



UNICO I+D Project
6G-SORUS-RIS

SORUS-RIS-A1.1-E1 (E4)

First version of the architecture

Abstract

The main objective of the three 6G-SORUS projects is to study the integration of UAVs with RIS and vRAN. This integration can provide several benefits, including increased coverage and capacity, improved spectral and energy efficiency, and enhanced security and privacy. UAVs can be used as flying base stations to provide wireless coverage to areas where it is difficult or impossible to deploy traditional base stations. By using RIS, the UAVs can enhance the signal quality and coverage, while vRAN can provide dynamic resource allocation and efficient management of the wireless resources. This document describes the architectural elements for the integration of RIS in the operation of the network.

Document properties

Document number	SORUS-RIS-A1.1-E1 (E4)
Document title	First Version of the Architecture
Document responsible	Pablo Serrano (UC3M)
Document editor	Pablo Serrano (UC3M)
Editorial team	Winnie Nakimuli, Marta Ferreira, Pablo Serrano (UC3M)
Target dissemination level	Public
Status of the document	Final
Version	1.0
Delivery date	31-12-2022
Actual delivery date	31-12-2022

Production properties

Reviewers	Marco Gramaglia (UC3M)
------------------	------------------------

Disclaimer

This document has been produced in the context of the 6G-SORUS-XXX. The research leading to these results has received funding from the Spanish Ministry of Economic Affairs and Digital Transformation and the European Union-NextGenerationEU through the UNICO 5G I+D programme.

All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability.

Contents

List of Figures	4
List of Acronyms.....	5
Resumen Ejecutivo	6
Executive Summary	7
1. Introduction.....	8
2. General system architecture.....	10
3. Specific RIS architecture	13
4. Summary and Conclusions	16
5. References.....	17
Acknowledgements	18

List of Figures

Figure 1 scenario of a uav-based network with ris and vran.....	10
Figure 2 General system architecture of the uav-based network.....	11
Figure 5. Specific ris architecture components.....	13

List of Acronyms

6G: Sixth Generation of Wireless Communication Technology

B5G: Beyond 5G

BS: Base Station

gNB: Next Generation NodeB

KPIs: Key Performance Indicators

LoS: Line of Sight

RIS: Reconfigurable Intelligent Surface

UAV: Unmanned Aerial Vehicle

UE: User Equipment

vRAN: Virtualized Radio Access Network

Resumen Ejecutivo

El diseño y funcionamiento de una red más allá del 5G (B5G en inglés) sostenible es especialmente relevante, ya que se espera que la 5G sea uno de los principales contribuyentes al aumento general del consumo de energía de los dispositivos móviles. El proyecto coordinado aborda la orquestación de redes B5G utilizando tres de las tecnologías más prometedoras para mejorar su cobertura y sostenibilidad, a saber:

- La virtualización, que está llegando al borde de la red (virtualización de la red de acceso radioeléctrico, vRAN). Gracias a la virtualización, las estaciones base (BS en inglés) pueden convertirse en partes de software que pueden desplegarse en diversas plataformas, como servidores básicos, pequeños dispositivos integrados o nodos móviles. Gracias a este cambio de paradigma, las redes podrán ofrecer flexibilidad de rendimiento, la densificación de la red será más fácil e incluso se reducirán los gastos.
- Superficies inteligentes reconfigurables (RIS). Las RIS ofrecen la posibilidad de configurar sus respuestas electromagnéticas, lo que permite un mayor grado de libertad para mejorar la capacidad y ahorrar energía, siempre que puedan orquestarse a su debido tiempo.
- Vehículos autónomos no tripulados (UAV en inglés). Los UAV, por su parte, pueden dar cobertura temporal o permanente a determinadas zonas con un coste de despliegue mucho menor. La integración de los RIS y los UAV abre nuevas oportunidades para mejorar la cobertura y reducir el consumo de energía.

Este subproyecto se centra en los retos que plantea la integración de vehículos aéreos no tripulados (p.ej., drones) con redes de acceso radioeléctrico virtualizadas (vRAN) y superficies inteligentes reconfigurables (RIS) en el despliegue y funcionamiento de una red B5G. Más concretamente, contribuye al diseño de una arquitectura que integre a la perfección el funcionamiento de torres celulares flotantes con tecnologías vRAN y RIS (incluidas las ampliaciones de los planos de gestión y control), el desarrollo de algoritmos y mecanismos para su orquestación, la elaboración de perfiles detallados del rendimiento de los UAV, vRAN y RIS en diferentes escenarios, y una evaluación del rendimiento que incluya el uso de prototipos reales para validar los desarrollos más relevantes del proyecto.

El subproyecto introducirá tecnologías y mecanismos novedosos para aquellos escenarios de aplicación en los que el uso de UAVs, vRAN y RIS podría ser más adecuado, como casos de emergencia o despliegue remoto, hotspots o zonas poco pobladas. Estas tecnologías mejorarían la eficiencia y la sostenibilidad de los despliegues de red, lo que puede fomentar la adopción de tecnologías en zonas típicamente desatendidas. De este modo, los avances tecnológicos pertenecen al sector de las telecomunicaciones, las tecnologías de la información y los drones/industria, pero su impacto se extiende a toda la sociedad.

Executive Summary

The design and operation of a sustainable beyond 5G (B5G) network is particularly relevant since 5G is expected to be one of the main contributors to the overall increase in power consumption of mobile devices. The coordinated project addresses the orchestration of B5G networks using three of the most promising technologies to improve their coverage and sustainability, namely:

- Virtualization, which is reaching the edge of the network (virtualizing the radio access network, vRAN). Thanks to virtualization, base stations (BSs) can be turned into softwarized stacks that can be deployed in diverse platforms such as commodity servers, small, embedded devices, or moving nodes. Thanks to this paradigm shift, networks will be able to provide performance flexibility, network densification would be easier, and eventually it would reduce expenses.
- Reconfigurable Intelligent Surfaces (RISs). RIS grant the chance of configuring their electromagnetic responses, which enables an increased degree of freedom for capacity improvements and energy savings, provided they can be orchestrated in due time.
- Unmanned Autonomous Vehicles (UAVs). UAVs, on the other hand, can temporary or permanently provide coverage to certain areas at a much lower deployment cost. The integration of RIS and UAVs opens new opportunities to improve coverage and reduce energy consumption.

This subproject focuses on the challenges introduced by integrating UAVs (i.e., drones) with virtualized radio access networks (vRAN) and reconfigurable intelligent surfaces (RIS) into the deployment and operation of a B5G. More specifically, it contributes to the design of an architecture to seamlessly integrate the operation of floating cell towers with vRAN and RIS technologies (including the extensions to the management and control planes), the development of algorithms and mechanisms for their orchestration, the detailed profiling of the performance of the UAVs, vRAN, and RIS in different scenarios, and a performance evaluation that includes the use of real-life prototypes to validate the most relevant developments of the project.

The subproject will introduce novel technologies and mechanisms for those application scenarios where the use of UAVs, vRAN, and RIS could be most adequate, such as emergency or remote deployment cases, hotspots, or underpopulated areas. These technologies would improve the efficiency and sustainability of network deployments, which can foster the adoption of technologies in typically underserved areas. In this way, the technological developments belong to the telecommunications, information technology, and drone/industrial sector, but their impact extends to the whole society.

1. Introduction

This project focuses on the challenges of integrating UAVs into the operation of a 6G network with RIS and vRAN technologies. The integration of UAVs with RIS and vRAN is an emerging area of research that has the potential to address several challenges in wireless communication systems. One of the main challenges in wireless networks is providing coverage and capacity to areas that are difficult to reach or where it is not feasible to deploy traditional base stations. UAVs can address this challenge by providing temporary or mobile coverage to areas such as disaster zones, rural areas, or crowded events.

However, the use of UAVs for wireless communication also brings several challenges, such as limited battery life, limited payload capacity, and the need for advanced navigation and control systems. RIS can help address some of these challenges by improving the signal quality and coverage, which can reduce the power consumption of the UAV's communication system. RIS can also be used to provide beamforming and interference management, which can improve the spectral efficiency of the wireless network.

Another advantage of using RIS with UAVs is that it can enable new applications such as wireless power transfer and backscatter communication. With wireless power transfer, the UAVs can be charged wirelessly using the RIS, which can extend their flight time and operational range. With backscatter communication, the UAVs can communicate with the RIS using low-power signals that are reflected off the RIS, which can reduce the power consumption and complexity of the UAV's communication system.

vRAN can also provide several benefits when integrated with UAVs and RIS. With vRAN, the radio access network is virtualized and can be dynamically configured and scaled based on the network traffic and user demand. This can improve the efficiency of the wireless network by optimizing the use of network resources and reducing network congestion. In addition, vRAN can enable new services such as network slicing and edge computing, which can provide low-latency and high-bandwidth services to specific UAV applications and users.

The main contributions of this document are as follows:

- We provide an overall vision of a 6G UAV-based scenario with RIS and vRAN. The objective of this vision is to create a highly efficient, flexible, and intelligent wireless communication system that can support a wide range of applications and services and enable new use cases that were not possible with previous generations of wireless networks.
- We focus on a particular Reconfigurable Intelligent Surface (RIS) system architecture, which is purpose-built to facilitate the upcoming 6G network. The architecture is composed of several components that are meticulously blended together to operate harmoniously, resulting in a wireless communication system that is both smooth and efficient.

This document aims to highlight the crucial role that RIS architecture plays in the overall system architecture of the project. By providing a detailed and comprehensive understanding of the specific architecture of RIS modules and their interconnections, this document serves as an essential resource for anyone interested in the potential of RIS technology in the global system architecture of the project. By providing a comprehensive overview of RIS architecture and its applications, the document aims to stimulate further research and development in this field.

This work is complemented by the following deliverables: 6G-SORUS-DRONES and 6G-SORUS-vRAN. Note that the general system architecture section will be shared across the other two deliverables.

2. General system architecture

In this section we describe a general system architecture of a 6G network to enhance the temporal or permanent coverage as well as the power consumption cost. We consider a scenario that includes UAV-based operation, Reconfigurable Intelligent Surfaces (RIS), and virtual Radio Access Networking (vRAN). An overall vision of the system is provided in Figure 1.

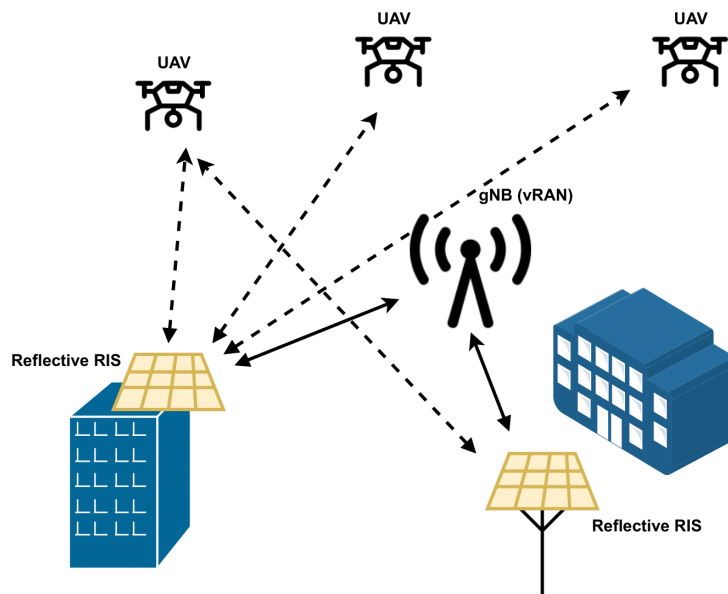


FIGURE 1 SCENARIO OF A UAV-BASED NETWORK WITH RIS AND VRAN.

Each UAV can actuate as User-Equipment (UE) or as a floating cell tower. On the one hand, by incorporating UAVs as UEs it is possible for the ground pilot to remotely control the UAV with substantially extended operation range (provided there is 6G coverage). It is also worth mentioning that is expected to enhance the performance of KPIs such as reliability, bandwidth, or security. On the other hand, by integrating UAVs as part of the network itself, i.e., as floating gNodeBs, it is possible to assist in the deployment of terrestrial wireless communications. In this case, the UAVs mount BS or relays as part of its hardware.

The main benefits of this approach are two: (i) UAV-mounted BS (Base Station) swiftly deployed on demand, which is quite attractive for use-case scenarios such as unexpected events or emergency response; (ii) due to the high altitude, UAV-mounted BS have better LoS (Line of Sight) connection with the ground users than terrestrial BS, thus providing more reliable links for communication. The aforementioned benefits make UAV-assisted communication a promising new technology to support the highly dynamic wireless data traffic in the future 6G networks.

The vRAN provides the necessary radio access network functions to enable the UAV to communicate with the core network and provide wireless connectivity to the users. The integration of UAV with vRAN can improve coverage and capacity by providing a flexible and scalable radio access network that can be dynamically configured and optimized based on the network traffic and user demand.

The vRAN can also reduce latency by providing a distributed and low-latency architecture that can process the wireless signals closer to the edge of the network.

Finally, the third key technology of the project is the use of Reconfigurable Intelligent Surfaces (RIS). An RIS is a planar structure designed with properties that enables a dynamic control of the electromagnetic waves. In addition to improving coverage on its own, RIS can also assist UAVs to overcome some of their limitations, enhancing the scenario. UAVs could also operate in collaboration with vRAN, i.e., deploying softwarized gNodeBs. Figure 2 provides an overview of the general system architecture, which comprises the main components of the architecture designed to improve coverage and sustainability, i.e., reduce resource consumption.

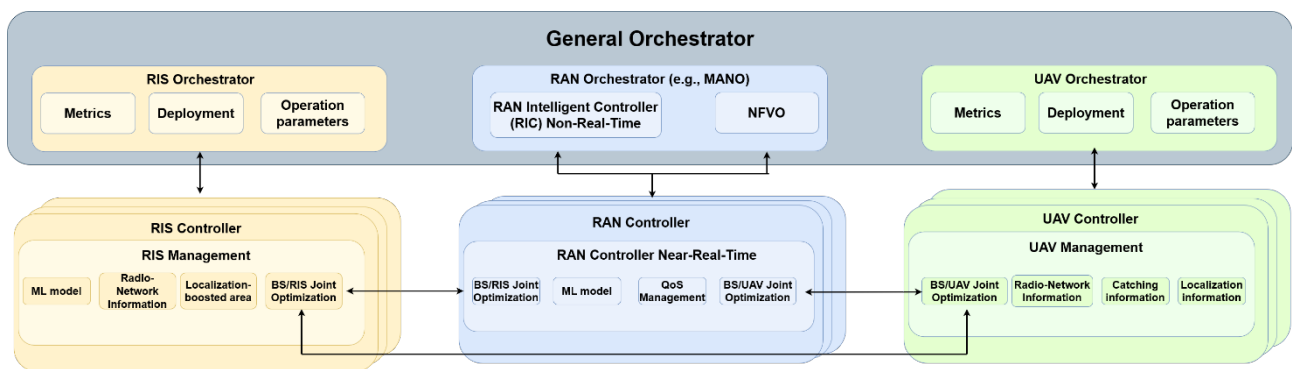


FIGURE 2 GENERAL SYSTEM ARCHITECTURE OF THE UAV-BASED NETWORK.

We next describe each block element within the general system architecture:

General Orchestrator: The general orchestrator is a software platform that enables the coordination and management of these three components to provide a seamless and efficient integration of the whole wireless communication system. By coordinating the resources and managing the network traffic, the orchestrator can provide a reliable and high-performance wireless communication system that can support a wide range of applications and services.

RIS Orchestrator: The RIS orchestrator acts as the brain of the RIS network, controlling the behavior of the individual RIS elements to achieve the desired communication goals. It uses advanced algorithms to optimize the performance of the network, taking into account factors such as signal strength, interference, and energy consumption.

RAN Orchestrator: manages and optimizes the performance of radio access networks. It is responsible for controlling and coordinating the RAN functions across multiple base stations and wireless access points, ensuring seamless connectivity and efficient use of network resources. It allows network operators to configure, monitor, and troubleshoot RAN infrastructure from a central location, reducing operational complexity and improving network reliability.

UAV Orchestrator: is a system or software that controls and manages the operations of multiple UAVs in a coordinated and efficient manner. It acts as a central hub that receives input from various

sources, including ground control stations, sensors, and other UAVs, and uses this information to make decisions on how to optimize the use of the UAV fleet.

RIS Controller: The RIS controller is responsible for configuring and controlling the behavior of each RIS element in the network, including setting the reflection and transmission coefficients for each element based on the signal strength and other parameters. The controller communicates with other components in the RIS network, such as the RIS orchestrator or other controllers, to ensure that the RIS is operating as efficiently and effectively as possible.

RAN Controller: is a device or system that manages the radio resources and access points of a wireless communication network. The RAN controller is responsible for controlling the flow of data between the core network and the end-user devices, such as UAVs.

UAV Controller: it acts as a gateway between the UAVs and the ground control station or other remote devices, enabling real-time communication and control of the UAVs. It can also monitor the status of the UAVs and the network and provide feedback to the ground control station or other devices.

The aforementioned general system architecture gives an overview of the entities involved in the 1st draft of the system architecture. Figure 1 illustrates an example of the different high-level interactions, so as the hierarchy of all components.

In the following sections we describe in detail the specific RIS architecture.

3. Specific RIS architecture

As in the previous case, the specific RIS architecture is basically composed by two components: RIS orchestrator and RIS controller. These two components are depicted in Figure 3.

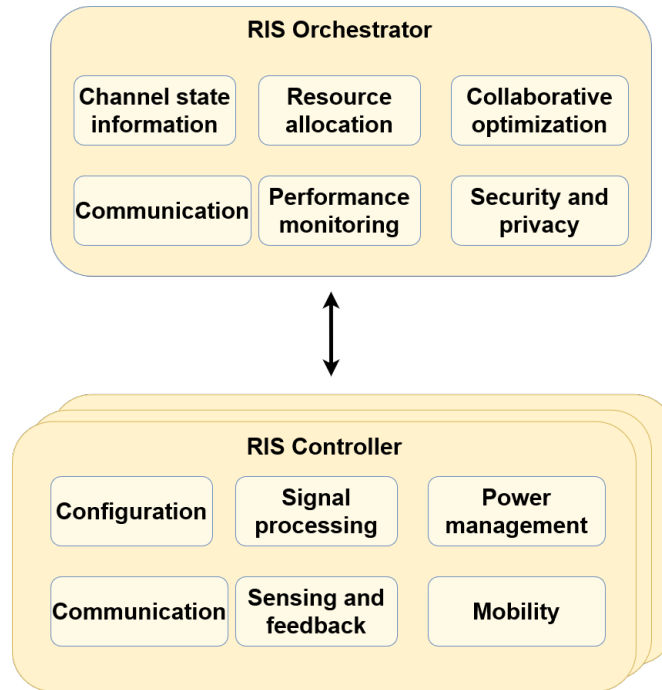


FIGURE 3. SPECIFIC RIS ARCHITECTURE COMPONENTS.

The RIS orchestrator component is responsible for coordinating the actions of multiple RIS units in a network, in order to achieve a common goal. It includes a set of software and communication systems that enable the RIS units to share information and work together to optimize the wireless communication link between a transmitter and a receiver.

The RIS orchestrator component typically includes several sub-components, such as:

1. **Channel state information (CSI):** This sub-component is responsible for acquiring CSI data from the wireless channel between the transmitter and the receiver. It includes systems for measuring the signal strength, phase, and delay of the wireless signal at various points in space.
2. **Resource allocation:** This sub-component is responsible for allocating resources (such as frequency bands, power levels, and time slots) to the RIS units in the network, in order to optimize the wireless communication link between the transmitter and the receiver. It includes systems for scheduling transmissions, selecting the optimal RIS configuration, and adjusting the transmit power of the transmitter.
3. **Collaborative optimization:** This sub-component enables the RIS units to collaborate on optimizing the wireless communication link between the transmitter and the receiver. It

- includes systems for sharing information about the wireless channel, the transmitter and receiver locations, and the performance of other RIS units in the network.
4. **Communication:** This sub-component enables communication between the RIS units in the network, as well as with the RIS management component and the user interface. It includes systems for transmitting resource allocation information, sharing CSI data, and exchanging status updates.
 5. **Performance monitoring:** This sub-component monitors the performance of the RIS units in the network and provides feedback to the RIS management component and the user interface. It includes systems for tracking the wireless signal strength, the RIS configuration, and other performance metrics.
 6. **Security and privacy:** This sub-component is responsible for ensuring the security and privacy of the wireless communication link between the transmitter and the receiver, as well as the RIS units themselves. It includes systems for encrypting and decrypting the wireless signal, authenticating users and devices, and protecting against unauthorized access or interference. It also includes systems for protecting the privacy of user data, such as location information, and for ensuring compliance with regulatory requirements related to data protection and privacy. Security and privacy are critical considerations in any wireless communication system, and the RIS orchestrator component must ensure that these requirements are met in the context of the RIS network.

The RIS controller component is responsible for controlling the operation of individual RIS units in a network, in order to optimize the wireless communication link between a transmitter and a receiver. It includes a set of software and hardware systems that enable the RIS units to dynamically adjust their surface properties to enhance the wireless signal.

The RIS controller components are described next:

1. **RIS configuration:** This sub-component is responsible for configuring the RIS units to reflect or refract the wireless signal in a way that enhances the signal strength at the receiver. It includes systems for adjusting the phase and amplitude of the reflected or refracted signal, and for selecting the optimal RIS configuration based on the channel state information (CSI) and other environmental factors.
2. **Signal processing:** This sub-component is responsible for processing the wireless signal to extract the CSI data, and for analyzing the data to determine the optimal RIS configuration. It includes systems for estimating the signal strength, phase, and delay of the wireless signal at various points in space, and for using this information to optimize the RIS configuration.
3. **Power management:** This sub-component is responsible for managing the power consumption of the RIS units, and for ensuring that the RIS units are powered on and off as needed to optimize the wireless signal. It includes systems for monitoring the power consumption of the RIS units, and for adjusting the transmit power of the transmitter to compensate for any power losses in the RIS.
4. **Communication:** This sub-component enables communication between the RIS controller component and the RIS units in the network. It includes systems for transmitting RIS configuration commands, receiving CSI data, and exchanging status updates.

5. **Sensing and feedback:** This sub-component is responsible for sensing the environment around the RIS units and providing feedback to the RIS controller to help optimize the RIS configuration. It includes systems for detecting changes in the wireless channel, such as the presence of obstacles or other sources of interference, and for providing feedback to the RIS controller to adjust the RIS configuration accordingly. This sub-component may also include sensors for monitoring environmental factors such as temperature, humidity, and air quality, to ensure that the RIS units are operating within safe and optimal conditions.
6. **Mobility:** In some applications, the RIS units may need to be mobile, for example in the context of unmanned aerial vehicles (UAVs) or autonomous vehicles. The RIS controller component must be able to support RIS mobility, by dynamically adjusting the RIS configuration to compensate for changes in the wireless channel as the RIS units move. This sub-component includes systems for tracking the position and velocity of the RIS units, and for adjusting the RIS configuration in real-time to optimize the wireless signal. It may also include systems for predicting the future movement of the RIS units and adjusting the RIS configuration proactively to minimize signal degradation.

4. Summary and Conclusions

This deliverable aims to provide a comprehensive overview of the 6G system architecture that leverages state-of-the-art technologies such as unmanned aerial vehicles (UAVs), reconfigurable intelligent surfaces (RIS), and virtual radio access network (vRAN) technologies. It explores the integration of these advanced technologies into a global system that can enhance communication capabilities and enable new applications and services.

In particular, this deliverable provides a valuable resource for understanding the integration of advanced technologies into the 6G system architecture, with a specific focus on the RIS components and their potential applications.

5. References

Mozaffari, M., Saad, W., Bennis, M., & Debbah, M. (2021). What Will the Future of UAV Cellular Communications Be? A Flight From 5G to 6G. *IEEE Communications Magazine*, 59(2), 75-81. doi: 10.1109/MCOM.001.2000261

Mozaffari, M., Saad, W., Bennis, M., Nam, Y. H., & Debbah, M. (2019). UAV Communications for 5G and Beyond: Recent Advances and Future Trends. *IEEE Wireless Communications Magazine*, 26(4), 120-127. doi: 10.1109/MWC.2019.1800080

Alexandropoulos, G. C., Phan-Huy, D. T., Katsanos, K. D., Crozzoli, M., Wymeersch, H., Popovski, P., ... & Strinati, E. C. (2023). RIS-Enabled Smart Wireless Environments: Deployment Scenarios, Network Architecture, Bandwidth and Area of Influence. arXiv preprint arXiv:2303.08505.

6G-RISE Project. (2021). Deliverable D2.5: RISE Network Architectures and Deployment Strategies Analysis: First Results. Available at: <https://www.6g-rise.eu/publications/6g-rise-deliverables/>

Acknowledgements

We thank Jesús Pérez-Valero for his feedback when discussing the different components and interfaces of the architecture.