Financiado por la Unión Europea NextGenerationEU

MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL

Plan de Recuperación, Transformación y Resiliencia

institute IMDEA networks

E1. Project Plan

Project: RISC-6G

PROGRAMA DE UNIVERSALIZACIÓN DE INFRAESTRUCTURAS DIGITALES PARA LA COHESIÓN UNICO I+D 5G 2021

UNICO I+D

Fecha: 31/08/2022

Versión: 1.0

1. Deliverable information

Description: Revision of the project vision, considering first results generated within the project, other relevant scientific, technological or market developments, including scenario and use case definitions, requirements, KPI and evaluation criteria.

Due date: 31/08/2022

Responsible: IMDEA Networks

Partners involved: IMDEA Networks

2. Project plan

The transition from fifth-generation (5G) to sixth-generation (6G) networks is expected to be a significant leap forward in wireless communication networks. While 5G networks have already brought about faster internet speeds and more efficient connectivity, 6G networks are expected to be even more advanced. One area of particular interest is the integration of joint communication and sensing (JCAS), also known as Integrated Sensing and Communication (ISAC), which is likely to play a key role in the development of 6G networks. By combining communication and sensing capabilities, 6G networks could offer more advanced features like real-time sensing and feedback for connected devices, improved accuracy and reliability of location tracking, and more efficient use of network resources. Historically, radar (for sensing) and communication technologies have advanced separately due to their distinct system requirements and different constraints in their respective applications. However, with recent developments toward the use of higher frequencies (millimeter wave and Terahertz) and massive antenna arrays, radar and communication systems are showing similarities in channel characteristics, hardware architecture, and signal processing techniques.

Reconfigurable Intelligent Surfaces (RIS) are a relatively new technology that has the potential to revolutionize the way we use wireless networks. RIS consists of a large number of small, inexpensive, and passive reflecting elements, which can be controlled and reconfigured using a controller; thus, allowing it to modify the propagation of electromagnetic waves. It means that RIS can be used to enhance signal strength, reduce interference, and even create new wireless channels. In other words, RIS has the capability of controlling the historically uncontrollable wireless environment. In the context of 6G networks, RIS can play a crucial role in improving JCAS capabilities. By using RIS to modify the wireless environment, it may be possible to create custom communication and sensing channels that are tailored to specific devices or applications. To this end, the vision of RISC-6G is to integrate RIS with different enabling technologies of 6G wireless networks to realize its true potential for sensing as well as communication. We plan to work in multiple directions during the life cycle of the project, including but not limited to the investigation of RIS-enabled mmWave networks, exploring JCAS through mmWave testbed deployment, and designing reconfigurable metasurfaces. Based on the findings of these activities, we plan to propose a final RIS-enabled JCAS system that can be incorporated in the pre-6G systems that are in line with the roadmap proposed by the 5G Infrastructure Association and the Sustainable Development Goals set by the United Nations. Last but not least, RISC-6G will complement the other part of the ENABLE-6G project (MAP-6G) by providing support to the enabling technologies of 6G on the lower layers of the protocol stack (physical and MAC layers).

Our project plan starts off on the following fronts, which are defined based on the inputs of activity A2 and the preliminary version of the architectural components defined in activity A3. Also, activities A9 and A10 related to energy harvesting and low power communication, respectively were kicked off.

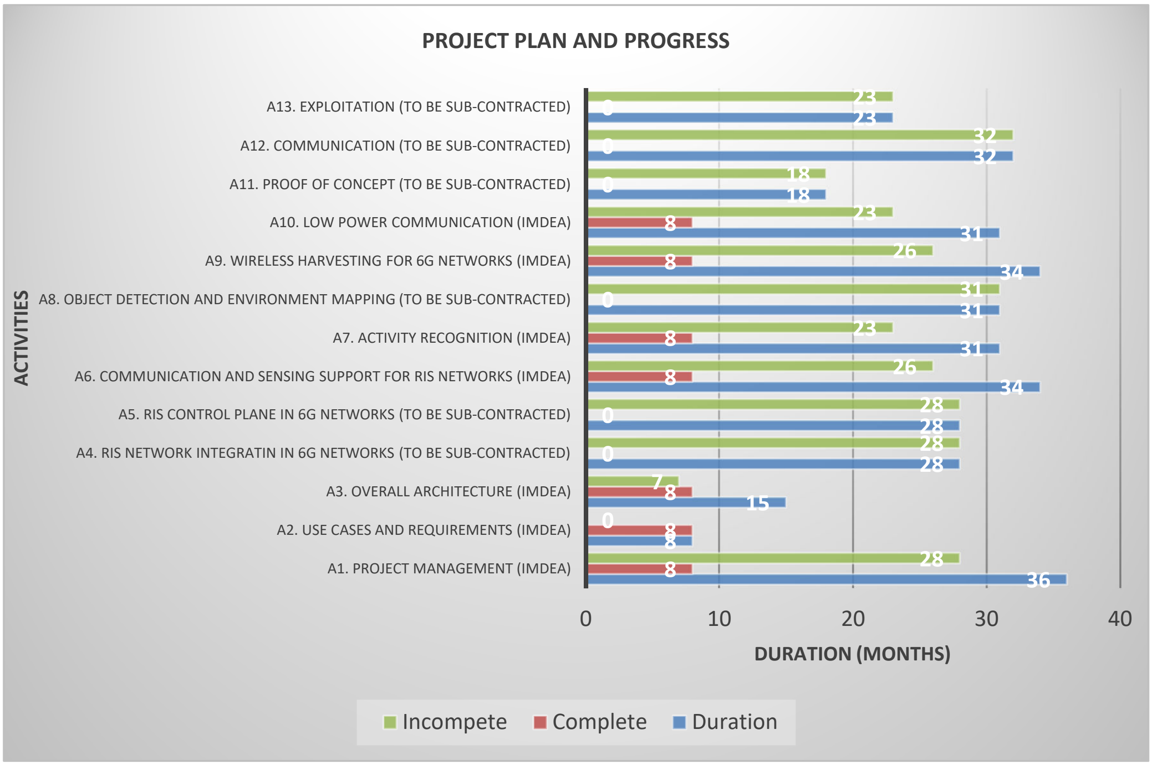

Figure 1: Project plan and status of the work packages activities as of August 2022

Regarding the project plan, in Figure 1, we show the status of the different activities that have been planned in the project. As it has been illustrated, some activities have started, and others are yet to start, while others are to be subcontracted. In the following section, non-technical and technical plans of the project are discussed.

2.1. Non-technical aspects:

The project begins by setting up project management tasks like creating mailing lists and shared folders, scheduling regular project meetings, and preparing tenders for sub-contracting activities. These activities are based on the inputs of activity A1.

Tenders are to be advertised to sub-contract activities A4, A5, A8, A11, A12, and A13 as per the project proposal, and industry sub-contractors are to be recruited via a highly competitive process.

Later, a kick-off meeting for the project will be organized to kick-start the collaboration with the sub-contractors.

2.2. Technical aspects

The technical plan of the project is discussed into following sections.

1- Integration of RIS and mmWave Networks for Better Communication Performance

mmWave communication is one of the key enabling technologies of 6G networks. mmWave networks use high-frequency electromagnetic waves to transmit data at extremely high speeds, which can greatly enhance the performance of wireless networks. However, mmWave signals can be easily blocked or attenuated by obstacles, which can limit their range and reliability. To this end, RIS can be used to enhance the performance of mmWave networks by reflecting and redirecting the signals to overcome obstacles and improve coverage. By placing RIS in strategic locations, it is possible to create a "smart" wireless environment that can adapt to the needs of different devices and applications. In addition, RIS can also be used to improve the energy efficiency of mmWave networks. One of the major challenges in establishing efficient RIS-enabled mmWave networks is channel estimation. Acquiring perfect instantaneous channel state information (CSI) of a RIS-enabled mmWave network is very costly and should thus be done infrequently. At the same time, finding an optimal RIS configuration when CSI is outdated is challenging. To investigate the impact of outdated CSI on the RIS configuration, we performed the statistical quality of service analysis of a RIS-enabled mmWave network. Our preliminary results demonstrate that better effective capacity can be achieved with suboptimal RIS configuration when the channel estimates are known to be outdated. It allows us to design system parameters that guarantee better performance while keeping the complexity and cost associated with channel estimation to a minimum.

Next, we plan to extend our system model for a multi-RIS environment, whereby multiple RISs are deployed to assist the mmWave communication network. Given that perfect channel estimates are difficult to estimate, we will leverage outdated CSI for all the candidate channels for our analysis. For channel estimation, we will explore path loss modeling for near-field as well as far-field RIS deployments. Moreover, we will investigate if and how different transmit beam widths affect the performance of a RIS-enabled mmWave network. We also plan to study and propose aggressive and conservative RIS configuration approaches based on the transmit beam widths. In the overall plan of the project, this research will help us achieve the goals mentioned in activities A4, A5, and A6.

2- Exploiting two-time Scale Variability in the Channel for RIS Configuration

RISs at mmWave bands are electrically very large (thousands of unit cells) to provide a sufficient link budget.

The typical approach of CSI acquisition and RIS optimization is challenging due to the vast overhead of CSI acquisition and the potentially complex subsequent RIS optimization. One approach to reducing the complexity of RIS configuration is to avoid optimizing the individual RIS unit cells and limit the search space to a set of phase-shift configurations (i.e., a codebook) designed offline. In the online phase, only one of the codebook entries is chosen. The advantage is that the complexity does not depend explicitly on the number of RIS unit cells but on the size of the RIS phase-shift codebook, which can be designed to be small.

At mmWave bands, the wireless channel is sparse; therefore, one may design the RIS based on the positions of users and channel scatterers, which implies that the RIS reconfiguration frequency is proportional to user/scatter movement speed, which is an order of magnitude slower (e.g., on a second scale for pedestrian), which is similar to beam management strategies in conventional mmWave systems. Such designs based solely on geometric/sensing data (e.g., angle of arrival (AoA)/angle of departure (AoD), node positions) may be efficient for strong and dominated line-of-sight (LoS) links but are inefficient in multi-path channels, even with a few scatters. To this end, we plan to investigate the following,

- To close the gap between these two extreme cases for the configuration of large RISs, i.e., using full CSI (best performance but huge overhead) and using only geometric data (low overhead but degraded performance), we intend to exploit the inherent two-time scale variability in the channel to configure the RIS.

- Furthermore, we intend to employ a two-time scale framework that allows a modular design of RIS by spatially dividing the RIS into sub-surfaces called tiles and using simple phase-shift codebooks (e.g., for realizing only anomalous reflection) per tile. Joint optimization of multiple tiles can realize more sophisticated RIS functionalities (e.g., beam focusing or splitting).

- Another major roadblock for RIS deployments is the need for a fast and complex control channel to adapt continuously to the ever-changing wireless channel conditions. We intend to investigate the feasibility of developing Self-Configuring solutions for RIS, which helps in the effortless and seamless installation of intelligent surfaces.

In the overall plan of the project, this research will help us achieve the goals outlined in activities A4, A5, and A6.

3- Exploring JCAS/ISAC through mmWave Testbed Deployment

Experimental deployments of mmWave networks for sensing and localization allow us to evaluate the performance of these networks for new technologies and use cases of 6G wireless systems. It is particularly important for object sensing, where the performance of the technology can be affected by factors such as object size, shape, and material, as well as the presence of interference from other wireless devices. By conducting experiments in real-world scenarios, we can evaluate the performance of the technology under a wide range of conditions and identify any limitations or areas for improvement. We have been putting efforts toward solving the limitations of practical bi-static and multi-static sensing in the context of mmWave systems. Most of the prior works in this area are either based on simulation-only environments or showcased by experiments in heavily controlled environments that prevent their applicability in real scenarios. We are also exploring the possibility to extend the capabilities of the Mimorph testbed to handle ISAC (also known as JCAS) configurations and to ease its use in dense deployment scenarios, which are of special interest in the context of multi-static ISAC scenarios.

Next, we plan to investigate the multi-band ISAC system, specifically, to design and implement a system that incorporates the advantages of low (sub-6GHz) and high (mmWave) frequency systems simultaneously. We want to leverage the rich multi-path profile of the sub-6GHz systems, which allows us to coarsely detect targets in the environment. However, it is challenging to detect multiple targets (and separate them) present in a close space using these systems due to their limited bandwidth availability. On the other hand, mmWave systems have large bandwidth at their disposal (due to the high-frequency spectrum) and, therefore, can provide high-resolution multi-object sensing in a close space and human activity recognition. By combining both of these systems, we plan to propose a multi-band ISAC system and then evaluate it using testbed deployment. The proposed multi-band ISAC system will leverage signals of cellular and non-cellular networks for activity recognition and object detection of active or device-free targets. In the overall plan of the project, this research will help us achieve the goals outlined in activities A3, A7 and A8.

4- Designing Reconfigurable Metasurfaces for Sensing in 6G Networks

Reconfigurable metasurfaces can achieve high sensitivity and resolution in sensing applications, which are at the core of research activities toward efficient 6G wireless systems. The metasurface can be designed to interact strongly with the target signal or object, enabling high signal-to-noise ratios and accurate detection. Moreover, metasurfaces can be designed to have a small size and footprint, making them suitable for integration with conventional devices and systems. It is important to design metasurfaces that provide accurate wireless sensing as well as an enhanced performance of communication systems. To this end, we plan to design a novel metasurface to boost sensing resolution in the face of traditional metasurfaces that focuses on increasing the coverage of wireless sensing and communication systems. Our planned metasurface will leverage the angular dispersion property of metasurfaces and integrates it with signal processing methods to improve sensing performance instead of relying on traditional beamforming and focusing functionality. Once designed, this metasurface will boost our efforts for experimenting with the proposed algorithms for multi-object detection and human activity recognition using practical deployments. In the overall plan of the project, this research will help us achieve the goals outlined in activities A6, A7, and A8.

5- 6G Architectural Design Extensions for Sensing and Localization

3GPP has conducted significant work in localization with Release 16 and 17, and in the recent Release 18 (called 5G Advanced), it has become one of most active areas. The 5G location architecture is based on the enhanced LoCation Service (eLCS) architecture defined in 3GPP to support location services. Upcoming 3GPP releases promise to further enable new techniques for accurate and low latency positioning, fulfilling stringent positioning requirements of new location-based services in sectors such as industry, healthcare, and intelligent transportation systems. Furthermore, the topic of wireless sensing has become part of study in the recently started Release 19.

We plan to study the key scientific and technological enablers of future 6G networks for location and sensing-based analytics and propose accordingly extensions of the 6G architecture. Specifically, we plan to leverage the insights of our preliminary design for the Location Management Function (LMF), expose its functionality to the RAN to be able to perform end-to-end experiments and design a new Sensing Management Function (SenMF). Unlike the LFM, the SenMF poses a high burden to storage management hence requires innovating significantly the existing network architecture. In the plan of the project, this aligns with A7 "Extensions to the 6G architecture for comprehensive Location Management Functions."

6- Low-power communications and wireless harvesting for 6G networks

Massive deployment of low power mobile devices could be derailed by their dependency on batteries. To alleviate this challenge, 6G presents a unique opportunity to design dedicated waveforms that can somewhat allow mobile devices to form as a backscattering node to piggyback its data to an incoming signal, enabling these devices to operate without batteries or on low or near-zero power consumption. Currently, RF backscatter operates with low spectrum efficiency, uses very simple modulations that are not robust to interference.

In this project, we will leverage visible light communication and RF backscatter to propose the following low-power communications and wireless harvesting techniques for 6G networks:

We plan to propose a combination of LiFi and RF backscatter technology to enable battery-free Internet of Things (IoT), enabling LiFi-enabled IoT deployments such as in the monitoring and control of next-generation green-houses. Leveraging LiFi and RF backscatter technology in our work would provide next-generation green-houses with low-power, yet efficient and flexible illumination.

We also plan to propose a new receiver architecture able to achieve joint communication and energy collection by mixing a photodiode signal with a locally generated radio frequency carrier signal. This architecture will intergrate both VLC and RF backscattter in its design through utilizing OpenVLC as the LiFi transmitter, and the photodiode to receive LiFi information and transmit it via the RF-backscatter mechanism.

Further, we plan to design a new modulation scheme based on On-Off-Keying (OOK) and Pulse Width Modulation (PWM). The modulation scheme will be simple, low cost, and yet efficient as it would exploit the densification of artificial lighting inform of visible light and infrared spectrum.

Table: Summary of Research Activities

	Research Direction	Activities
1	Integration of RIS and mmWave networks for better communication performance in 6G	A4, A5, A6
2	Exploiting two-time scale variability in the channel for RIS configuration	A4, A5, A6
3	Exploring JCAS/ISAC through mmWave testbed deployment	A3, A7, A8
4	Designing reconfigurable metasurfaces for sensing in in 6G networks	A6, A7, A8
5	6G Architectural Design Extensions for Sensing and Localization	A7
6	Low-power communications and wireless harvesting for 6G networks	A9, A10

3. Subcontracting plan

<u>Report on the bidding process for RISC-6G.</u>

The Ministry of Economy and Digital Transformation published the model specifications for the tenders corresponding to the UNICO subprojects in March 2022. The first template included some mistakes that were fixed in the following months, so we couldn't complete the bidding documents for RISC-6G until the end of June.

Tender announcement: The date of publication of the contract notice has been fixed in various sources:

- Portal de la Contratación de la Comunidad de Madrid: July 5, 2022.
- Diario Oficial de la Unión Europea: July 8, 2022.
- Boletín Oficial de la Comunidad de Madrid: July 15, 2022.

Lots offered: 3 for MAP-6G.

Approval: The estimated date of approval of the award by the Delegate Commission (Region of Madrid) and the Secretaría de Estado de Telecomunicaciones is in October 2022.

Assignment and Commencement of Tasks: The award is expected for October or November 2022, and the corresponding tasks are expected to start in late 2022 or early 2023.

Work report delivery dates: Despite the delay in the bidding process, the delivery dates of the work reports of the subcontracted companies are maintained in order to continue with the project deliverables plan without changes.

In conclusion, the bidding process for MAP-6G is expected to progress as planned, with the awarding of the lots in October or November 2022, and the start of the corresponding tasks by the end of 2022 or beginning of 2023. Despite the delays in the process, it is expected that the delivery dates of the work reports of the subcontracted companies will be met.