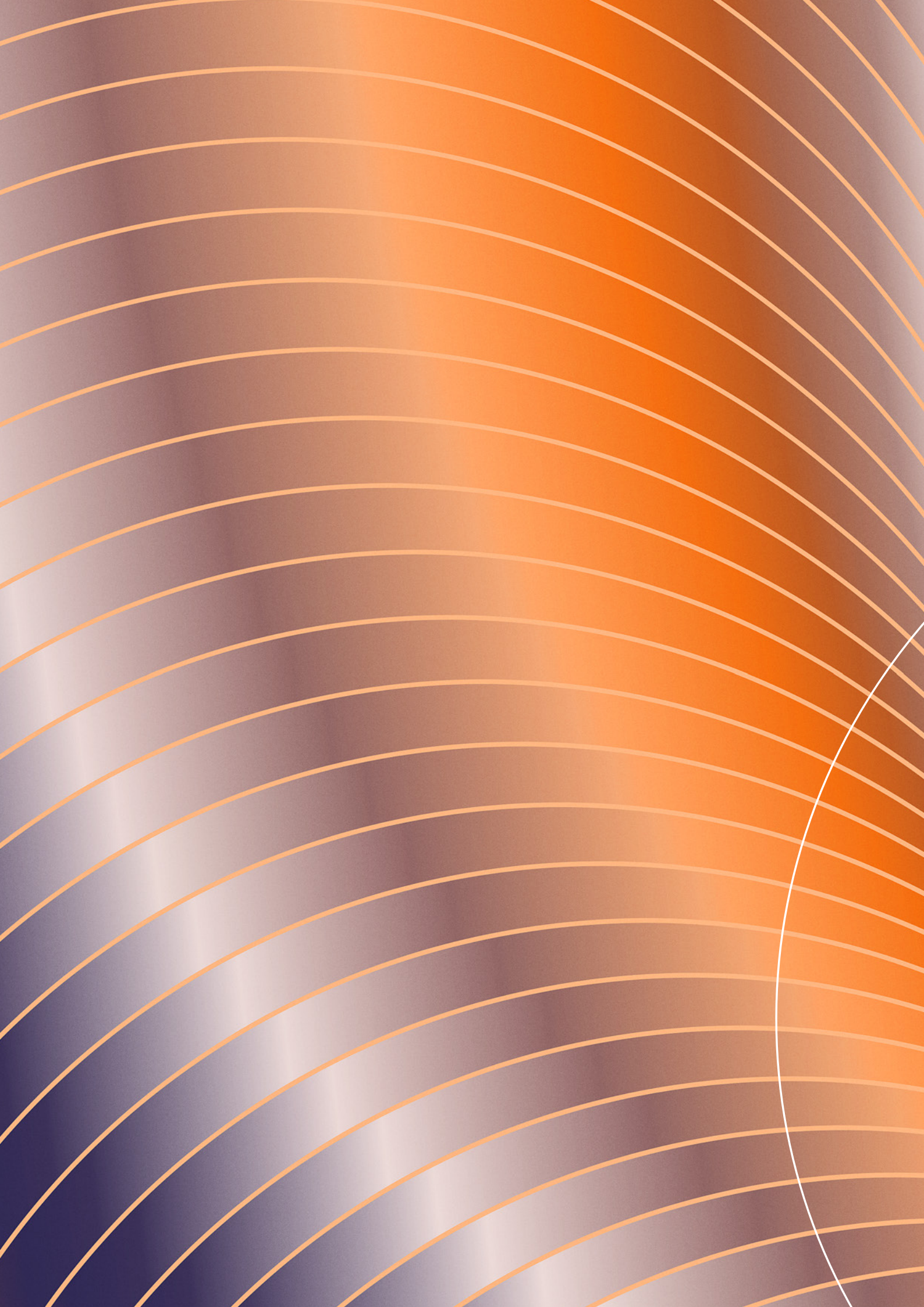
Annual report

cttc

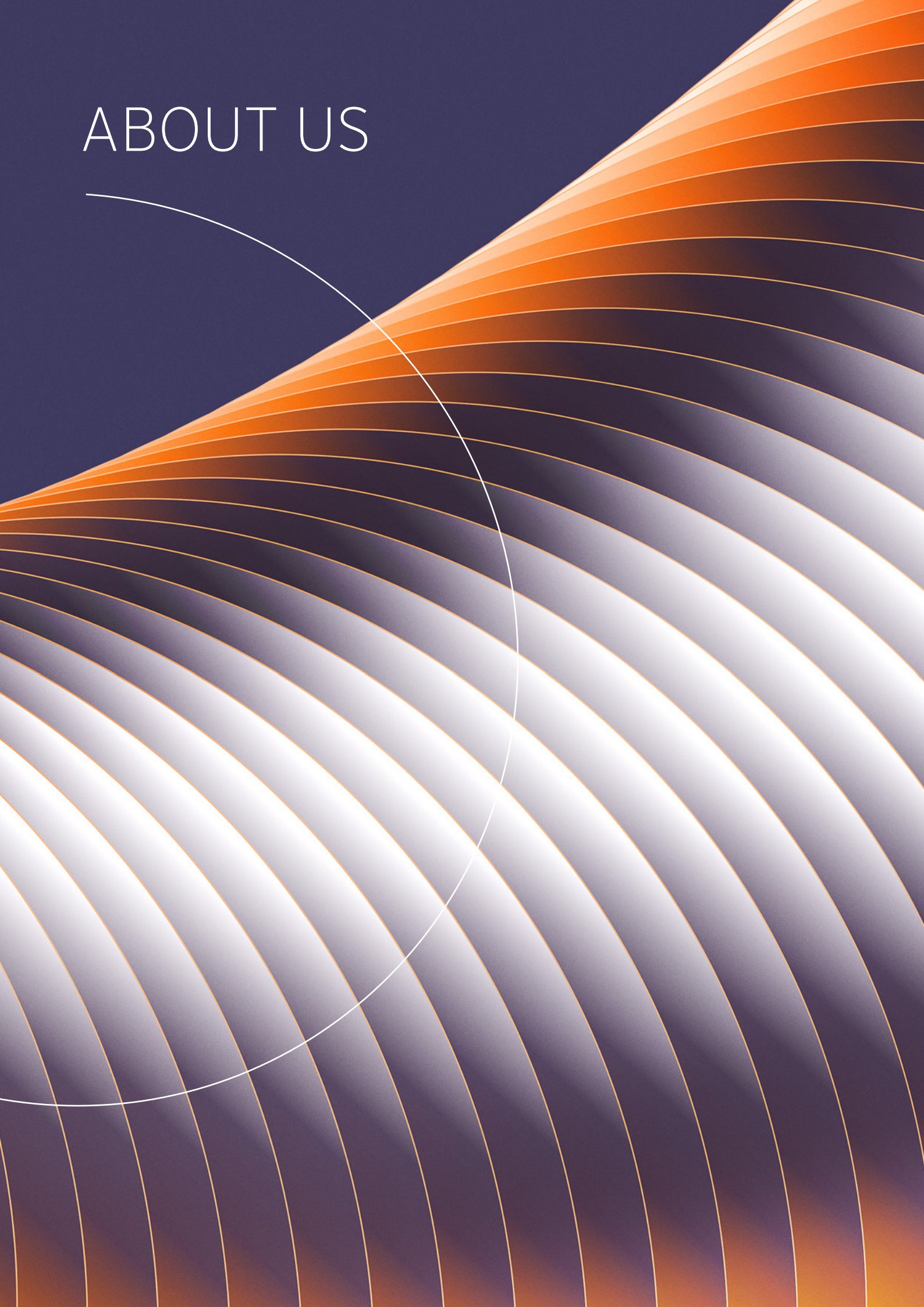
Advanced research for everyday life

Annual Report



Outline

ABOUT US



The Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) is set to reinforce its role as a leader in telecommunications and geomatics research through a strategy centered on excellence and investment on singular infrastructure for long-term growth. Building on its mission to drive innovation for a future digital society and serve as a connector between academia, industry, and the public sector, CTTC has launched some initiatives to advance its vision of being a lighthouse for research of excellence. In this memory you can find a good summary of them.

At CTTC, we continue with our commitment to develop next-generation technologies in a sustainable way to help mitigate the effects of climate change and support adaptation strategies. Our research covers a broad range of communication technologies – from sensors and wireless or wired networks to satellites – and is backed by deep in-house expertise across the full telecommunications spectrum, from physical devices to network services and orchestration. This is further strengthened by our advanced capabilities in remote sensing and geomatics, enabling a holistic approach to climate-related challenges. We focus on sustainable innovations such as eco-friendly printed electronics, energy-efficient hardware, integrated communication and sensing systems for circular models, and energy monitoring and optimization across network infrastructures, including mobile, optical, and satellite networks, as well as data centers. Our work also includes the development of distributed and lightweight AI models, inspired by brain architecture and physics, and the integration of satellite and ground-based sensing with ICT networks. All of this is carried out in close collaboration with key application sectors such as the Internet of Things, Artificial Intelligence of Things, smart buildings and cities, smart grids, mining, landslide and glacier monitoring, biomass and soil moisture estimation, and coastal and urban environmental monitoring.

CTTC leading the sustainable Telcos

With more than 90% increase in self-raised funds in 2024—driven largely by the Next Generation national funds—CTTC enters 2025 with strong momentum and renewed strategic capacity. The center's commitment to advancing future telecommunications technologies remains exceptional. CTTC is powered by a multidisciplinary team of 123 researchers, part of a total staff of 150 professionals representing 29 nationalities. This reflects a 40% increase in research personnel since 2022. Among them, women account for 20% of the research staff, underscoring ongoing efforts to improve gender representation in STEM fields. To promote diversity and inclusion, the institution has implemented mentorship and leadership development specifically for women in STEM, complemented by a supportive internal network. CTTC has also expanded its talent pipeline by launching Starting Research grants for highly qualified master's students and Young Talent Research Stays for undergraduates, aiming to foster early engagement in scientific careers. Supporting this growth, the organization will continue to improve career development processes, ensuring researchers have clear paths forward through open calls, mentorship, and recognition systems. CTTC unites researchers, engineers, and innovators across diverse domains such as wireless communications, networking, and sensing technologies. Through active collaboration with academia, industry, and government institutions, the center continues to serve as a catalyst for transformative innovation—translating cutting-edge research into tangible, real-world solutions.

Ana Isabel Pérez-Neira
Director

Management

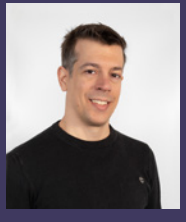
CTTC's Director
PROF. ANA ISABEL PÉREZ-NEIRA

MERCÈ CARRASCO
General Administrator

DR. MONICA NAVARRO
Director of Institutional Relations & Communication

DR. MICHELA SVALUTO MOREOLO
Director of Quality Programs

DR. CARLES ANTÓN-HARO
Director of European Programs & Industry Contracts



DR. MIQUEL PAYARÓ
Director of National Programs and their Industry Leads (Open Innovation & Science)

DR. XAVIER MESTRE
Scientific Coordinator

Research Units

Dr. Josep Mangues
Head of Services as Networks (SaS)

Dr. Raül Muñoz
Head of Packet Optical Networks and Services (PONS)

Dr. Sandra Lagén
Head of Open Simulations (OpenSIM)

Dr. Paolo Dini
Head of Sustainable Artificial Intelligence (SAI)

Dr. Jesús Gómez
Head of Information and Signal Processing for Intelligent Communications (ISPIC)

Dr. Nikolaos Bartzoudis
Head of Adaptive Processing Technologies (ADAPT)

Dr. Miquel Ángel Vázquez
Head of Space and Resilient Communications and Systems (SRCOM)

Dr. Carles Fernández
Head of Navigation and Positioning (N&P)

Dr. Michele Crosetto
Head of Geomatics (GM)

Board of Trustees

The Board of Trustees is the highest governing and representative body of the CTTC. It is constituted by the representative members of the promoting institutions: the Generalitat de Catalunya, the Universitat Politècnica de Catalunya – Barcelona TECH (UPC) and the Ramon Llull University (URL).

Representative members (as of 31st of December 2024)

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Consellera for Research and Universities

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Chancellor of the Universitat Politècnica de Catalunya – Barcelona Tech (UPC)

Rector Mgfc. Josep Antoni Rom Rodríguez
Chancellor of the Ramon Llull University (URL)

Sr. Joan Gómez i Pallarès
Director General for Research, Department of Research and Universities

Sr. Marc Darder i Solé
Head of Technical Cabinet at the Department of Territory

Sr. Júlia Rubert i Tayà
Responsible of the Research and Innovation Area, Technical Cabinet of the Department of Territory

Sr. Albert Tort i Pugibet
Secretary of Telecommunications and Digital Transformation

Sra. Laia Pellejà i Puxeu
Director of the CERCA Institute (I-CERCA)

Scientific Advisory Board

The Scientific Advisory Board offers independent guidance on our research strategy and provides expert evaluation of the scientific quality of CTTC's R&D activities. Composed of internationally renowned scientists, the Scientific Advisory Board advises the Director and the Management Team.

Members in alphabetical order

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Universitat Politècnica de València

Prof. Carla Fabiana Chiasserini
Politecnico di Torino

Dr. Markus Dillinger
Huawei Technologies

Prof. Octavia Dobre
Memorial University

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New York University

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European Space Agency

Dr. Rosa María Mateos Ruiz
Instituto Geológico y Minero de España

Dr. Carolina Pinart
Nestlé

Dr. Colin Willcock
Nokia Networks

FACTS & FIGURES

CTTC in NUMBERS

Total income distribution

Others
1.206.987 €

R&D services
2.059.580 €

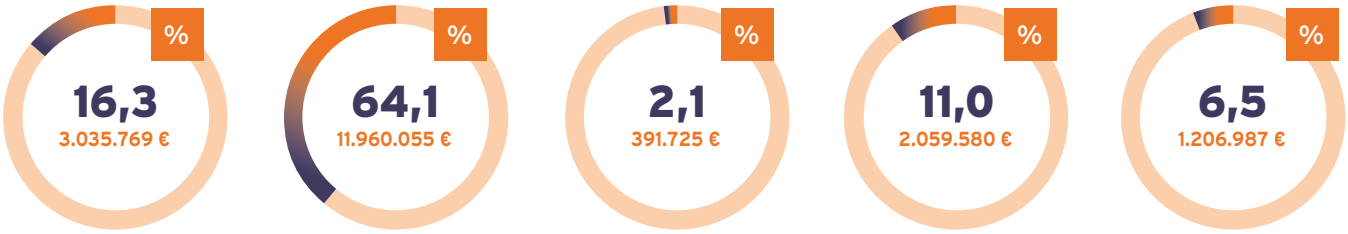
Core funding
3.986.622 €

Competitive funds
15.387.549 €

Total self-raised funds

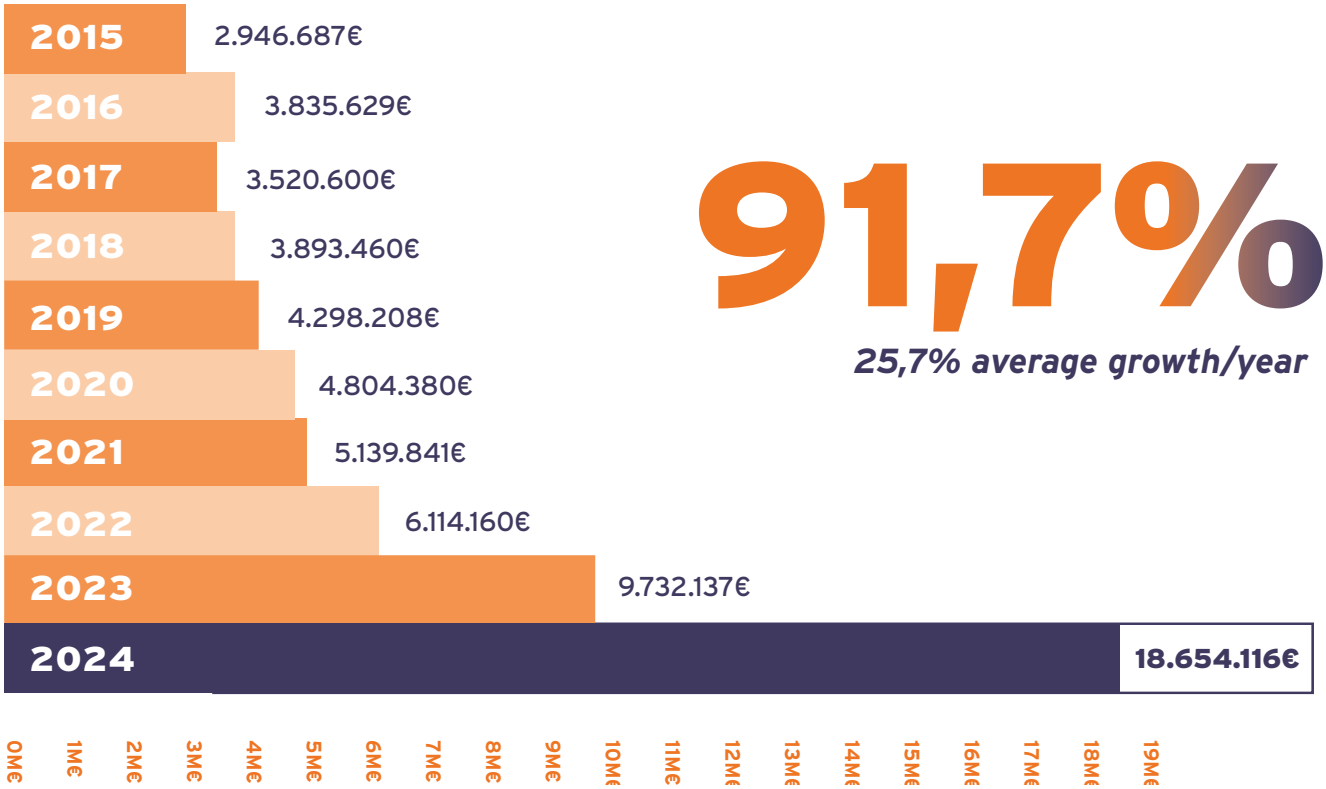
18,65 M€

R&D distribution



Number of R&D projects

Income evolution



91,7%

25,7% average growth/year

Scientific Publications

76
Journals (indexed)

130
Conferences

43 **56,6%**
First quartile

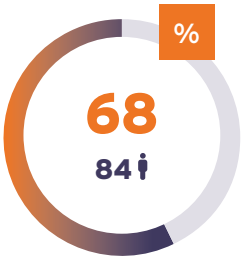
5,2 *Average Impact Factor*

Knowledge and Technology Transfer

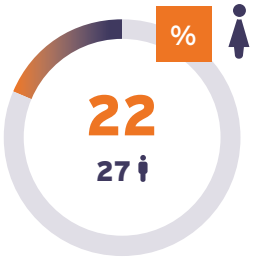
Granted patents in force **28**

Industry innovations **25**

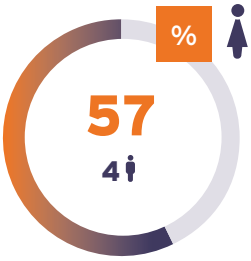
STAFF



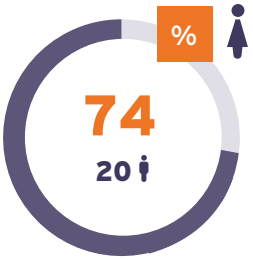
Doctors



Women in Research



Women in Management



Women in Administration & Support

82% Researchers

18% Admin & Support

4% Management

123

27

7

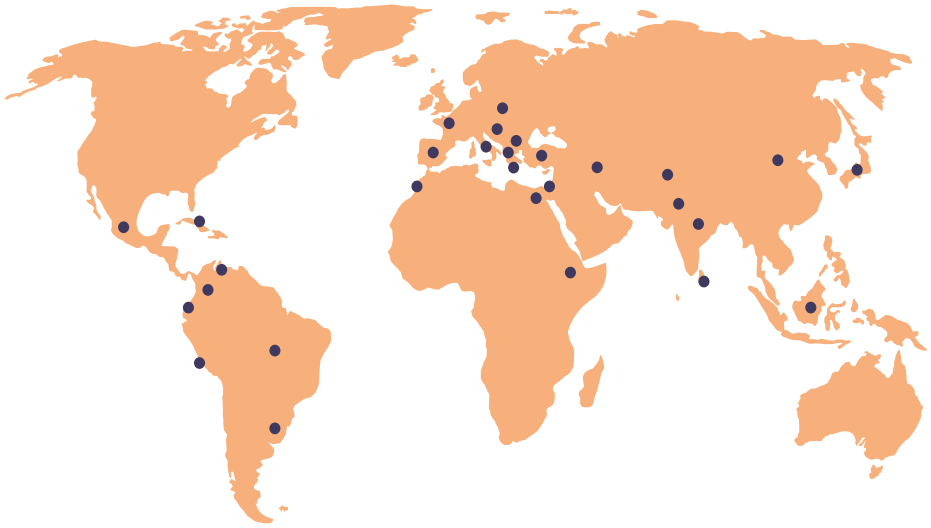
25 **20%** Research Trainee *R1*

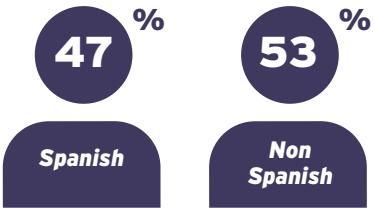
56 **46%** Researcher *R2*

27 **22%** Senior Researcher *R3*

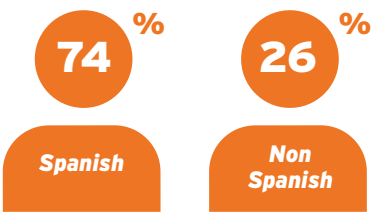
15 **12%** Research Director *R4*

29 different nationalities





RESEARCHERS



ADMIN. & SUPPORT

RESEARCH HIGHLIGHTS

Technology at the Service of Society – With and For Sustainability

In CTTC we are committed to designing the next generation technologies in a sustainable fashion to mitigate as much as possible the effects of climate change and to provide the most advanced tools for adaptation.

Our research directly involved in sustainability embraces a comprehensive set of communication technologies: from sensors, through wireless and wired networks, to satellites. Leveraging on in-house long-term expertise covering the full spectrum of telecommunication technologies (from physical layer access and devices to network layer services, protocols and orchestration), complemented with the strong group in remote sensing and geomatics CTTC is very well positioned to pursue a holistic approach for the challenging climate change problem.

Some examples of the sustainable technologies we are addressing are in the fields of

- Printed electronics with eco-friendly materials,
- Energy-efficient hardware design,
- Joint communication and sensing for a circular paradigm,
- Radio access network energy monitoring and optimization,
- Energy monitoring and optimization specifically catered for the different network segments (mobile networks, optical transport networks, satellite networks) and com puting components (datacenters).
- Distributed AI models (federated and decentralized) and lightweight machine learning models with brain-inspired and physics-informed solutions
- Satellite remote sensing, Ground-based sensing and its integration with the ICT networks.

Knowledge advance and technology development is carried out in close interactions with verticals and applications. To cite a few: Internet of Things, Artificial Intelligence of Things, Smart buildings, Smart cities, Smart grids, Mining, Landslide, Glacier/snow monitoring, Biomass estimation, Soil moisture estimation, Coastal monitoring, Urban monitoring.

As an example of the specific contributions, we list here only a few of the technical contributions:

Sustainable AI/ML

Lightweight brain-inspired ML models have been considered to enable easier deployment of Reservoir Computing solutions, which establish the grounds for research solutions that compete with state-of-the-art AI deployed applications and for its deployment in real-world settings and resource-constrained devices. Hyperparameters optimization was identified as a major bottleneck in Reservoir Computing adoption, and we proposed an adaptive ϵ-greedy search strategy to significantly reduce the time and energy costs associated with offline tuning.

Technology components

Development of energy-aware technology building blocks for radio access:

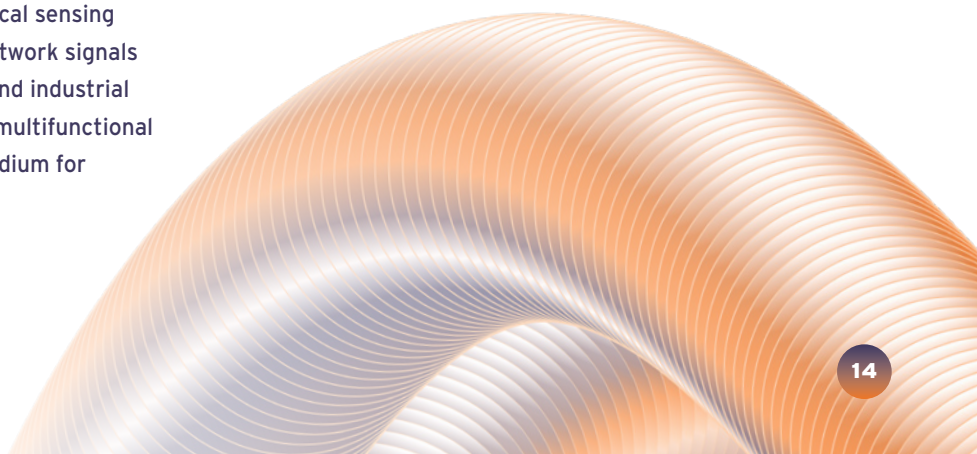
- Within the new open-source O-RAN paradigm we looked at energy-proportional radio micro-orchestration solu tions to develop a framework for optimizing power con sumption at the digital and the analog radio functions. This work leverages expertise on system-on-chip FPGA prototyping for 5G radio and power amplifier digital predistortion techniques.
- Continue to develop signal processing and lower layer solutions aimed at reducing power consumption: these efforts include emerging light Medium Access Control (MAC) protocols that reduce signaling overhead and focus on energy-efficient AI/ML algorithms; efficient de signs for large and distributed multi-user and multi-an tenna systems and distributed computing.
- Development of Kubernetes simplified with AI-pow ered automatic scaling to optimize cloud resources/ performance trade-off, reducing unnecessary resource consumption and the subsequent carbon emissions. Further implementation of collection mechanisms for energy measurements (from physical devices, virtual functions and computing resources) is on-going.
- Development of power consumption models for optical transport infrastructure, combining optical transponders, optical switches, optical amplifiers and AI-assisted SDN controller.
- Design of sensors for physical and chemical sensing (pressure, temperature, gas) using 6G network signals with applications in climate monitoring and industrial security. For example, we demonstrated multifunctional hardware like microwave cable with palladium for hydrogen and CO2 detection.

Network architecture and services

Projects such as SEASON and 6G-RAISING are examples of activities addressing sustainability from a network architecture and operation point of view. The first one is developing power-efficient Digital Signal Processing (DSP), and multiband SDM optical switching (MBoverSDM) to reduce the number of optical/electrical/optical (O/E/O) conversions by allowing traffic aggregation/router bypassing, and converged packet-optical solutions. The second is developing micro-orchestration services for edge-assisted energy efficient transceivers that allow the reconfiguration of key low-PHY functions, such as the digital predistortion, and other 6G radio transceivers components with the use of AI/ML techniques.

CTTC technologies at service of Earth & climate monitoring

Leveraging CTTC's multidisciplinary research team, a new internal working group started to develop a holistic approach towards enabling technologies for carbon credit measuring and offsetting exchanges. Integrating remote sensing satellite data, sensor data and ICT network infrastructure with AI algorithm for prediction and anomaly detection, we are developing enhanced tools for CO2 measuring and CO2 offsetting tools.



R&D Projects

R&D efforts remain focused on the development of 6G, tackling challenges that range from core technology components and enabling building blocks to network architectures and services. As previously mentioned, a key area of research is the sustainability of ICT technologies and the role ICT—alongside complementary technologies—can play in addressing environmental challenges. In the context of future network development, advancing in close collaboration with vertical industries, network architectures and services continue to play a crucial role, alongside the emerging convergence of communication, computing and intelligence power. Notable progress has been made in integrating terrestrial and non-terrestrial networks, leveraging 5G standards towards 6G designs.

The diversity of technological challenges and contributions is also reflected in the different nature of R&D projects, involving self-funded initiatives, direct industrial contracts and collaborative consortiums established from competitive funded activities.

Technical expertise and advice are also put to the service of society through specific applications and the close involvement of verticals. Some relevant examples are the development of remote sensing and geomatic techniques for Earth Observation and climate monitoring.

AI-powered Evolution towards Open and Secure Edge Architectures - VERGE is based on three conceptual pillars: i) the "Edge for AI" (Edge4AI), responsible for enabling the unified compute continuum environment, encompassing the heterogeneous pool of computing resources from the edge to the cloud; ii) the "AI for edge" (AI4Edge), a portfolio of AI methods to optimize and automate different aspects of the computing and network performance in diverse and dynamic B5G/6G environments; and iii) the "Security, Privacy and Trustworthiness for AI"(SPT4AI), addressing relevant challenges on robustness, privacy, safety, and explainability of the developed AI models, targeting to enhance their overall trustworthiness. CTTC, which leads Proof-of-Concept demonstrations, has made valuable contributions to all 3 pillars by

- designing a hierarchical micro-orchestrator for functions hosted in FPGA SoC accelerators encountered in Radio and Distributed Units (RU and DU respectively),
- providing a feasibility study of an edge-assisted AI-ML DPD model for RUs,
- generating a dataset for RAN AI/ML algorithm training and
- building a PoC demonstration where the concept of the micro-orchestrator has been tested and validated.

6GBLUR focuses on i) smart decision-making algorithms for efficient end-to-end resource management and ii) joint RAN and transport network control/orchestration mechanisms, for blurred and disaggregated network architectures. The project led by CTTC has developed various proofs of concepts and explored multiple key concepts, including network digital twin, non-public networks, AI/ML monitoring, QoS management and radio stack optimization. The activity benefited CTTC's experimental infrastructure and simulation tools. More specifically,

- CTTC's EXTREME testbed® was extended with Ericsson digital twin equipment and connected with Telefonica premises for an end-to-end zero-touch orchestration demonstration,
- open-source system level simulator ns-3 5G-LENA evolved with various QoS scheduling mechanisms and fronthaul control methods.

6G Radio Access Network Intelligence and Micro Orchestration for Edge-Assisted Energy-Efficient Transceivers - 6G-RAISING - Despite the significant advancements in 5G systems—particularly the introduction of zero-touch automation in radio access networks through artificial intelligence and machine learning (AI/ML) models—the physical layer (PHY) and digital front-end linearization functions within radio units (RUs) have largely remained a black box. These components are typically configured during design or implementation and remain virtually unchanged throughout their operational lifetime. However, this trend is being challenged by the functional splits introduced in 3GPP and the specifications of the open radio access networks (O-RAN) alliance, which opens the door to reconfigurable RUs by including the management place (M-plane) and new programming interfaces that enable access to relevant RUs parameters. O-RAN is evolving in 6G, with a study group focusing on how to complement the existing non-real-time and near-real-time RAN intelligent controllers (RIC) with a real-time RIC; the latter will serve new highly reconfigurable 6G RUs, able to address the extreme and conflicting requirements of the foreseen 6G applications (e.g., ultra-high performance under an energy sustainable operation framework). In this context, 6G-RAISING is proposing timely innovations that will allow the reconfiguration of key low-PHY functions -starting from the digital predistortion (DPD) one- and 6G radio transceivers components with the use of AI/ML techniques. To succeed, it is essential to expose key radio unit (RU) configuration, initialization, sensing, calibration data, and signal captures—to the O-RAN RAN Intelligent Controllers (RICs). These inputs allow AI/ML models to drive a new level of automated RU reconfigurability, delivering significant gains in performance and sustainable operation. Thus, 6G-RAISING is actively monitoring 3GPP and ETSI MEC standardization efforts, along with the evolution of O-RAN specifications, with a particular focus on reconfigurable RUs in future 6G systems.

Programmable Reconfigurable Optical Transport for Efficiently offering Unconstrained Services in 6G - PROTEUS-6G focuses on designing spatially diverse point-to-multi-point optical fronthaul networks, supporting the requirements for high capacity and low latency by deriving novel transceivers, and developing novel ML service management and orchestration to enable Flexible Functional Splits. CTTC contributed with the derivation of the transport requirements (capacity and latency) that are imposed by various 6G envisioned scenarios and technologies and the design of the 6G x-haul network architecture, including the general architecture of PROTEUS network elements and the data plane network architecture.

Automated zero-touch cross-layer provisioning framework for 5G and beyond vertical services - ACROSS is a secure, end-to-end network and service management platform that aims to address the dynamic and complex requirements of modern and future services in a cloud processing environment. It provides a highly scalable service orchestration layer, managed by a multi-domain cloud-native service orchestrator, to manage multi-faceted infrastructures across geographically distributed edge-to-core deployments. It increases security and trust over underlying devices and data sources while jointly exploiting data, programmability, and AI to improve performance and outsmart existing service orchestration. It employs zero-touch mechanisms for multi-objective service management optimizations and fosters a democratized cloud ecosystem for multiple stakeholders. It is built on principles such as event and data-driven microservices, open and standardized APIs, and true unsupervised real-time automation using AI. It aims to be the first of a new breed of AI-driven zero-touch service deployment and management platforms and has a concrete roadmap for proof-of-concept demonstrations to selected standards. CTTC leads activities on Software-Defined Security (SDS), including a novel standards-based SDS platform, and its integration with ETSI TeraFlowSDN controller and ETSI OpenSlice service orchestrator.

Self-managed sustainable high-capacity optical networks – SEASON is designing and validating a sustainable transport network infrastructure able to support beyond 5G and new emerging services. The infrastructure relies on the joint usage of optical Multi-Band (MB) and Space Division Multiplexing (SDM), spanning the access, aggregation, and metro/long-haul segments, supporting the requirements for x-haul, further integrating the packet/optical and computing layers, and targeting cost-effective capacity increase. A critical objective of such architecture is to ensure energy efficiency. Thus, the project is developing power-efficient Digital Signal Processing (DSP), multiband over SDM (MBoSDM) optical switching, point-to-multipoint transceivers allowing traffic aggregation/router bypassing, and converged packet-optical solutions that reduce the number of O/E/O conversions. Such complex infrastructure requires rethinking the control and orchestration systems towards autonomous optical networks, addressing not only the integration – in overarching control systems – of the Radio Access Network (RAN), access and transport segments but also adopting more agile DevOps methodologies. SEASON leverages on cognitive networks powered by streaming telemetry, real-time network measurements and Artificial Intelligence/Machine Learning (AI/ML)-aided service management and orchestration for near-real-time network operation, moving intelligence as close as possible to the data plane, and devising a distributed system based on multiple communicating agents and data-driven closed control loops. CTTC contributed to data plane element design and implementation, such as multiband SBVT and MBoSDM optical nodes and designed an SDN control plane for advanced optical networks with MBoSDM and coherent pluggable transceivers. AI/ML algorithms heuristics for packet/optical networks were also devised.

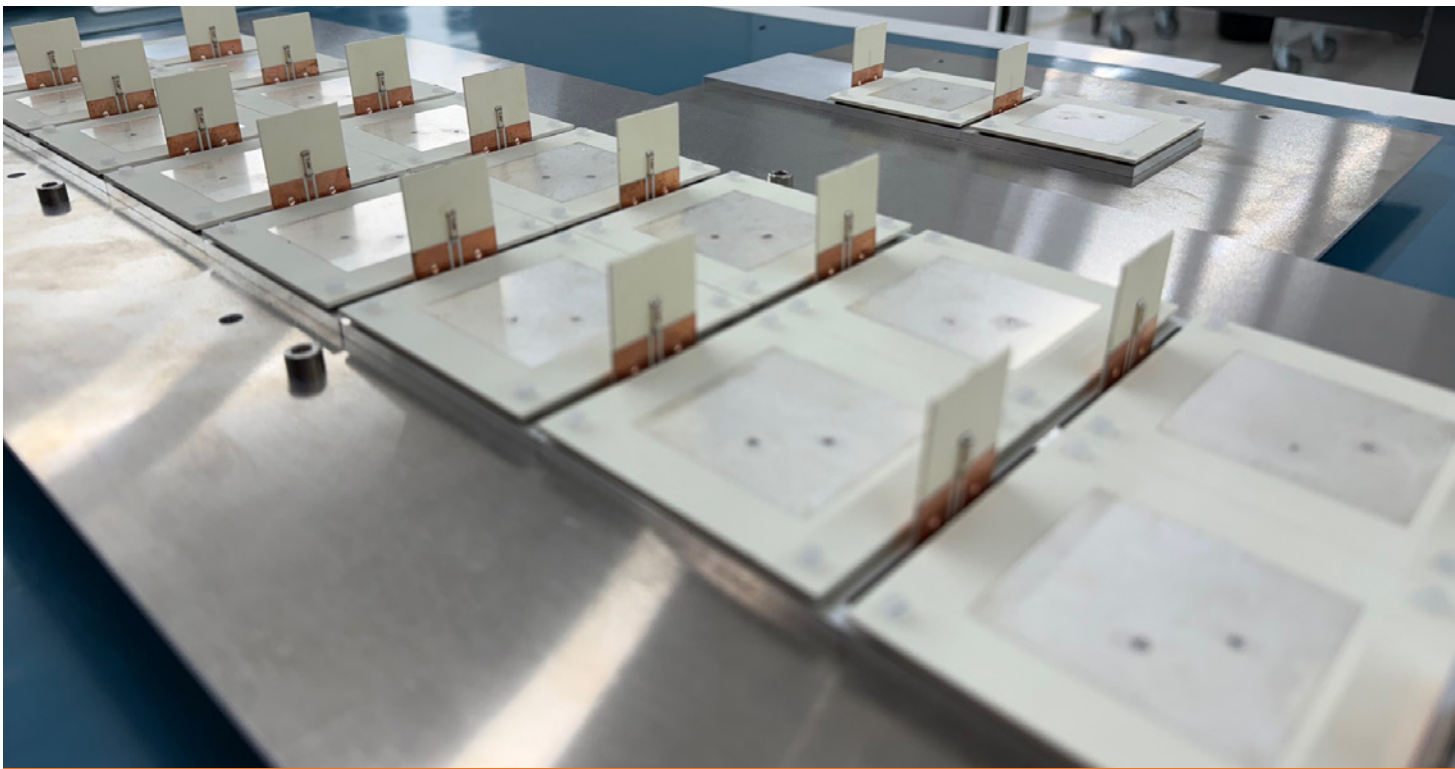
5G+ Evolution to Flexible Multiorbit Multiband Networks – TRANTOR is leading the development of 5G non-terrestrial networks evolving towards 6G. It targets the in-orbit validation of a complete satellite value chain involving an automated management of satellite resources across multiple bands, satellites, and orbits, and a converged radio access network. In 2024 Europe's first 5G-NTN fully compliant and interoperable broadband transmission was performed over one of the GEO satellites of Hispasat, partner in the project. The test included the user terminal 3GPP NTN compliant developed at CTTC.

Pervasive and Sustainable Intelligence (PSI) is an internal project focused on AI solutions for pervasive and liquid AI for distributed systems. In particular for enabling edge devices, regardless of their resources, to accomplish training and inference with the same accuracy of cloud AI in a sustainable manner. So far the project has investigated lightweight brain-inspired ML models, having been able to enable easier deployment of RC solutions for fostering the research for competing with state of the art AI applications and for its deployment in real-world settings and resource-constrained devices. HPs optimization was identified as a major bottleneck in RC adoption and we proposed an adaptive €-greedy search strategy to significantly reduce the time and energy costs associated with offline tuning. Our approach demonstrated a 70% reduction in optimization time and up to 88% energy savings, making RC a more viable solution for resource-constrained edge devices. By consolidating HPs search with an empirical study, we propose an €-Greedy-inspired strategy tailored to the unique characteristics of RC. Beyond optimization, we extended RC frameworks to support online transfer learning and inference, enabling fast and energy-efficient adaptation to real-world scenarios, such as air-quality measurements and room occupancy for smart buildings. Our enhancements allowed seamless online learning with only a 1% accuracy drop while using 66% less memory in the worst case compared to baseline approaches. These contributions mark a step forward in making RC a scalable and adaptable alternative to computationally expensive deep learning models. Consequently, this approach enables easy access for new adopters and facilitates the research and development of RC technology.

Taming the environmental impact of mobile networks through GREEN EDGE computing platforms - GREENEDGE is a research and training network focusing on the design and implementation of green-by-design edge computing systems. CTTC has investigated the sustainability issues of artificial intelligence and machine learning. The focus has been given to the design of innovative algorithms that can be implemented in resource-constrained devices (e.g., edge nodes) and models that can continuously adapt to new experiences and data streams. The proposed techniques may lead to energy savings up to 50% lower compared to state-of-the-art solutions, while maintaining similar performance. With these results, new frontiers for the sustainable development of the next generation AI-based systems are opened.

EmMAC3 explores different machine learning methods to train an L2 layer that interacts with the underlying L1 layer via PHY API commands. The main challenge consists in reducing the training complexity that arises from operating on a very large action space, to close in on the long-term goal of replacing major parts of the L2 layer by a single AI agent.

EMERGE6G is a highly intensive in equipment acquisition, to deploy sufficiently general, modular and versatile experimental infrastructure that is capable of supporting research across multiple areas of the B5G/6G physical layer featuring a large number of antennas. Although experiments focus on the sub-6GHz and millimeter bands, its modular architecture facilitates extension to other frequency bands in the future. In the sub-6GHz band, over-the-air communications demonstrations with Extra Large Antenna Arrays (ELAA) and cell-free massive MIMO are planned to be conducted with the 3 modules equipped with 32 antennas - each based on software defined radio (SDR) technology-. In the case of ELAA (with up to 96 antenna elements), the system will be configured to allow for experiments in the near field region. If the modules work independently, and thanks to the fact that each module will have some mobility, it will be possible to perform cell free experiments with different configurations.



6G-REFERENCE contributes to European leadership in microelectronic solutions for communication infrastructure by developing hardware components for dense and cell-free deployments. These are aimed not only at coherent data transmissions but also at high-precision localization and sensing, thereby bridging the physical, digital, and human worlds. 6G-REFERENCE is also concerned with the green transition by considering dense deployments of distributed, low-power nodes capable of enabling enhanced multi-user beamforming schemes for both data transmission and accurate sensing. This will support the densified deployment of distributed radio units with lower energy consumption. CTTC is developing the low-power sensors that would integrate into the network infrastructure.

GA4 is an industrialization project of a smart antenna for the protection of Global Navigation Satellite System (GNSS) receivers against electromagnetic interference. The main objective of this project is the development of a commercial product based on an intelligent antenna capable of autonomously controlling its radiation pattern, providing robustness against attacks aimed at service denial or deception of the GNSS receiver. The digital signal processing algorithms, antenna architecture, and initial prototypes have been developed at CTTC. Furthermore, a licensing agreement for the exploitation of intellectual property rights has been established with a leading manufacturer in the sector.

6GOASIS investigates the role of open radio access networks and its intelligent radio resource management for providing beyond-5G vertical services. The focus has been on the design and implementation of an urban hazard detection system, enabling real-time alarms of possible collisions among vehicles and other road objects (e.g., pedestrians, bicycles, etc.). It is based on an advanced computer vision algorithm integrated with a 5G-in-house network implementation and an edge computing orchestration platform. The proof-of-concept is available for demonstration in our laboratory.

Plaza6G/Plaza6G+ (6G Innovation and Experimentation Hub) projects aim to create general-purpose innovation hub, a versatile, user-friendly infrastructure for experimentation in advanced mobile networks, including 5G, 6G, and future generations. Built on the existing EXTREME Testbed®, Plaza6G introduces three key elements:

- a hierarchical continuous integration and deployment (CI/CD) environment for network experimentation,
- end-to-end instrumentation to perform metrics meas urements and manage all phases of the experiment life cycle,
- and three adaptable environments—simulation, indoor lab, and outdoor settings—to support various research and development stages.

Plaza6G+ expands on Plaza6G with five main improvements: scaling the infrastructure (including network expansion, computing power, and GPUs); deploying open RAN systems aligned with O-RAN Alliance specifications; enabling indoor and outdoor private 5G networks complemented by small/micro/pico/femto cell technologies; integrating equipment for emerging 6G use cases like AR/VR/XR, eHealth, and digital twins; and enhancing usability through APIs and a web-based platform. Both platforms will sup port the testing and development of products and services requiring high-performance networks, sup porting negligible latency and high bandwidth. So far, the design of the new experimental infrastructure architecture is defined, including the detailed definition and requirements of the new equipment and infrastructure to be acquired, taking special consideration on the energy requirements.

Fifth Generation Services HUB for European Union Governmental Satellite Communications - 5G-HUB

aims to evolve the flagship European initiative EU- GOVSATCOM to improve the flexibility of satellite network operators in allocating their resources to the needs of GOVSATCOM UEs. This flexibility will be translated into the integration of a 3GPP 5G-based non-terrestrial network (NTN) into the GOVSATCOM-HUB (G-HUB) component, which acts as a broker of satellite resources and communication chains. 5G-HUB will develop the required interfaces and entities of the 5G-NTN network (core, gNB, UE) following a software approach incorporating cloud-native principles. Additionally, 5G-HUB addresses interoperability issues, allowing the 5G-NTN UE GOVSATCOM terminals to connect to different space assets, eventually including terrestrial systems. This work will be validated through three trials: a lab trial devoted to the validation in a laboratory environment of system performance in terms of resource allocation, quality of service provision, and capacity to switch communication (traffic steering) from satellite networks (Ku, X bands) to the terrestrial network and two trials devoted to critical scenarios of emergency management and telemedicine for Humanitarian aid where there is the need to coordinate teams in remote areas and the maritime area. CTTC is leading the design of the architecture enabling the integration of 5G-based NTN networks into G-HUB for a flexible allocation and configuration of satellite communications based on 5G standards. This integration will promote the interoperability between vendors (ground and terminal), fostering technological advances and introducing economies of scale in the management of satellite resources. In lab proof-of-concepts and field trials are planned to assess the suitability of the proposed architecture to fulfill the requirements of the use cases of the project and the integration of cloud-native 5G principles in a G-HUB ecosystem.

Permafrost in the Pyrenees – The changing mountain - PERMAPYRENEES

In Southern Europe, the cryosphere of the Pyrenees is undergoing one of the most significant impacts. The components of the cryosphere interact as reliable indicators of climate change and are easily noticeable by society. Despite the efforts, little is currently understood about permafrost, except that it is typically found in the highest elevations of the mountain range (above 2600 m). This study of permafrost is providing new indicators for monitoring the impact of climate change on the cryosphere and shall aid in foreseeing risks arising from its degradation, such as slope instability (rockfalls) and moraine collapses. PERMAPYRENEES brings together experts from different regions of the POCTEFA territory to use innovative in-situ and remote monitoring methods to detect permafrost and any associated instability. CTTC oversees the data collection and analysis using remote sensing techniques, based on radar images acquired from satellites. In particular, it uses SAR interferometry techniques, combined with the use of artificial reflectors already installed in the study areas in the Catalan Pyrenees. First measurements are being analyzed.

European Ground Motion Service Advisory Board – GMAB2

CTTC continues to serve as Chair of the Advisory Board of the European Ground Motion Service under the Copernicus program of the European Environment Agency; and provides technical support for the new service of Copernicus Land. Copernicus is the Earth Observation Programme of the European Union. This project deals with the technical specification of the service, supervises the production, the Service Products, and the Service Validation. The project also devotes considerable efforts to dissemination and user uptake activities. The Advisory Board oversees the technical aspects of the service, supervises production, quality control, and validation, and is responsible for disseminating the service results.

Scientific Publications

This section draws attention to some of this year's most notable scientific publications.

Network Architectures & Services

M. Dalgitsis, N. Cadenelli, M. A. Serrano, N. Bartzoudis, L. Alonso and A. Antonopoulos, "Cloud-Native Orchestration Framework for Network Slice Federation Across Administrative Domains in 5G/6G Mobile Networks," in IEEE Transactions on Vehicular Technology, vol. 73, no. 7, pp. 9306-9319, July 2024, doi: 10.1109/TVT.2024.3362583.

Recent advances in cellular Vehicle-to-Everything (C-V2X) and edge computing enable new use cases for connected and automated vehicles featuring strict performance requirements. Such services demands may be guaranteed following the 5G/6G core serviced-based approach and the cloud-native Open Radio Access Network (O-RAN) principles, by means of network slicing technologies. However, maintaining network slice continuity across mobile operators remains challenging. This work presents a cloud-native orchestration framework for network slice federation, using standardized interfaces to exchange service and slice resource templates among operators. The framework aligns with standardized models and GSMA efforts on edge federation fundamentals to support mobile inter-operator network resource sharing. A federated 5G experimental platform was designed and implemented to evaluate performance. Results show that federation directly impacts setup time, while slice deployment strategies significantly influence infrastructure performance and end-user quality of service.

S. Barrachina-Muñoz, F. Rezazadeh, L. Blanco, S. Kukliński, E. Zeydan, A. Chawla, L. Zanzi, F. Devoti, V. Vlahodimitropoulou, I. Chochliouros, A.M. Bosneag, S. Cherrared, L. Vettori, J. Mangues-Bafalluy, "Empowering Beyond 5G Networks: An Experimental Assessment of Zero-Touch Management and Orchestration," in IEEE Access, vol. 12, pp. 182752-182762, 2024, doi: 10.1109/ACCESS.2024.3510804.

Effective zero-touch management and orchestration (ZSM&O) are crucial technologies for scaling network slicing, particularly for transitioning towards Beyond 5G (B5G) and 6G networks. This paper empirically validates a new approach to automated network slicing—an essential feature for managing complex services in future 5G and 6G networks. Developed through the EU's MonB5G project, the framework introduces a flexible model where "umbrella slices" coordinate specialized service slices across different network domains. The work tests the practicality of the solution in a 5G cloud-native 5G testbed using a virtual reality (VR) streaming scenario, incorporating advanced techniques like federated learning for CPU forecasting, anomaly detection, and deep reinforcement learning for RAN optimization. The paper offers insights from technically demanding experimental tests and highlights challenges and development paths for managing next-generation mobile networks.

Adanza, D., Gifre, L., Alemany, P., Fernández-Palacios, J. P., González-de-Dios, O., Muñoz, R., & Vilalta, R. (2024), "Enabling traffic forecasting with cloud-native SDN controller in transport networks", Computer Networks, 250, 110565.https://doi.org/10.1016/j.comnet.2024.110565

Network bandwidth is a limited resource that operators must monitor to address future traffic demands and plan for additional transceiver and fiber deployments. Traditionally, traffic analysis has been conducted offline due to the high computational load and challenges in obtaining real-time data from network devices, particularly when integrating Machine Learning to predict future link usage by enabling the use of traffic forecasting methods. This paper introduces an architecture for real-time traffic monitoring and forecasting in SDN controlled packet-optical transport networks. Built on a microservice framework, the SDN controller simplifies deployment for continuous data collection and analysis. The study proposes four machine learning methods for predicting future link usage, aiming to support proactive network planning. Tested on two network topologies, the random forest algorithm delivered the highest accuracy—79.98% and 95.88%—with efficient processing times. The results demonstrate the viability of integrating machine learning into SDN controllers for accurate and timely traffic forecasting.

A.Petrella, M. Miozzo and P. Dini, "Mobile Traffic Prediction at the Edge Through Distributed and Deep Transfer Learning," in IEEE Access, vol. 12, pp. 191288-191303, 2024, doi: 10.1109/ACCESS.2024.3518483.

This paper presents a fully decentralized AI-based framework for mobile traffic prediction -crucial to efficiently optimize mobile networks-, aiming to reduce energy consumption and data transmission overhead by processing data locally at base stations. Leveraging edge computing and Deep Transfer Learning (DTL), the framework uses real-world datasets (comprehensive measurement campaign) and two deep learning models—Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs). Both approaches were evaluated based on simulations, showing CNNs outperforming RNNs in both accuracy and energy efficiency. DTL improves prediction accuracy in 85% of cases and significantly reduces training energy consumption—by 60% for CNNs and 90% for RNNs. Additionally, explainable AI techniques are applied to interpret models' behavior.

F. Rezazadeh, S. Barrachina-Muñoz, H. Chergui, J. Mangues, M. Bennis, D. Niyato, H. Song, L. Liu, "Toward Explainable Reasoning in 6G: A Proof of Concept Study on Radio Resource Allocation," in IEEE Open Journal of the Communications Society, vol. 5, pp. 6239-6260, 2024, doi: 10.1109/OJCOMS.2024.3466225.

This paper introduces TANGO, a novel graph reinforcement learning (GRL) framework designed to bring explainability and trust into AI-native 6G network operations—particularly critical for applications that demand high reliability. Unlike traditional post-analysis explainable AI methods (XAI), TANGO integrates explainability rules (contextual explanations for guiding the learning process) directly into the learning process using symbolic reasoning and a Bayesian graph neural network (GNN) Explainer. Tested for a real-world gNodeB resource allocation problem, TANGO in-hoc explainability approach expedites convergence for optimizing radio resource allocation (PRBs), compared to standard GRL baselines. TANGO dynamically adjusts its learning-based metrics such as performance in AI, complexity, energy consumption, robustness, network, scalability, and explainability metrics, achieving a notable accuracy (96,39%) in terms of optimal PRB allocation in the inference phase.

L. Ballotta, G. Peserico, F. Zanini and P. Dini, "To Compute or Not to Compute? Adaptive Smart Sensing in Resource-Constrained Edge Computing," in IEEE Transactions on Network Science and Engineering, vol. 11, no. 1, pp. 736-749, Jan.-Feb. 2024, doi: 10.1109/TNSE.2023.3306202.

This paper addresses how smart sensors in edge computing systems—such as those in drone networks or autonomous vehicles—can best balance speed and accuracy when sending data to a central base station for global monitoring. Because sensors can either send raw data (inaccurate but timely) or process it locally (better accuracy but introduces delay), there's a trade-off between timeliness and precision. The authors propose a reinforcement learning-based framework to solve the optimization problem embedding computation and communication latency, that helps sensors dynamically decide based on current conditions, whether to transmit raw measurements or rely on local processing to maximize network monitoring performance. Simulations show this method improves monitoring accuracy under limited computational capacity at the base station, especially by enabling adaptive online sensor selection.

J. Viana, H. Farkhari, L. Campos, K. Koutlia, B. Bojovic, S. Lagen, R. Dinis, "Deep Attention Recognition for Attack Identification in 5G UAV Scenarios: Novel Architecture and End-to-End Evaluation", IEEE Transactions on Vehicular Technology, vol. 73, no. 1, pp. 131-146, Jan. 2024, https://doi.org/10.1109/TVT.2023.3302814

This paper addresses the potential vulnerability of 5G-based unmanned aerial vehicle (UAV) communications, particularly in Air-to-Ground (A2G) links, despite the inherent security features of 5G. It proposes a Deep Attention Recognition (DAtR) mechanism using a lightweight deep learning model embedded in authenticated UAVs to detect attacks based on two observable parameters: SINR and RSSI, and the combination of both. The approach is tested under Line-of-Sight (LoS), Non-Line-of-Sight (NLoS), and mixed conditions, with variable attacker positions and interference from terrestrial users. The tested scenarios include complex configurations including both aerial and terrestrial users. DAtR integrates new pre- and post-processing techniques to improve detection accuracy. Benchmarking shows that DAtR outperforms six widely used classifiers, including XGB, with over 4% higher accuracy in LoS conditions.

Radio Access

Bartzoudis N, Rubio Fernández J, López-Bueno D, Román Villarroel A, Antonopoulos A. Agile FPGA Computing at the 5G Edge: Joint Management of Accelerated and Software Functions for Open Radio Access Technologies. Electronics. 2024; 13(4):701. https://doi.org/10.3390/electronics13040701

ReproRun is a modular runtime framework enabling partial reconfiguration of FPGAs in software-defined radio (SDR) platforms. It supports dynamic updates of programmable logic (PL) functions and associated processing system (PS) firmware without disrupting other ongoing processes. Built using AMD-Xilinx tools and OpenAMP, ReproRun includes a controller (REWIRE) that manages firmware updates via TFTP. Each reconfigurable region (RR) in the FPGA is updated with corresponding firmware for seamless integration. Designed for flexibility, ReproRun supports FPGA-based accelerators in open RAN, adaptive radio technologies, and edge servers running virtualized functions.

K. Koutlia, S. Lagen, "On the impact of Open RAN Fronthaul Control in scenarios with XR Traffic", Computer Networks, Volume 253, 2024, https://doi.org/10.1016/j.comnet.2024.110722.

This paper explores the impact of Open RAN, a key technology for next-generation mobile networks, on time-critical applications like eXtended Reality (XR) and Cloud Gaming (CG). While Open RAN offers flexibility, automation and intelligence, its disaggregated architecture can create bottlenecks—especially in the Open Fronthaul link—affecting performance for time-critical traffic. Using the ns-3-based 5G-LENA simulator, the study evaluates XR and CG traffic under 3GPP scenarios and introduces a new Fronthaul Control mechanism combined with modulation compression to mitigate capacity issues. Results show that without such enhancements, XR and CG applications suffer significant performance degradation, emphasizing the need for optimized fronthaul solutions.

M. A. Jadoon, A. Pastore, M. Navarro and A. Valcarce, "Learning Random Access Schemes for Massive Machine-Type Communication With MARL," in IEEE Transactions on Machine Learning in Communications and Networking, vol. 2, pp. 95-109, 2024, doi: 10.1109/TMLCN.2023.3345273. https://ieeexplore.ieee.org/document/10366306

This paper explores scalable multi-agent reinforcement learning (MARL) strategies for grant-free random access (RA) in massive machine-type communication (mMTC) systems with low-power devices. It evaluates the impact of omitting agent identifiers in observations, aiming to reduce complexity while maintaining performance. Using value decomposition networks (VDN), QMIX with parameter sharing, and comparing with deep recurrent Q-networks (DRQN), the study shows improved throughput-fairness trade-offs without agent-specific conditioning. A correlated traffic model, reflecting realistic mMTC patterns, is introduced to test adaptability to non-stationary conditions. Simulation results confirm the robustness and scalability of the proposed MARL-based RA schemes.

Technology Components & Devices

J. Gómez-Vilardebó, X. Mestre, M. Navarro and J. Quintanilla, "On Noncoherent FSK Reception with Doppler Frequency Uncertainty for Space Communications," in IEEE Journal on Selected Areas in Communications, vol. 42, no. 5, pp. 1292-1303, May 2024, doi: 10.1109/JSAC.2024.3365881.

This paper investigates non-coherent receivers for frequency-shift keying (FSK) modulations in deep-space communications. More specifically it derives the mutual information for a general form of orthogonal M-FSK modulations, focusing on non-coherent detection and Doppler frequency uncertainty at the receiver. The signal model encompasses classical MFSK and special MFSK modulations, the latter of which has been utilized in space communications to report spacecraft status and events during critical phases. The study examines the optimal code rates that minimize the energy-per-bit to noise power spectral density ratio necessary for reliable communications. Additionally, it proposes optimal and suboptimal metrics for soft-decoders applicable to non-fading channels, with or without average signal and noise power estimation, to evaluate the performance of LDPC channel codes.

Kumari, M., Mishra, S.K. "Design and investigation of symmetric bidirectional VCSEL laser incorporated extensive reach OWC system using considering channel impairments for beyond 5G application", Opt Quant Electron 56, 1448 (2024). https://doi.org/10.1007/s11082-024-07401-8

This study explores a high-speed, bidirectional optical wireless communication (OWC) system using vertical cavity surface emitting lasers (VCSEL) technology, aimed at enhancing 5G network performance. The proposed system supports 4 x 10 Gbps data rates in both uplink and downlink directions and achieves transmission distances over 130 km, even under channel impairments such as noise and signal attenuation. VCSEL features high operating power and high reliability. In this work maximum link attenuations (downlink and uplink) are below 2.25 dB/km while keeping bit error rates as low as 10-9. The work demonstrates the viability of VCSEL-based OWC systems for extending the reach and capacity of 5G networks.

Artiga X, Vázquez MÁ, "5G new radio multiuser precoding in geostationary satellite network", Int J Satell Commun Network. 2024; 1-13. doi:10.1002/sat.1515

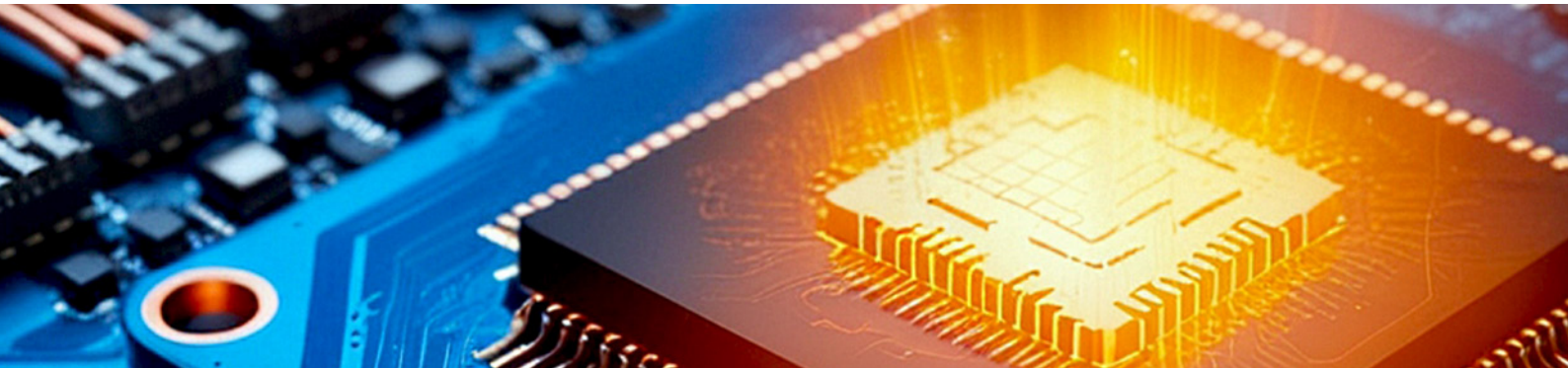
The integration of non-terrestrial networks in the 3GPP standardization framework opens for new technology advancement opportunities. This study investigates how standardized multiuser precoding methods from 3GPP New Radio (NR) can be adapted to improve satellite communications, particularly for geostationary satellites integrated into 5G non-terrestrial networks. Current NR codebooks are shown to be ineffective in managing inter-beam interference and are better suited for channel estimation. To enhance performance, the authors propose modifications to the codebooks, allowing user equipment (UE) to report more beams and evaluate effects such as overhead signaling, channel aging, quantification effects, etc. Alternative strategies, like sequential reporting, are also evaluated. The work provides key insights for extending terrestrial 5G standardized techniques to satellite systems, supporting future high-capacity global connectivity.

Brito-Brito, Z.; Velázquez-González, J.S.; Mira, F.; Román-Villarroel, A.; Artiga, X.; Mishra, S.K.; Vázquez-Gallego, F.; Kim, J.-M.; Fontana, E.; de Melo, M.T.; et al. Wireless Sensor Node for Chemical Agent Detection. Chemosensors 2024, 12, 185. https://doi.org/10.3390/chemosensors12090185

This paper presents SensorQ, a compact light-weight standalone wireless sensor node designed to detect toxic chemical agents. The prototype includes a fiber optic sensor that supports the surface plasmon resonance (SPR) phenomenon and operates on the 2.4 GHz LoRa communication protocol band. The prototype includes other standard elements such as microcontroller, RF transceiver, dual-band antenna, four other integrated sensing devices and a rechargeable battery. Its sensing component uses a hetero-core fiber structure with a titanium/gold/titanium coating and zinc oxide layer to detect Di-Methyl Methyl Phosphonate (DMMP), a simulant for Sarin gas, via surface plasmon resonance. Experimental tests at multiple DMMP concentrations confirm the system's detection capability. SensorQ shows strong potential for integration into wireless sensor networks for chemical threat detection and field safety monitoring.

Nadal, L., Martínez, R., Ali, M., Vílchez, F. J., Fàbrega, J. M., Svaluto Moreolo, M., & Casellas, R. (2024). Advanced optical transceiver and switching solutions for next-generation optical networks. Journal of Optical Communications and Networking, 16(8), D64-D75, https://doi.org/10.1364/JOCN.522102

This paper explores next-generation optical transceiver and switching solutions for 6G networks, emphasizing flexibility, energy efficiency, sustainability, and interoperability that can support the increasing traffic and demands for emerging applications. It proposes and experimentally validates innovative architectures for multiband spatial division multiplexing (MBoSDM) switching technologies and sliceable bandwidth/bit rate variable transceivers (S-BVT). These innovations support high-capacity, adaptable transmission—achieving speeds up to 180.9 Gb/s in back-to-back setups and success-

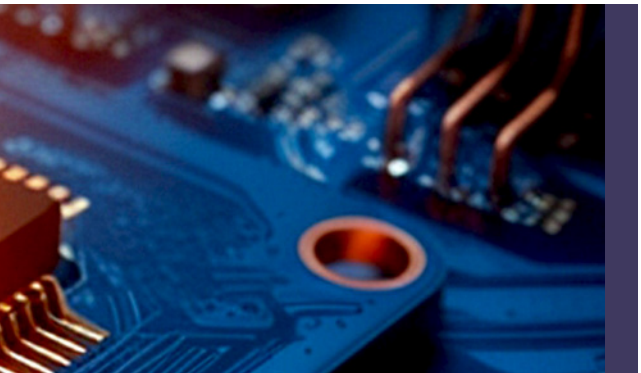


ful operation over a 19-core multi-core fiber spanning 25.4 km. The modular and scalable transceiver design enables multiple slices to operate across different bands beyond the C-band, enabling for higher capacity. A power efficiency analysis outlines the integration roadmap of the transceiver with a SDN control plane supported by energy-aware AI/ML models.

Positioning, Remote Sensing & Applications

Majoral, M.; Arribas, J.; Fernández-Prades, C. Implementation of a High-Sensitivity Global Navigation Satellite System Receiver on a System-on-Chip Field-Programmable Gate Array Platform, Sensors, Volume 24, Issue 5, March 2024, Article number 1416, doi: 10.3390/s24051416

This paper presents the design, proof-of-concept implementation, and preliminary performance assessment of an affordable real-time High-Sensitivity (HS) Global Navigation Satellite System (GNSS) receiver, specifically tailored to capture and track weak Galileo E1b/c signals. The receiver aims to support research focused on advancing GNSS signal processing algorithms, particularly in scenarios with significant signal attenuation. Utilizing System-on-Chip Field-Programmable Gate Array (SoC-FPGA) technology, the design combines the adaptability of Software Defined Radio (SDR) concepts with the robust hardware processing capabilities of FPGAs, enhancing power efficiency compared to conventional designs that rely on general-purpose processors. The receiver features a modular GNSS baseband engine, offering a flexible platform for testing new algorithms. Live signal tests confirm it can operate effectively even at low signal strengths (as low as 20 dB-Hz), still providing navigation solutions. This development supports the advancement of affordable, high-sensitivity GNSS receivers and serves as a useful tool for researchers working on experimental GNSS signal processing.



Angelats, E.; Gorreja, A.; Espín-López, P.F.; Parés, M.E.; Malinverni, E.S.; Pierdicca, R. Enhanced Seamless Indoor-Outdoor Tracking Using Time Series of GNSS Positioning Errors. ISPRS Int. J. Geo-Inf. 2024, 13, 72. https://doi.org/10.3390/ijgi13030072

This paper presents a novel method for identifying indoor, outdoor, and transition areas by analyzing time series of GNSS error statistics. This environmental context improves the selection between GNSS and Visual-Inertial Odometry (VIO) for trajectory estimation, enhancing positioning robustness and accuracy. The approach involves: segmenting the environment into distinct area types (indoor, outdoor, and transition), evaluating two classification methods using GNSS error statistical data, and refining the trajectory estimation strategy using contextual knowledge. Real-world validation confirms its effectiveness, achieving trajectory accuracy consistently under 10 meters across diverse scenarios, making it suitable for seamless indoor-outdoor navigation applications.

Shahbazi, S.; Barra, A.; Gao, Q.; Crosetto, M. (2024). Detection of buildings with potential damage using differential deformation maps. ISPRS Journal of Photogrammetry and Remote Sensing, 218, 57-69. https://doi.org/10.1016/j.isprsjprs.2024.10.008

This study presents a new software tool that leverages data from the European Ground Motion Service (EGMS) to automatically detect buildings at risk of structural damage due to ground deformation. Using high-resolution Sentinel-1 satellite data, the tool is designed for the automatic identification of urban structures potentially susceptible to damage from differential movements. The tool can be applied to different area sizes (from local to country-size scale) and displacement maps data source (e.g. EGMS, in-SAR-derived). In this work the tool enables calculating spatial deformation gradients for individual buildings and classifies them by risk level, factoring in measurement uncertainty and producing differential deformation maps. Tested in Barcelona using both EGMS and COSMO-SkyMed datasets (between years 2017-2021), the method consistently identified at-risk structures and was validated through field surveys. This approach enhances the practical use of satellite-based displacement maps, supporting large-scale, data-driven urban risk assessments and supporting informed urban management.

PhD Theses

We are proud of our new PhD graduates, which defended their doctoral work in 2024.

A Flexible System-on-Chip FPGA Architecture for Prototyping Experimental GNSS Receivers

Marc Majoral (Sabadell, 1974) earned his M.S. degree in Electrical Engineering from the Polytechnic University of Catalonia (UPC) in 1998. He joined the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) in January 2007, where he currently works as a researcher within the Navigation and Positioning research unit. His work focuses on the design and development of real-time signal processing communication devices, computationally intensive DSP algorithms, Software-Defined Radio (SDR) systems, Field Programmable Gate Array (FPGA)-based systems, and embedded systems. He has contributed to various industrial and publicly funded projects, enhancing the technological capabilities of his field.

The rapid evolution in Global Navigation Satellite System (GNSS) technology necessitates advanced prototyping tools to explore new signals and develop innovative systems. Prototyping is crucial in the design and development process, allowing researchers to test and refine their ideas on a smaller scale before full implementation.

Using commercial GNSS receivers for prototyping presents challenges. While these receivers are beneficial due to their low power consumption, compact size, and affordability, they are limited in flexibility. In contrast, GNSS receivers that utilize free and open-source software are highly valued in research and development for their adaptability. However, these software-based receivers typically consume more energy than hardware-based counterparts, as they run on general-purpose processors which are less efficient in power usage.

This thesis proposes a low-cost architecture and design methodology for prototyping experimental GNSS receivers, based on System-on-Chip Field Programmable Gate Arrays (SoC FPGAs). This architecture addresses the limitations of commercial GNSS receivers by enhancing adaptability, flexibility, and reprogramming capacity. It also offers improved energy efficiency over software-based receivers.
The effectiveness of this architecture is demonstrated through the development of three prototypes: a GNSS receiver designed for low Earth orbit (LEO) applications, a GNSS signal rebroadcaster, and a high-sensitivity GNSS receiver. Each prototype showcases the practical applications and advantages of the proposed architecture in real-world scenarios.

A Flexible System-on-Chip FPGA Architecture for Prototyping Experimental GNSS Receivers

cttc

PH.D. THESIS

A Flexible System-on-Chip FPGA Architecture for Prototyping Experimental GNSS Receivers

Marc Majoral Ramoneda

Supervisors:
Dr. Javier Arribas Lázaro
Dr. Carles Fernández Prades
Tutor:
Prof. Ana Isabel Pérez Neira

Misbehaviour Detection and Trustworthy Collaboration in Vehicular Communication Networks

Roshan Sedar received his European Master's degree in Distributed Computing from the Universitat Politècnica de Catalunya (UPC) and KTH Royal Institute of Technology in 2014. In 2019, he joined the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), where he currently works as a researcher in the Sustainable Artificial Intelligence (SAI) research unit. During his time at CTTC, he has actively participated in several EC-funded projects, including 5GCroCo and INSPIRE-5Gplus. He is currently involved in the VERGE, SUCCESS-6G, and FREE6G-SECURITY projects. His research primarily focuses on cybersecurity in wireless communication, including artificial intelligence and machine learning, and distributed systems.

The integration of advanced wireless technologies, e.g., cellular and IEEE 802.11p, in modern vehicles enables vehicle-to-everything (V2X) communication, fostering the next-generation Internet-of-Vehicles (IoV) paradigm. The rise of IoV leads to more connected vehicles on roads, capable of making informed and coordinated decisions through real-time information sharing among vehicles, communication infrastructure, pedestrians, or roadside units. Implementing such technologies across all modes of passenger and freight transport systems can significantly enhance safety, efficiency, and sustainability, ultimately reducing environmental impact. Nonetheless, the transformative V2X and IoV technologies inadvertently bring unprecedented challenges involving security and privacy vulnerabilities. Security threats and attacks can emerge from both malicious outsiders and insiders in V2X communication. Detecting and containing misbehaviours, particularly those initiated by rogue insiders, present challenging yet critical tasks for ensuring road safety. These actions involve transmitting falsified or erroneous data in safety-critical situations, thereby posing serious threats. Furthermore, the pervasive use of artificial intelligence and machine learning (AI/ML) tools across various aspects poses potential threats to secure V2X communication system operation. Motivated by these challenges, this doctoral thesis focuses on enhancing the security, robustness, and trustworthiness of V2X communications by enabling efficient and effective misbehaviour detection and fostering trustworthy collaboration. Specifically, we focus on (i) achieving effective and efficient misbehaviour detection with high accuracy and minimal false alarms, leveraging diverse spatiotemporal characteristics in vehicular data, and (ii) facilitating trustworthy information sharing for collaborative misbehaviour detection, with an emphasis on generalisability and the ability to detect previously unseen and partially observable attacks.

Misbehaviour Detection and Trustworthy Collaboration in Vehicular Communication Networks

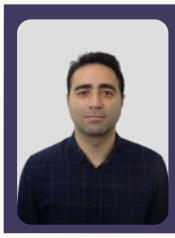
PH.D. THESIS

Misbehaviour Detection and Trustworthy Collaboration in Vehicular Communication Networks

Roshan Sedar

Supervisors:
Dr. Jesus Alonso-Zarate
Dr. Francisco Vázquez-Gallego
Tutor:
Prof. Luis Alonso

Advanced Modeling of InSAR Time Series for Ground Displacement Hazard Assessment



S. Mohammad Mirmazloumi received his Geomatics and Remote Sensing engineering BSc and MSc in Iran in 2008 and 2012. He started his PhD journey in CTTC as research assistant in November 2019 and pursued his degree at UPC. The focus of his activities was on modeling ground displacements using InSAR data to assess hazards. He has been working on different applications of Earth Observation data and GeoAI, such as land cover classification, soil moisture retrieval, agricultural drought monitoring, evapotranspiration, etc. He is currently involved as a researcher in projects funded by ESA in Germany.

Natural movements of Earth and human-based activities generate continuous ground displacements, affecting human life and the economy. In order to mitigate and reduce the impact of such displacements, accurate and frequent monitoring of their spatial and temporal characteristics is necessary. Remote sensing technology offers diverse temporal and spatial assets that are suitable for actively monitoring and measuring the intensity of ground displacements. This information can then be used to prevent risks, forecast occurrences, and manage the associated hazards. One active remote sensing system, known as synthetic aperture radar (SAR), enables accurate and anytime measurements of ground displacements using a technique called interferometric SAR (InSAR). InSAR allows for millimeter scale monitoring of deformations over small to wide areas affected by geohazards such as earthquakes, volcanic activities, landslides, and subsidence. With the increasing availability of large data, short revisits, and higher spatial resolution of SAR images, a massive amount of InSAR products is now provided. These products need to be properly analyzed and prepared for ground displacements monitoring to offer valuable information for geohazard risk management and monitoring. This PhD study is pursuing development of methodologies to model ground displacements behavior of InSAR time series (TS). Hence, an empirical analysis and modeling of displacements TS is performed to investigate various and dominant trends using robust statistical approaches. To achieve this, an automatic classification tool for InSAR TS is proposed to accurately classify seven types of displacement trends using step-wise statistical tests and conditions. The proposed workflow is applied and evaluated on simulated and real InSAR TS datasets from Barcelona and three landslide cases in Granada, Spain. Furthermore, the study explores the idea of modeling and classifying displacement TS through machine learning (ML) models, which have revealed beneficial insights in classifying temporal data. Multiple supervised models are employed, incorporating customized features, such as autocorrelation and decomposition, to classify ground displacements into the afore-mentioned trends. The conventional performance assessment of ML models, along with pairwise intersections within random samples compared to the model-based method, are observed to compute the reliability and precision of TS classifier outputs. Finally, a forecasting tool is presented to support the prediction and identification of failures in hazardous regions. The tool is designed as an input for early warning system that utilizes spatio-temporal outcomes from a deep learning model known as long short-term memory (LSTM). It aims to support the activation of reliable alarms prior to high-risk events. Three failure cases in mining areas in Spain, Brazil, and Australia are considered to demonstrate the significance of temporal and spatial characteristics of InSAR data in detecting areas at risk of potential collapses in the near future.

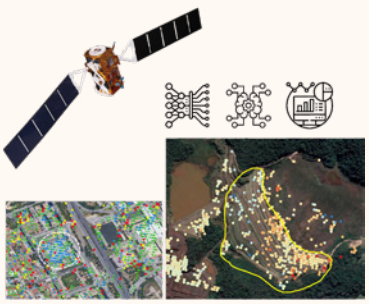
Advanced Modeling of InSAR Time Series for Ground Displacement Hazard Assessment

PH.D. THESIS

Advanced Modeling of InSAR Time Series for Ground Displacement Hazard Assessment

Seyedmohammad Mirmazloumi

Supervisors:
Dr. Michele Crosetto
Dr. Oriol Monserrat
Tutor:
Prof. Carolina Puig



TESTBEDS, EXPERIMENTAL FACILITIES & SOFTWARE TOOLS

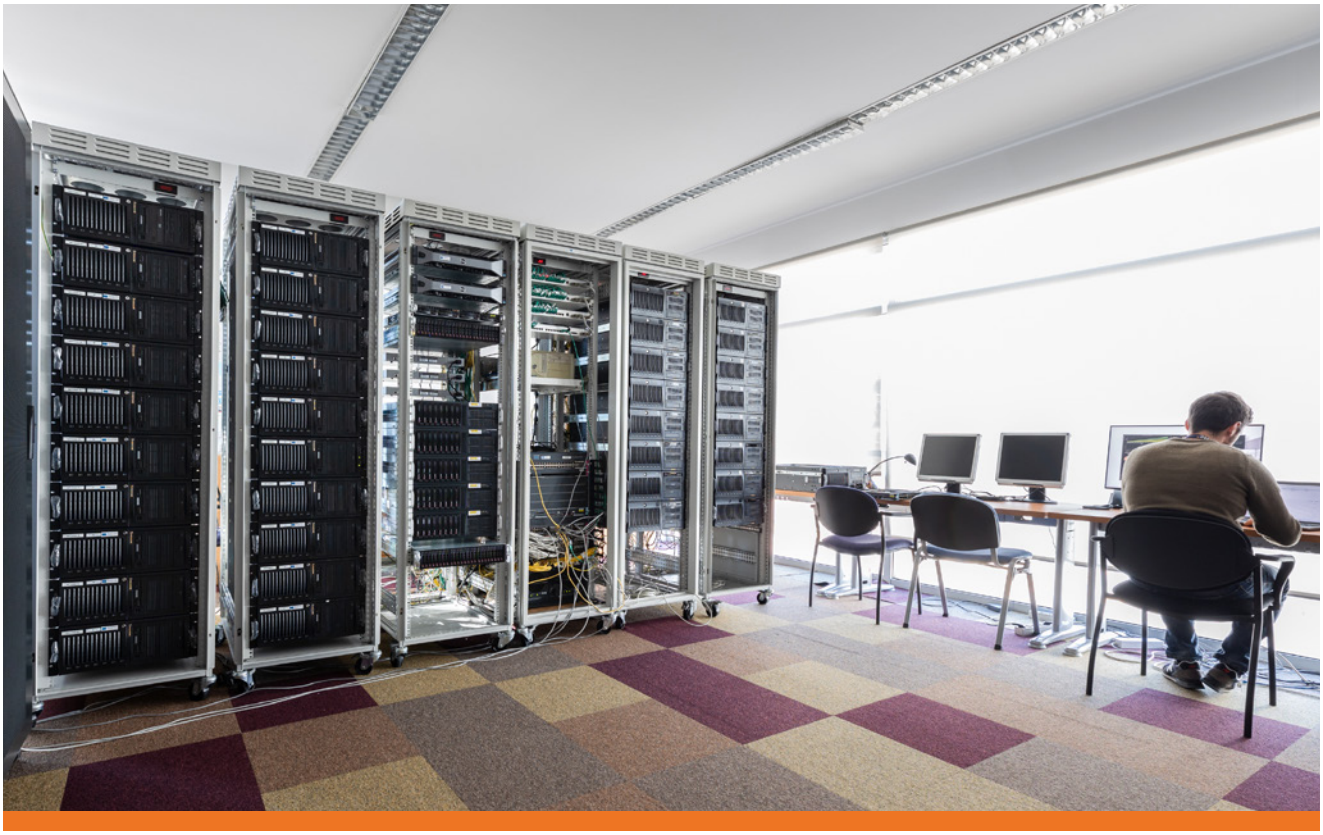
CTTC's testbeds and experimental facilities are one of CTTC most relevant assets, having significant resources devoted each year to extend experimental infrastructure and tools and better condition the experimental spaces. The testbeds, laboratories, and research platforms are developed and managed by in-house specialized research personnel. They have been a key resource for the realization of flagships R&D projects, such as the Horizon Europe program or the Spanish UNICO I+D. They also are fundamental to delivering competitive results in industrial direct contracts.

The experimental infrastructure of CTTC has been developed along three different axes, namely:

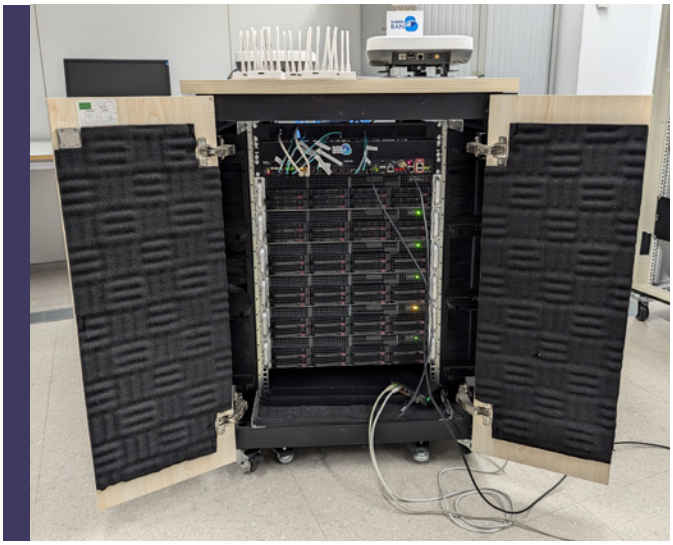
- ***Network Architecture***
- ***Radio Access***
- ***Navigation & Positioning***

In 2024 the conditioning of spaces continued to accommodate new equipment, integrated into the different testbeds and laboratories.

EXTREME Testbed® **(Experimental testbed for research on xG Cloud Mobile Networks)** migrated over 20 servers and GPUs building a fully integrated and scalable experimental infrastructure. The migration was accompanied by targeted equipment upgrades, ranging from advanced computing servers and 5G-capable Customer premises equipment to high-performance laptops and smartphones, enhancing functional capacity, connectivity interfaces, and user accessibility. Efforts were dedicated to improving its accessibility and usability by external third parties, with a preliminary version of a framework for enabling experiment-as-a-service developed in the context of Plaza6G(+) UNICO-5G projects. This framework is set to significantly streamline the design and execution of experiments. The EXTREME Testbed® also supported proof-of-concept validations and experimental activities across several R&D projects, such as the demonstrated cloud autoscaling for video-on-demand, the enabled application relocation with multi-UPF traffic steering, or the hosted multi-agency deployments for mission-critical communications with dynamic service scaling. Additional use cases and pilots further illustrated EXTREME Testbed®'s flexibility and its role as a critical enabler for advanced experimentation.



ADRENALINE Testbed® **(Experimental research testbed on high-performance and large-scale intelligent optical transport networks)** expanded with new equipment for introducing quantum secure technology and a waveform generator and a real-time oscilloscope to implement high-speed Bandwidth Variable Transceivers (BVT). The new equipment was integrated into the Experimental Platform for Optical OFDM Systems (EOS) to upgrade Multi-Band Opto-Electronic front ends in Sliceable-BVTs (S-BVT). Including two 6GHz RF System-on-Chip kits for real-time Digital Signal Processing, an O-band tunable laser, a PDFA amplifier, and a 40GHz Intensity modulator with RF Driver. Two OCM modules were also acquired for rackable optical sensing prototypes; and four C-band Wavelength Selective Switch modules, with 6.25GHz granularity, were obtained to complete the migration to flexigrid in optical links. Additionally, a new 24-SMF link between ADRENALINE Testbed® and the Data Processing Center was installed to enable future experiments with external entities, interconnecting the photonic mesh to Xarxa Oberta de Catalunya. Complementing the equipment acquisition, specialized in-house training was provided to CTTC personnel by the equipment vendors. This new equipment allowed enhanced demonstrations on energy monitoring and virtual reality, conducted during dissemination activities and visits.

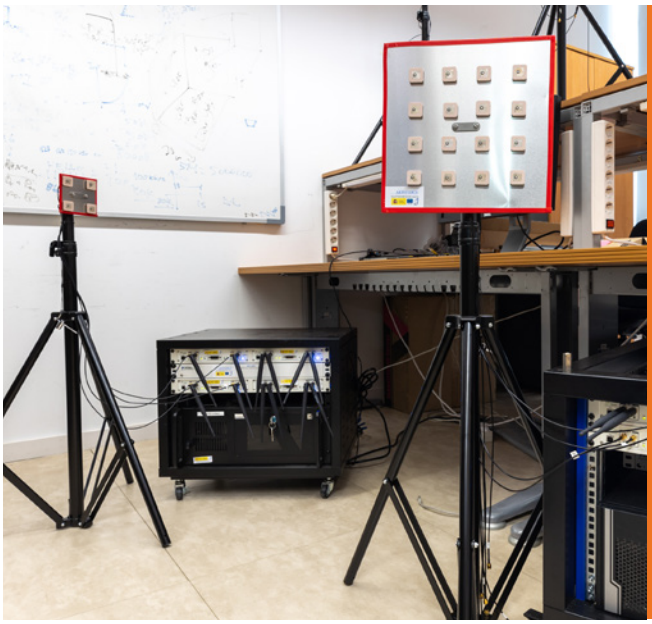


Regarding the GEDOMIS® testbed **(GEneric DemOnstrator for intelligent SDR and edge coMputIng Solutions)** it was upgraded and transformed into a fully cloud-native, end-to-end (E2E) O-RAN testbed, enabling advanced AI-driven RAN operations across the telco continuum. This evolution was made possible by integrating BubbleRAN's MX-PDK 5G/6G O-RAN platform, built on a Kubernetes (K8s) cluster deployed across six servers, two commercial band n78 7.2 split O-RAN radio units (RUs), and six user equipment (UEs), with the potential for further expansion. The testbed supports widely used open-source, cloud-native, 5G-compliant core network implementations (Open5GS, OAI) and gNBs (srsRAN, OAI), along with software-defined radio (SDR) boards and UEs (OAI, 5G modems, mobile phones). It also features a proprietary service management and orchestration (SMO) layer running on top of the native K8s orchestrator, incorporating a non-real-time RIC and example rApps. Additionally, the platform includes near-real-time RIC (FlexRIC) and reference xApps that support KPM, RAN Control, and custom O-RAN service models. The automated lifecycle management of containerized RAN virtual network functions is enabled by deploying AI/ML models. This data-driven intelligence is supported by the platform's built-in observability layer, which facilitates the collection and exposure of rich RAN metrics.

Experimental facilities on satellite, Non-Terrestrial Networks (NTN) and their integration with terrestrial 5G standards have been enhanced by the installation of two identical satellite transponders (Ku-band) that increases the connectivity via additional satellite links. This was made possible through the partnership with satellite operator Hispasat and other related R&D projects. As part of the **CASTLE platform®** testbed, the infrastructure supports end-to-end 5G over-the-air testing, satellite communication links via a geostationary and low orbit satellites. Additionally, the CASTLE platform® enables remote testing and development of various radio standards without the need for dedicated hardware or software installation. It includes a satellite communication channel emulator, mmWave frontend for 5G FR2 with 64 antennas, and an AI/ML-based simulation environment.

The **AI Wireless platform** is a cutting-edge facility dedicated to advancing the future of wireless physical-layer technology through innovative research and development, pioneering deep learning and reinforcement learning applications for wireless systems, alongside the design of advanced error-correcting codes and protocol learning for semantics-aware communications.

The equipment was used to develop several proofs-of-concept and demonstrations (e.g. Non-Orthogonal Multiple Access (NOMA) wireless uplink demonstrator), showcased at the Mobile World Congress and the IEEE International Conference on Machine Learning for Communications and Networking. The new equipment being acquired favors experimental research for massive and ultra-massive MIMO distributed base stations, cell-free systems, intelligent surfaces, three-polarization communications and near-field communications. All powered by AI-based designs. The demonstrator introduced a dual-mode operation, supporting both individual message recovery and coded over-the-air computation, paving the way for practical applications in 6G tasks like wireless federated learning and distributed sensing.



Open Source & Software Tools

Complementing its experimental facilities, CTTC continues to lead and support open-source software initiatives and tools that are key to advancing research activities and facilitating knowledge transfer

In 2024, the open-source software-defined receiver GNSS-SDR **(https://gnss-sdr.org)** introduced significant enhancements in interoperability, maintainability, portability, and reliability. In summary:

- New signal sources were added for improved hardware support for the GNSS-SDR embedded receiver, including SoC FPGA platforms, different radio-frequency front ends and Direct Memory Access-based configurations. A new signal source compatible with ION GNSS metadata was also introduced and the Monitor and PVT blocks can now stream data to multiple UDP ports, improving flexibility in data distribution.
- Reliability was strengthened with default support for Galileo's Open Service Navigation Message Authentication (OSNMA), enabling verification of signal authenticity.
- Maintainability improved through the transition to the modern Abseil libraries, supporting C++17/20 and reducing legacy dependencies; OpenSSL is now pre ferred over GnuTLS for cryptographic functions due to updated license compatibility, though GnuTLS re mains supported and build system improvements ex panded compatibility to architectures such as loon garch64 and enhanced detection of macOS environments.
- Usability enhancements include a reorganized c onfiguration folder and new install/uninstall targets for utility tools.

These updates make GNSS-SDR a more robust, flexible, and future-ready platform, better suited to meet the needs of modern GNSS research, prototyping, and development.

The 5G-LENA (https://5g-lena.cttc.es) ns-3 system-level simulator modules for LTE/LTE-A and 5G networks was extended with the following main features: new single user MIMO model (using an hybrid beamforming architecture and closed-loop MIMO mechanism), PMI, RI and CQI feedbacks, 3GPP codebook-based precoding Type-I, with up to 32 antenna ports and 4 streams/UE, various PMI/RI selection algorithms, multiple code optimizations for faster MIMO computations, and new fronthaul control methods. Also, New Radio (NR) is now independent of the upstream LTE module from ns-3. The maintainer and development team at CTTC also contributed to training through Goggle Summer of Code supervising two projects on RL-based QoS schedulers and new channel models for 5G-LENA. New traces, measurements, helpers, tests, examples, CI jobs, and bug fixes have been included. During 2024, four releases of the simulator were produced and released in open source, in particular: v3.0, v3.1, v3.2 and v3.3.
URL release v3.0: https://gitlab.com/cttc-lena/nr/-/tree/5g-lena-v3.0.y
License: https://gitlab.com/cttc-lena/nr/-/blob/5g-lena-v3.0.y/LICENSE

In 2024, ETSI Software Development Group TeraFlowSDN (SDG TFS) (https://tfs.etsi.org/), chaired by CTTC, made significant progress in advancing open-source SDN platforms through key software releases, technical events, and industry engagement. In April, TFS Release 3 introduced major

enhancements including an Optical SDN Controller, support for disaggregated networks using gNMI/OpenConfig, dynamic topology discovery via BGP-LS, and predictive analytics through a new Forecaster module. This was followed by Release 4 in November, which added integration with ETSI ZSM architecture, Quantum Key Distribution (QKD) support, logical inventory retrieval via NETCONF/OpenConfig, and blockchain-based security via Hyperledger Fabric.

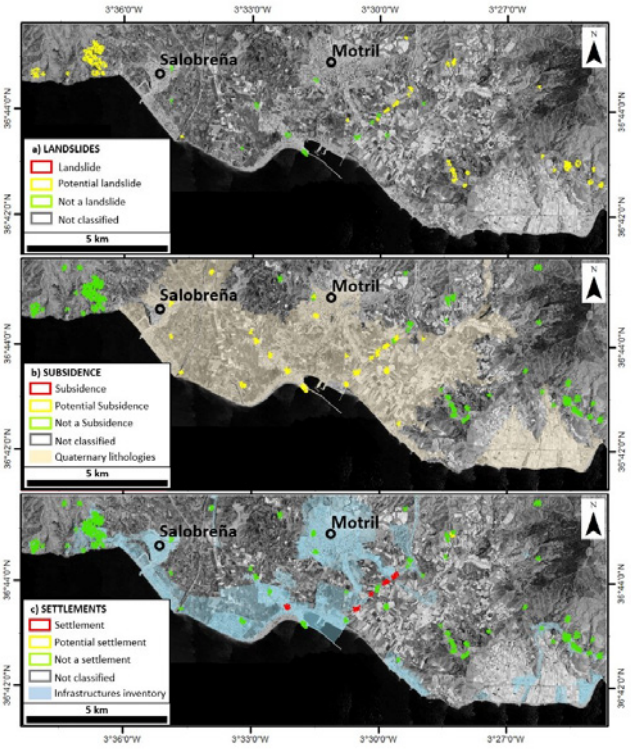
Two hackfests helped strengthen the developer community. The fourth hackfest, held in Athens, focused on Release 3 capabilities such as BGP-LS-based discovery and gNMI-based IP router configuration. The fifth hackfest, co-located with the ETSI SNS4SNS event in Sophia Antipolis, offered hands-on tutorials and onboarding sessions for new contributors.

TeraFlowSDN also featured prominently at the ETSI Software and Standards for Smart Networks and Services (SNS-4SNS) conference, with demos highlighting zero-touch 5G deployments and traffic verification using Ordered Proof of Transit (OPoT). These activities showcased TFS's alignment with next-generation networking goals, such as automation, security, and multi-domain orchestration.

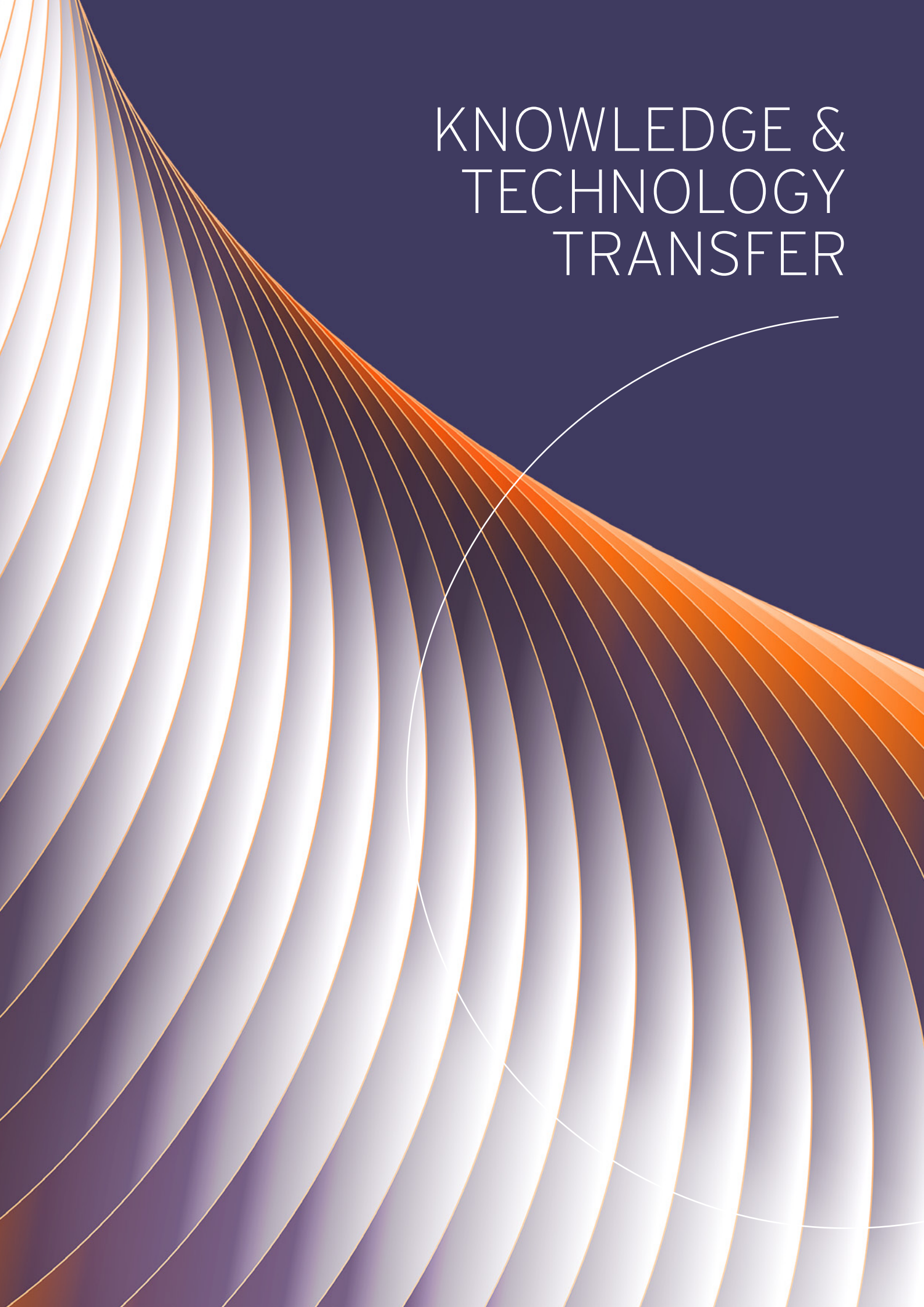
ADAtools software packages are not open source but can be used free of charge according to the respective licenses.

They belong to the category of Earth Observation research activities, providing tools for interferometry and the detection and classification of terrain deformations: GEOKINESIA PSIG® Persistent Scatterer Interferometry: is a remote sensing SAR tool that allows to monitor small terrain deformations with high sensitivity; ADA (Active Deformation Area) Tools includes several tools for the detection and classification of areas with active deformations and terrain movements. These tools facilitate the postprocessing of GEOKINESIA PSIG® output or any other software that returns interferometric measurements for an improved management and classification of such detected deformations. Major improvements are related to a brand-new version of the ADAclassifier tool, with much better decision trees devised to identify the reasons why the ground may be moving. These trees use a much larger number of physical parameters to perform their classification tasks. Furthermore, new kinds of datasets describing ground movement processes have been incorporated (e.g., measuring vertical displacement data, slope, or aspect), and new formats, such as GeoTiff, are now accepted as inputs.

A second release of the European ADA web map (https://groundmotionadas.com) is publicly available thanks to the integration of ADAfinder tool and the information provided by the European Ground Motion Service (EGMS, https://egms.land.copernicus.eu/). From billions of measured points to just a few Active Deformation Areas (ADAs) ADAfinder helps the experts to identify the areas where the ground is moving, whereas ADAclassifier goes one step beyond, trying to identify the reasons why said ADAs do move.



KNOWLEDGE & TECHNOLOGY TRANSFER



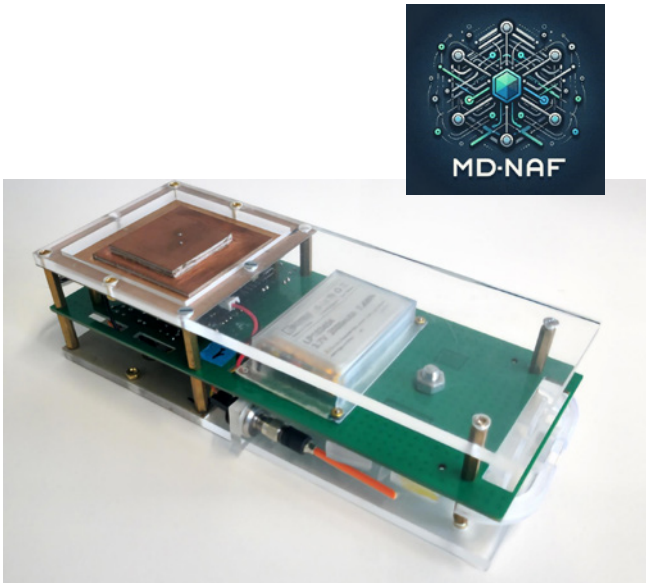
Spin-offs

GeoKinesia, S.L., the spin-off from CTTC established in July 2020, continues to leverage advanced remote sensing techniques that originated from CTTC's intellectual property portfolio. These techniques, which utilize satellite radar images, are instrumental in measuring and monitoring deformations across a diverse array of scenarios and applications. Such applications encompass mining operations, the detection of urban terrain deformations, comprehensive risk management associated with landslides or subsidence, and the ongoing maintenance of critical infrastructure, including roads and railway lines. The satellite-based remote sensing solution empowers GeoKinesia to deliver its services with a global reach. This 2024, CTTC divested its shares in GeoKinesia. This strategic divestment is anticipated to allow both CTTC and GeoKinesia to sharpen their respective strategic focuses and pursue independent growth trajectories, expecting to lead to enhanced operational and financial performance for both entities. GeoKinesia continues to exploit CTTC IPR assets, operating under a technology transfer agreement that remains actively in place, ensuring the continued application of CTTC's innovative solutions in the field.

IPR protection and product development

As one of its tools to foster technology transfer, CTTC relies on intellectual property protection through the national and international patent systems. In 2024, CTTC filed a patent application for its invention "MD-NAF - Massively Decentralized Network Automation Framework", which goes one step beyond current state-of-the-art network control and management systems and paves the way for network and infrastructure operators worldwide to adopt Network Automation technology empowered with Artificial Intelligence. This new technology has a high impact potential in the Network Automation market where, until recently, innovation cycles have been slow, due to slow buying cycles of telecom industry and infrastructure operators.
2024 has also been the year where the Board of Trustees of CTTC approved the update of its Intellectual Property Policy, which regulates the rules of to the ownership, protection and commercial exploitation of the Intellectual Property created by CTTC researchers. This update enabled the alignment of CTTC's internal policies with both the Catalan and Spanish Science Acts ("Llei 9/2022, de 21 de desembre, de la Ciència" and "Ley 17/2022, de 5 de septiembre, de la Ciencia").

Finally, in 2024, the second call of Business Development internal projects was held and two new initiatives with high business potential were started. The first one involves a workflow manager SW for Persistent Scatterer Interferometry, which is a remote sensing technique offering high precision in measuring minuscule movements on the Earth's surface. The second one pertains to the domain of low-cost wireless sensors for nerve agent and hydrogen gas detection.



Industrial Collaboration

Throughout 2024, CTTC has made significant strides in its mission to bolster the national industrial fabric by successfully signing two pivotal, confidential license agreements. These agreements were established with two prominent Spanish enterprises operating within the strategically vital sector of Space, Security, and Defence. The core objective of these collaborations is to empower these companies to bring to market their advanced, cutting-edge products, now substantially augmented and improved through the integration of CTTC's proprietary and innovative technology. Consequently, by facilitating such technology transfer, CTTC actively persists in its commitment to fortifying the local Spanish industry, thereby enhancing its overall capabilities and significantly boosting its competitive standing on the global stage, fostering innovation and economic growth.

PROFESSIONAL, SCIENTIFIC, TRAINING & DISSEMINATION EVENTS

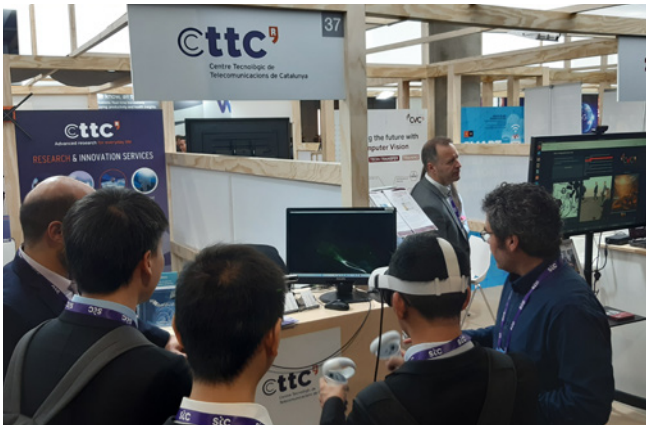
CTTC actively participates in a variety of events with the aim of:

- Increasing international visibility
- Fostering new institutional relations and collaboration agreements
- Establishing new R&D partnerships
- Contributing to the training of specialized R&D talent
- Disseminating scientific and technological knowledge and encouraging vocations in science and engineering

CTTC leverages large international congresses in Barcelona to showcase its work to a global audience. These exhibition opportunities are instrumental in showcasing CTTC technologies, testbeds, and demo portfolios; and interact with to interact with authorities and wide range of professionals. In 2024, CTTC exhibited at the Mobile World Congress (MWC) and IoT Solutions World Congress.

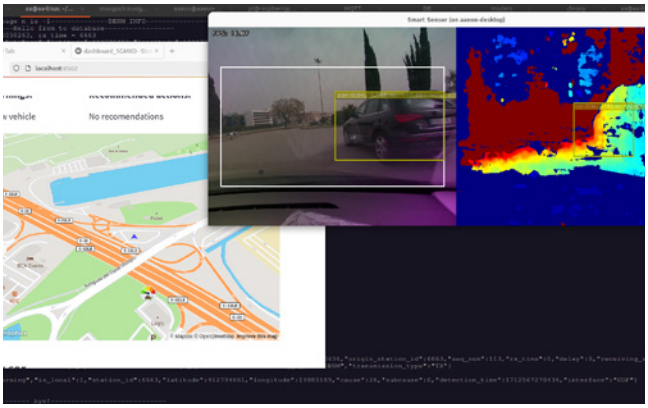
Visitors from the European Commission, ETSI standardization and the Catalan Government.

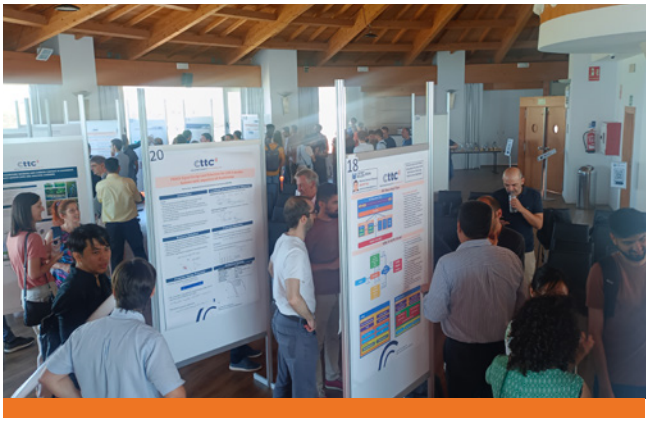
CTTC presented results from ongoing R&D projects and showcased demos on: high-experience virtual-reality gaming service leveraging on ETSI Fifth Generation Fixed Service (F5G) outcomes and CAMARA project integrated telco network and infrastructure management; an explainable AI solution for radio resource management; or an online hazard detection system for driving applications.



At the IoT Solutions World Congress (IoTSWC), we showcased the **Smart-Eye** sensor system—an advanced solution designed to identify and assess road objects in real time, significantly enhancing vehicle safety. Equipped with a **Telematics Control Unit (TCU)**, a **Vehicle-to-Everything (V2X)** communication stack, and embedded **AI models**, the Smart-Eye system featured an intuitive dashboard that delivers real-time alerts to drivers, including notifications of approaching pedestrians and the precise location of nearby vehicles.

Additionally, at the **Agora IoT Barcelona Activa**, we presented innovative solutions focused on **sustainable AI** and the role of **AI in enabling sustainable next-generation (xG) networks.**





Conferences, Workshops & Training Events

2024 was prolific in the organization and hosting of international conferences, workshops and training schools. A highlight is provided next.

The biannual internal workshop "**CTTC Day & Workshop**" was hosted in Sitges including a comprehensive technical program (https://cttcworkshop2024.cttc.es/) with a keynote and vibrant poster sessions for technical discussion between CTTC colleagues. This informal discussion space is valued very positively by CTTC personnel since it fosters personal relationships and opportunities for internal collaborations.

The final **workshop of RASTOO**L took place in February in Madrid. The International Workshop was celebrated at the National School of Civil Protection (Escuela Nacional de Protección Civil (ENPC) – DGPCyE), with more than 110 attendees (present and remotely), representing more than 15 European countries. The workshop presented final RASTOOL results, which main goal was to provide Civil Protection authorities with tools able to generate derived products from raw measurements provided by EGMS (European Ground Motion Service) data, in order to improve ground motion hazards and risk management.

Workshop on ns3 open-source initiative was hosted in June at CTTC. This annual workshop gathers world leading experts on network simulation tools, ns-3 maintainers and developers, together with networking simulation practitioners and users. Chaired by Sandra Lagén, the workshop extended over four days with an intensive program including basic ns-3 training for those initiating in ns-3 system level simulator; advanced tutorials and invited talks; technical meetings for the ns-3 consortium members, technical paper presentations and open software development discussions among software modules maintainers and interested attendees. Discussions on new simulation models, technical design and implementation aspects, validation models, integration with emulators or real-life frameworks, were some of the topics addressed. As leaders of the ns-3 5G-LENA module, CTTC provided a seminar on 5G new radio (NR) module.

The workshop included a visit to CTTC labs and to Telefonica Innovación Digital in Barcelona. A total of 29 students attended the workshop with a diverse representation across European research institutions and universities. Attendees from Spanish research centers mostly came from Barcelona and Madrid.

5th International Conference on Network of the Future - NoF 2024 took place in October, with the General Co-chaired represented by Raul Muñoz. This annual conference covers advances in the area of Future Internet design, with emphasis on enabling technologies, architectures and services. The program included two tutorials provided by CTTC researchers on the topics of large language models and data engineering for distributed deployments applied to B5G/6G networks: "Utilizing LLMs for Understanding, Monitoring, and Control of 6G Networks, and "Leveraging Data Engineering and Distributed Ledger Technologies for the Realization of B5G/6G Networks".

Training schools and workshops focused on PhD students and post-docs included topics on **The interplay between Machine Learning and Communication Systems**, a five-day workshop brought expert lecturers contributing to the state-of-the-art research approaches in distributed ML, energy-efficient algorithms and understanding of the interplay with communication systems to achieve pervasive and sustainable sensing, computing, and communication platforms.

As participants and members of the Steering Committee in the COST action **Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions** (INTERACT), CTTC organized and hosted the training school on AI/ML for 6G Communication Networks (and Beyond). As part of the program the **panel** discussion on **AI-native 6G radio interfaces: greatest hype or hope?** with renowned experts from the industry and academia, was opened for free on-line attendance. Organized in hybrid mode the panel debated their views on the feasibility of seeing truly AI native designs in the 6G radio interface, the key drivers and main technical challenges and algorithmic bottlenecks lying ahead, including the role to be played by standardization bodies.

Satellite Network of Experts School (SatNEx V) gathered over 42 early-stage researchers and industry professionals, including PhD students and postdoctoral researchers, interested in exploring the latest advancements in satellite communications and their applications. The Satellite Network of Experts School combined lectures from leading academics and industry experts around different topics like deep space, aeronautical, 6G NTN or AI activities among others. The participants arrived from a total of 21 universities/institutes from 10 different countries, across Europe and a few overseas countries. Partially sponsored by Teleco Renta, dissemination reached out at national and international level.

Shorter events such as the **seminar on quantum secure communications** aimed to bring closer to undergraduate and master students the new developments on Quantum-Key-Distribution and its integration into standard fiber optical transport networks. The seminar brought students from local universities and gave them the opportunity to interact with CTTC expert Michela Svaluto Moreolo and visit an in-campus company developing QKD devices.

Other activities involving training and dissemination dealt with the elaboration of multimedia and video recordings. To promote engineering telecommunication studies and its research career path and opportunities, David Calle - well-known disseminator and on-line teacher - visited the CTTC and the PMT to interview researchers and to show a snap-shot on the daily activity of a researcher, raising awareness of pioneering work that has been done in information and telecommunication technologies and related industries at the national level. This activity was carried out under the scope of the collaborative project Teleco Renta (https://www.instagram.com/telecorenta/)

CTTC also engaged with undergraduate students through student fairs at various universities, offering internships, final studies thesis work and research job opportunities. This year we visited MEMEnginy24 at the Universitat Autònoma de Barcelona (UAB), with follow-up actions publishing in the newsletter distributed among engineering students from the Escola d'Enginyeria.

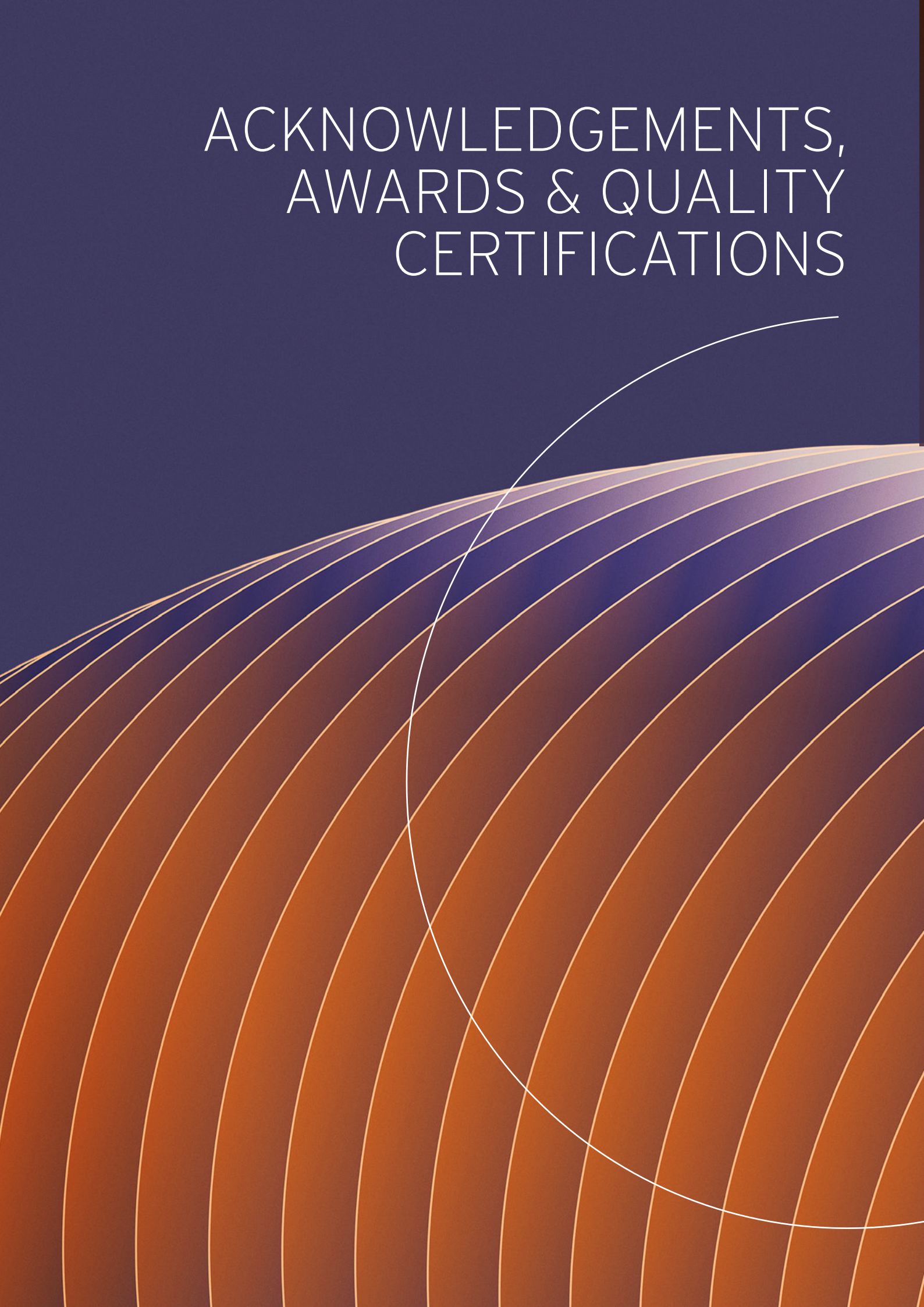
Besides the **open-day sessions** typically organized during the Science Week, dissemination events were expanded, targeting secondary school students to include in-house visits to the schools. We participated in the orientation open day at Bon Soleil Campus 2024 (Bon Soleil Lycée International, Gavà) and visited Escola Sant Gervasi (Mollet del Vallès) to present ESO 4-th grade classes, telecom engineering studies and the CTTC, as an example of research centers the can found near home.

CTTC open-day was extended to senior citizens offering a practical workshop on positioning and localization techniques in CTTC labs. The student agenda included basic talks on the evolution of the mobile networks from 1G to 5G, the importance of sustainability in IA, and other topics related to CTTC's activity including visits to the labs and the workshop. Over 100 students from professional training (Cicles Formatius) and secondary education 4-th grade attended the open-day.

On a regular basis CTTC hosts recipients of the extraordinary high-school prize awarded by the Department d'Educació i Formació Porfessional (Generalitat de Catalunya) within the ACER (Associació Catalana d'Entitats de Recerca) internship program. This one-week program offers students the opportunity to gain first-hand insight into the operation and activities of a research center. This year we hosted two students who accompanied researchers from the different research units in their research activities. The program ended with a discussion session where students shared their experience and acquired knowledge.

Citizen science sessions on how to combat air pollution continued this year in the cities of Barcelona and Mollet del Vallès. Additionally, CTTC participated in public initiatives like the BCNspiracy that took at the CosmoCaixa Science Museum during the Science Week. Eduard Angelats delivered two sessions on remote-sensing and geomatics as a tool for crop monitoring to over 200 people within the thematic program dedicated to soil health, nutrition, and related topics ("Salut del sòl, alimentació")

ACKNOWLEDGEMENTS, AWARDS & QUALITY CERTIFICATIONS



CTTC Director Prof. Ana I. Pérez Neira was recognized with the prestigious Narcís Monturiol Medal award for her contributions in signal processing for communications and multi-antenna systems, covering satellite and wireless cellular networks. The medals were presented later in 2025 by the Minister of Research and Universities to 10 researchers in the Catalan research system in recognition of their scientific career and contributions.

CTTC acknowledges the peer recognition and trust laid up in our colleagues from the different associations, bodies, and panels.

Dr. Raul Muñoz (Research Director and Head of the PONS research unit) and Dr. Abdelmoula BEKKALI (Research Director at SRCOM research unit) were elected members of technical committees of the top scientific societies devoted to the knowledge and technology advance on optical networking and optical systems: the IEEE Communications Society's Optical Networking (ONTC) and Transmission, Access, and Optical Systems (TAOS) Technical Committees, respectively.

CTTC's Scientific Director, Dr. Xavier Mestre was elected a member of the EURASIP Board of Directors, serving as Director for Conferences between the years 2024-2027.

Dr. Michela Svaluto Moreolo is Coordination Board Member of the Catalonia Quantum Academy.

Others continue to serve as representatives in industrial and academic bodies like Dr. Carles Antón, which is member of the 6G Smart Networks and Services Industry Association (6G-IA) Governing Board; Dr. Michele Crosetto, co-chair of the EGMS Advisory Board ; Dr. Josep M. Fabrega, member of Board of Stakeholders of Photonics 21 European Technology Platform; Dr. Ramon Casellas, Optical Society of America/Optica representative for the IEEE/OSA Optical Fiber Communication (OFC) conference Steering Committee and Technical Steering Team (TST) member at the Linux Foundation Open Network Modelling and Interfaces (ONMI); and Dr. Michela Svaluto Moreolo, member of AMETIC quantum technologies work group. This list is not meant to be exhaustive but representative of service and peer recognition.

Other notable technical recognitions are the best fast track paper award to Daniel Adanza, Ricard Vilalta, Raul Muñoz, Pol Alemany and Lluis Gifre for his scientific publication at the flagship international conference IEEE NFV-SDN 2024, with title ""A Hybrid Method to Predict Network Traffic Demands for Each Link"; and the Jack Bono Award for Engineering Communication from SEPE Foundation awarded to M. Eulàlia Parés and Eduard Angelats for their work on "Use of Unmanned Aerial Systems in Outdoor Firefighting". This award recognizes authors who have significantly contributed to the advancement and application of professional fire protection engineering.

As a public institution we welcome visitors and are open to explore collaborations. During 2024 we welcomed numerous academic, professional and institutional visitors.

Our commitment to excellence is supported by the, high quality standards for research policies and career development that are in place, with the UNE 166002 on R&D management systems being certified by AENOR and the HR Excellence in Research being awarded (since 2015) from the European Commission. This is a recognition of the institution's commitment to developing an HR Strategy for Researchers in the framework of the HRS4R Human Resources Strategy for Researchers, designed to bring the practices and procedures in line with the principles of the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers. As a CERCA center, CTTC is adhered to CERCA's code of conduct.

We thank you all our collaborators and staff to support CTTC's mission.

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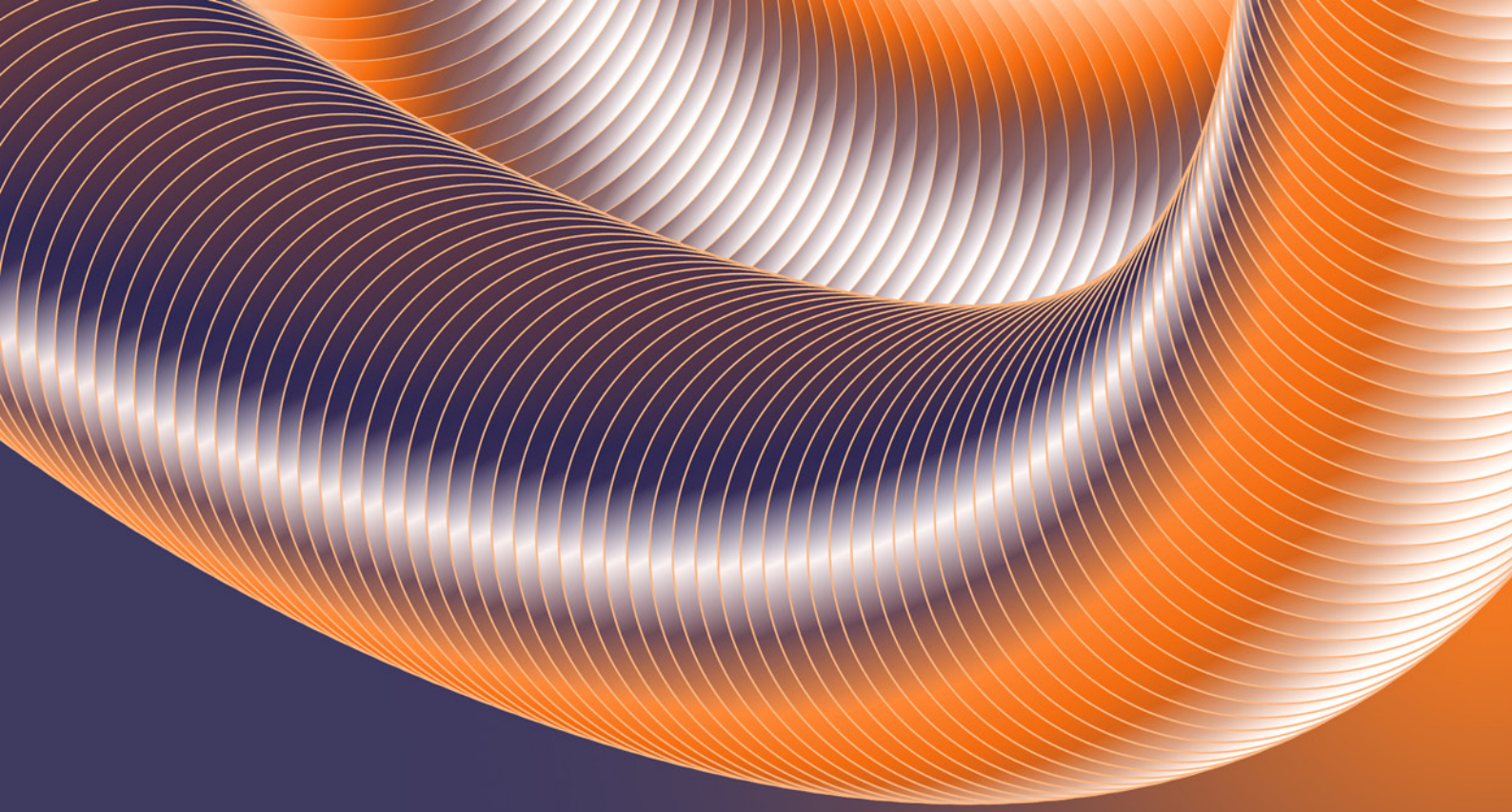

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