UNICO I+D Project
6G-SORUS-RAN

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

First version of the architecture

Abstract

The main objective of this document 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 vRAN in the operation of the network.

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List of Acronyms

6G: Sixth Generation of Wireless Communication Technology

BS: Base Station

B5G: Beyond 5G

C-RAN: Centralized RAN Controller

gNB: Next Generation NodeB

KPIs: Key Performance Indicators

LoS: Line of Sight

RIS: Reconfigurable Intelligent Surface

UAV: Unmanned Aerial Vehicle

UE: User Equipment

vANT: Virtualized Antenna

vBBU: Virtualized Baseband Unit

vRAN: Virtualized Radio Access Network

vRF Driver: Virtualized RF Driver

vRU: Virtualized Radio Unit

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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 focus on a specific system architecture for virtualized Radio Access Networks (vRANs), which is tailored to meet the demands of the forthcoming 6G network. This architecture incorporates several intricately interconnected components that operate in sync, resulting in a wireless communication system that is both streamlined and effective.

This document primarily emphasizes the significance of the RAN architecture in the global system architecture of the project. It provides a comprehensive understanding of the topic by thoroughly discussing the specific architecture of the vRAN modules and their interconnections.

This work is complemented by the following deliverables: 6G-SORUS-DRONES and 6G-SORUS-RIS. 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.

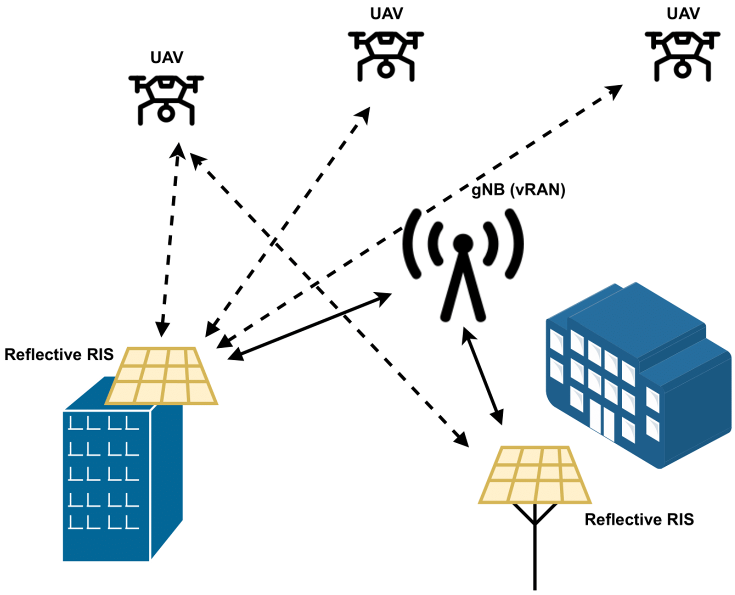

FIGURE 1 SCENARIO OF A UAV-BASED NETWORK WITH RIS AND VRAN.

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.

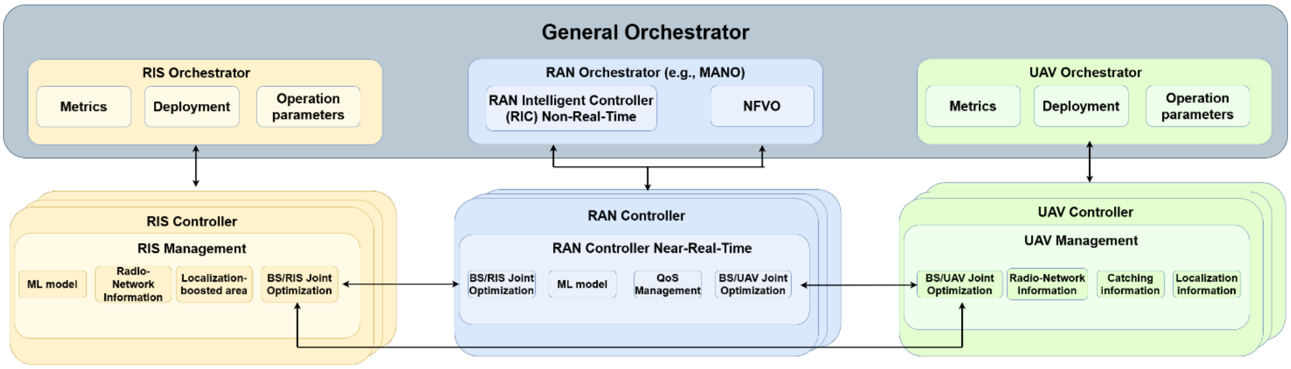

FIGURE 2 GENERAL SYSTEM ARCHITECTURE OF THE UAV-BASED NETWORK.

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 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 vRAN architecture.

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3. Specific vRAN architecture

The specific vRAN architecture is composed by two components: vRAN orchestrator and vRAN controller. These two components are depicted in Figure 3.

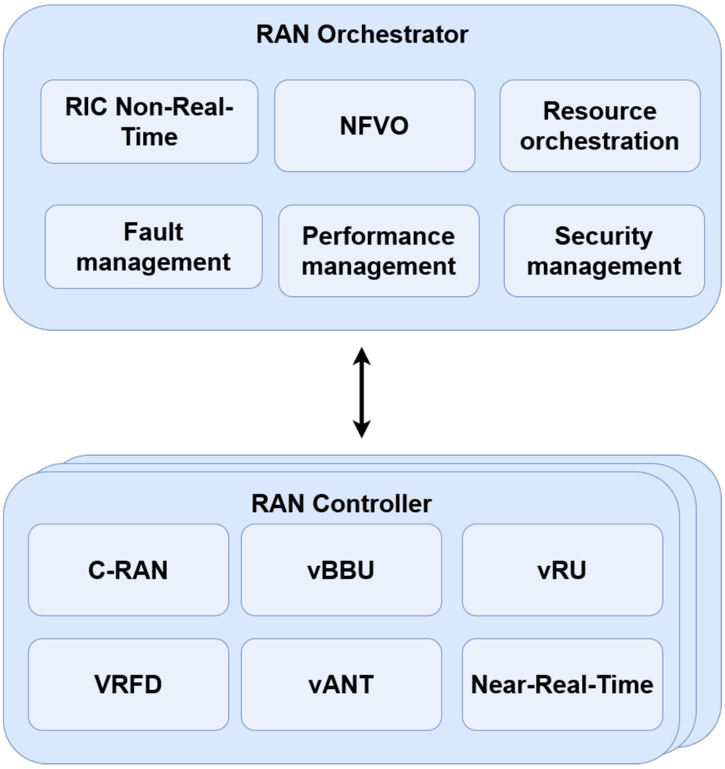

FIGURE 3. SPECIFIC VRAN ARCHITECTURE COMPONENTS.

The vRAN orchestrator is responsible for coordinating the instantiation, scaling, and termination of VNFs, as well as managing the resources required to support them. We describe its components next:

1. **The RIC (Radio Intelligent Controller) non-real-time vRAN orchestrator**: is a component of the network architecture that is designed to orchestrate non-real-time vRAN functions. It is responsible for managing the non-real-time network functions of the vRAN, such as resource allocation, configuration management, and performance monitoring.
2. **NFVO**: is a component of a network architecture that aims to virtualize the Radio Access Network (RAN) functions. It provides orchestration and management of vRAN network functions, including virtualized baseband units, radio remote heads, and other virtual network functions that make up the vRAN.
3. **Resource Orchestration:** This component is responsible for resource orchestration across the vRAN, including computing, storage, and networking resources. It manages the allocation and de-allocation of resources as needed to support the services running on the vRAN.

4. **Fault Management:** This component is responsible for detecting and handling faults and failures that occur within the vRAN. It provides mechanisms for fault detection, isolation, and recovery, as well as proactive fault prevention.
5. **Performance Management:** This component is responsible for monitoring and managing the performance of the vRAN. It collects and analyzes performance metrics from across the vRAN, and provides mechanisms for performance optimization and tuning.
6. **Security Management:** This component is responsible for managing the security of the vRAN. It provides mechanisms for ensuring the confidentiality, integrity, and availability of network resources, as well as detecting and responding to security threats.

The vRAN controller is responsible for managing and controlling the radio access network functions that are virtualized as software functions or Virtualized Network Functions (VNFs) on a common computing infrastructure. The main components of the vRAN controller are described as follows:

1. **Centralized RAN (C-RAN) Controller:** This component serves as the brain of the vRAN system, providing overall control and management of the network. It is responsible for configuring and orchestrating the various virtualized network functions (VNFs) that make up the vRAN architecture. The C-RAN controller also provides intelligence for optimizing the use of network resources, such as spectrum, power, and capacity.
2. **Virtualized Baseband Unit (vBBU)**: The vBBU is the core processing unit of the vRAN architecture, responsible for the digital signal processing (DSP) functions needed to support radio access technologies (RATs) like LTE, 5G, and beyond. It provides functions such as channel coding/decoding, modulation/demodulation, and interference cancellation.
3. **Virtualized Radio Unit (vRU):** The vRU is responsible for the physical layer (PHY) functions of the vRAN architecture, including converting digital signals into analog signals and vice versa. It also handles radio frequency (RF) processing, such as amplification and filtering.
4. **Virtualized RF Driver (vRFD):** The vRFD is responsible for managing the RF signals between the vRU and the outside world. It provides functionality such as antenna tuning, radio calibration, and dynamic power control.
5. **Virtualized Antenna (vANT):** The vANT is a software-defined antenna that can be dynamically configured and managed by the vRAN controller. It supports features like beamforming, which enables directional transmission and reception of signals, improving overall network performance.
6. **RAN Controller Near-Real-Time:** The NC-RT is a component that provides near-real-time control of the radio resources in a virtualized Radio Access Network (vRAN) architecture. The NC-RT is responsible for managing and controlling the radio resources in real-time to ensure optimal performance and quality of service (QoS) for the end-users.

4. Summary and Conclusions

This deliverable offers a general overview of the 6G system architecture, which integrates cutting-edge technologies such as unmanned aerial vehicles (UAVs), reconfigurable intelligent surfaces (RIS), and virtual radio access network (vRAN) technologies. It explores the integration of these technologies into a cohesive system that enables efficient and reliable communication.

Furthermore, the document specifically focuses on describing the different components of vRAN technology. It discusses the architecture of vRAN, which is a virtualized implementation of the traditional RAN, allowing the network to be more flexible, scalable, and cost-effective. The different modules that comprise the vRAN, such as the virtual baseband unit (vBBU), virtual remote radio head (vRRH), and centralized unit (CU), are also discussed in detail. The interconnections between these modules are also explained to provide a comprehensive understanding of the vRAN technology.

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