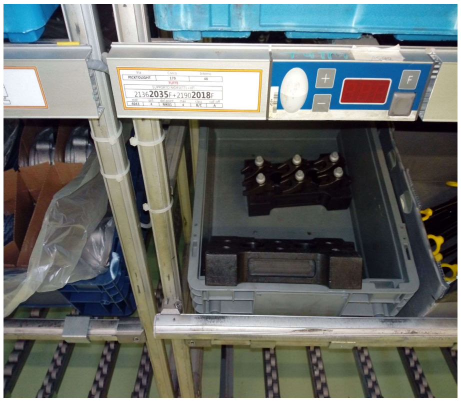


Figure 5-5 – Gravity rack with containers.

Description: The management of full and empty containers flow between the central warehouse and the kit/sequencing areas can be improved by monitoring the contents of the containers, as shown in the figure above. In the considered application, this function will be enabled by the RIS element, in order to, together with the data coming from the different production management software (MES), optimize the material call and use of the logistic resources.

Actors and enablers: The transport of the container from the central warehouse is generally performed, on the basis of the components' characteristics, by a tugger train, a forklift or an AGV. The production management software contains information about the production schedule, logistic resources organization and warehouse components level. RIS would be positioned next to or in the container.

Issues: integration, and consequent calibration, between the detection system realized in the use case and the different production software system which manage the kit area logistic flows.

Business value: An effective monitoring of the container contents can generate different advantages related to the reduction of the number of missions, increasing the logistic resources load saturation and optimizing the component variants supply on the basis of the production schedule.

Business KPIs: Number of missions per component, saturation of logistic operators, distribution of residual components levels on refilling

5.1.7 Human-robot interaction and hazards

Figure 5-6 – Robot virtual fencing.

Description: the mapping of the area is performed using RIS. The focus is on monitoring the respective position of operators and robots and identifying potential threats to the operator, as shown in the figure above. In particular this gives the opportunity to reduce the speed of the robot or change the path of the AGV/UAV in order to avoid potential risks to the human operator.

Actors and enablers: Logistics operator; Maintenance operator; Assembly operator; Robots (AGV/ UAV)

Issues: Precision of the map should be around 1 meter, depending on the objective; Frequency of map update should be higher than 10Hz.

Business value: Avoid potential threats to the operator

Business KPIs: incidents and near misses.

5.1.8 Monitoring of assembly steps by human operators

Figure 5-7 – Sequence of operations.

Description: the mapping of the area is performed using RIS. The focus is on the sequence of operations and in particular the monitoring of actions at lineside from operators performing picking, kitting, subassembly or assembly actions, as shown in the figure above. We intend to verify that the operators perform the correct sequence of actions as identified in the cycle analysis.

Actors and enablers: Logistics operator; Maintenance operator; Assembly operator.

Issues: Precision of the map should be under several centimeters; Frequency of map update should be higher than 1Hz.

Business value: to give an indication of the adequacy of the actual sequence to the predefined one.

Business KPIs: Cycle time; NVAA estimation.

5.1.9 Monitoring of ergonomic load of production operators

Figure 5-8 – Ergonomics of assembly.

Description: the mapping of the area is performed using RIS. The focus is on the ergonomics of the operations and in particular the monitoring of lineside for operators performing picking, kitting, subassembly or assembly actions, as shown in the figure above. We intend to identify such events as unique or repetitive positions with low physical ergonomics KPIs.

Actors and enablers: Logistics operator; Maintenance operator

Issues: Precision of the map should be under several centimetres; Frequency of map update should be higher than 1Hz

Business value: to give a warning on potential physical ergonomics issues

Business KPIs: operator health and stress

5.1.10 Identification of hazards in internal logistics

Figure 5-9 – Corridors in plant.

Description: the mapping of the area is performed using RIS. The area can be either outdoors or indoors. In indoor mapping, the focus is on the safety of the operations and in particular the monitoring of the material handling systems (AGVs, forklift, containers, etc) and components. We intend to identify such events as pallets blocking the way for an AGV or components blocked on a conveyor, as shown in the figure above. This enables the automatic trigger of actions such as: maintenance, recovery, problem solving.

Actors and enablers: Material handling systems; Containers and components; Logistics operator; Maintenance operator.

Issues: Precision of the map should be under several centimetres; Frequency of map update could be several times per minute.

Business value: to enable the automated actions for maintenance, problem solving, recovery; to reduce or eliminate the need for vision systems at the workshop level.

Business KPIs: Operator time and cost; Manual and non-added-value activities.

5.1.11 Identification of logistic systems loading status

Figure 5-10 – Components Warehouse.

Description: the mapping of the area is performed using RIS. The area can be both outdoors or indoors, as shown in the figure above. In the first case the trucks' position and possibly the quantity of material (the truck has lateral openings) is retrieved. In indoor mapping, the focus is on warehousing areas with for example full containers, open full containers enabling the mapping of the contents. This enables the automatic trigger of actions such as: loading/ downloading operations, material call, checking/ updating of the stock level in WMS.

Actors and enablers: Warehouse Management Systems (WMS); Trucks; Containers.

Issues: Precision of the map: should be under several centimetres; Frequency of map update: several times per minute.

Business value: to enable the automated actions for loading, material call and stock level monitoring; to reduce or eliminate the need for vision systems at the workshop level.

Business KPIs: Operator time and cost; manual and non-added-value activities.

5.1.12 Remote Human-robot interaction and robot control

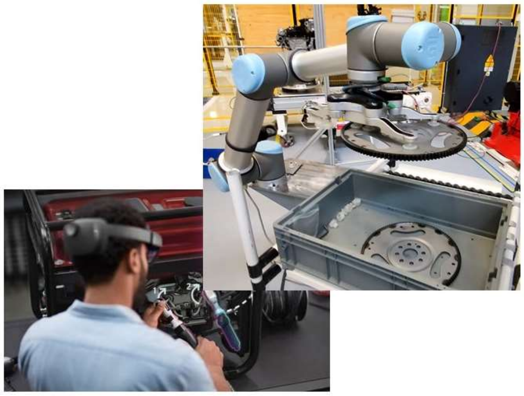


Figure 5-11 – Robot remote control.

Description: the mapping of the local area in the workshop is performed using RIS. The map is represented to a remote operator and used to enable the remote control of the robot in case of problems occurring during the movement, picking or handling of the component. The remote operator sends commands to the local system and automatically recognises on the map the updated position of AGV, robot and other local systems (containers, gravity racks, etc), as shown in the figure above.

Actors and enablers: the remote operator interacting with the local system; the AGV and/ or robotic arm guided by the remote operator; containers, gravity racks, etc; RIS with accurate position.

Issues: Precision of the map should be under several centimetres; Realtime mapping with a refresh frequency > 1Hz.

Business value: to enable the remote interaction of an operator with workshop machines; to reduce or eliminate the need for vision systems at the workshop level.

Business KPIs: Vision system cost; Operator time and cost.

5.2 Railway station use cases

5.2.1 Coverage difficulties or network extension (B2C/B2B)

Figure 5-12 – Railway station.

Description: the connection coverage of the area is enhanced using RIS. In general, it might happen that users may experience in some areas connection disruptions. A proper deployment of RISs can help in reaching such users and significantly improve the overall communication performance.

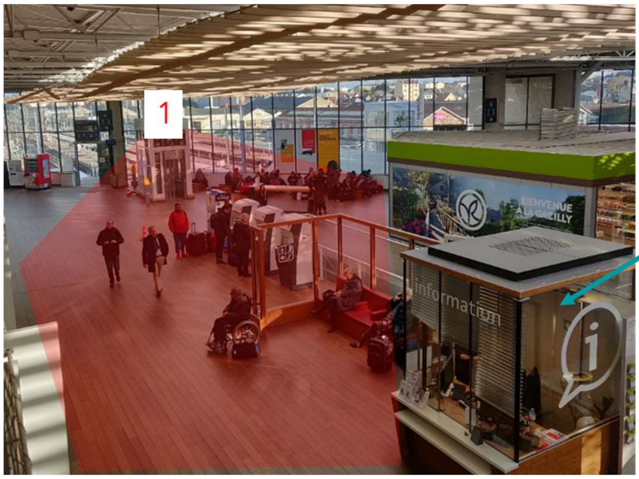
Actors and enablers: Station architects and managers; workers or travellers in need of connectivity; RIS design to make it blend into the station architecture.

Issues: Performance of connectivity.

Business value: to avoid additional antennas or active repeater/amplifier; to provide a homogeneous, resilient and performant telecom service.

Business KPIs: Signal coverage; Download rate.

5.2.2 EMF protection for workers or specific public (B2C/B2B)



The 26GHz signal should be blocked on demand within the booth.

Figure 5-13 – EMF-free zones.

Description: Arrival of 5G equipment in stations and usage of new type of frequency brought awareness and tension among the SNCF agents and even general public. Workers representatives ask for an effective way to diminish the EMF exposition of agents that spend most of their workday inside the station, and sometimes just in front of an antenna. Fragile public, such as children, should also be considered. For workers, they should choose if they want to use 5G services, or to block the signal. For children, some areas, especially the dedicated “playground waiting area” should be “EMF free”.

Actors and enablers: Station architects and managers; RIS design to make it blend into the station architecture; Workers representation.

Issues: ability to control RIS action with a remote-like system; precision of the EMF control.

Business value: General public and SNCF agent reassurance; 5G acceptability; EMF limitation to keep ANFR regulations at the lowest rate.

Business KPIs: Signal blockage.

5.2.3 Dedicated download areas (B2C)

Figure 5-14 – Dedicated download areas (B2C).

Description: Railway Stations are structured to maximize people flow from the entrance to the train's platforms. We see people waiting in areas where they have a good coverage (WIFI, 4G) to play, study, work, check the SNCF app or download their media contents (Netflix, Prime etc.). We want to control the connectivity in terms of localization and quality to make it compliant with the station flowing patterns. Some areas would be dedicated to eMBB and clearly indicated with physical signage as shown below. In these areas only, the coverage and high-bandwidth service would be "best of breed".

Actors and enablers: Station architects and managers; RIS design to make it blend into the station architecture; Physical signage designer; Telecom engineering.

Issues: Precision of the EMF control to cover only a dedicated area; mmWave signal to get such a precise and limited emission.

Business value: Connectivity as a visible service in the station; 5G acceptance for clients in dedicated areas (EMF communication).

Business KPIs: Download rate; Coverage limitation.

5.2.4 EMF protection for private areas (B2B)

Description: Crisis management rooms in regional station (such as "Rennes station") are private areas in which major SNCF incidents are discussed in relationship with crisis rooms all over the country. To ensure privacy (preventing eavesdropping as well) and avoid jamming or telecom problematics that could occur during such event, the crisis room must be free from any telecom signal other than the one dedicated to such private and secured communication.

Actors and enablers: Station architects and managers; Crisis management team; Indoor telecom services team.

Issues: n/a.

Business value: Crisis room with guarantee of privacy and high reliability telecom service.

Business KPIs: Quality of EMF isolation.

5.2.5 Travelers flow modelisation (B2B)

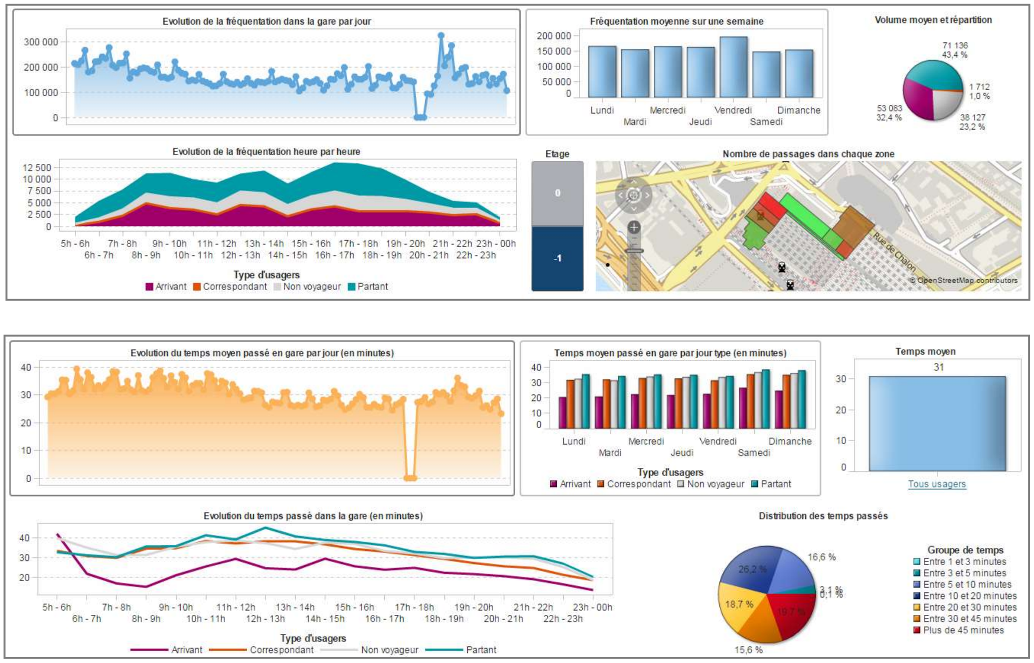


Figure 5-15 – Travelers' flow dashboard.

Description: Station free WIFI system is used to get anonymous and statistical presence of people. This allows SNCF to get a basic model of people flow, consolidated over several weeks, but also in real-time. This data is used to study the impact of station renovation on the flow management, but also for operational reasons with real-time analysis of congestions (alerting system). This WIFI based system is not very accurate and only provides rough evaluation "hall by hall". A RIS-based system could greatly improve the accuracy of the data.

Actors and enablers: Big Data and analytics teams; MNO cooperation; Indoor telecom services team.

Issues: Accuracy of the measurement: 10m².

Business value: Useful for daily security operations (real time), as well as long term study of the station "behaviour" profile; No need for several existing (and expensive) counting systems: laser, IR, people manually counting etc.

Business KPIs: Accuracy of the geolocation and count; Real time analytics.

5.2.6 People geolocation system (B2B/B2C)

Figure 5-16 – People geolocation system (B2B/ B2C).

Description: SNCF stations are equipped with WIFI and BLE beacons. They are used to provide a geolocation system for SNCF and third-party apps. Users need to have BLE opened on their device, and it's very sensitive to local EMF. Getting a good triangulation and correct directions is not very easy, and the overall system does not give full satisfaction. It is still absolutely impossible to guide a visually impaired travellers with this type of technology. Therefore, RIS technology may play a relevant role and enable unprecedented services where geolocation may be provided with high accuracy.

Actors and enablers: E-Marketing teams; App dev kit; Indoor mapping and points of interest.

Issues: Accuracy of the geolocation: 1 to 5 meters.

Business value: No need for several existing (and expensive) geolocation systems; Maps & directions to services and shops are a key business factor for the stations.

Business KPIs: Accuracy of the geolocation; Simplicity of the integration.

5.2.7 Isolated agents' detection at night (B2B)

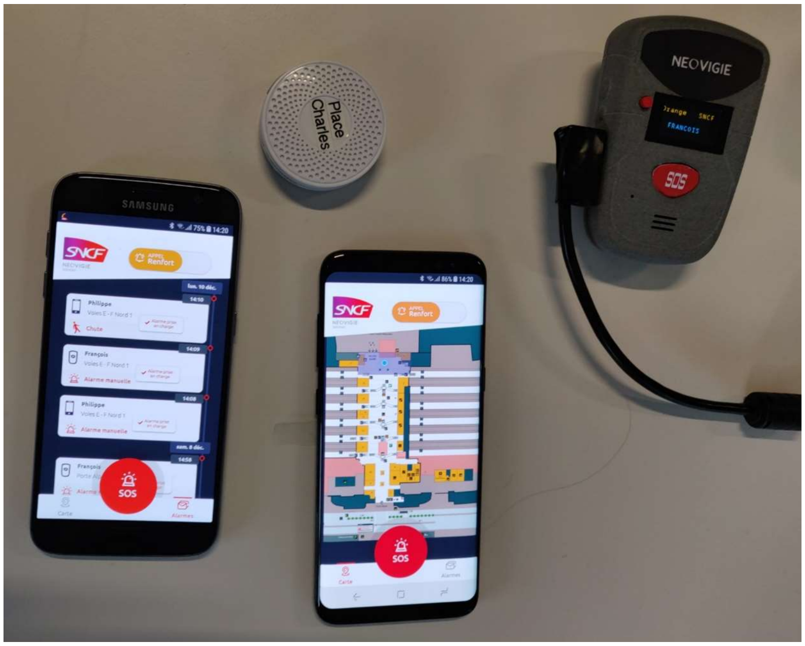


Figure 5-17 – Isolated agents' detection at night (B2B).

Description: SNCF agents are working at night in stations, and during closed hours there are a few security agents to watch the perimeter. They are equipped with a smartphone, and we developed a dedicated LTE-M portable device to alert in case of aggression. In addition to the alerting mechanism, we need to retrieve their precise location for a quick intervention and rescue. RIS can help improving the location system.

Actors and enablers: Station security staff; App dev kit; Indoor mapping and points of interest.

Issues: Accuracy of the geolocation: 1 to 5 meters.

Business value: Contribute to improve the safety of isolated agent at night.

Business KPIs: Accuracy of the geolocation; Simplicity of the integration.

6 Conclusions

This deliverable provides an overview about Task 2.1 activities presenting preliminary results collected in the first project months.
In particular, the deliverable aimed at identifying reference scenarios compared to conventional ones where RIS can play a role. Such scenarios are collected within different categories according to the expected achievable performance. In addition, relevant use-cases are also discussed. A direct matching with field-trial demonstrations is performed: experienced problems, expected solutions and achievable KPIs are listed to further validate all project suggested solutions.

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