Annual Report

2025

cttc

Advanced research for everyday life

ttc

Annual Report

2025

Outline

About us

Ana Isabel Pérez-Neira
Director

CTTC has strengthened its scientific, technological and societal impact

The year 2025 marks the completion of the first four-year period of my mandate as Director of CTTC. Looking back, I do so with gratitude and confidence: gratitude for the collective effort that has made this journey possible, and confidence because CTTC has demonstrated its ability to grow sustainably while strengthening its scientific, technological, and societal impact.

During these four years, CTTC has consolidated its position as a leading European research center in telecommunications and geomatics. Our activity has combined scientific excellence, international leadership in 6G and AI-driven communications, and a growing capacity for technology transfer and innovation. In 2025 alone, CTTC surpassed 27M€ in total income, with more than 23M€ corresponding to self-raised funds, reflecting the robustness and sustainability of our model. At the same time, the scientific impact of our research has continued to increase steadily, reinforcing CTTC's international reputation as a center capable of combining deep technological research with high-value scientific contributions.

The year 2025 has also been marked by significant growth in strategic domains such as space and optical communications, areas in which CTTC has strengthened its European visibility and leadership. The consolidation of activities related to non-terrestrial networks, satellite communications, Earth observation, optical networking, and integrated terrestrial-space infrastructures reflects our commitment to addressing the future convergence of connectivity technologies. In parallel, our research activity has become increasingly interdisciplinary, integrating expertise across communications, artificial intelligence, sensing, photonics, quantum technologies, geomatics, and experimental infrastructures to tackle emerging technological challenges from a holistic perspective.

This progress has been accompanied by important organizational transformations. Inspired by the principles highlighted in the management review process, we have continued fostering a more participatory, agile, and innovation-oriented institution: strengthening collaboration between research and administration, reducing unnecessary bureaucracy, integrating AI tools into management processes, and involving the entire organization in strategic reflection and continuous improvement.

One particularly meaningful milestone has been the incubation of the WaveMaster spin-off, constituted after years of technological maturation inside CTTC. This achievement reflects our commitment to transforming deep technological research into societal and industrial value, while reinforcing a culture of entrepreneurship and knowledge transfer.

At the same time, we have continued investing decisively in experimental infrastructures, talent development, and international leadership. CTTC today contributes actively to Europe's 6G vision, participates in defining future strategic research agendas, and promotes open innovation ecosystems that connect academia, industry, and society. Thanks to this trajectory, CTTC is also strongly positioned to contribute to the next European Framework Programme, FP10, where the convergence of communications, AI, cloud, quantum, and space technologies will define a new generation of strategic research and innovation priorities.

As we enter 2026, CTTC opens a new stage of reflection and ambition. Guided by our Scientific Advisory Board and Board of Trustees, we have initiated the preparation of a new Strategic and Functional Plan that will define our priorities for the coming decade. This process is intentionally participatory, because CTTC is, above all, a community united by a shared purpose: to serve society and help shape the future in the AI era through telecommunications research and innovation.

MANAGEMENT

Prof. Ana Isabel Pérez-Neira
CTTC's Director

Òscar Carbó
General Administrator

Dr. Carles Antón-Haro
Director of European Programs & Industry Contracts

Dr. Monica Navarro
Director of Institutional Relations & Communication

Dr. Miquel Payaró
Director of National Programs and their Industry Leads (Open Innovation & Science)

Dr. Michela Svaluto Moreolo
Director of Quality Programs

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)

Dra. 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

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 2025)

- ***Hble. Sra. Núria Montserrat Pulido (President)***
  Consellera for Research and Universities
- ***Rector Mgfc. Francesc Torres i Torres***
  Chancellor of the Universitat Politècnica de Catalunya – Barcelona Tech (UPC)
- ***Rector Mgfc. Josep Antoni Rom Rodríguez***
  Chancellor of the Ramon Llull University (URL)
- ***Sra. Teresa Sanchís***
  Director General for Research, Department of Research and Universities
- ***Sr. Marc Darder i Solé***
  Head of Technical Cabinet at the Department of Territory
- ***Sra. 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

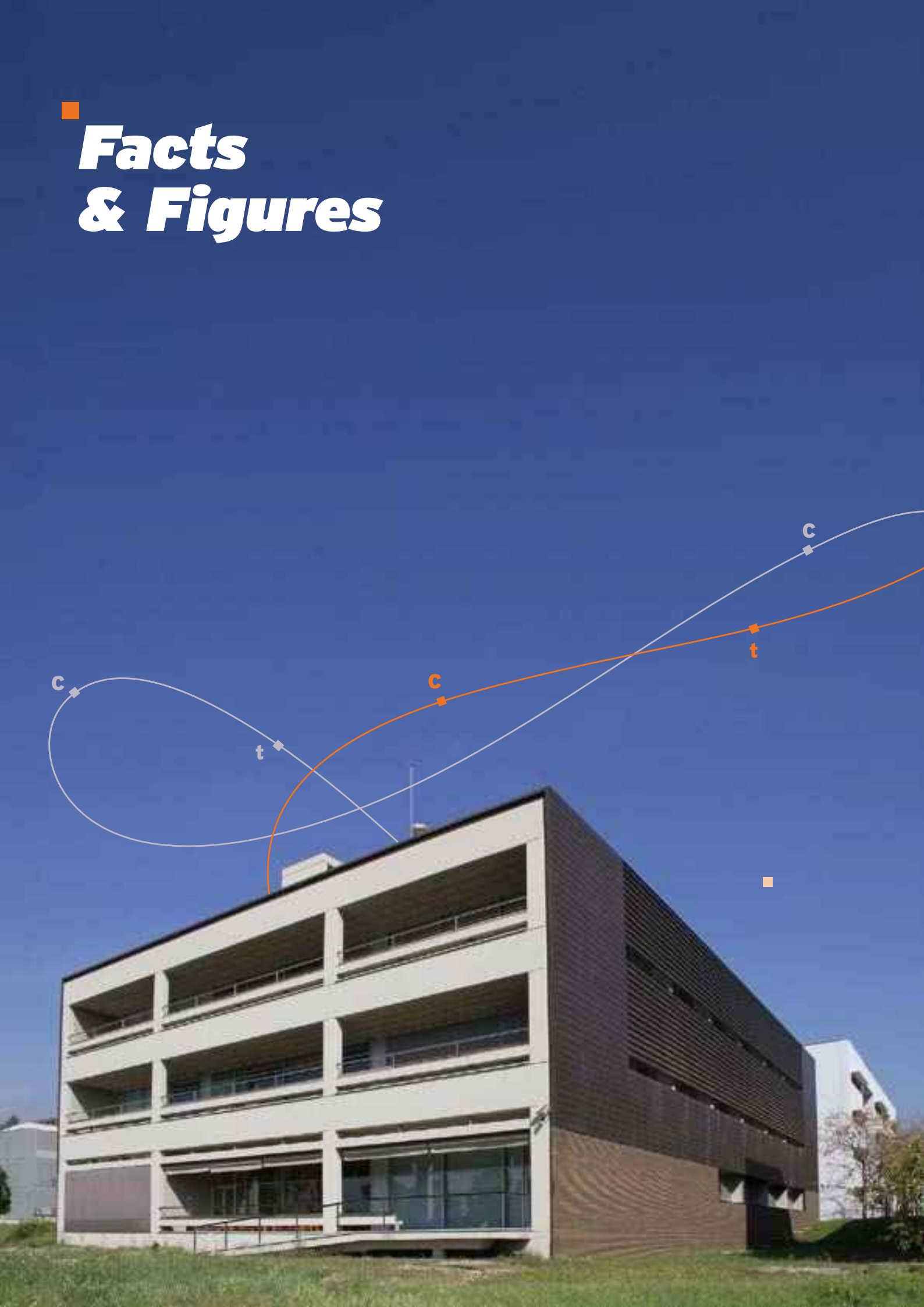
The Scientific Advisory Board offers independent guidance on our research strategy and provides expert evaluation of the scientific quality of CTTC's R&D activities. Composed of internationally renowned scientists, the Scientific Advisory Board advises the Director and Management Team.

Members (as of 31st of December 2025) in alphabetical order

- ***Prof. José Miguel Azañón Hernández***
  Universidad de Granada
- ***Prof. José Campmany***
  Univeritat Politècnica de València
- ***Prof. Carla Fabiana Chiasserini***
  Politecnico di Torino
- ***Dr. Markus Dillinger***
  Huawei Technologies
- ***Prof. Octavia Dobre***
  Memorial University
- ***Prof. Elza Erkip***
  New York University
- ***Dr. Riccardo De Gaudenzi***
  European Space Agency
- ***Dr. Carolina Pinart***
  Nestlé
- ***Dr. Colin Willcock***
  Nokia Networks

The 11th Scientific Advisory Board Meeting took place in Castelldefels on July 10th, 2025, bringing together Board Members, the Direction Unit and Research Units Heads in a collaborative session focused on strategic scientific guidance.

Facts & Figures



CTTC IN NUMBERS

Total income distribution

Total income

27.313.735 €

Core funding	Competitive funds	R&D services	Other
4.085.730 €	19.470.187 €	2.745.129 €	1.012.690 €

Total self-raised funds

23,228 M€

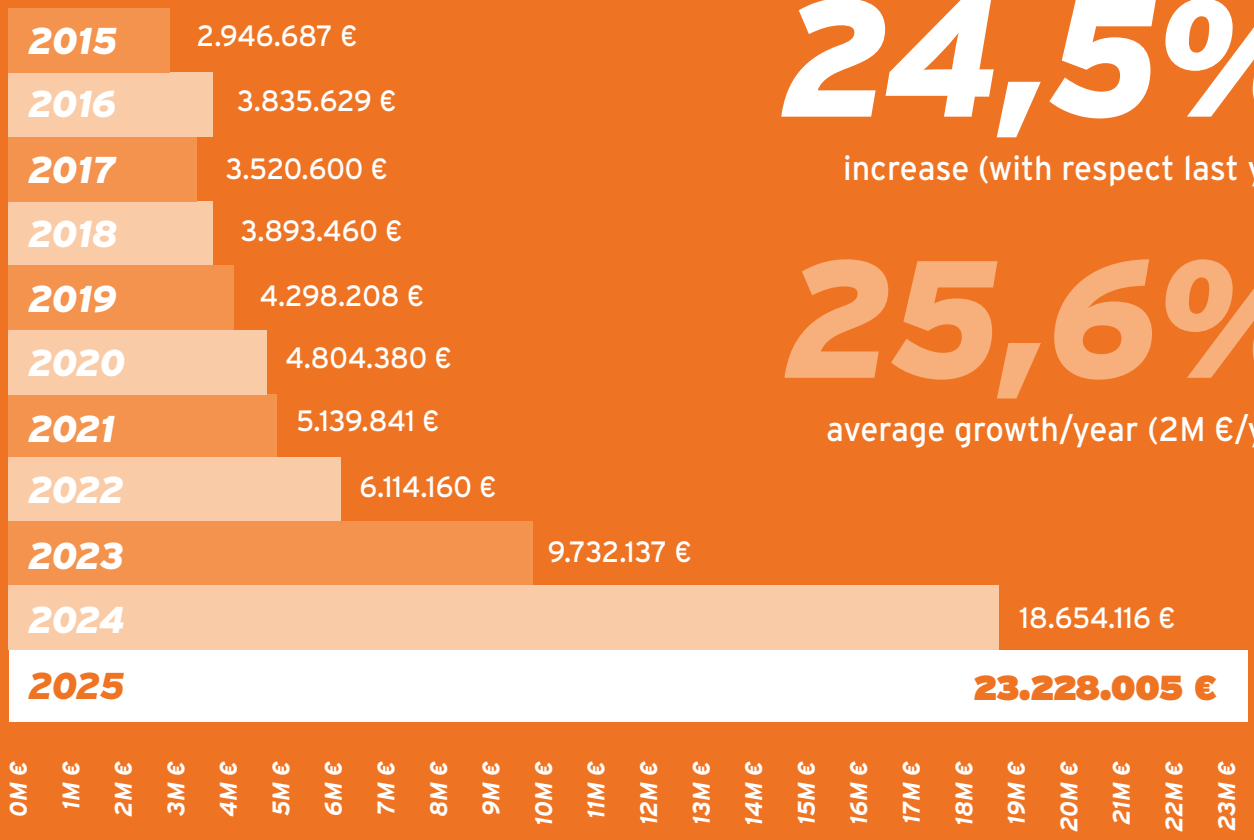
R&D distribution

European administration	Spanish administration	Catalan administration	Direct R&D contracts	IPR	Outreach & Training
14,7 %	70,6 %	1,8 %	12,3 %	0,2 %	0,4 %
3.292.181 €	15.770.222 €	407.783 €	2.745.129 €	34.077 €	96.593 €

Number of R&D projects

28	19%	Competitive (European)
67	46%	Competitive (National)
38	26%	Direct contracts (Industry)
5	3%	Internal
7	5%	Others

Income evolution



24,5%
increase (with respect last year)

25,6%
average growth/year (2M €/year)

Scientific Publications

105
Journals (indexed)

155
Conferences

64 | **67,4%**
First quartile

5,56
Average Impact Factor

Knowledge and Technology Transfer

2
Spin-offs

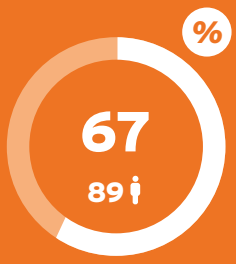
IN FORCE

27
Granted patents (Patent portfolio with 9 patent families)

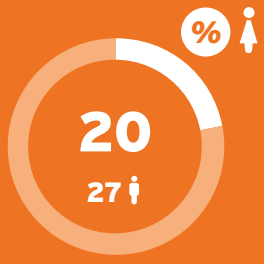
28
industry innovations

Staff

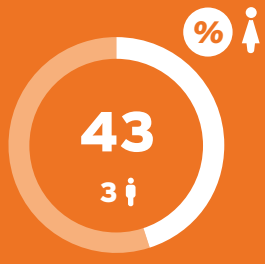
159
Total



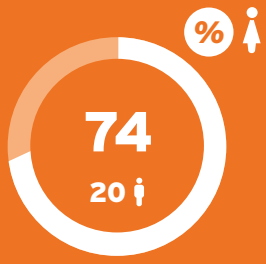
Doctors



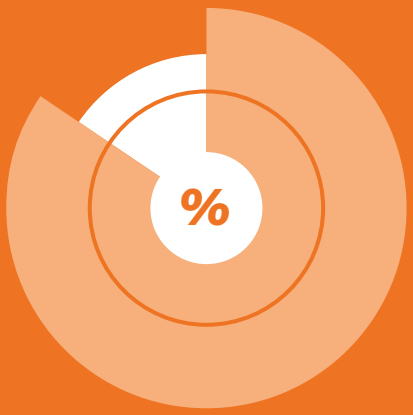
Women in research



Women in Management



Women in Administration & Support



83% Researchers **132**

17% Admin and Support **27**

4% Management **7**

29	22%	R1
59	45%	R2
29	22%	R3
15	11%	R4

31 different nationalities

Research & Impact

Research impact is highlighted in three main impact areas:

SUSTAINABILITY

is understood both in terms of the development of environmentally responsible ICT technologies, with sustainability embedded as a core design principle, and through the application of these technologies to domains such as Earth Observation and environmental monitoring.

The internal cross-disciplinary Sustainability Working Group is already generating tangible impact by promoting a holistic research approach.

- It encompasses heterogeneous systems where the newest advanced devices coexist with outdated simpler ones, **allowing devices to prolong lifetime**.
- The group also drives research on the integration of communication and sensing technologies where new materials play an important role and **bio-inspired, lightweight AI algorithms**, particularly tailored for wireless and mobile networks, where distributed and frugal learning approaches are critical.
- In addition, sustainability efforts incorporate societal dimensions, such as **AI explainability, trustworthiness**, and data sovereignty, ensuring that emerging technologies remain aligned with ethical and societal expectations.
- International visibility was further strengthened through participation in the EU Climate Pact Event in Brussels, contributing to discussions on citizen engagement through AI.
- These activities also influence education and talent development, for example through CTTC's invitation to the Erasmus Mundus Joint Master's Program CoDaS Associate Board.

A notable milestone is GAIA project, awarded in 2025 within the EIC Pathfinder Open Call, which **pioneers sustainable, biodegradable IoT systems**. On a different axis, environmental monitoring is being developed in programs of citizen science and awareness. One notable effort is the **legacy program "Signals of change"** developed during the organization of the international conference on Signal Processing and Acoustics (ICASSP2026) in close collaboration with the Barcelona Convention Bureau (Barcelona *Turisme*). A deeper understanding of the planet and the human–environment ecosystem is essential to advancing energy-efficient, bio-compatible, and human-centric technologies. Examples are projects like Lacuna Colombia that quantifies biomass and carbon content in Colombian mangroves, sen2rice that studies rice fields threatened by climate change like Deltebre region, aforementioned.

TECHNOLOGY TRANSFER & SOVEREIGNTY

are key mechanisms through which CTTC delivers societal impact, equipping socio-economic stakeholders with the technological capabilities needed to address emerging challenges. 2025 marked a major milestone with the creation of the **new spin-off WaveMasters** commercializing technologies to enhance robustness and security of satellite-based positioning systems, with direct impact on citizen safety and critical services.

Programs such as the **UNICO** have reinforced **technology sovereignty**, driving a strong industrial tractor effect by enabling advanced **5G/6G prototype** development in collaboration with **Spanish industry**. Early work on **non-terrestrial networks** (NTN) **integration with 5G** shows strong potential for ubiquitous connectivity, with initial applications in **civil protection and emergency response**.

In parallel, activities in Earth Observation and geomatics continue to deliver impact through InSAR-based monitoring for natural hazard detection and infrastructure safety, and remote sensing solutions for climate and agriculture (e.g., *PermaPyrenees*, permafrost monitoring, or *sen2rice* in rice monitoring), supporting sustainable resource management and biodiversity preservation across local and international contexts. KTT agreements with Geokinesia (CTTC's spin-off) are having a particular impact on mining and civil engineering.

STANDARDIZATION & OPEN-SOURCE

are key drivers of impact in telecommunications, translating research into globally adopted protocols and frameworks. Beyond academic output, contributions to standards bodies (e.g., 3GPP, ETSI, IEEE) and open ecosystems (e.g., O-RAN, SDN) enable interoperability, faster innovation cycles, and reduced time-to-market.

CTTC plays an active role in this ecosystem, holding membership in ETSI and 3GPP and contributing to the evolution of 5G and future 6G systems. In 2025, its leadership included roles such as Rapporteur in ETSI F5G and Chair of TeraFlowSDN (two new releases were issued), advancing cloud-native SDN and network automation.

CTTC also contributed to emerging multiple access technologies (e.g., ETSI ISG-MAT group report for 3GPP "ETSI GR MAT 001 v1.1.1") and pre-standardization initiatives such as the NTN Forum, supporting the integration of non-terrestrial networks with 5G/6G. Additional contributions span optical networks (IETF, ITU-T SG15) and wireless coexistence (IEEE/Wi-Fi), reinforcing CTTC's role in shaping future communication infrastructures.

Complementary to standards, CTTC contributes to policy guidance and decision making in several Administrations, with notable impact and participation at European level.

Open-source has fundamentally transformed the way industry develops products, shifting from closed, proprietary approaches to collaborative, community-driven innovation models. This paradigm enables companies, developers, and researchers to co-develop technologies, accelerate time-to-market, and validate solutions earlier through shared frameworks and open ecosystems. As a result, open-source has become a cornerstone for agility, interoperability, and large-scale technology adoption, particularly in communication and computing networks.

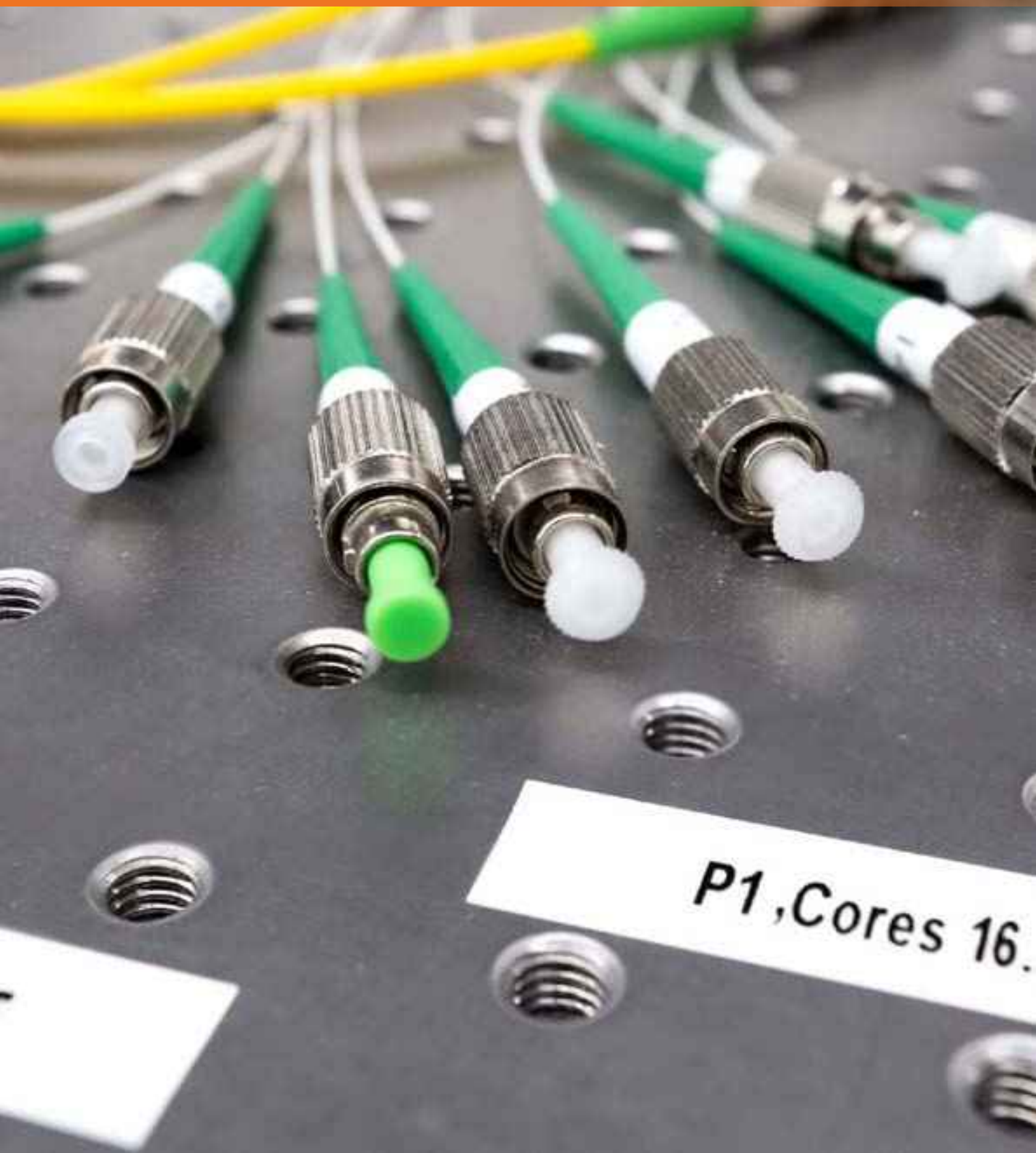
CTTC has been an early adopter of this approach, pioneering initiatives for over 15 years. A flagship example is GNSS-SDR (**device-level innovation**), an open-source software-defined receiver for global satellite positioning and navigation. Recognized in 2025 with the SourceForge Open Source Excellence badge, it has become an international reference for GNSS receiver development. This initiative also directly enabled the creation of CTTC's first deep-tech spin-off, WaveMaster, demonstrating how open-source can translate into industrial products and market-ready technologies.

In parallel, CTTC has actively contributed to open simulation platforms, such as ns-3 / 5G-LENA (**simulator-level innovation**), which have gained widespread adoption across academia and industry. These tools allow stakeholders to test and validate 5G network protocols and services in realistic environments, significantly reducing the need for costly and complex real-world deployments. Their strong uptake, including by major international technology companies, highlights their value in accelerating innovation cycles and de-risking product development.

More recently, the TeraFlowSDN initiative (**SDN controller and network automation innovation**) illustrates the impact of open-source in shaping next-generation network architectures. Originating from a European R&D project, it has evolved into an ETSI-led open-source software development group where operators, vendors, and service providers collaborate on cloud-native SDN controllers and automated network management frameworks. This demonstrates how open-source not only supports research dissemination but also directly influences industrial practices and the evolution towards 6G networks.

All three initiatives are led and technically supported (implementation and maintenance) by CTTC.

R&D Projects



EARTH OBSERVATION

This activity focuses on the development of advanced Earth Observation services based on satellite data, particularly Copernicus and Interferometric SAR technologies, combined with in situ measurements and digital modelling. It enables large-scale monitoring of ground deformation and environmental impacts, supporting risk assessment, resource management, and decision-making through innovative geospatial analytics and digital twin capabilities.

Funded by the European Union | Horizon Europe, Innovation Action

MOSMIN *Multiscale Observation Services for Mining-related Deposits develops* **services for the geotechnical and environmental monitoring of mining-related deposits** based on a combination of Earth Observation and in situ geophysical data. Using Copernicus Earth Observation data, especially Sentinel-1 data, for large-scale monitoring of ground deformation and surface composition the project has improved the efficiency and reliability of monitoring, maximised resource utilisation and helped mitigate environmental risks and the impact of mining operations. The tools and procedures developed in this project have been tested in mining sites located in Europe, Africa and South America, being the main beneficiaries of the project, mining and raw material companies.

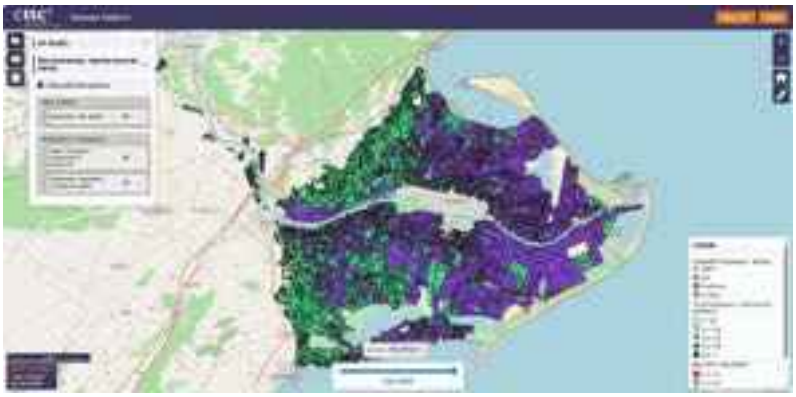
Funded by the European Union | Digital Strategy

DestinE (Destination Earth) **Platform** – *Advanced Applications and Services onboarding* is an initiative of the European Commission that aims to develop a highly accurate **digital model (digital twin) of the Earth** to monitor and model natural phenomena, hazards, and related human activities. This initiative seeks to achieve breakthroughs in the reliability, accuracy, and applicability of services, enhancing their modelling capabilities, temporal and spatial resolution, and user experience in relation to climate change. In a consortium with GeoKinesia, CTTC proposes onboarding three Interferometric Synthetic Aperture Radar based services: a land deformation monitoring service; and Active Deformation Area service; and a Differential Deformation Map service. The first service is used to detect land deformation; it can be used as a base to develop early warning systems. This is accompanied by two new, downstream services (the Active Deformation Areas and the Differential Deformation Maps) that extend the use of Interferometric SAR data by providing additional promotional tools for such data and more generally for the DestinE ecosystem.

Cofinanciado por la Unión Europea

Generalitat de Catalunya | Digital Strategy

Sen2rice project applies advanced satellite remote sensing techniques to improve the monitoring of rice production and sowing practices at plot level in the Ebro Delta. By generating high-resolution maps and temporal analyses using Sentinel-2 data and cloud-based processing, the project provides valuable tools for local authorities and stakeholders. Its results will contribute to more sustainable agricultural practices, improved resource management, and better adaptation to climate change, while supporting biodiversity conservation. The initiative aims to deliver strong social impact by empowering local stakeholders through accessible data, fostering informed decision-making, and promoting the digital transformation of the agricultural sector.



TOWARDS 6G

SPANISH ECOSYSTEM

With the completion of UNICO-5G I+D program CTTC led significant advancements, prototypes and deployments within the Spanish eco-system towards 6G. The technology solutions were accompanied by a significant investment on equipment and infrastructure that enhanced the outcomes with innovative proof-of-concepts and hardware. The specific section on experimental facilities and testbeds provides further details.

Funded by the European Union NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

UNICO 5G I+D
Coordinator

6GBLUR structured around the SMART and JOINT subprojects, was successfully completed with significant technical results in advanced 5G/6G network automation. The project addressed two complementary challenges: smart decision-making algorithms for efficient end-to-end resource management and joint RAN–transport control and orchestration mechanisms for blurred, disaggregated network architectures; delivering several proofs of concept and advanced key research areas **including network digital twins, non-public networks, AI/ML-based monitoring, QoS management, and radio stack optimization**. Use cases were demonstrated on the EXTREME Testbed®, including **agentic AI-based automated management of O-RAN and core networks**, as well as **cloud-native end-to-end orchestration across O-RAN, transport, and core domains**. In parallel, CTTC enhanced the ns-3 5G-LENA simulator with **several functional split implementations, PDU-set-aware scheduling capabilities, and O-RAN extensions**, reinforcing its role as a reference open-source simulation platform for 5G/6G research.

Funded by the European Union NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

UNICO 5G I+D
Coordinator

6G-OPENSEC designed and developed a security and trust network management solution that allowed the deployment of services from different security providers across multiple domains to protect the End-to-End service from an operator while managing the trustworthiness of the providers based on their performance to deliver the expected protection. The key aspect of this solution is the merge of different technologies such as the use of Security/Trust SLAs, DLT and Close-Loops with AI/ML features. Results were presented with a demo in the 2025 ETSI SECURITY CONFERENCE and an OJCOMS article. It also designed and developed flexible QKD solutions, software-controlled via SDN, to secure future 6G networks, promoting efficient integration within deployed infrastructure. Quantum-classical channel coexistence was analyzed, assessing the impact of multiple parameters, optimizing channel allocation and performance. Final validation was successfully performed at CTTC using the ADRENALINE testbed, integrating the open-source TeraFlowSDN controller with a real CV-QKD system for remote configuration and dynamic channel allocation, enabling coexistence with programmable sliceable transceivers and efficient resource utilization. Results were presented with a demo in the 2025 ETSI SECURITY CONFERENCE and an OJCOMS article and ECOC 2025, as top ranked paper upgraded to invited talk.

Funded by the European Union
NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

UNICO 5G I+D
Coordinator

6G-OPTRAN experimentally validated an open optical transport network architecture across data, node and control layers, attaining relevant scientific and standardization impact, and reinforced Spanish and European leadership in sustainable 6G network technologies. On the one side, the project targeted the data plane, delivering novel multiband optical transmission technologies that substantially extend capacity. It prototyped and experimentally validated transceivers, amplifiers and monitoring subsystems operating beyond the conventional C band; to demonstrate the feasibility of multiband and space division multiplexing. Also, the network node layer was addressed by developing disaggregated packet/optical nodes based on whitebox hardware and open network operating systems. A major achievement was the integration of multi vendor packet switching and coherent optical transmission under a common open NOS, exposing standardized APIs and telemetry. This enabled full SDN based programmability, monitoring and automation, which were validated through public demonstrations. Finally, it provided the control and intelligence layer, delivering an SDN control plane, a streaming telemetry framework and a dynamic network planning tool. Using open models and protocols (e.g., TAPI, OpenConfig and gNMI), it enabled end to end service provisioning, closed loop operation and multi domain optimization, paving the way toward autonomous optical networks.

Proyectos de Generación de Conocimiento
Coordinator

6G-RAISING *6G Radio Access Network Intelligence and Micro OrcheStratIoN for EdGe-Assisted Energy-Efficient Transceivers*, address Agentic AI for 6G, edge intelligence deployment, and FPGA-based RAN acceleration. More specifically, the project introduced an Agentic AI framework for autonomous 6G management, alongside a scalable FPGA SoC resource management layer for radio units. Experimental validation included real-time edge deployments, heterogeneous acceleration, and AI-driven orchestration. These contributions advance system maturity toward higher TRLs (TRL 5), demonstrating feasibility in realistic edge/RAN environments. Key outcomes include reusable software/hardware architectures for AI-driven RAN control, FPGA resource orchestration frameworks, and edge AI deployment models. The work aligns with O-RAN and emerging 6G standardization efforts, contributing concepts such as intent-based management and AI-native control loops, supporting national leadership in 6G.

EUROPEAN ECOSYSTEM

Within EU ecosystem CTTC is coordinating and leading a significant portfolio of projects which positions CTTC at the forefront of Europe's strategic ambition to lead the transition toward 6G-enabled, sustainable, and intelligent digital infrastructures. It combines foundational research, system-level innovation, and large-scale validation across the full communications stack—from physical-layer technologies (like XL-MIMO, compression algorithms) to network architectures (Open RAN, optical x-haul, NTN-TN integration) and application-driven use cases. A defining strength is the integration of AI-native design principles into next-generation networks, advancing beyond incremental optimization toward autonomous, self-evolving systems. Through initiatives such as UNITY-6G, VERGE, and SEASIDE, the portfolio contributes to the development of distributed intelligence, edge-native orchestration, and collaborative learning paradigms, enabling real-time adaptability, scalability, and resilience across heterogeneous environments.

Projects like GAIA and SEASIDE pioneer energy-efficient AIoT and biodegradable devices, while network-oriented efforts embed resource efficiency and carbon-awareness into architectures and protocols. This positions the portfolio as a key contributor to green digital transformation and circular economy principles in ICT.

Another strategic pillar lies in seamless integration of terrestrial and non-terrestrial networks, as demonstrated in GOVSATCOM-related projects, enabling ubiquitous, mission-critical connectivity for governmental, industrial, and humanitarian applications. These efforts reinforce Europe's technological sovereignty and operational resilience in critical communication infrastructures.

Funded by the European Union

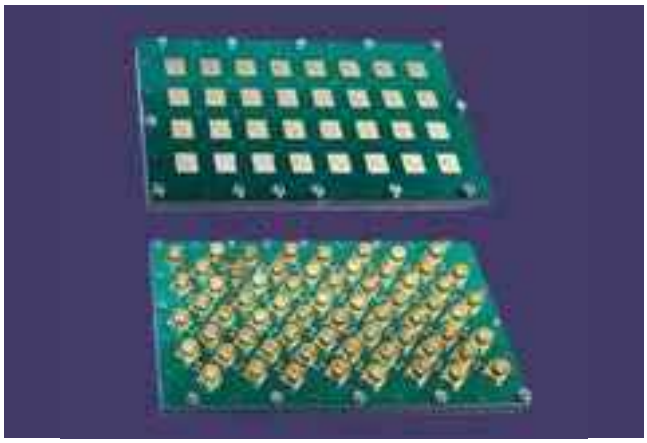
Horizon Europe | Digital, Industry and Space | **Coordinator**

UNITY-6G Unified architecture for Open RAN-enabled distributed, scalable and sustainability-enhanced 6G Networks, aims to create a highly sustainable and scalable integrated AI-native architecture that can support the diverse requirements of 6G networks by relying on advanced technologies, such as distributed ledger technology, semantic communications, digital network twinning to enhance the performance, cost-efficiency and trustworthiness of integrated 6G network services and applications. The focus is on scalability and sustainability for integrated networks (Non-Terrestrial and Terrestrial Networks, xHaul, Open RAN, Non-Public Networks, Edge, Core and Cloud). Furthermore, UNITY-6G aims to evolve to real-time distributed and network state-aware Open RAN that can leverage the integration of distributed applications in the integrated architecture. This will enable fine-grained data-driven management and control via incorporating dApps, distributed applications that complement existing xApps/rApps and use cases with stricter timing requirements in an integrated network. The selected uses cases include: i) Sustainable networks for disaster handling, (ii) Immersive Experience with Real-time XR/holographic communications, (iii) Digital Twin for Integrated 6G Network Evaluation, (iv) Multi-RAT O-RAN enabled NPN for supporting time sensitive applications for Industry 4.0.

Funded by the European Union

Horizon Europe | Digital, Industry and Space | **Coordinator**

6G-REFERENCE *6G haRdware Enablers For cEll fRee cohEreNt Communications & sEnsing* develops sustainable solutions for future 6G distributed radios. CTTC contributions to 6G REFERENCE include project coordination, research work on antenna design with integrated filtering for interference mitigation and reconfigurable intelligent surfaces using diodes and liquid metal that allows enhancing antenna performance by extending wireless coverage around obstacles. The project has already developed a high-performance antenna implementation.



CTTC´s research efforts also focus on integrated sensing and communication components, including security related sensors for volatile organic compound detection in factory or warehouse scenarios. 6G REFERENCE was included in the top 10 SNS key achievements for the work related to time modulated arrays supporting both receive and transmit.

Funded by the European Union

Horizon Europe | The European Innovation Council (EIC) | WP leader

GAIA *Bridging Sustainability and Ubiquity in Next-Gen IoT awarded by the end of 2025 under EIC-Pathfinder-OpenCall program lies under the umbrella of sustainable and biodegradable architecture for a circular IoT* ecosystem. GAIA reimagines the Internet of Things (IoT) by leveraging breakthroughs in biodegradable electronics and ambient communication to deliver a transformative vision: a seamless, sustainable, and circular IoT ecosystem. It introduces a new class of transient, ultra-low-power microelectronic systems that combine sensing, computation, and communication in a single biodegradable architecture--free from batteries, active radios, or persistent microcontrollers. Using 6G Ambient IoT backscatter concepts, GAIA devices operate autonomously and interface natively with existing cellular infrastructure. Designed to degrade naturally after use, they offer a battery-less, zero-waste solution that unites infrastructure compatibility with environmental responsibility. This marks a key step toward an infrastructure-aligned IoT that avoids long-term ecological impact while maintaining advanced digital functionality. Over three years, GAIA follows a phased strategy--from component validation to system-level verification--culminating in a disruptive proof of concept, led by CTTC. This demonstrator, focused on smart logistics and cold chain tracking, will showcase a fully transient IoT system with ultra-low cost, power consumption, and seamless cellular interoperability. GAIA aims to enable transformative applications in human and industrial contexts requiring (near) real-time tracking, sensing, and identification, without compromising sustainability. The project adopts a vertically integrated approach--from biodegradable materials to system design and telecom infrastructure--paving the way for digital objects at near-zero cost and minimal environmental impact. GAIA aligns with the EU's strategic goals, advancing high-impact innovation, strengthening sovereignty in critical technologies, and pioneering a new class of IoT.

Funded by the European Union

Horizon Europe | Digital, Industry and Space | SNS-JU | WP leader

PROTEUS-6G *Programmable Reconfigurable Optical Transport for Efficiently offering Unconstrained Services in 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 support Flexible Functional Splits (FFS) and high-capacity cell-free massive MIMO use case scenarios. Results include the final design of the 6G x-haul network architecture, employing a sophisticated optical switching and multiplexing infrastructure, integrating multi-layer SDN orchestration system, and incorporating AI for traffic prediction and resource optimization; the definition of a day/night use case for application of FFS and the derivation and testing of FFS algorithms using the 5G-LENA simulator, and 3) the final design and preliminary implementation of the PROTEUS-6G service management, orchestration and control enablers, including the management of DSCM optical pluggable modules.

Funded by the European Union

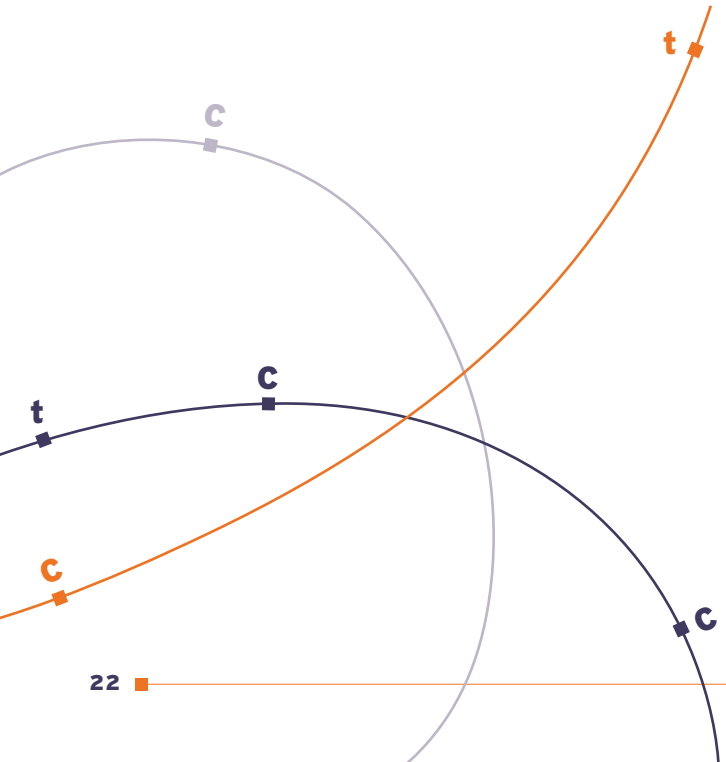
Horizon Europe | Digital, Industry and Space | SNS-JU | WP leader

VERGE *AI-powered evolution towards open and secure edge architecture*, delivered a proof-of-concept on smart micro-orchestration in disaggregated softwarized RAN elements (TRL4) which supports network operators and vendors by enabling more efficient, programmable, and scalable RAN management. Technology that improves connectivity, energy efficiency, and service flexibility; showcased at major international events such as the MWC and EuCNC in 2025.

Funded by the European Union

Horizon Europe | Digital, Industry and Space | EUSPA | **Coordinator**

5G-GOVSATCOM *Fifth Generation Technology Standard for European Union Governmental Satellite Communications*, targets the development and evaluation in controlled lab environment first and then in a natural user environment of different key enabling technologies that aim to provide full integration of 5G non-terrestrial networks (5G-NTN) satellite networks in the EU-GOVSATCOM (European governmental satellite services) framework. The technological framework is validated in two field trials on humanitarian aid scenarios with Open Arms and the Italian Red Cross. More specifically, for inter-networking segments, 5G-GOVSATCOM has successfully tested seamless handover between terrestrial networks and NTN in lab. The complete architecture was implemented, including smart gateways (SGW) on both the client and server sides that enable seamless handovers through the use of VPNs. An API was designed to enable SGW functionalities to organizations exploiting the framework (e.g., humanitarian aid organizations), such as VPN instantiation and handover requests. This API was refined to integrate other partners handover algorithm, which required the SGW to extract performance metrics from standard terrestrial (TN) UEs. Two different core networks have been deployed in the lab, and the TN side has been implemented with Amarisoft callboxes. For NTN side, Keysight's channel emulator simulated GEO satellite characteristics, enabling full in-lab testing of the seamless handover between TN and NTN links. Field trials Mission Critical (MCx) application, as videocalls and Push-To-Talk (PTT) functionalities are also evaluated.



Funded by the European Union

Horizon Europe | Digital, Industry and Space | EUSPA | **Coordinator**

5G-HUB *Fifth Generation Services HUB for European Union Governmental Satellite Communications* develops a new interface between the G-HUB and the 5G core network alongside microservices for network management. The project is addressing interoperability, enabling GOVSATCOM user terminals to connect with various space assets and terrestrial systems. It also validates the G-HUB functions through three trials focused on a unified 5G NTN terminal in Ku and X bands. Live demonstrations on NTN-TN Integration Through Geostationary Satellite in Cloud-Native 5G Networks were held at WMCN, showcasing SDR-based access, realistic channel emulation, ETSI MANO-driven orchestration, and seamless connectivity between terrestrial and non-terrestrial network segments for beyond-5G systems.

Funded by the European Union

European Research Council
Established by the European Commission

Horizon Europe ERC

UNIDACT *Universal Data Compression with Circular Context Trees*, is an ERC proof-of-concept jointly implemented by UPC and CTTC. The goal of the project is to prototype universal data compression algorithms, which has significant compression gains over the state-of-the-art commercial algorithms, and to conduct a market analysis for licensing opportunities and establish an IPR protection mechanism that is most suitable for the UNIDACT algorithm, creating specialised applications for compressing satellite observation data and genomic information. CTTC is leading the algorithm generalization to arbitrary size alphabets and extending the basic binary version to more general alphabets, which already achieved improvements in the complexity of the binary version of the algorithm, advanced on the source coding with side information problem and implemented and tested the encoder and decoder along several functions and modules of the generalized version of the algorithm.

Funded by the European Union

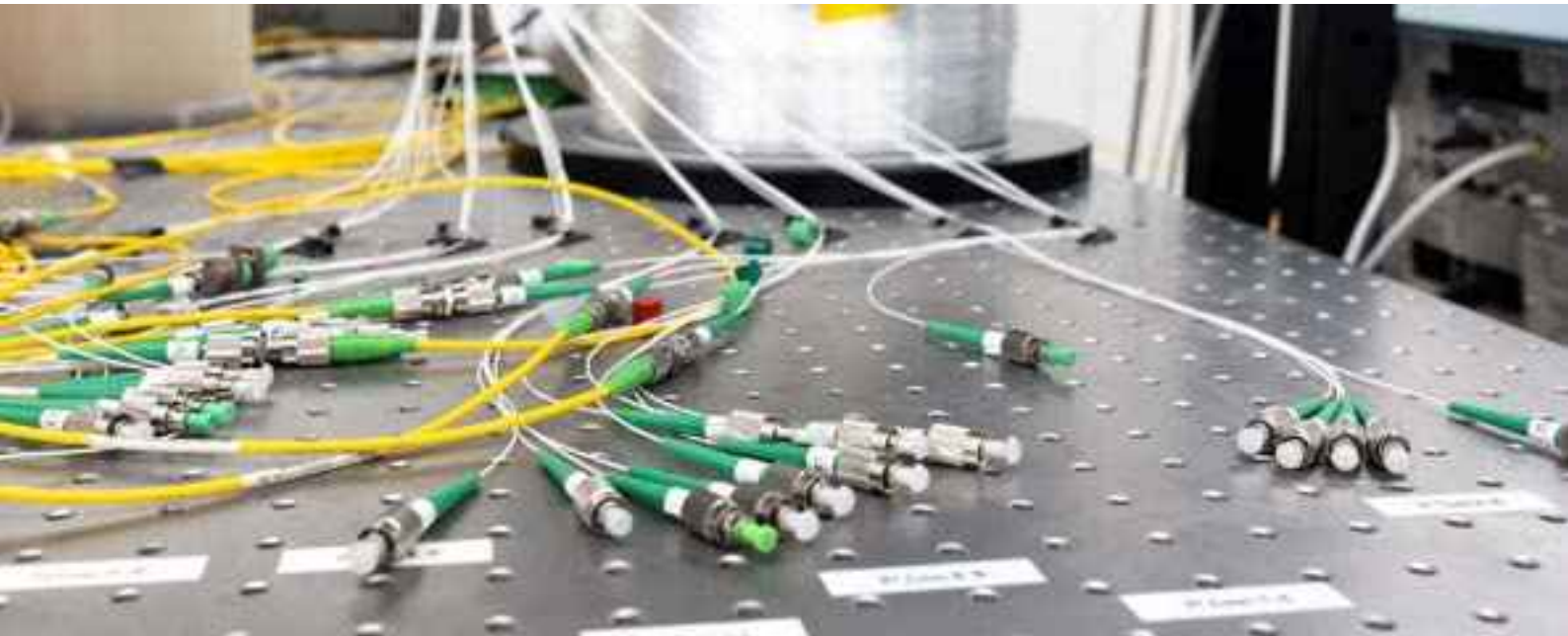
Horizon Europe | Digital, Industry and Space | SNS JU| **Coordinator**

Proyectos de Generación de Conocimiento, **Coordinator**

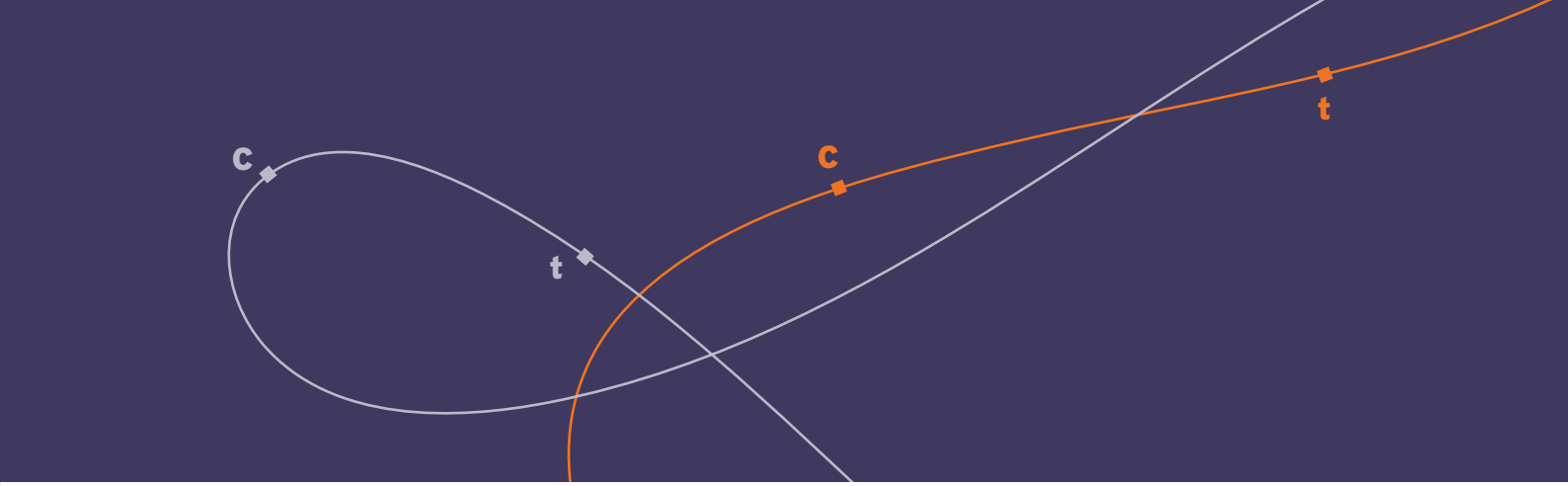
SEASIDE *Sustainable and robust AIoT for edge-based Services* aims to improve scientific knowledge at the intersection of the Internet of Things and Artificial Intelligence, with focus on mitigating their environmental footprint. Over the past decade, the environmental impact of Information and Communication Technology and Artificial Intelligence has grown exponentially, diverging from the IPCC recommendation of halving CO2 emissions due to human activities by 2030. Current research often prioritizes higher accuracy and performance by leveraging large number of sensors, big data, dense communication network deployments and computationally complex AI models, without considering the energy consumed. SEASIDE seeks to reverse this trend by developing sustainable and trustworthy machine learning (ML) models alongside distributed and collaborative computing architectures. Our solutions target extremely high energy efficiency, while maintaining performance levels comparable to state-of-the-art, energy-intense approaches. SEASIDE conceives a liquid AIoT scenario, where every device participates in the learning process, regardless its capabilities, and federates the acquired local knowledge with direct communication (when possible) to other trusted peers, to form a shared collective intelligence and solve complex tasks.

Proyectos de Generación de Conocimiento, **Coordinator**

WAVE-XL *Wireless Advancement Via EXtra Large MIMO project aims to advance Extra-Large MIMO* (XL-MIMO) technologies, a key enabler for future wireless systems beyond 5G/6G. Traditional wireless networks face performance limits due to increasing connectivity demands; XL-MIMO and Holographic MIMO architectures expand multi-antenna apertures and unlock transformative gains in capacity, spectral efficiency, and beamfocusing capabilities. WAVE-XL is exploring the fundamental limits of spatial wave processing by integrating electromagnetic (EM) theory, information theory, and signal processing; proposing novel signal and information processing techniques for computationally efficient XL-MIMO transceivers and demonstrating real over-the-air feasibility with hardware experiments. Core research topics include EM wave processing, advanced multiple access, AI/ML integration, data compression, protocol learning, and over-the-air/coded computing to enable scalable and practical deployment of massive transceiver arrays.



Scientific Publications



This section highlights a few selected publications both in journals and flagship conferences according to editorials and scientific associations most relevant to CTTC's activity. The most represented editor is IEEE, across the different societies, heavily centered around: Communications Society, Signal Processing Society and Photonics Society, with additional contributions from Geoscience and Remote Sensing Society, Computer Society, AI-related societies, and interdisciplinary councils: Vehicular Technology, Sensors, Internet of Things, Machine Learning in Communications and Networking.

Assessing the impact of ground motion and satellite remote sensing services on infrastructure safety and environmental monitoring

These studies exploit results from the Copernicus European Ground Motion Service, a flagship European program to which CTTC contributes as a leading developer and scientific partner.

Shahbazi, S., Barra, A., Navarro, J. A., & Crosetto, M.

From EGMS to Potential Damage Maps: Assessing the Potential Impact of Ground Motion on Exposed Buildings.

IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 18, 26699, 2025.
https://doi.org/10.1109/JSTARS.2025.3618479

This paper presents a methodology to transform raw European Ground Motion Service data into interpretable maps estimating potential building damage. The approach introduces an automated tool for analyzing differential deformations at the individual-building level, a key parameter in structural and civil engineering assessments. The methodology is validated through surveys assessing the observed building damage level.

Garcia, D., & Parés, M. E.

Assessing Nitrogen Dioxide Monitoring Techniques: A Comparative Analysis of Sentinel-5 Precursor Satellite and Ground Measurements in Catalonia.

Atmospheric Measurement Techniques, 18, 5569-5590, 2025.
https://doi.org/10.5194/amt-18-5569-2025

This study evaluates the consistency between satellite-derived nitrogen dioxide concentrations from Sentinel-5P and in-situ ground measurements across Catalonia. Satellite and surface observations are temporally and spatially aligned to assess correlation patterns and monitor reliability. The results highlight strengths and limitations of both data sources and demonstrate the value of their integration for air-quality monitoring, supporting environmental assessment and public-health policy development.

AI-driven Automation and Trust in 6G Networks

Contributions towards automation span across diverse network technologies, including optical, mobile/wireless and wired packet oriented, with Intent-driven network and service orchestration approaches leveraging on the automated translation of high-level goals into network specific commands and resource configurations. Trust and resilience exploit technologies such as block chain and machine learning (from distributed to nature inspired learning algorithms).

Antonopoulos, A., Kartsakli, E., Bartzoudis, N., Brodimas, D., et al.

AGILE-6G: Agentic AI for Autonomous Management of 6G Network/Application Services.

IEEE Network, 2025.
https://doi.org/10.1109/MNET.2025.3644039

This paper introduces AGILE-6G, a framework for autonomous management of 6G networks based on Agentic Artificial Intelligence. The proposal defines Domain Agentic Systems (DASs), modular multi-agent subsystems responsible for specific orchestration domains such as RAN, transport, core, and security, coordinated by a global agentic intelligence layer. Agents operate following the PREPARE cognitive model, integrating perception, reasoning, planning, action, reflection, and memory, and interact through standardized protocols. The framework complements existing 3GPP infrastructures rather than replacing them. Two representative use cases—robotic service management and resilient surveillance—demonstrate how AGILE-6G enables intent-driven provisioning, self-healing, and adaptive reconfiguration across the network-compute continuum.

Alemany, P., Muñoz, R., Ojaghi, B., Vilalta, R., et al.

Defining Intent-Based Service Management Automation for 6G Multi-Stakeholder Scenarios.

IEEE Open Journal of the Communications Society, 6, 2373-2396, 2025.
https://doi.org/10.1109/OJCOMS.2025.3554250

This paper investigates the requirements and challenges of intent-based management systems for 6G multi-stakeholder environments. It analyzes evolving telecommunications roles, identifies functional enablers, and proposes a structured framework for end-to-end intent-driven service orchestration. Representative service examples illustrate how intent negotiation, translation, and closed-loop control can enable scalable automation across heterogeneous domains. The work consolidates and extends ongoing standardization efforts toward future intent-native networks.

Larrañaga, A., Lagén, S., Fàbrega, J. M., Rivas-Moscoso, J. M., Fernández-Palacios, J. P., Tomkos, I., & Muñoz, R.

Fronthaul/Midhaul Networks: Capacity and Latency Requirements Imposed by 6G Disaggregated RANs.

IEEE Communications Magazine, 63(5), 86-93, 2025.
https://doi.org/10.1109/MCOM.002.2400419

This article analyzes the capacity and latency requirements of fronthaul and midhaul networks supporting disaggregated 6G radio access networks. It evaluates the impact of emerging technologies such as multi-connectivity, coordinated multi-point, and relay nodes across different deployment scenarios. Transport network architectures are proposed for flexible function splits and cell-free MIMO, providing guidelines for future 6G x-haul network design.

Khowaja, S., Khuwaja, P., Dev, K., Singh, K., Li, X., Bartzoudis, N., & Comsa, C.

Block Encryption Layer (BELA): Zero-Trust Defense Against Model Inversion Attacks for Federated Learning in 5G/6G Systems.

IEEE Open Journal of the Communications Society, 6, 807-819, 2025.
https://doi.org/10.1109/OJCOMS.2025.3526768

This work proposes BELA, a zero-trust block encryption layer designed to protect federated learning systems in 5G and 6G networks against model inversion attacks. BELA mimics batch normalization layers while introducing client-specific randomization and encrypted parameters that are never shared with the server, preventing gradient-based data reconstruction. Theoretical analysis confirms compatibility with standard convolutional neural networks. Experimental evaluations across multiple datasets and architectures show that BELA significantly increases reconstruction error while maintaining model accuracy. The solution provides a practical and deployable approach to enhancing privacy in AI-driven mobile networks.

Javed, F., Mangues-Bafalluy, J., Zeydan, E., & Blanco, L.

Trustworthy Reputation for Federated Learning in O-RAN Using Blockchain and Smart Contracts.

IEEE Open Journal of the Communications Society, 6, 1343-1362, 2025.
https://doi.org/10.1109/OJCOMS.2025.3540159

This paper proposes a blockchain-enabled reputation framework to enhance trust and transparency in federated learning-based O-RAN systems. Smart contracts automate participant registration, model verification, and reputation scoring, while secure off-chain computation is supported through a scalable layer-2 blockchain. Experimental validation demonstrates improved accountability and collaboration in AI-driven network environments.

Mendula, M., Miozzo, M., Bellavista, P., & Dini, P.

Reservoir computing for enhanced fidelity in hierarchical digital twin ecosystems

Future Generation Computer Systems, Volume 176, 2026, 108146,
https://doi.org/10.1016/j.future.2025.108146

Cyber-Physical Systems in industry and manufacturing require better ways to represent complex, heterogeneous processes and assets. Hierarchical Digital Twins (DTs) address this by extracting meaningful insights and structuring data in transparent layers, enabling more effective analysis. However, many Intelligent DT (I-DT) engines rely on computationally expensive Deep Learning. This work explores Reservoir Computing (RC) as a lightweight alternative, offering faster, energy-efficient modeling of system dynamics. To better evaluate such systems, the study introduces "Fidelity," a new metric that goes beyond accuracy to include maintainability and deployability. Experiments show that RC-based approaches can achieve higher accuracy and significantly lower energy consumption, demonstrating strong practical advantages in real-world applications.

Efficient & Scalable Networking

Energy efficiency, scalability and open RAN environments are explored in this set.

Pereira, R., Famá, F., Kalala, C., & Dini, P.

Energy-Efficient Federated Learning for AIoT Using Clustering Methods

IEEE Internet of Things Journal, vol. 12, no. 17, pp. 35602-35618, 1 Sept.1, 2025,
https://doi.org/10.1109/JIOT.2025.3579583

Federated Learning (FL) in Artificial Intelligence of Things (AIoT) environments is often optimized for performance and communication, but its energy impact is less studied. This work analyzes energy consumption across three key stages: preprocessing, communication, and local training, all contributing to the overall energy footprint. Recognizing that device selection strongly affects convergence, the authors propose clustering-informed methods that group devices with similar label distributions. These methods alleviate the heterogeneity often encountered in real-world distributed learning applications. Throughout extensive numerical experimentation, it is demonstrated that the proposed clustering strategies typically achieve high convergence rates while maintaining low energy consumption when compared to other recent approaches available in the literature.

Fàbrega, J. M., Muñoz, R., Marom, D. M., Tomkos, I., et al.

FLEX-SCALE: A Disruptive Approach Toward Flexibly Scalable Energy-Efficient Networking.

IEEE Communications Magazine, 63(9), 86–93, 2025.
https://doi.org/10.1109/MCOM.001.2400283

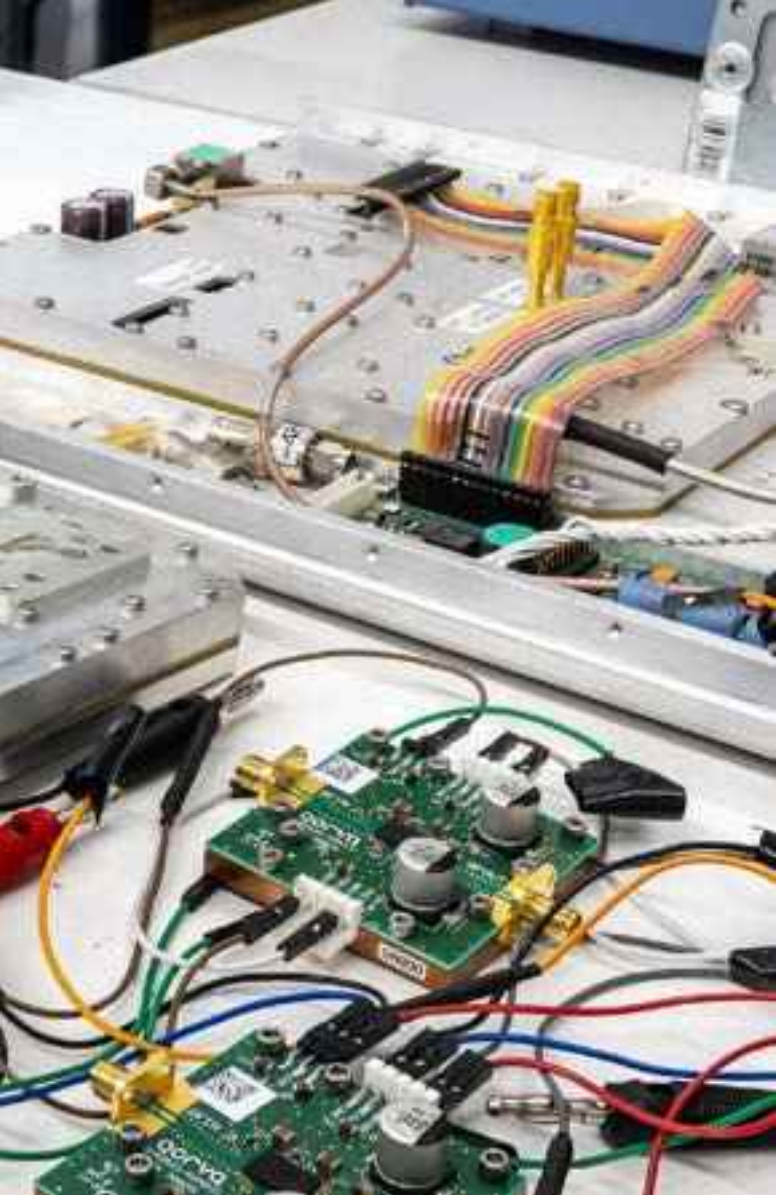
This article presents the FLEX-SCALE architecture for energy-efficient optical x-haul networks supporting future 6G requirements. The approach combines multi-granular optical nodes with ultra-wideband space- and frequency-multiplexed links to enable all-optical switching at petabit-scale capacities. Cloud-native control and orchestration enhanced with traffic engineering and machine learning ensure low latency, reliability, and sustainability, positioning FLEX-SCALE as a reference architecture for scalable 6G transport infrastructures.

Kasuluru, V., Blanco, L., & Zeydan, E.

Enhancing Open RAN Operations: The Role of Probabilistic Forecasting in Network Analysis.

IEEE Transactions on Network and Service Management, 22(4), 3676-3691, 2025.
https://doi.org/10.1109/TNSM.2025.3565268

This paper evaluates probabilistic forecasting techniques for estimating physical resource block demand in Open RAN environments. A comprehensive comparison with point estimators shows superior accuracy and robustness of probabilistic models. The proposed Dynamic Percentile Adjustment approach enables adaptive resource allocation, effectively managing over- and under-provisioning in real-time multi-tenant scenarios.



Next frontiers in radio access and integrated sensing

6G introduces new physical-layer challenges, driving active research on large and intelligent antenna systems and novel approaches to integrated communication and sensing. These advances aim to enhance spectral efficiency, spatial resolution, and the ability to simultaneously transmit data and sense the environment, enabling new network capabilities.

Mestre, X., & Agustin de Dios, A.
Beamfocusing Capabilities of a Uniform Linear Antenna Array in the Holographic Regime.
IEEE Transactions on Signal Processing, 2025.
https://doi.org/10.1109/TSP.2025.3624973

This paper establishes the first rigorous theoretical framework for near-field beamfocusing using uniform linear antenna arrays operating in the holographic regime. Analytical conditions for true spatial focusing are derived, including explicit requirements on array size and geometry. By bridging electromagnetic modeling and signal-processing theory, the work provides foundational insights for holographic MIMO and extra-large antenna systems, with direct implications for future 5G and 6G network design.

Agustin, A., & Mestre, X.
Exploiting Multiple Polarizations in Extra-Large Holographic MIMO.
IEEE Transactions on Wireless Communications, 25, 6130–6144, 2026.
https://doi.org/10.1109/TWC.2025.3623866

This paper analyzes the spatial multiplexing capabilities of extra-large antenna arrays operating in line-of-sight, near-field conditions by exploiting multiple orthogonal polarizations. Using a holographic approximation, the asymptotic MIMO channel behavior is characterized for both linear and planar arrays, and achievable rates are derived assuming perfect channel state information. Results identify optimal antenna surface dimensions that maximize spectral efficiency, advancing theoretical understanding of XL-MIMO systems for future wireless networks.

Bojović, B., & Lagén, S.
3GPP-Compliant Single-User MIMO Model for High-Fidelity Mobile Network Simulations.
Computer Networks, 256, 110912, 2025.
https://doi.org/10.1016/j.comnet.2024.110912

This paper presents a 3GPP-compliant closed-loop single-user MIMO simulation model implemented in the ns-3 5G-LENA framework. The model incorporates hybrid beamforming, CSI feedback, and Type-I codebook-based precoding, supporting up to 32 antenna ports and four data streams. Extensive simulations validate accuracy and complexity trade-offs, enabling realistic performance evaluation of advanced 5G and beyond networks.

Dutta T., Safinezhad A., Zhuldybina M., Garro I.L., Velázquez-González J.S., Sharma A.K., Ung B., Mishra S.K.

Advances in integrated quantum photonics for quantum sensing and communication

Journal of Materials Chemistry C. Vol. 13. No. 23. pp. 11521-11561 June 2025.
https://doi.org/10.1039/d4tc05290k

Integrated photonics has transformed quantum technologies in recent years, motivating a timely assessment of state-of-the-art approaches during the second quantum revolution. This overview examines current challenges and future directions across diverse technological platforms, drawing on advances. It highlights progress in subfields with emphasis on quantum sensing and quantum communication. Notably, quantum photonic chips have enabled developments in communication and the emerging quantum internet through their scalability, robustness, low cost, and compact footprint. The work also reviews key fabrication platforms and essential system components, presenting innovative concepts and cutting-edge achievements while addressing limitations, integration challenges, and unresolved issues requiring further research.

Space communications: from NTN/T integration to deep-space missions

Contributions in space communications address both the integration of terrestrial and non-terrestrial networks, supporting ongoing standardization efforts for global connectivity, and advanced deep-space communication systems.

Sevillano J.F., Irizar A., Bustamante P., Gomez-Vilardebo J., Mestre X., Navarro M., Quintanilla J.

Non-Coherent Feed-Forward MFSK Software Receiver for Encoded-Data Transmission in Deep-Space Missions

Proceedings Of The 2025 10th International Workshop On Tracking, Telemetry And Command Systems For Space Applications, Ttc 2025. January 2025.
DOI:10.1109/TTC66953.2025.11289005

Telemetry, Telecommand, and Control are critical functions for deep-space mission tracking and spacecraft operations. Deep-space communication systems must operate under extremely low link budgets, very high Doppler dynamics,

and severe channel impairments, such as solar scintillation distortion. These challenges are compounded by stringent transceiver requirements, particularly for onboard systems. This work, awarded Best Conference Paper, presents a real-time, software-based receiver for Multiple Frequency-Shift Keying (MFSK) signals in deep-space missions. The proposed receiver implements a feed-forward, full baseband architecture—including synchronization, soft-symbol estimation (or tone detection), and packet decoding—on a multi-core CPU and GPU platform. This flexible implementation pioneers SW-based real-time processing prototype development while enables efficient simulation of diverse reception scenarios: from safe & survival mode to encoded signal reception under solar scintillation conditions, demonstrating the advantages of coding in this particularly challenging deep-space communication environment.

Carla Amatetti 1, Marius Caus 2, Musbah Shaat 2, Riccardo Campana 3, Bruno De Filippo 1, Alessandro Guidotti 1 4, Alessandro Vanelli-Coralli 1

Chapter 5 - The evolution of non-terrestrial network technologies from 5G-Advanced to 6G

In book, Non-Terrestrial Networks -Paving the Way Towards Global Connectivity

Edited by: Muhammad Zeeshan Shakir and Aryan Kaushik
Academic Press ISBN: 978-0-443-26526-6
https://doi.org/10.1016/B978-0-443-26526-6.00008-6

The evolution toward 5G-Advanced and 6G aims to deliver higher performance and widespread connectivity for many applications. A key step is integrating non-terrestrial networks (such as satellites) to enable global coverage. However, this introduces technical challenges, especially in radio access technologies (RATs). This work reviews these challenges and explores solutions for 6G systems, focusing on flexible waveform design to handle channel limitations, multi-antenna technologies to improve efficiency, and advanced radio resource management. These innovations are essential to ensure reliable communication across terrestrial and space networks and will play a key role in shaping future standards.

PhD Theses

CTTC continues to train experts through its PhD program. In networks, the defended theses focus on making next generation infrastructures more autonomous, resilient, and trustworthy: one develops SDN-based control for elastic optical networks enhanced with Machine Learning (ML) to optimize routing, spectrum assignment, VNF placement, and secure coexistence of quantum key distribution with classical channels, while another proposes a hybrid blockchain and Distributed Ledger Technologies (DLT) framework that integrates public and private blockchain infrastructures to balance transparency and confidentiality. The framework enables automating inter-provider agreements for end-to-end network slicing in 6G, with design trade-offs for scalability, confidentiality, and continuous monitoring (including federated-learning-style interactions). In signal processing and wireless communications, the theses target 6G complexity by advancing hybrid model and learning driven multi-antenna designs for core receiver/transmitter tasks (channel estimation, symbol detection, precoding, and hybrid beamforming) and by reframing the discrete cosine transform (DCT) as a structured basis for nonlinear signal processing and task-oriented communications, presenting a unified framework for nonlinear representation, learning and communications.

Farhana Javed is a researcher at CTTC's Sustainable Networks unit, Spain, and a Ph.D. candidate at Universitat Politècnica de Catalunya. Her work integrates Blockchains, DLTs, and Web3 into telecom networks, [illegible]

The transition toward Sixth Generation (6G) networks promises transformative advancements in performance and flexibility, enabling rapid and transparent resource sharing across multiple administrative domains. Central to this transformation are technologies such as Network Function Virtualization (NFV), which enable dynamic orchestration of network services and promote infrastructure sharing among diverse stakeholders.

This work contributes to the development of trustworthy, automated inter-provider agreements for next-generation networks by proposing a hybrid decentralized framework based on Distributed Ledger Technologies (DLTs). Advancing beyond existing blockchain solutions, the framework integrates public and private blockchain infrastructures to balance transparency and confidentiality.
We first formalize the requirements for decentralized inter-provider agreements, which inform the design of a hybrid architecture combining public Layer 1, public Layer 2, and private Layer 1 blockchains. At its core, we develop a modular Decentralized Framework realized through a DApp integrating components such as the Credential Manager, Blockchain Adapter for off-chain data handling, Data Storage Layer, and Privacy Manager. Unlike conventional DApps, our framework explicitly addresses the challenges of integrating blockchain with telecom infrastructure.
We evaluate smart contract deployment and DApp operation on public Layer 1, public Layer 2, and private Layer 1 platforms. Additionally, we assess the framework's suitability for continuous monitoring use cases, including collaborative AI/ML scenarios such as Federated Learning (FL), which require frequent, secure interactions in emerging 6G applications. From this extensive evaluation, we derive operational guidelines and design tradeoffs that balance cost-efficiency, scalability, and confidentiality. These insights serve as a reference for blockchain-enabled service orchestration in future 6G networks.

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2025

Blockchain-enabled Trustworthy Inter-Provider Agreements for End-to-End Network Slicing in 5G and Beyond Networks

PH.D. THESIS

Blockchain-enabled Trustworthy Inter-Provider Agreements for End-to-End Network Slicing in 5G and Beyond Networks

Farhana Javed

Supervisors:
Dr. Josep Mangues Bafalluy
Tutor:
Prof. Miguel Soriano Ibáñez

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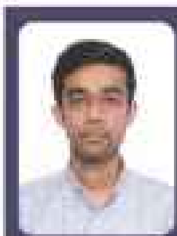

Dhanraj Raju Kumar received the Master's Degree in Applied Telecommunications and Engineering Management from Technical University of Catalonia (UPC). He obtained the B.E. degree in Electronics and Communications Engineering [illegible] From 2020 to 2024, he was a Research Assistant with the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC). His research interests are in the areas of [illegible] signal processing, and their applications in wireless communications.

As wireless networks evolve toward sixth-generation (6G) systems, the integration of advanced technologies like massive MIMO, millimeter-wave communications, intelligent reflecting surfaces, and massive multiple access schemes has led to significant increases in system complexity. Traditional signal processing and optimization techniques are grounded in explicit modeling and mathematical tractability. They increasingly fall short in addressing the high-dimensional, dynamic, and often non-linear behaviors of these systems. To bridge this gap, Artificial Intelligence and Machine Learning (AI/ML) methods have emerged as powerful alternatives, capable of learning directly from data and adapting to complex and uncertain environments. Rather than relying solely on conventional models or pure data-driven solutions, this dissertation advocates for hybrid approaches that combine model-based structures with learning-based flexibility. Hybrid methods mitigate the high data demands and limited interpretability of black-box models while overcoming the rigidity and assumptions of traditional schemes. This balance makes them particularly well-suited for the complex, imperfectly modeled conditions encountered in wireless systems. This PhD dissertation focuses on applying such hybrid methods to four key tasks in the wireless signal processing chain: channel estimation, symbol detection, digital precoding, and hybrid beamforming. Though each task poses unique technical challenges, they collectively contribute to the overarching goal of enabling robust, efficient, and scalable communications in next-generation systems.

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2025

AI-Driven Multi-Antenna Designs for Next Generations of Wireless Communication Systems

PH.D. THESIS

AI-Driven Multi-Antenna Designs for Next Generations of Wireless Communication Systems

Dhanraj Raju Kumar

Supervisors:
Dr. Carles Antón-Haro
Dr. Francesc Xavier Mestre
Tutor:
Dr. Francesc Rey Micolau

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Marc Martínez-Gost received the M.E. degree in 2020 in telecommunication engineering from Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, where he is a Ph.D. student in the Department of Signal Theory and Communications. He is also with the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC). His research interests include digital processing for communications, iterative receivers based on factor graphs, and satellite communications. He is a Graduate Student Member of IEEE.

This dissertation addresses two fundamental and increasingly connected challenges in modern information processing: nonlinear learning and task-oriented communications. Both fields require compact, interpretable and efficient representations of nonlinear functions. These representations are essential for building learning models as well as for transmitting information relevant to a downstream task. Traditional approaches, often dominated by black-box architectures and data-driven approaches, face limitations in interpretability, scalability and robustness. This motivates the search for structured and principled alternatives. At the core of this work lies the discrete cosine transform (DCT), a classical signal processing tool reinterpreted here as a unifying framework for nonlinear modeling and communication. By leveraging its mathematical properties, such as orthogonality, energy compaction and recursive structure, the DCT is shown to offer advantages far beyond its traditional role in image compression. The dissertation explores how the DCT can support more efficient learning algorithms and the design of newer modulation strategies that jointly encode data and computation. Altogether, this work demonstrates that the DCT, a tool introduced nearly 50 years ago, can be revitalized as a foundational building block for modern signal processing. Its structure offers a powerful, interpretable and efficient foundation for addressing contemporary challenges in intelligent information processing. By bridging classical signal processing with contemporary machine learning and communication challenges, the dissertation presents a unified framework for nonlinear representation, learning and communications.

The DCT as the Basis for Nonlinear Signal Processing and Task-Oriented Communications

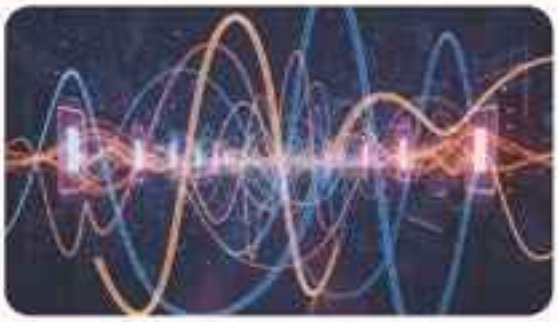
ttc

PH.D. THESIS

The DCT as the Basis for Nonlinear Signal Processing and Task-Oriented Communications

Marc Martínez-Gost

Supervisor:
Dr. Ana Isabel Pérez Neira



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2025

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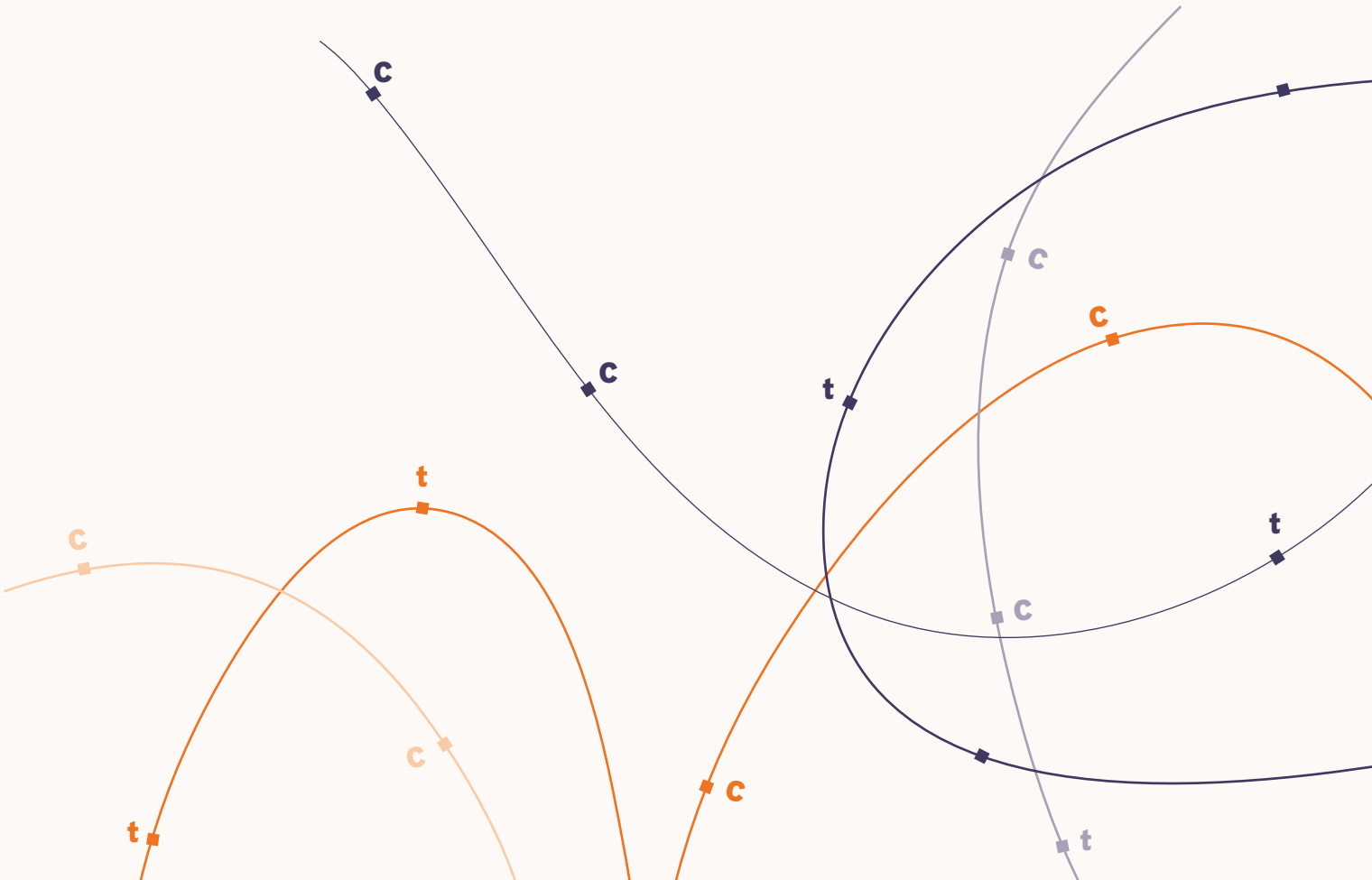
UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Department of Signal Theory and Communications



Testbeds & Experimental Facilities

During 2025, new experimental assets acquired from different competitive projects were integrated into the experimental facilities and infrastructure, enhancing and extending testbeds and platforms capabilities to boost research and innovation in 6G.

Notably in

Space Communications has integrated the acquired satellite and aerospace channel emulator, the small-sat AI-powered payload prototyping platform, and additional satellite links in Ka/Ku bands, along with an S/UHF radio station for antenna pointing control, facilitating the creation of the **Hispasat Lab by CTTC**. Launched in 2025 as a joint initiative between Hispasat and CTTC, the lab aims to boost innovation in satellite connectivity technologies by combining a state-of-the-art experimental framework with specialized personnel.

It provides a controlled and reproducible environment for the development, testing, and validation of 5G NTN technologies, focusing on use cases related to aerial and maritime mobility, remote areas, and enhanced resilience for critical networks and industrial applications. Hispasat Lab by CTTC combines satellite network emulation, terrestrial stations, and advanced 5G nodes to support interoperability experimentation for 5G/6G terrestrial–satellite integration, while also exploring the integration of free-space optical communications.

Radio Access experimental capabilities are being significantly extended with a fully controlled, custom-made ELAA featuring reconfigurable intelligent surface applications, an XL-MIMO base station, and two UEs. These are complemented by a cloud-native O-RAN experimental platform and a dedicated radio unit for low physical-layer processing, all supported by a high-performance AI/ML computing system and a digital twin for RAN applications.

Network Architecture and Services

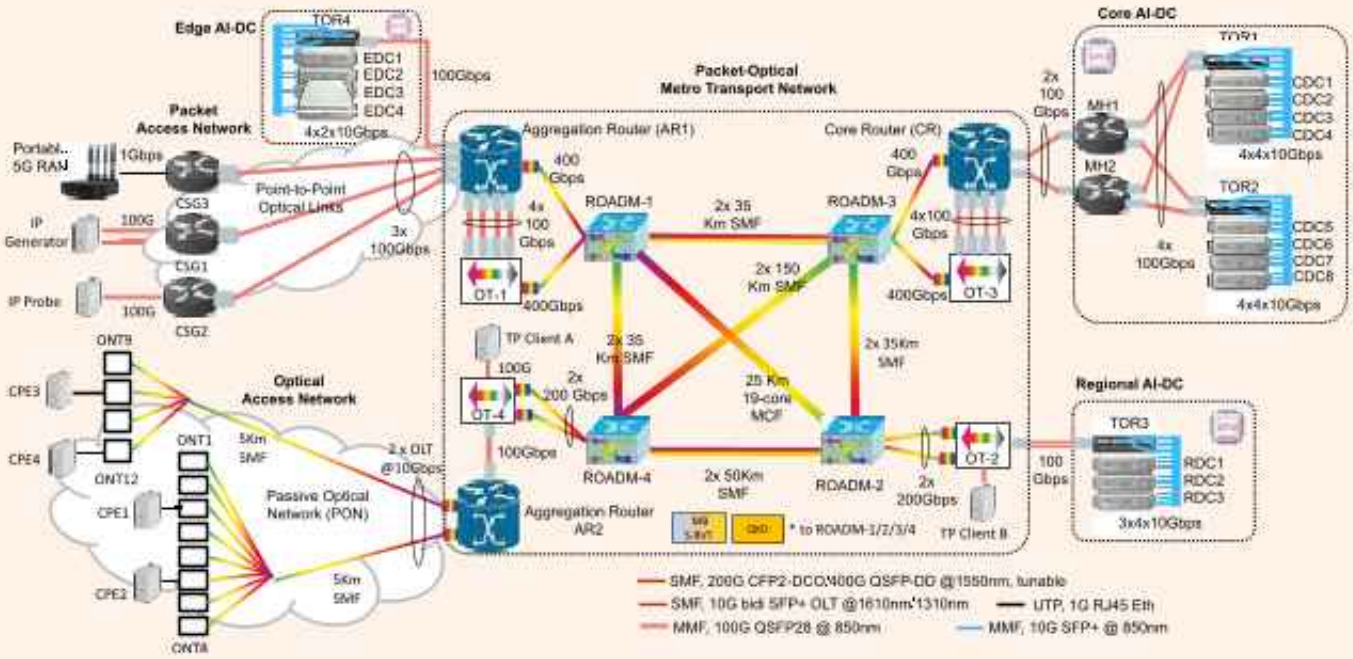
have expanded in the fixed access and transport network domain through the integration of a quantum key distribution system, along with additional high-performance testing equipment for optical transmission (e.g., arbitrary waveform generator, oscilloscope), open optical transponders and IP routers for the access, aggregation and core network segments with optical pluggable transceivers at 100, 200 and 400 Gb/s, and a telco edge cloud infrastructure composed with GPU-enabled servers for AI edge and core data centers.

The new fixed network infrastructure integrates edge, access, regional and core AI datacenters (DCs) with the end-to-end packet-optical access and transport network that support a diversity of heterogeneous workloads and tasks, supporting awareness, on-demand, QoS assurance, resiliency and AI-native services that characterize 6G and AI ready networks. It enables experimental research in environments close to production systems, allowing researchers to deploy, validate and quantify the performance of implementations, control and management workflows, new methods, algorithms and heuristics for aspects such as path computation or resource allocation.

The mobile networking domain has been complemented by a multi-band indoor/outdoor 5G private network (incl. mmwave), AI powered multi-purpose telco edge/cloud data centers, an O RAN 5G network, and related test equipment for emulating any part of the O-RAN network. A state-of-the-art modular multicamera anechoic chamber testing system, with programmatic control and full automation (via web-based interface or API), provides a high-performance controlled over-the-air multi-band validation of end-to-end services (incl. RAN).

RAN segment extensions also support a comprehensive set of hardware and software components for end-to-end experimentation with beyond 5G O RAN compliant systems and advanced AI native RAN architectures. The implementation of the Experiment-as-a-Service approach reached a milestone in 2025 by unifying cloud resources with next-generation wireless infrastructure under a common orchestration layer and enabling user-friendly access through an LLM-based interface that interprets natural-language requests and automatically configures computing and wireless resources. This design allows users with minimal expertise to deploy and manage the lifecycle of complex experiments without manual scripting or configuration.

These new acquisitions and the conditioning of more than 300 m2 for experimental development and validation, uniquely positions CTTC as an Open Innovation Hub in 6G at national and European level.



High level representation of the packet-optical access, transport and core network segments

OPEN-SOURCE & SOFTWARE TOOLS

This section provides an overview of the new features and developments in the open-source and software tools developed and maintained by CTTC.

The open-source software-defined receiver GNSS-SDR **(https://gnss-sdr.org)** experienced improvements in reliability, with the implementation of the **Galileo Open Service Navigation** Message Authentication (OSNMA), a data authentication function for the Galileo Open Service worldwide users. OSNMA provides receivers with the assurance that the received Galileo navigation message is coming from the system itself and has not been modified.

The new release can be downloaded from **https://github.com/gnss-sdr/gnss-sdr/releases/tag/v0.0.20**

During 2025, the 5G-LENA (https://5g-lena.cttc.es) ns-3 system-level simulator modules for LTE/LTE-A and 5G networks produced three releases (v4.0, v4.1, and v4.1.1), in open-source mode, accessible at

URL release v4.0: https://gitlab.com/cttc-lena/nr/-/tree/5g-lena-v4.0.y

License: https://gitlab.com/cttc-lena/nr/-/blob/5g-lena-v4.0.y/LICENSE

These new releases included the following main features: CSI-RS signals for channel estimation, CSI-IM for inter-cell interference measurements, multiple single-panel antenna arrays per UE, sub-band CSI feedback, sub-band aware scheduler, multiple RI/PMI selection alternatives, Kronecker beamforming, initial association based on maximum RSRP instead of shortest distance, RL-based scheduler, NYUSIM, FTR and legacy channel models, inclusion of the resource assignment matrix, wraparound model and support for hexagonal deployments, updated Indoor and Outdoor calibration examples, and new random TDMA and OFDMA schedulers. New releases are accompanied by regular bug fixes, new traces, measurements, helpers, tests, examples, and CI jobs. The maintainer and development team at CTTC also contributed to training through Google Summer of Code supervising one project on the development of an NTN Helper and a LEO example for 5G NR.

ETSI Software Development Group TeraFlowSDN (SDG TFS) (https://tfs.etsi.org/) also issued two new releases:

- Release 5 advanced in network automation and optimization with the integration of the Network Slice Controller and enhanced telemetry capabilities. Such tool delivers a more dynamic, agile, and efficient network infrastructure.

- Release 6 includes new features across automation, observability, optical integration, and security, establishing TeraFlowSDN as a programmable and intelligent SDN controller that bridges IP and optical domains with full lifecycle orchestration.

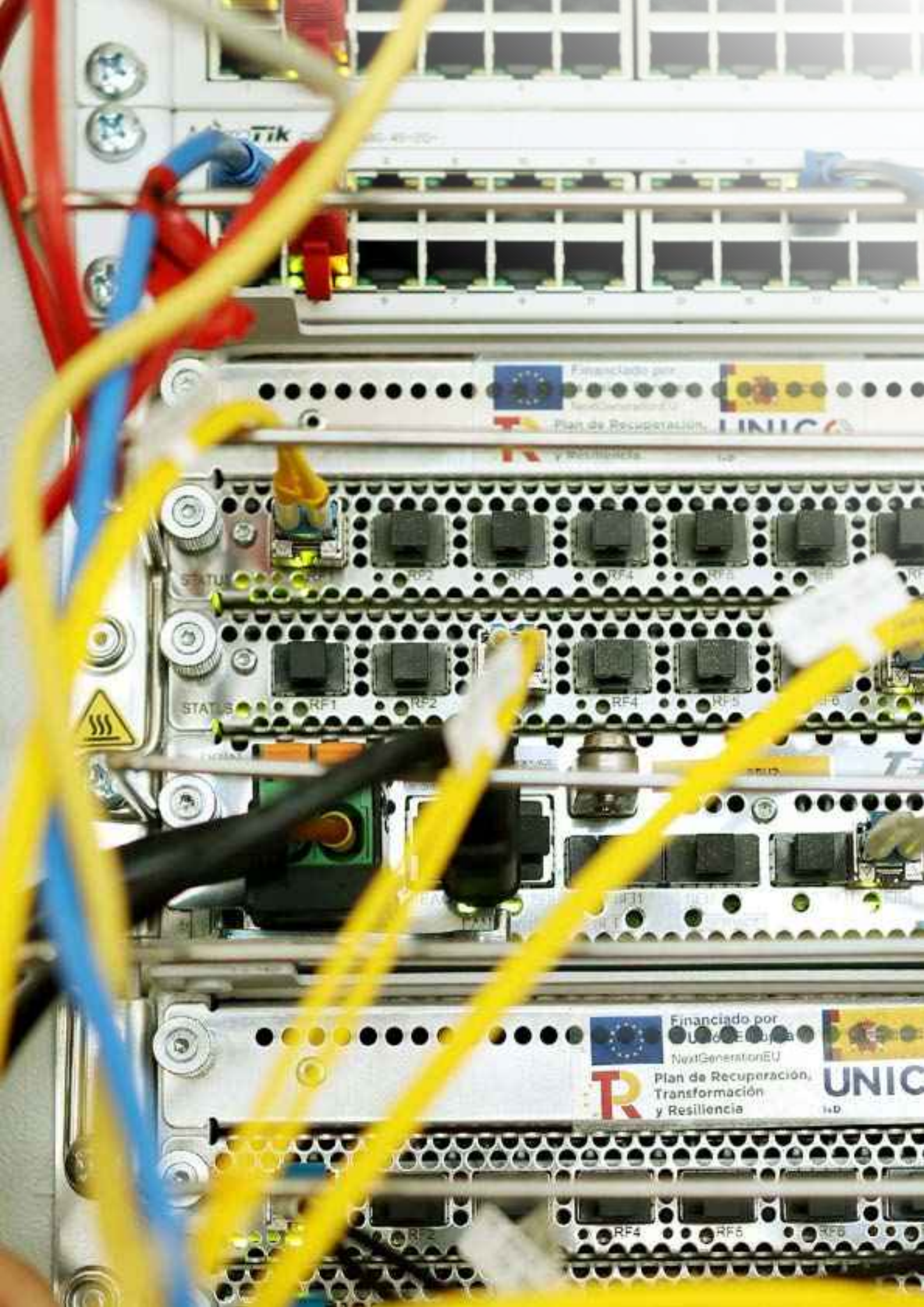
These new releases are the result of the collaborative work, and related hackathons organized within the ETSI SDG TFS, chaired by CTTC.

ADAtools software packages are not open source but can be used free of charge according to the respective license: **https://adatools.cttc.es/**

They belong to the category of Earth Observation research activities, providing tools for interferometry and the detection and classification of terrain deformations. They have been adapted to operate extremely large data volumes associated with services such as the European Ground Motion Service (**EGMS, https://egms.land.copernicus.eu/**) and ease the interface to read them.

ADAtools feature:

- **GEOKINESIA PSIG® Persistent Scatterer Interferometry**, a remote sensing SAR tool that allows to monitor small terrain deformations with high sensitivity.
- **Active Deformation Area** (ADA) tools for the detection and classification of areas with active deformations and terrain movements, which includes ADA Finder (identifies ground displacement areas), ADA Classifier (identifies ground displacement phenomena) and ADA Impact (provides a potential impact assessment and risk analysis).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Knowledge and Technology Transfer

In 2025, CTTC continued to reinforce its commitment to knowledge transfer through the promotion of entrepreneurial initiatives rooted in its research activity. A particularly relevant milestone was the creation of WaveMasters, a new CTTC spin-off established in December 2025. **WaveMasters is a deep-tech company** focused on commercializing innovative technologies developed at CTTC to improve the robustness and performance of satellite-based positioning systems, especially in challenging environments. Its portfolio includes a compact dual-antenna module designed to mitigate GNSS jamming threats, as well as high-performance, modular RF front-ends enabling real-time multi-band and multi-constellation reception for next-generation software-defined receivers. The company was co-founded by Dr. Javier Arribas and Dr. Carles Fernández, both from CTTC, together with Dr. Miguel Ángel Gómez, and was awarded a grant and a one-year incubation period at the ESA Business Incubation Centre.

This initiative builds on CTTC's company creation plan and on the systematic identification of Invention & Innovation results with market potential.

IPR PROTECTION AND PRODUCT DEVELOPMENT

As one of its core tools to foster technology transfer, CTTC continued to rely on intellectual property protection through national and international patents, as well as on the structured identification and valorization of research results. In 2025, CTTC maintained the Invention & Innovation declaration process initiated in 2017, following practices inspired by WIPO recommendations and widely adopted by leading research institutions. This process defines authorship, identifies tangible assets at an early stage, and enables the Centre to select the most appropriate protection and exploitation route according to technological maturity, researcher effort, market evolution, and potential competitors.

In 2025, three Invention & Innovation declarations were recorded related to custom GNSS antennas, a graphical software suite to visually integrate workflows of remote sensing console applications in a zero-code manner, and a software radio peripheral for radio-frequency systems. These results illustrate the continued generation of exploitable assets in strategic fields such as GNSS technologies, remote sensing workflows, and advanced radio-frequency systems.

CTTC's research and innovation activities have resulted, since 2006, in the processing of more than thirty patent families. During 2025, CTTC continued investing in and maintaining those patent files with the highest potential to deliver future impact. Among the most relevant actions, CTTC filed a European patent application related **to non-intrusive sensing using optical fiber**, submitted a patent application for a sensor for CO2 and humidity detection, and filed a US patent application for a framework used for decentralized network automation. In addition, the European Patent Office certified the grant of the Unitary Patent EP4447392, entitled "**Distributed intelligence for evolved open radio access network management and corresponding method**", and the Spanish Patent and Trademark Office granted patent ES2976583 on "**Anticipatory network slicing according to predicted cross-border movements of user equipment in a 5G network**".

European Patent Office

Oficina Española de Patentes y Marcas

CTTC also continued to participate as a partner in CERCA's GINJOL Patent Fund, while reporting the evolution of previously presented innovation projects through annual monitoring meetings. This activity strengthens the Centre's ability to access competitive calls for innovation projects and to continue advancing the exploitation of protected research outcomes

CERCA GÍNJOL

BUSINESS DEVELOPMENT AND INDUSTRIAL VALORIZATION

In parallel with its IPR protection activity, CTTC continued to advance business development projects linked to Invention & Innovation results. In 2025, an important **license agreement** was signed by CTTC and an industrial partner, that will exploit results of CTTC researchers in the area related to the **integration of terrestrial and non-terrestrial mobile networks**. These initiatives represent a continuation of CTTC's internal business development strategy, aimed at bringing selected research results closer to the market and preparing them for licensing, productization, or company creation pathways.

The progress achieved in 2025 confirms CTTC's capacity to transform scientific and technological excellence into tangible innovation assets. Through new invention disclosures, patent filings and grants, business development projects, and the creation of WaveMasters, CTTC has continued to consolidate a technology transfer model that combines intellectual property protection, entrepreneurial activity, industrial valorization, and long-term support to **strategic sectors** such as **space, security, sensing, GNSS, optical technologies, and future communication networks.**

Professional, Scientific, Training & Dissemination Activities

In 2025, CTTC reinforced its position as an internationally recognized research center through a highly active agenda of outreach, collaboration, and knowledge transfer activities. Its engagement in both international and national fora has been instrumental in strengthening global visibility, fostering institutional partnerships, and expanding R&D collaboration networks, while also advancing its commitment to training the next generation of specialized talent and promoting scientific vocations.

By strategically leveraging high-impact events, particularly major international congresses hosted in Barcelona such as the Mobile World Congress (MWC) CTTC effectively showcases its cutting-edge technologies, experimental platforms, and demonstrators to a diverse global audience, including industry leaders, policymakers, and research stakeholders.

Resources are also put towards the organization of major scientific conferences and workshops, which capitalize on the research units' expertise to increase their visibility. The organization of these events has aligned with legacy programs in the territory creating added value beyond the conference itself. Complementary, CTTC hosted regular project meetings and work sessions for standardization working groups.

A representative summary is provided.

CTTC exhibited at the Catalonia Pavilion at **Mobile World Congress - MWC2025**, receiving visits from partners and frequent collaborators, representatives of public authorities, and potential clients. The stand showcased live demonstrations in artificial intelligence, 6G/5G networks, and their applications in media, as well as connected and autonomous mobility. The MWC continues to provide a major opportunity to present our latest innovations and foster new collaborations.

CTTC Co-Chaired this reference conference in Satellite Communications, sponsored by the European Space Agency and relevant industrial players in the sector. This edition focused on space and 6G, addressing standardization and deployment aspects, secure connectivity via satellites, with EC representatives informing on IRIS^2 program, equipment manufacturing, attracting over 150 attendees.

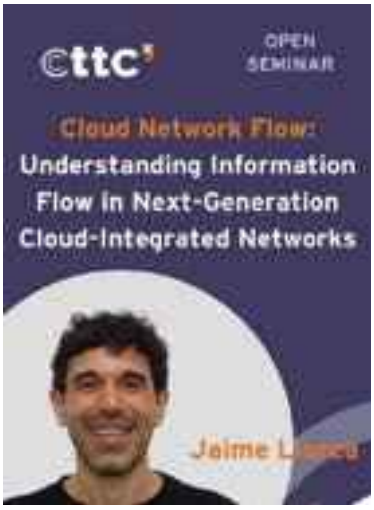
Acknowledged expertise in Machine Learning and Artificial Intelligence within the scope of communication systems brought the IEEE International Conference on Machine Learning for Communication and Networking to Barcelona, which has consolidated as a leading conference at the intersection between artificial intelligence and telecommunications, with more than 200 professionals from across the globe.

CTTC participated in other discussion forums with strong social impact focus. An example is the **Giga Government Technology Exchange Program** (GTEP) where we had the opportunity to exchange ideas for connecting schools with delegates from South Africa, Namibia, Mozambique, Tanzania, and project Giga representatives. CTTC Director, accompanied by CTTC researchers, presented success projects and results on satellite image processing, sustainable telecommunications infrastructures as well as how 5G satellite and terrestrial networks that could help in humanitarian aid and emergency management.

Projects activities were also disseminated in settings like the **EC Security Research Event** where Dr. Anna Barra, coordinator of RASTOOL-DoS presented the most recent advances on satellite monitoring for civil protection applications.

As part of scientific dissemination activities CTTC also organizes regular seminars, open to external personnel. The format combines talks hosted at CTTC with hybrid events that can also be followed online in real time. The **CTTC Seminars** series and Invited talks are advertised over the digital communication channels, posting recorded sessions on CTTC's YouTube channel.

CTTC Seminars series covers several purposes: they are part of continuous training, reinforce the collaboration network spreading nationally and internationally, provide a welcome space for new recruitments where they introduce their research work and background to the rest of the team, and encourage casual gathering between personnel across research units and the administration.



Alongside CTTC Seminars series, CTTC encourages the hosting of project meetings and other technical events that bring added value to daily activities. In 2025 CTTC hosted over 20 events among project meetings, standardization working groups, training events and workshops, etc.).

5G-HUB (Fifth Generation Services HUB for European Union Governmental Satellite Communications) work meeting hosted at CTTC (Technical Coordinator).

MOSMIN Consortium meeting discussed progress on the holistic approach that combines ground, aerial and satellite data to facilitate 1) identifying the environmental risks associated with mining waste; 2) measuring the potential to extract valuable materials from mining waste.

We continue to welcome institutional visits and maintain an open-door policy.

DISSEMINATION, TRAINING & TALENT

Actions focused on strengthening dissemination and visibility within the local ecosystem.

In 2025, the university extension program for lifelong learning "Aula ExperienTia Castelldefels" was consolidated. This initiative, promoted by CTTC and the Castelldefels City Council, enabled the creation of a new university extension program for citizens aged over 55. Its success is evidenced by sessions, held every fortnight, that consistently reached full capacity throughout the academic year. Due to high demand, the sessions are now held in a larger auditorium on campus, further strengthening collaboration within the Parc Mediterrani de la Tecnologia community. In addition to hosting the sessions, CTTC contributed to the program by delivering a talk on geolocation and citizen science and the invitation to the Open Doors session held within the Science Week.

Local links were extended within region by joining the INNOBUS program, an initiative of INNOBAIX, the innovation agency from the Baix Llobregat and L'Hospitalet. This innovation route brought young graduates from very diverse discipline backgrounds to visit CTTC and other research centers at the PMT, along with other visits to local business and industries with the aim of expanding their career opportunities and stimulating innovation.

As regular participants in the "Estades Premi Extraordinari de Batxillerat" we hosted one student who enjoyed one-week on-the-job experience with researchers across the different research units. They explained and encouraged the student participation in their current activities. By the end of the week Marc acknowledged learning lessons who shared with the training team.

Specific talent programs from CTTC are developing in good health: from the Young Talent Research Stay program that targets undergraduate and master students to the Starting Research Contract and PhD programs, we offered specialized training and early-stage career development to over 15 people, noting a high endorsement from local Universities, students and CTTC staff. The programs are presented in student forums, such as the one organized by UPC onsite the campus. Talent programs are complemented by the Mobility program, which hosts visiting scholars from international institutions.

The campus also offers good opportunities to share our experience and insights with other institutions that request them, often welcoming them in our facilities.

COMMUNICATION

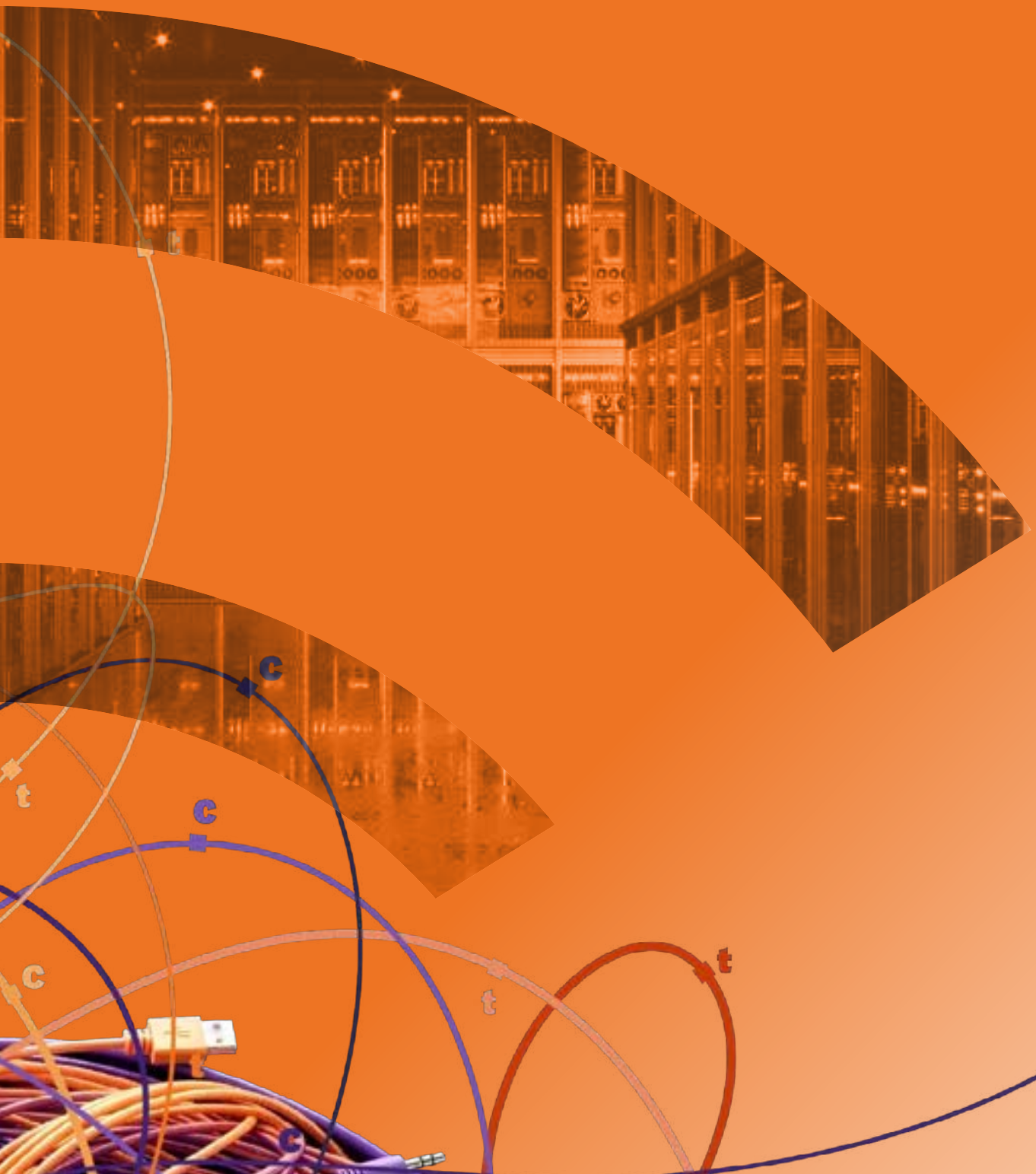
The communication plan was strengthened in 2025 by enhancing CTTC's social networks. While LinkedIn remains the main platform for information, communication and dissemination, Instagram provided a different perspective on CTTC's research activities and agenda. Instagram aims at local audiences, with Catalan as the primary language used, while presenting research and innovation activities in a more approachable way for non-experts.

One example is the new series "Coneix els nostres investigadors" (Meet CTTC researchers) launched in 2025, in which diverse profiles were selected in terms of career stage, research topic, and affiliation with CTTC (staff, students, visitors, ...) to make Catalan research and its impact more accessible to the public.

A few examples are presented below. The initiative has received a very positive response.

Media presence was increased through the participation in radio broadcast programs. Radio appearance by researcher M. Eulàlia Parés Calaf on the program "Fils de ciutat" on Ràdio Sabadell, discussed the latest developments in citizen science technologies and methodologies to improve air quality. Her appearance was aligned with her participation in the 4th Congrés de la Qualitat de l'Aire in Sabadell, where she moderated sessions dedicated to tools for citizen involvement and air quality modelling.
Also, the interviews of Monica Navarro and Carles Antón on the program "Diga-li Ciència" on ràdio4 (rne) provided a wider view of the leading role and strong impact telecommunication engineering is having in the digitalization of society and the rapid deployment and adoption of AI.

Acknowledgements, Awards & Quality Certifications



The Director of CTTC, Prof. Ana I. Pérez-Neira, was elected a member of the Royal Academy of Engineering of Spain (Real Academia de Ingeniería de España). She delivered her inaugural lecture, entitled "Radio Communications Between Machines that Decide," and was awarded Medal No. XIII upon her formal induction into the Academy in May 2025. She was also distinguished with the Salvà i Campillo Award for Outstanding Personality (Premi Salvà i Campillo a la Personalitat Destacada), granted by the Associació Catalana d'Enginyeria de Telecomunicació i Tecnologies Digitals (telecos.cat) during the annual event "La nit de les telecomunicacions i la informàtica."

Recognitions for professional excellence were also awarded to Dr. Raül Muñoz, Head of the Packet Optical Networks and Services Research Unit, who was elected **Fellow Member of Optica by the Optica** Society's Board of Directors, in recognition of his pioneering contributions to the efficient orchestration of optical networking technologies. This prestigious distinction is limited to no more than ten percent of the membership and is reserved for members who have served with distinction in the advancement of optics and photonics.

Dr. Muñoz was also elected Vice-Chair of the IEEE Optical Networks and Services (ONS) Technical Committee, alongside Dr. Abdelmoula Bekkali who serves as Secretary of the IEEE Transmission, Access, and Optical Systems (TAOS) Technical Committee (TC), both within the IEEE Communications Society. The service particularly addresses research on optical networking technologies and Broadband Access and Green Communication Systems and Networks, respectively.

The outstanding quality and impact of doctoral and undergraduate work were also recognized through several awards:

Dr. Eduard Angelats (Geomatics Research Unit) and Dr. Pol Alemany and Dr. Behnam Ojaghi (PONS Research Unit) were awarded the Extraordinary Doctoral Award (Call 2025 – Cohort 2022/2023). These distinctions, granted by the Doctoral School of the Universitat Politècnica de Catalunya (UPC) – BarcelonaTech, acknowledge the outstanding quality and impact of their doctoral research in the fields of Science and ICT Engineering, respectively.

Yaoyao Zhao, a participant in CTTC's "Young Talent Research Stay" program and supervised by Dr. Eduard Angelats from the Geomatics Research Unit, received the Pedro R. Muro-Medrano Award for her final studies project (TFE), entitled "Geo-tools for Monitoring the Shoreline and Megacusps at Regional Level Using Sentinel-2." This award, granted by the University of Zaragoza, aims to promote and support outstanding final studies projects focused on the development and integration of technologies for open data processing, geospatial data analysis, and multi-source data integration.

Besides the personal awards, research work at CTTC was internationally recognized by several bodies:

The GreenEdge project was selected as **Success Story by the European Commission** for its pioneering work and results in sustainable ICT. The project team focused on creating energy-efficient methods for training and deploying AI models within network environments, alongside the design and implementation of hardware optimized for reduced power consumption. They also assessed the potential of renewable energy sources, such as solar power, to support network infrastructure. In addition, the project advanced innovative edge computing algorithms that deliver substantially improved energy efficiency compared to existing approaches.

Three projects led and participated by CTTC were selected among the 2025 "**Top-10 Key Achievements**" of the Smart Networks and Services Joint Undertaking (SNS JU) – a very remarkable distinction within a highly competitive portfolio of 79 active SNS JU projects across Europe.

Two in the category of Significant Technology Development:

- **6G REFERENCE – CTTC** Project Coordinator, Dr. Ignacio Llamas (Navigation & Positioning Research Unit) for the key innovations in time-modulated MIMO arrays dynamically control antenna elements to support multiple users simultaneously with far lower power, cost, and complexity.
- **SEASON – CTTC** Technical Manager, Dr. Ramon Casellas (Packet Optical Networks and Services Research Unit) for the key innovations in high-speed point-to-multipoint (P2MP) coherent transceivers with power-based optimization to mitigate reflections enabling single-fibre/ single-laser BiDi at 200–400 Gb/s.

One in the category of Sustainability Solution

HEXA-X-II – CTTC Task Leaders Dr. Raul Muñoz and Dr. Ricard Vilalta (Packet Optical Networks and Services Research Unit) for service management automation and network programmability activities.

Scientific publications were also distinguished with best paper awards:

- Best conference paper award at ESA TT&C 2025 Conference "Non-Coherent Feed-Forward MFSK Software Receiver for Encoded-Data Transmission in Deep-Space Missions" related to SW-based receiver implementation for non-coherent MFSK reception for Deep-Space missions.
- Best student paper award at IEEE International Conference on Space Optical Systems and Applications (ICSOS) for the paper: "SPPINN for OAM demultiplexing", related to optical communications and orbital angular momentum (OAM) signal demultiplexing using physics-informed neural networks.

During 2025, CTTC actively prepared the renewal of quality certifications such as the **adaptation** of the Spanish norm UNE 166002:2021 (Management of R+D+I) to the international upgrade **ISO 56001:2024** on **Innovation management system**, and the design and development of a Further Improved Action Plan for the second cycle of the Renewal Phase for the Human Resources Strategy for Researchers (HRS4R).

Building on these achievements, CTTC remains committed to delivering research excellence and generating impact for society.

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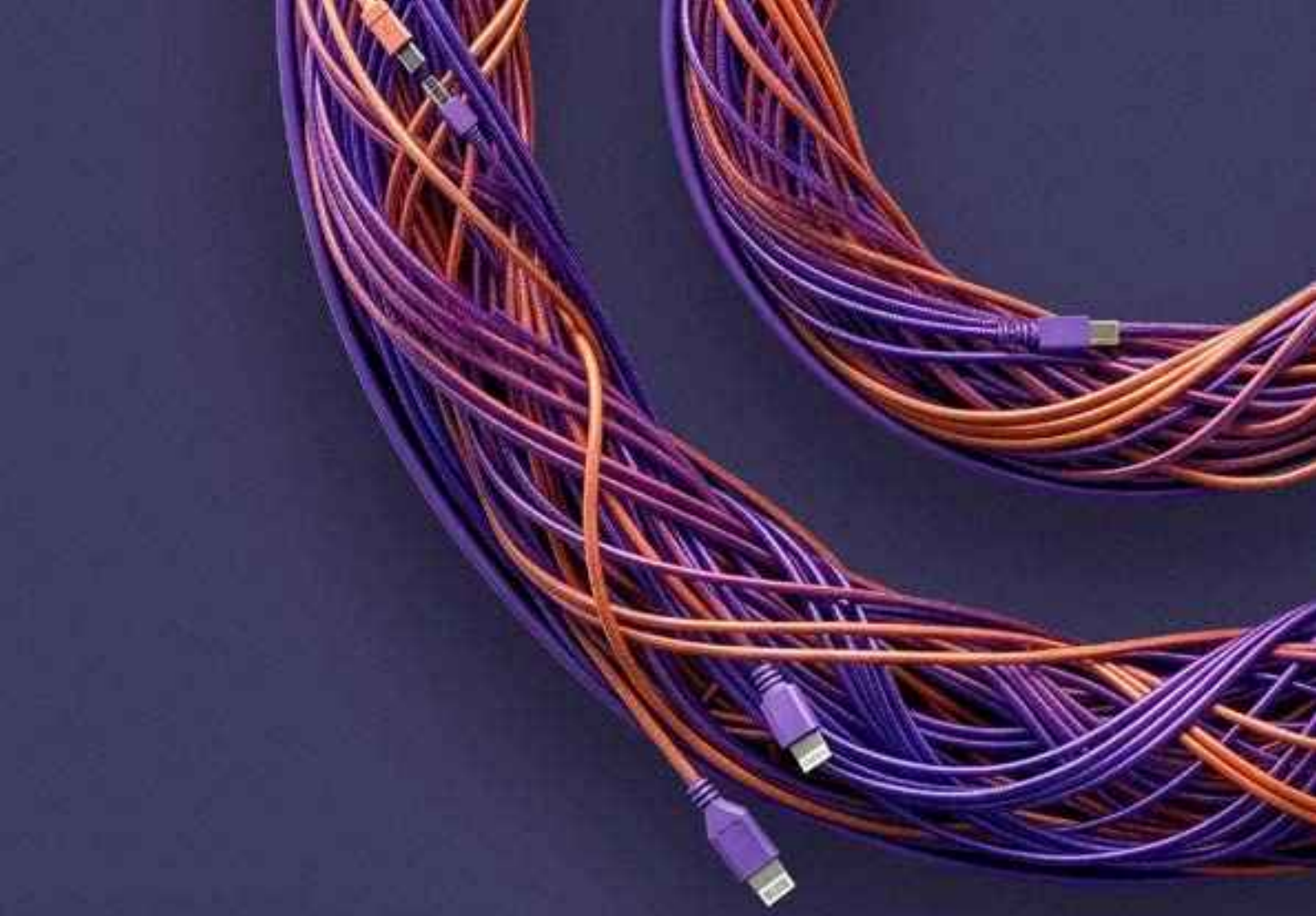

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