UNICO I+D Project
6G-SORUS-DRONE

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

First version of the architecture

Abstract

The main objective of the three 6G-SORUS projects 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 UAVs in the operation of the network.

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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

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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.

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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.

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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 investigate a specific unmanned aerial vehicle (UAV) system architecture that is designed to support 6G network. The architecture comprises several components that are carefully integrated to work in tandem and create a seamless and efficient wireless communication system.

This document focuses on the significance of the UAV architecture in the overall system architecture of the project, providing a detailed understanding of its specific modules and interconnections.

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Through a comprehensive exploration of UAV technology, the document aims to illustrate the potential benefits that this technology can bring to wireless communication.

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

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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.

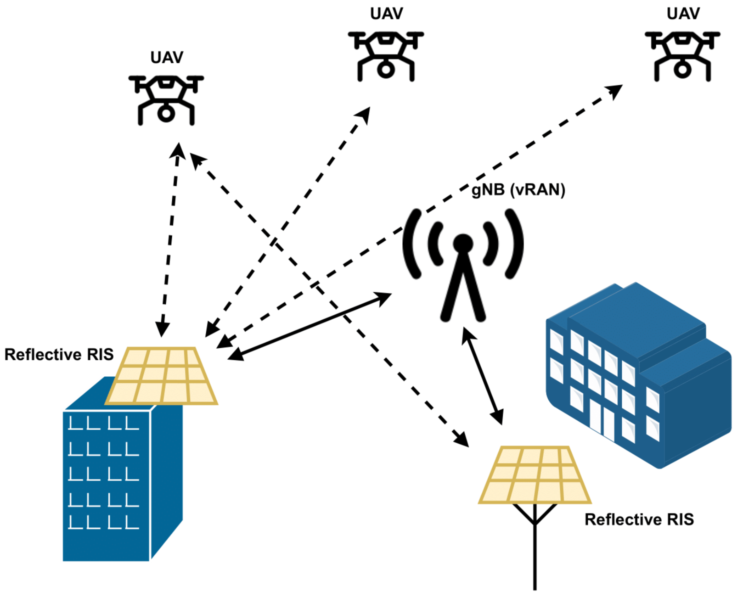

FIGURE 1 SCENARIO OF A UAV-BASED NETWORK WITH RIS AND VRAN.

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.

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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 Reconfiguranble 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.

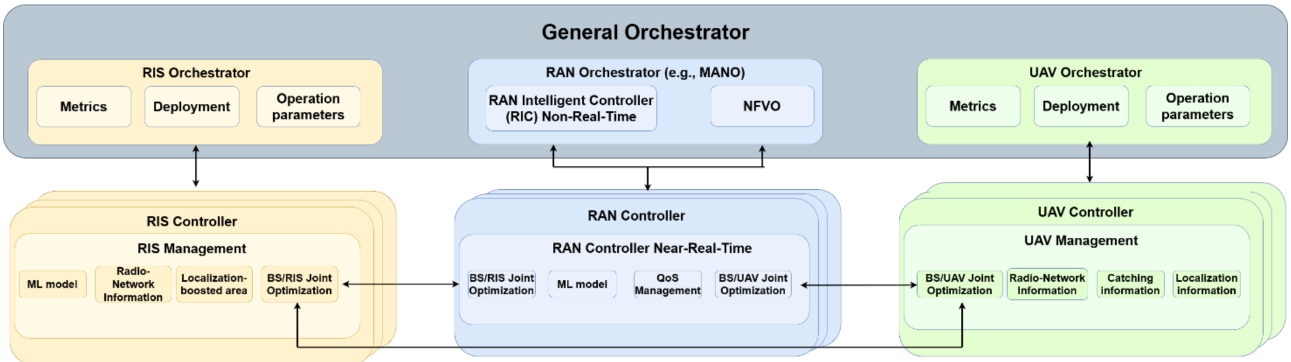

FIGURE 2 GENERAL SYSTEM ARCHITECTURE OF THE UAV-BASED NETWORK.

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

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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 UAV architecture.

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3. Specific UAV architecture

The specific UAV architecture consists mainly in two modules: UAV orchestrator and UAV controller. These two components are illustrated in Figure 3.

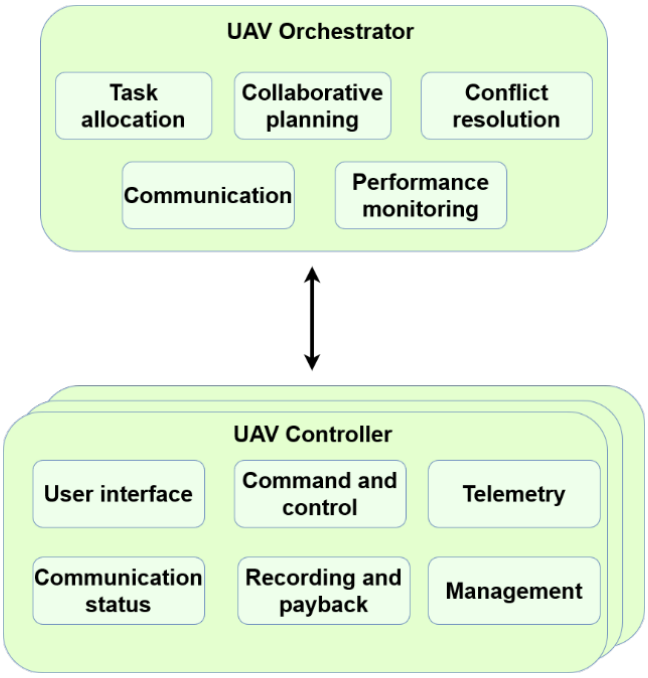

FIGURE 3. SPECIFIC UAV ARCHITECURE COMPONENTS

The UAV orchestrator component is responsible for coordinating the actions of multiple UAVs in a fleet, in order to achieve a common goal. It includes a set of software and communication systems that enable the UAVs to share information and work together to perform complex tasks.

The UAV orchestrator components are described next:

1. **Task allocation**: This sub-component is responsible for allocating tasks to the individual UAVs in the fleet, based on their capabilities and availability. It includes systems for prioritizing tasks, assigning them to specific UAVs, and monitoring progress.
2. **Collaborative planning**: This sub-component enables the UAVs to collaborate on planning and executing complex tasks. It includes systems for sharing information about the environment, the task requirements, and the progress of other UAVs in the fleet.
3. **Conflict resolution**: This sub-component is responsible for resolving conflicts that may arise between different UAVs in the fleet, such as collisions or interference with each other's sensors. It includes systems for detecting and avoiding potential conflicts, and for re-routing UAVs if necessary.
4. **Communication**: This sub-component enables communication between the UAVs in the fleet, as well as with the UAV management component and the UAV controller component. It includes systems for transmitting task assignments, sharing sensor data, and exchanging status updates.

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5. **Performance monitoring**: This sub-component monitors the performance of the UAVs in the fleet and provides feedback to the UAV management component and the UAV controller component. It includes systems for tracking flight time, battery life, sensor performance, and other performance metrics.

The UAV controller component is responsible for providing a user interface that allows an operator to control and monitor the UAV. It typically consists of software that runs on a computer or mobile device and communicates with the UAV management component to send commands and receive telemetry data.

The UAV controller component are the following:

1. **User interface**: This sub-component provides an intuitive graphical user interface (GUI) that allows the operator to interact with the UAV. It typically includes features such as a map display, camera controls, and flight planning tools.
2. **Command and control**: This sub-component provides the operator with the ability to control the UAV's flight, including take-off, landing, and autonomous flight. It allows the operator to set waypoints, specify flight parameters such as altitude and speed, and adjust the UAV's flight path in real-time.
3. **Telemetry**: This sub-component displays telemetry data from the UAV, such as altitude, speed, battery life, and sensor readings. It allows the operator to monitor the UAV's performance and identify any potential issues.
4. **Communication status**: This sub-component allows the operator to communicate with the UAV management component and other UAVs in the fleet. It includes systems for transmitting flight commands, receiving telemetry data, and exchanging status updates.
5. **Recording and playback**: This sub-component allows the operator to record the UAV's flight path and sensor data for later analysis. It also allows the operator to replay the flight and review the data in real-time or at a later time.
6. **Management**: This sub-component is responsible for managing the operations and logistics of a fleet of UAVs. It includes a set of software, hardware, and communication systems that allow operators to remotely control and monitor the UAVs, as well as track their location and performance.

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4. Summary and Conclusions

The document at hand focuses on the importance of UAV architecture within the global system architecture of the project. It presents a thorough exploration of the specific modules that make up the UAV architecture, as well as their interconnections. By providing a comprehensive understanding of the UAV architecture, the document aims to highlight the potential benefits of utilizing UAV technology to enhance wireless communication. The document aims to encourage further research and development in this area.

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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/

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