ANNUAL REPORT

2020

Centre Tecnològic de Telecomunicacions de Catalunya

INDEX

Welcome to 2020:

The year of change

2020 has been a very special year, I believe I would not exaggerate by defining it as a year that changed everything. We started 2020 and concepts like "lockdowns", "social distancing", "R index", "death excess" and "mask mandates" were unknown to most of us. We have learned a lot and these terms are now part of our everyday language, as the pandemic continues to impact all aspects of our lives.

From CTTC we have faced this challenging and transforming year with optimism. Since 12 of March 2020, as everybody in the northern hemisphere, CTTC started operating remotely, without any official previous notice. We quickly learned how to work with more uncertainty than ever. Similarly to every other working environment around the world, as a result of lockdowns, health and economic crisis, many of our families faced emotional, logistic, conciliation and economic difficulties during 2020, which from CTTC we have done our best to mitigate, offering support and flexibility. I believe the consequences of what we are living are still unclear, especially in our sector where the impact on funding opportunities becomes evident in the medium and long term. In the short term, as the reader will deduce analyzing the data in this report, our results have been excellent, which means we successfully navigated the emergency and in the process we learned a lot, but I would not celebrate it as a win yet, as the impact to the future is still to know. My hope for the future is for CTTC to become increasingly better at innovating and get back soon to meet, socialize, travel.

I give the merit for our success in 2020 to a trajectory of 20 years during which we have consistently worked to pursue scientific excellence and technological rigor, combining long term theoretical research to accurate experimental proof of concept, with the implementation of 7 testbeds and experimental platforms. I also believe that the stability of the majority of working positions, consolidated with our vision of an institution able to provide long term research opportunities to brilliant researchers (currently we count with approx. 60 and 20 permanent positions, in research and administration, respectively), has played an important role in providing to the staff the security and balance to work at the best they could in this extremely stressful and uncertain epoch. I want to thank all the staff at CTTC for the great effort they made this year to conciliate work and life, the work council for their irreplaceable support in this emergency, and their empathy to the Director's concerns, and the executive committee for keeping high standard as always, ensuring the day to day operation, maintaining our R&D accreditations and even starting new projects as the new communication plan.

We are lucky and proud to have contributed to our research community in such a symbolic year when research has revealed itself as the powerful force that it is to combat crisis and emergencies. In fact, the pandemic has demonstrated something that was already well known to all of us who have decided to devote our career to research: research in progress has a tremendous impact on

our lives. The countries who have traditionally nurtured research and an economy of knowledge have resulted to be the most resilient to the economic crisis. Researchers around the world from fields as multi-disciplinary as biomedicine, virology, physics, data analytics, and artificial intelligence have contributed to combat this pandemic, with thousands of peer-reviewed publications and contributions in many heterogeneous formats and have literally saved lives.

When we think of the research impact for this 2020, we celebrate and acknowledge the incredible results that the scientific community has achieved in the area of vaccines and Covid-19 cures, which will hopefully drive us out of this health crisis soon enough. To go from the discovery of a deadly new virus to the creation, production and distribution of multiple tested vaccines in less than a year is unprecedented in scientific history. I believe the amazing progress in advancing the vaccine through surely sets a new standard for what can be achieved when sufficient resources and scientific focus is invested in a strategic area, and we should all learn from this.

Besides these undeniable progresses in global health, I would also like to underline another scientific area that has made a huge difference during 2020: ICT technologies, whose technological advance is the focus of our work at CTTC, had in this crisis a major role to keep our life go on. Wired and wireless technologies have provided us with all the means we needed to work remotely, to make our economy more resilient, to keep us closer to family and friends, who suddenly we got forbidden to meet and visit, to keep our kids educated, to entertain us during hours and hours of streaming services. ICT technologies have made a great work in mitigating the negative affect of the pandemic, and we will never be able to completely understand and evaluate the real impact that they had at so many levels. Studies in literature demonstrate that the massive use of ICT technologies during the lockdown have promoted the perception of social support, which has significantly mitigated the psychological impact of the lockdown itself. ICT applications have been used to guide authentic information, support clinical and political decisions, enable contact tracing and patient registry. Further applications of digital technologies are numerous, ranging from tactile robots to assist medical operation in hospitals, telemedicine, drones operations to monitor crowds or to deliver essential medical supplies to remote areas, artificial intelligence and deep learning models to understand pandemic trends, support for e-learning and video-conferencing technologies.

I believe it is vital to acknowledge the importance of ICT technologies and the need to follow investing in them as a country towards the evolution to 6G, to fight for the digital inclusiveness and connect what still remains unconnected. In this annual report you will be able to dive into the activities we carried out at CTTC in this vibrating and impactful area of research during 2020.

As a final note to this long letter, I seize the occasion to remind that this year CTTC celebrates its 20th anniversary, at the same time I am about to retire from my role as CTTC's Director. I wish to remark how proud I am that CTTC has become an important actor in our research and industrial community, after contributing during the last 20 years to the fundamental technological growth of ICT technologies that we have witnessed. I wish all the best for the years to come to all CTTC's employees, who make of CTTC such a great work environment and to the future

M. Ángel Lagunas
Director of CTTC

Mission and Vision

Our vision

CTTC is a non-profit research center, from a public initiative and with a high degree of self-financing, open to the participation of other public and private bodies, as well as to partnership with the industrial and business sectors.

CTTC has a professional scientific management, a critical mass of researchers and projects, real possibilities of growing and establishing durable links with the industrial and business sectors, and the capacity of leadering technological projects, both national and international.

The expertise accumulated at CTTC makes us one of the primary addresses for Spanish telecom industry, as well as one of the leading European institutions for research at physical, access and network layers in telecommunications.

Our mission

CTTC's core activity is the conception, design and implementation of research and development projects, which have to produce innovative results in all their development phases, in both scientific and engineering terms. The acquisition of an international reputation in its scientific and technological activity, shaped in terms of scientific production, will favour CTTC's mission of becoming an Excellence Center.

CTTC aims at fostering innovation potential by making new scientific knowledge accessible and supporting its implementation.

In this way, CTTC significantly contributes to consolidating Barcelona's position as an important center of technology, besides helping expand Spain's role within the European telecommunications research community and industry. Finally, CTTC contributes to the economic growth of the Catalan industrial context, by becoming a partner of solid reputation in research and technological development, as well as a provider of knowledge and human resources for the industrial research.

Board of Trustees & Scientific Advisory Board

Board of Trustees

The Board of Trustees is the management organ and is currently constituted by members of the five promoting institutions.

- Department of Economy and Knowledge (DECO) of the Autonomous Government of Catalonia, General Direction of Research of Autonomous Government of Catalonia.
- Technical University of Catalonia (UPC).
- Ramon Llull University (URL).
- Department of Territory and Sustainability of Autono mous Government of Catalonia.
- Secretary of Telecommunications, Cybersecurity and Digital Society of Autonomous Government of Catalonia.

As of the 31st of December 2020, the members' representatives were:

- **Ramon Tremosa I Balcells**
  Ministry of the Department of Economy and Knowledge (DECO)
- **Francesc Torres**
  Chancellor of the Technical University of Catalonia (UPC)
- **Josep M. Garrell**
  Chancellor of the University Ramon Llull (URL)
- **Joan Gómez I Pallarès**
  Director of Research of the Department of Research and Universities
- **Xavier Baulies I Bochaca**
  Responsible of Research & Innovation of the Department of Territory and Sustainability
- **Oriol Puig I Godes**
  Sub-Director of Planification & Projects of the Department of Territory and Sustainability
- **David Ferrer I Canosa**
  Secretary of Telecommunications, Cybersecurity and Digital Society

Scientific Advisory Board

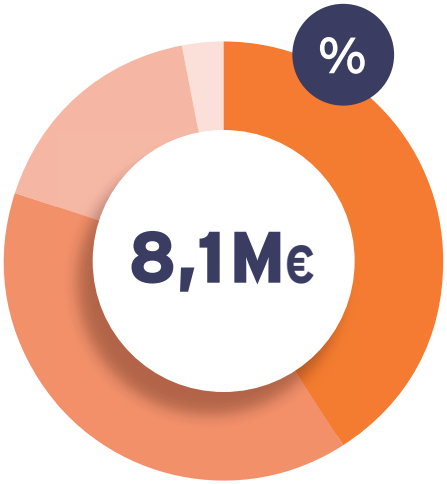
The Scientific Advisory Board is responsible for the orientation and scientific evaluation for the CTTC and ensures external advice concerning the adequateness of CTTC's research strategy and of the scientific quality of research work performed. The Scientific Advisory Board is composed of internationally distinguished scientists, and advises CTTC's Director and Board of Trustees. As of the 31st of December 2020, the members' representatives were:

- **Prof. Lluís Jofre**
  Universitat Politècnica de Catalunya, Spain
  Secretary
- **Prof. Jose Antonio Gili Ripoll**
  Universitat Politècnica de Catalunya, Spain
- **Prof. Yonina Eldar**
  Weizmann Institute of Science, Israel
- **Prof. John M. Cioffi**
  Stanford University California, USA
- **Dr. Markus Dillinger**
  Huawei, Germany
- **Dr. Riccardo De Gaudenzi**
  European Space Agency ESTEC Noordwijk
  The Netherlands
- **Mr. José Jiménez**
  Spain
- **Dr. Antonio Manzalini**
  Telecom Italia Lab., Italy
- **Mr. Pedro Mier Albert**
  Mier Comunicaciones SA, SpainSociety

Facts & Figures

CTTC 2020 in numbers

FUNDING



39% Core Funding
41% Public Competitive
17% R&D Services
3% Other Funding

▶ Competitive Funding

4,8M€

20 National projects

35 European projects

36 Industrial projects

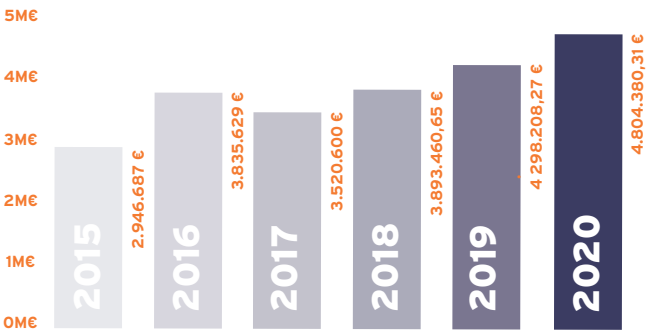
▶ Project proposals submitted

142

▶ Growth rate

39%

GROWTH RATE IN THE PAST 6 YEARS



▶ 5G PPP EC projects granted in 2020

4

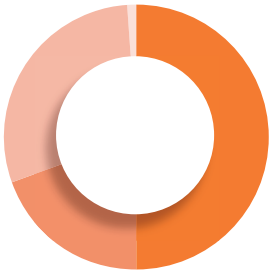
▶ H2020

SUCCESS RATE

GRANTED PATENTS IN FORCE

26

PUBLICATIONS



- 83 Journals
- 126 International Conferences
- 4 Books & Chapter

INDUSTRY INNOVATIONS

15

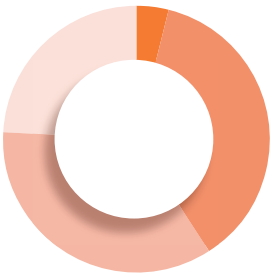
STAFF

133

TEAM MEMBERS

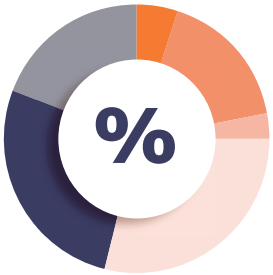
- 24 Nationalities
- 78% Researchers
- 54% PhD
- 27% Women
- 27% Women in management team

R&D Personnel



- 4 Fellow Researchers
- 37 Senior Researchers
- 35 Researchers
- 24 Research Assistants

Staff

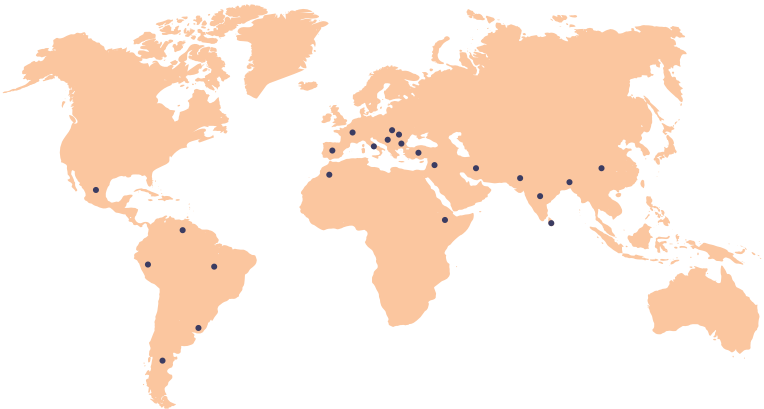


- 5% Direction
- 17% Support
- 3% Fellow Researchers
- 29% Senior Researchers
- 27% Researchers
- 19% Research Assistants

Nationalities

%

- 58 Spain
- 8 Italy
- 6 Iran
- 5 Grecia
- 5 India
- 4 Mexico
- 3 Pakistan
- 2 Brazil
- 1 Venezuela
- 1 Argentina
- Bangladesh
- Bulgaria
- China
- Etiopia
- France
- Hungary
- Morocco
- Palestina
- Perú
- Serbia
- Slovakia
- Srilanka
- Turkey
- Uruguay



27% Female

73% Male

Social & **Industrial Impact**

AUTOMOTIVE & INTELLIGENT TRANSPORT SYSTEMS SMART MOBILITY SMART GRID AND ENERGY MANAGEMENT SMART CITIES SMART HEALTH SUSTAINABILITY ENHANCED MEDIA INDUSTRY 4.0 RURAL ENVIRONMENTS DRONES DEEP SPACE EXPLORATION CIVIL ENGINEERING EARTH SCIENCES CIVIL PROTECTION ENVIRONMENTAL AGENCIES

Research

CTTC has worked on the roadmap for its research and development activities. Research at CTTC deals with the physical, data link and network layers of communications systems. Currently, it is organised in four Research Divisions.

DIVISIONS & DEPARTMENTS

CND

ONS Optical Networks & Systems

MONET Mobile Networks

COMMUNICATION NETWORKS

- Machine learning based multi-layer and multi-domain network management
- SDN/NFV/MEC for verticals
- Coexistence of fixed and mobile networks (incl. NR-U, LAA, mmwave)
- Software-defined optical transmission and performance monitoring
- Optical systems and subsystems exploiting novel photonic technologies
- Testbed development and ns-3 mobile LTE/NR simulation/emulation framework

CSD

ASIP Advanced Signal and Information Processing

A&MSP Array and Multi-Sensor Processing

SI Statistical Inference for Communications and Positioning

COMMUNICATION SYSTEMS

- Signal and information processing for the communications systems air interface
- Positioning and tracking: C-ITS, high precision agriculture, advanced GNSS SDR receivers
- Spectrum sharing techniques, machine learning for communications, signal processing for big data and the smart grid
- Technologies: 5G, satellites (GEO/LEO), URLLC, MIMO/arrays, spectral efficient/robust moderns, system-on-chip SDR/HW prototyping
- Experimental platforms: hybrid satellite/terrestrial, GNSS/INS/Indoor (radio) positioning

CTD

M2M Machine to Machine Communications

PHYCOM PHYLayer Implementation of High Performance Comms Systems

SMARTECH Smart Energy Eficient Comms Technologies

COMMUNICATION TECHNOLOGIES

- Analog devices for wireless communications and sensors for vertical applications
- 5G/B5G AI-enhanced transceiver front-end prototyping
- Cooperative-Intelligent Transportation Systems based on V2X networks
- Data driven and slicing solutions for B5G/6G networks
- Design of Energy Efficient Management for 5G and Beyond networks
- Experimental framework for 5G-ready vertical services

GMD

RSE Remote Sensing

GEON Geodesy and Navigation

GEOMATICS

- Radar remote sensing
- Optical remote sensing
- Deformation monitoring
- UAV mapping
- Multi-sensor navigation
- Sensor orientation and calibration
- Geodetic trajectory determination

CND

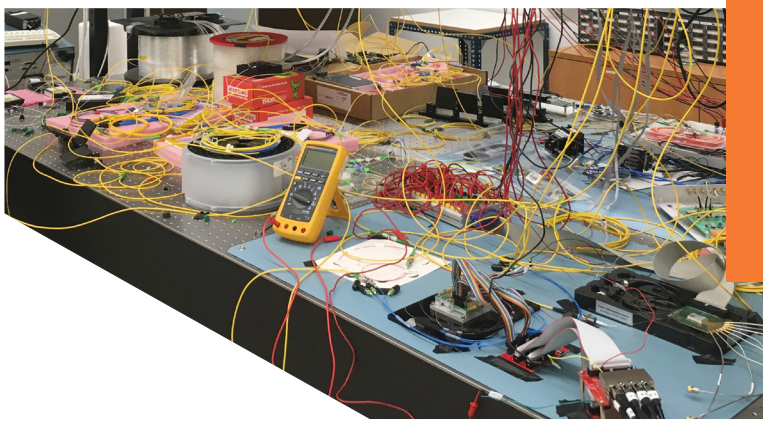
Communication Networks Division

The Communications Networks Division (CND) aims at optimizing the network infrastructure (virtual and physical) end-to-end and the vertical services it serves. This includes core, metro, and access, optical and wireless, transport and aggregation, fixed and mobile networks, edge and cloud computing. Its research does not stop at the theoretical level, but also moves to an experimental stage by developing complete simulation frameworks as well as testbeds, proof-of-concepts, and pilots with the goal of transferring the technology to industry.

This research division comprises the following departments

Optical Networks & Systems (ONS): The goal of ONS is to contribute to defining the evolution of future transport networks (spanning from metro packet/circuit aggregation to core optical networks) towards intelligent (dynamic, self-star), high-capacity, low-cost, highly-flexible, scalable, and energy-efficient software-defined optical networks seamlessly integrated with massive cloud/fog computing and storage services.

Mobile Networks (MONET): The goal of MONET is the design and optimization of programmable heterogeneous and dynamic (wireless) networks.



KEYWORDS

5G SDN/NFV 5G/6G testbeds Slicing Orchestration MANO Automated network management
Edge computing Microservices Cloud services Vertical Industries Performance evaluation Data Science Machine Learning
Elastic Optical Networks WDM/SDM Photonic transceivers Optical disaggregation Optical transport testbeds Optical telemetry
Optical network automation Optical network security LAA/LTE-U/NR-U Sustainable computing Spectrum Sharing Unlicensed LTE/NR
NR simulation 5G NR D2D ProSe Public Safety Energy Harvesting O-RAN

HIGHLIGHTS

- Participation in more than 30 projects with public funding and industry
- Participation in several projects and proof-of-concepts on automated network management.
- Participation in industrial projects on NRV2X, spectrum sharing, fronthaul compression.
- Publications in more than 30 journals and 60 international conferences including best paper awards.
- Fully virtual organization of the 24th international conference on optical network design and modelling (ONDM 2020).
- 3 PhD thesis defended.

5GCroCo, 5Gtango, BLUESPACE, METRO-HAUL, ONFIRE, PASSION, 5GROWTH, NSPIRE-5G+, MOMENTUM2, MOMENTUM3, AURORAS, Go2Edge, CIVIQ, INT5GENT, 5GMED, FEMIOT, 5G-REFINE, 5G-LAB, NIST_NRV2X, HUAWEI_ML_SON, S3_LLNL, SCAVENGE, 5G-FOREST

CSD

Communication Systems Division

The Communication Systems Division (CSD) aims at leading fundamental research in wireless communications, wireless radio positioning and information processing networks. We also provide technology transfer and state-of-the art solutions to the industry and business ecosystem. We have over 20 years proven experience in delivering advanced transceivers, and signal and information processing solutions in the following areas of technology: cellular communications (LTE, 5G and beyond), satellite and space communications (high throughput satellites, mobile satellite services, deep-space comm.), large-scale communication and information systems (massive MIMO), GNSS and hybrid sensor-fusion positioning and navigation. Current interest focuses on beyond 5G radio access technologies development and spectrum sharing solutions, Machine learning and AI solutions for wireless and satellite communications, and rapid prototyping (including system-on-chip with HW acceleration) of real-time PHY communication and positioning systems (terrestrial and space segments).

This research division comprises the following departments

Advanced Signal and Information Processing (ASIP): ASIP investigates new signal processing and communications methods in order to address these challenges.

Array and Multi-Sensor Processing (A&MSP): A&MSP gives signal and big data processing solutions to satellite communication systems and to hybrid satellite/terrestrial systems.

Statistical Inference for Communications and Positioning (SI): SI is focused on fundamental problems in statistics, with an emphasis on disruptive applications in Communications, Positioning, and Life Sciences. Carrying out mixed theoretical/applied research is one of our characteristics, and thus we have very strong experimental capabilities.

KEYWORDS

Satellite CommunicationsBeamformingAntenna Array Beyond 5G Transceiver DesignAdvanced Coding Solutions Interference ManagementHybrid PositioningGNSS receivers Sensor FusionRapid prototypingBig Data AnalyticsMachine Learning for CommunicationsNR simulation5G NRD2D ProSePublic SafetyEnergy HarvestingO-RAN

HIGHLIGHTS

- Participation in more than 30 projects with public funding and industry
- Fully virtual organization of the 45th International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2020). The conference hold over 16.000 registrants, increasing over five time the highest number of ICASSP registration ever.
- Publications in more than 14 journals and 25 international conferences including best paper awards.
- 1 PhD thesis defended.

VLADIMIR, SATNEX IV_PHASE II, RFSPS, SAT-AI, KYUBI_ANTENA, ROSETTA MENTORING, TERESA, SATNEX V, WINDMILL, ARISTIDES, 5G-LAB, 5GCoding-SRS, IRACON, GNSS-in-Space, GNSS-in-Space II, 5GCoding-SRS II, FASTTRACK, FASTTRACK II, IMMUNET, IRACON, GNSS-ARRAY, G-INSter, CATERPILLAR2, DRONE-EXTENDER, 5G-MERCABARNA, Multi-RF GNSS Dongle, TFUSE, FEMIOT

CTD Communication Technologies Division

The Communication Technologies Division (CTD) aims at addressing the energy and flexibility challenges of 5G networks and their evolutions by proposing innovative solutions mostly on PHY, MAC and NET layers. Precisely, one of the main differentiating aspects of CTD research is that our methodology is strongly based on the experimentation, with our testbeds and experimental platforms being a core element of this methodology. In order to structure our ambitious research objectives of energy-efficiency and flexibility, the CTD research is divided in three Departments. The first two focus on protocols and algorithms for 5G and beyond networks including machine- and human-type communications, respectively:

Smart Energy Efficient Communication Technologies (SMARTECH): SMARTECH aims to enhance the energy efficiency of the future wireless networks by proposing algorithms and models for different communication layers. In this context, the main directions of the Department are: i) design of energy efficient dynamic and massive network slicing solutions with zero touch configuration and ii) deployment of novel energy efficient techniques for future key vertical applications, including smart grid, content and media delivery as well as deployment of an experimental framework for 5G-ready vertical services.

Machine to Machine Communications (M2M): The M2M Department conducts research, development and innovation actions in the area of ICT technologies with a focus on endowing the network with flexibility features. The gluing concept along all conducted actions within the department is Machine-to-Machine (M2M) communications, also referred to as Machine-Type Communications (MTC). This term refers to the connection, interconnection, and Internet-connection of and between machines, devices, objects and/or things. Such (hyper-)connectivity makes it possible to realize the holistic concept of the Internet of Things (IoT) and becomes a key and necessary enabler for emerging vertical applications in different domains, such as Industry 4.0, Connected Cars and Automated Mobility, Smart Cities, or eHealth, among others all with very different requirements that a single flexible network has to address.

The experimental activities of these first two Departments include research on the IoTWORLD testbed, an innovative 5G testbed for the Internet of Things (IoT), whose main features are:

- Network Function Virtualization (NFV) based on open standards.
- Integration of 5G technologies: Network slicing, Cloud-RAN, mmWave.
- Flexible and scalable edge-cloud network architecture.
- Heterogeneity of wireless technologies.
- Traffic shaping using Software Defined Networking (SDN).
- End-user involvement

Physical-layer Implementation of High Performance Communication Systems (PHYCOM): PHYCOM focuses on multiple research topics, which start from implementation of signal processing techniques for agile software defined radio (SDR) systems and expand to the prototyping of artificial intelligence (AI)-enhanced solutions for next generation radio access network (RAN) and mixed-signal processing techniques for efficient fifth generation (5G) and beyond transmitters. The department was recently enriched with a new capacity related to design and prototyping of fixed and reconfigurable analog devices for wireless communications and sensors for safety-critical and industrial applications.

KEYWORDS

IoTM2MVirtualized DSPInnovationPrototypingC-ITSCybersecurity5G Trials6GMEMSWireless CommunicationsSDRFunction SplitGreen ICTDPDAntenna DesignArtificial IntelligenceZero touch configurationAnalog devices and components

HIGHLIGHTS

- Participation in more than 24 projects with public funding and industry.
- Publications in more than 18 journals and 21 international conferences including best paper awards.
- IEEE Vehicular Technology Magazine "Paring a Circular Economy and the 5G-Enabled Internet of Things".
- Special impact with the 5GCroco project. This project trials 5G technologies in the cross-border corridor along France, Germany and Luxembourg. In addition, 5GCroCo also aims at defining new business models that can be built on top of this unprecedented connectivity and service provisioning capacity. Ultimately, 5GCroCo impacts relevant standardization bodies from the telco and automotive industries.

GIMS, AGENTSENSOR, 5GCroCo, DRONE-EXTENDER, KYUBI_ANTENNA, SENSORQ, 5G-TRIDENT, ULTRA5G, 5GROUTES, CONVERGE, INSPIRE-5G, METRO-LINK+, SPOT5G, MOM5G, 5GMED, FEMIOT, FIREMAN, 5G-SOLUTIONS, SEMIOTICS, 5G-LAB, CONNECT,5GROUTES, DARLENE, OPTIMIST, PROGRESSUS, SEMANTIC, 5G STEP-FWD, PANDORA

GMD

Geomatics Division

The Geomatics Division focuses its activities in two main areas of Geomatics: the area of positioning and navigation, and the area of remote sensing, which involves Earth observation through images and data collected by sensors onboard satellites, aircrafts, and ground-based instruments.

This research division comprises the following departments

Geodesy and Navigation Department (GEON): GEON does research in the integration of any available sensor for local geodetic applications both in their geometric and physical aspects.

Remote Sensing Department (RSE): RSE has the objective to carry out research related to the generation and analysis of spaceborne, airborne and ground-based data and to develop thereof scientific and technical applications.

KEYWORDS

Positioning GNSS Indoor positioning Remote sensing Radar Deformation measurement

HIGHLIGHTS

- Participation in more than 22 projects with public funding and industry.
- Publications in more than 20 journals and 17 international conferences.
- Impact of the Sea level rise scenarios along the Mediterranean coasts-2 (SAVEMEDCOASTS-2 project). The project aims at preventing natural disasters caused by combined effects of sea level rise (SLR) and land subsidence (LS) in the major exposed coastal zones of the Mediterranean region.

GIMS, RISKCOAST, MOMPA, C-AQM-Construïm, CATERPILLAR2, G-IN-Ster, FGC, FGC_bis, 5G-LAB, IOPES, IPOLE_Producte, GMAB, POCRISC, DEMOS, HEIMDALL, BGR_ADA-Training, CUPRUM, CUPRUM2, GBASTUR, TAMAGOCHI 2, VIGOR, GMAB, SAVEMEDCOAST2


UNLICENSED LTE/NR
VIRTUALIZED DSP
SDN/NFV
RADAR
WDM/SDM
O-RAN
6G
FUNCTION SPLIT
GREEN ICT
MANO
6G/5G TESTBEDS
5G TRIALS
D2D PROSE
CLOUD SERVICES
DPD
PUBLIC SAFETY
IOT
GNSS RECEIVERS
GNSS
C-ITS
NR SIMULATION
SDN/NFV
ENERGY HARVESTING
MEMS
LAA/LTE-U/NR-U
ARTIFICIAL INTELLIGENCE
REMOTE SENSING
ORCHESTRATION
INDOOR POSITIONING
OPTICAL DISAGGREGATION
BEYOND 5G TRANSCEIVER DESIGN
M2M

Industry

IPR Assets

One of the main objectives of CTTC is to promote the technological innovation. After more than 10 years of Research and Development (R&D) activities, this objective is pursued by growing an IPR (Intellectual Property Right) Portfolio based on Testbed, trade marks and patent applications. In particular, CTTC has registered eleven trade marks and has submitted 26 family patents to national and international offices.

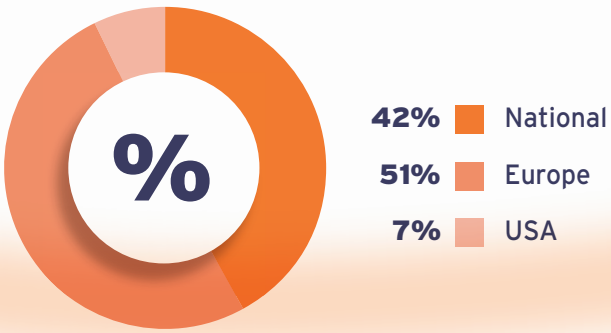
From 26 patent families submitted, 6 granted are still in force as is shown in the Table 1:

PATENTS			
Title	**Priority date**	**Publication Number**	**National Number**
METHOD FOR EQUALIZING FILTERBANK MULTICARRIER (FBMC) MODULATIONS	19/03/2013	2782304	EP2782304:DE,ES,FR,UK US8,929,495
METHOD AND SYSTEM FOR PROVIDING DIVERSITY IN POLARIZATION OF ANTENNAS	30/01/2014	WO2015/113603	EP3100371:DE,ES,FR,UK
A METHOD FOR MONITORING TERRAIN AND MAN-MADE FEATURE DISPLACEMENTS USING GROUND-BASED SYNTHETIC APERTURE RADAR (GBSAR) DATA	26/07/2010	2413158	EP2413158: ES, DE,IT
IMPROVED SURVEYING POLE	30/12/2015	WO2017/114577	EP3397923: FR, DE, IE, IT, ES, SE, CH, UK US16/075,912
DELTA SIGMA CONVERTER WITH PM/FM NON-LINEAR LOOP	02/08/201	WO2018/024316	EP3494640 US16/332,978
METHOD AND SYSTEM FOR CLOUD-NATIVE APPLICATIONS-BASED NETWORK OPERATIONS	16/10/2019	EP 19 382 906	

TRADEMARKS			
Title	**Granted date**	**Registration Number**	**Global Brand Database**
CTTC	13/04/2005 14/03/2011	003462538008 161705	EUIPO EUIPO
ADRENALINE TestBed	09/02/2007	M2720065	OEPM
EXTREME TestBed	09/02/2007	M2720067	OEPM
GEDOMIS	08/02/2007	M2720061	OEPM
GEMMA NAVIGATION	21/05/2015	013710223	EUIPO
GESTALT	13/07/2015	M3554104	OEPM
GNSS-SDR	04/03/2015	M3532706	OEPM
IoTWORLD	10/08/2016	M3605133	OEPM
CASTLE PLATFORM	09/04/2016	M3609849	OEPM

SOFTWARE			
Title	**Granted date**	**Copyright registration**	**Number**
SOFTWARE BEMIMOMAX	01.06.2012	US	TXu1-813-759
Geokinesia PSIG	21.10.2020	Notarial Act	2611
GNSS-SDR	09/02/2007	GPL v3	v0.0.10

Next Illustration shows the geographical areas where the CTTC Intellectual Property assets are protected:



Inventions / Innovations

Innovation activities are classified in two categories:

a) the generation of industrial property portfolios with patents and trademarks, which started in 2005.

b) the increment of Products & Solutions portfolio. This portfolio with different TRLs initiated in 2105, aims at transferring value to the market later, trying, above all, to converge the efforts of products and solutions with those of the patents applied for. This strategy goes in line with defining a specific CTTC's IP policy, which replaced Director's declaration "CTTC letter Policy regarding Industrial and Intellectual Property" and provided detailed objectives, strategy and procedures for its implementation.

The policy, denoted by "Intellectual Property Policy @ CTTC", was defined according to recommendations and references from the WIPO (World Intellectual Property Office).

This policy contributes to the recommendation provided by the HR Strategy for Researchers, HSR4R quality label. The CTTC's "Intellectual Property Policy" was approved at the 33rd Extraordinary Meeting of the Board of Trustees that was held on April 5th, 2019.

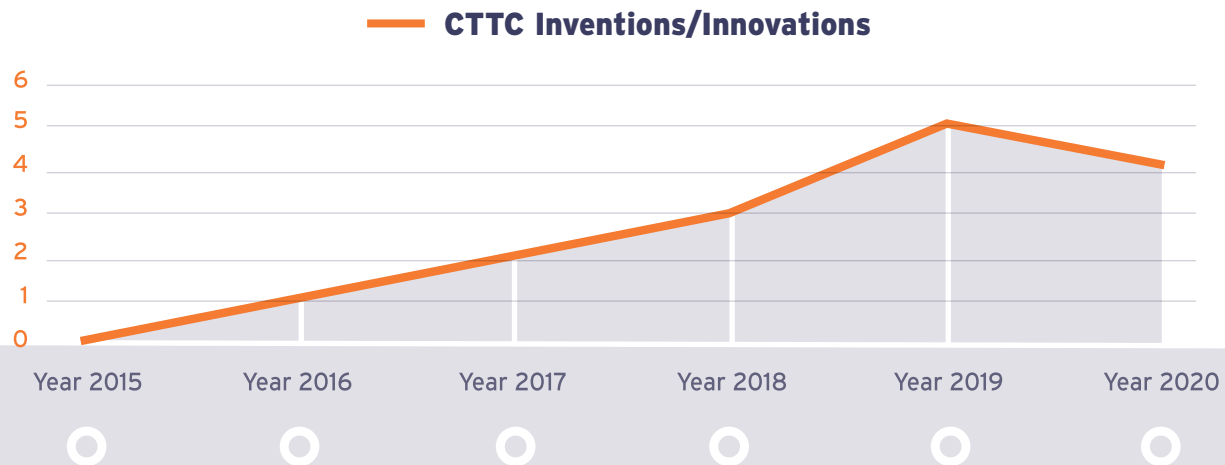
As a result, and following the WIPO's own instructions, we have created the "CTTC Invention / Innovation declaration form" as a tool available to researchers to value their ideas and propose to consideration tangible assets to value and continue to develop to make economic returns. All CTTC Invention/Innovation declaration forms are brought to the CTTC Board of Directors for evaluation.

During the year 2020 we have obtained the following four declarations of Invention / Innovation corresponding to:

- Ipole
- Timon – Sensor Fusion Position
- PSIG Software
- Active Reflector

As a result of this new way of orienting assets towards inventions and innovations, at the end of 2020, the list included the following contributions:

- **@iPole** lead by Dr. Eulàlia Parés
- **@avemedia** lead by Dr. Josep Maria Fabrega
- **@GLIGHT** lead by Dr. Carles Fernàndez
- **@SaC** lead byDr. Eulalia Parés
- **@Equalization of time-varying channels in OFDM systems** lead by Dr. Xavier Mestre
- **@Simplified Equalization of OFDM Wave forms with Insufficient Cyclic Prefix** lead by Dr. David Gregoratti
- **@C-AQM:** A Crowdsourced Air QualityMonitoring System lead by Dr. Eulalia Pares
- **@microSDNcontrol** lead by Dr. Ricard Vilalta
- **@Flexiband RF software driver** lead by Dr. Javier Arribas
- **@IP cores for GNSS signal generation** lead by Dr. Carles Fernández
- **@IP cores for embedded GNSS-SDR** lead by Dr. Carles Fernández
- **@Hardware platform for GNSS-SDR** lead by Dr. Carles Fernández
- **@TIMON** – Sensor Fusion Position lead by Dr. Mònica Navarro
- **@PSIG Software** lead by Dr. Michele Crosetto
- **@Active Reflector** lead by Dr. Michele Crosetto



Likewise, during the year 2020, some of the innovation projects were submitted to different calls to be able to advance in their development, of TRL (Technology Readiness Level) level. The following one was accepted:

- @iPole lead by Dr. Eulàlia Parés.
  It was presented at the PRODUCTE 2019 Knowledge Industry call and, in the 2020 resolution, was accepted for co-fi nancing by the European Regional Development Fund (ERDF). The Product Grants are intended for obtaining prototypes and for the valorisation and transfer of research results generated by research teams in Catalonia.

Participation in the GINJOL program

The CTTC participates as a partner in the GINJOL Patent Fund of CERCA. This gives us the opportunity to apply for competitive calls for innovation projects. Once the projects have been selected and evaluated, the investment from the GINJOL Patent Fund is obtained, in particular to finance industrial property costs. The investment received must be returned under certain conditions when there is a return, according to the data of the operating plan presented in the innovation project.

Currently, three evaluated innovation projects have received Investment, these are: Avemedia 2016, iPole 2015 and GLIGHT 2017.

During the year 2020, in the 7th edition of the Gínjol Patent Fund program, the invention / innovation project "microSD-Ncontrol" was presented.

Invention / Innovation Protection

As a result of the research, invention and innovation activities, the most appropriate protection is derived.

The first step, for researchers, is to declare ownership of the invention / innovation. Once the statement has been approved by the CTTC Board of Directors, it is passed on to the IP Services Agent for proper evaluation (IP Protection Analysis).

During 2019, in compliance with the New Law 9/2017 on Public Sector Contracts, by which the contracting of the "Service of Advice and management of industrial and intellectual property (IP)" must be awarded by means of an open procedure.

Once the process is properly understood and evaluated, if approved, a subsequent study on patentability (Patent Study), trademark registration (trademark registration) or software registration (Program Registration) or even considering it an industrial secret, is carried out. For all options, the process stops at this point except the patent. In this case, the IP service agent is given the mandate to write the patent report in close collaboration with the CTTC researchers.

Innovations for the industry

The CTTC, from its foundation, has fostered the creation of start-ups and spin-offs, born either from the institution or from people linked to the CTTC.

However, most of these initiatives did not led to revenue generation for the Center; since, in most cases, the CTTC was not directly involved as a partner. A special case is CTTC-HK Limited company in Hong Kong, which was created to obtain business opportunities from the Asian market and which has always been 100% owned by the CTTC. It was active until 2017, when it was closed following the agreements adopted by the Board of Trustees.

Considering the advice of the evaluations carried out on the center, such as the review by the external Scientific Committee or the evaluation from the CERCA Institution, CTTC focused its efforts on the maintenance of relevant patents and cancelled those less likely to lead to potential revenues per license or sale. Following this rethinking of CTTC strategy, the need to have a spin-off and start-ups plan was identified as critical to respond to all the points mentioned above and to increase the future CTTC's revenues from the outcomes of the R&D projects and their research results.

The plan for the creation of Spin-offs is based primarily on the coordination of the procedures of the R&D management system of the center itself and the combination with existing and available mechanisms in the public domain, articulated by the Knowledge Industry program (IdC). This program includes the private sector, through calls made by companies. The program is detailed in the "REGLAMENT SPIN_OFFs del CTTC", document that has been presented and approved at the 33rd Extraordinary Meeting of the Board of Trustees, held on April 5th, 2019. The plan and the regulation are the objectives that were set to reach the objectives defined in the strategic multi-year framework planning of the Center.

All instruments available to increase the invention innovation projects TRL level, are continuously surveyed, studied and applied. From those, the Collider Program was identified as the most suitable to achieve the creation of an Spin-off. The Collider is a pioneering program of innovation and technology transfer that tries to close the gap between science and the market to create disruptive technology-based spin-offs. It is an initiative of the Mobile World Capital Foundation promoted by the Ministry of Economy and Business, the Generalitat de Catalunya, Barcelona City Council, Fira de Barcelona and GSMA. The Mobile World Capital Foundation also has the support of private companies that contribute to the development of Barcelona's digital ecosystem.

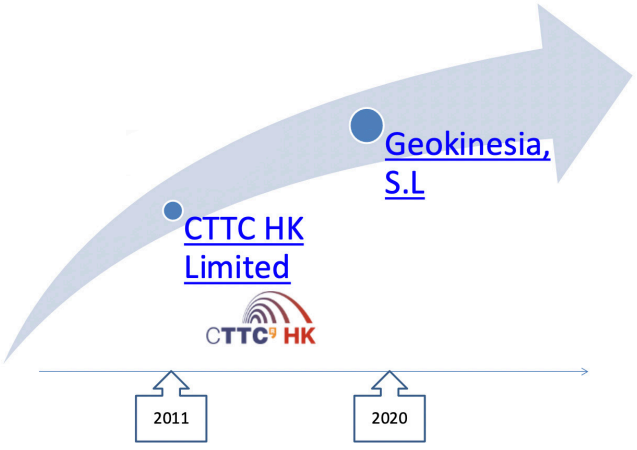
Additionally, "The Collider Awards" is created with the aim of distinguishing those researchers who are part of research groups affiliated to research institutions, including universities, research centers and technology centers at the state level, which, as a result of their work have obtained results aimed at being able to be exploited commercially and to respond to the proposed industrial challenges ("health and well-being", "mobility", "industry and energy").

Through The Collider, the program seeks to connect scientific talent with the entrepreneurial talent to create highly innovative, science-based companies (spin-offs) that transform the results of scientific research from universities and research centers into marketable products or services.

As a result of the participation in this program CTTC constituted a new spin-off. First it involved the presentation, through its OTRI, of its iPOLE technology (developed by Eulàlia Parés) to the 2019 Collider call. Which later on April 3rd, 2020 received the approval and support of The Collider resulting in the constitution of Geokinesia, S.L.

Geokinesia, S.L. was approved in an extraordinary session of the Board of Trustees dated July 22nd, 2020. CTTC owns a 15% stake. The Barcelona Mobile World Capital Foundation has also a participation stake. The historical data can be found in the web link of the CTTC http://www.cttc.es/spin-offs_startups/.

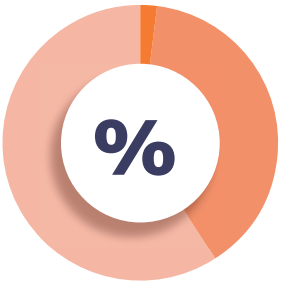
Illustration 2: Spin-offs historical data



Publications

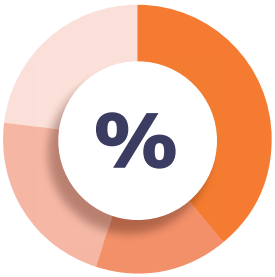
CTTC is committed to contribute to excellence and to the advancement of knowledge in the area of communications, networking and geomatics technologies, through an intense and first-rank production of scientific publications. In addition, it is also committed to the open access distribution of its research results, by adhering to Open Access policies.

Scientific Publications



2%	Books & Chapters
39%	Journals
59%	International Conferences

Divisions Journal Production



39%	Communication Networks
16%	Communication Systems
22%	Communication Technologies
23%	Geomatics

Scientific Journals Rankings

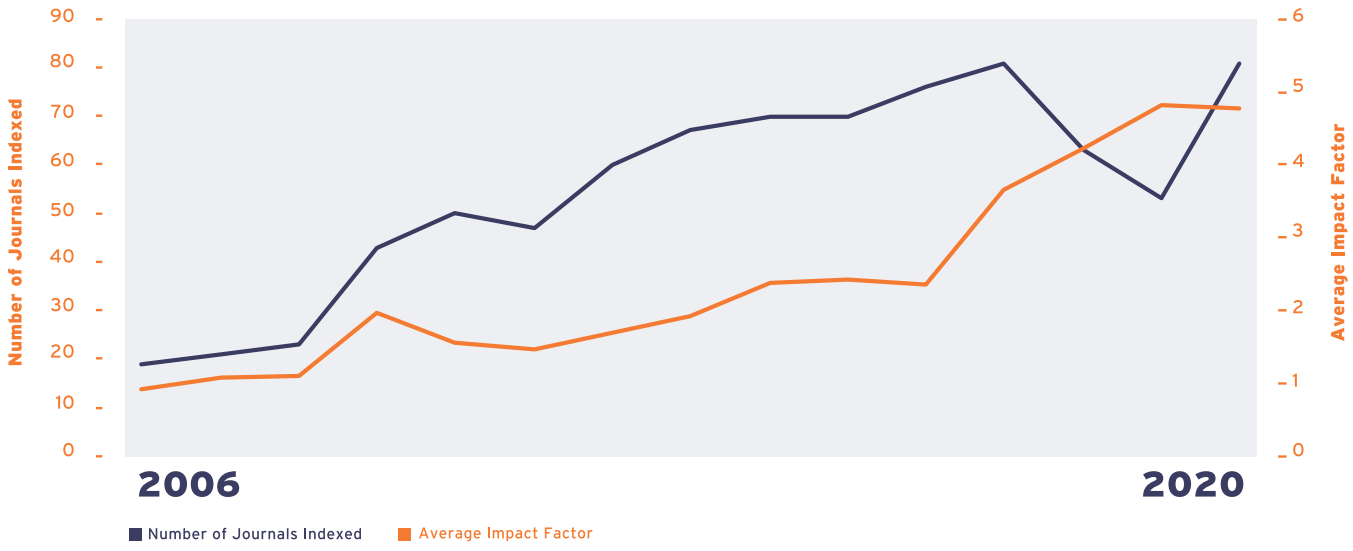
81 JOURNALS

62% 1st quartile

4.70 Average Impact Factor

100%

Impact Factor



Scientific Publications 2020

CTTC is committed to contribute to the excellence and the advance of knowledge in the area of communications, networking and geomatics technologies, through an intense and first-rank production of scientific publications. In addition, it is also committed to the open access distribution of its research results, by adhering to Open Access policies.

During 2020 there was a considerable increase in the number of published papers in conferences and a significant growth in the number of articles in journals of high impact. More specifically, CTTC published 81 articles in technical magazines, 77 of which are in journals indexed in the database of Institute of Science Index (ISI) and 127 articles in international conferences. Next, we list some of the most cited works.

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8. L. Solari, M. Del Soldato, F. Raspini, A. Barra, S. Bianchini, P. Confuorto, N. Casagli, M. Crosetto, **Review of Satellite Interferometry for Landslide Detection in Italy**, Remote Sensing, Vol. 12, No. 8, April 2020.

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ONDM 2020 - Castelldefels, Barcelona, Spain

ICASSP2020 Barcelona

isprs information from imagery

IEEE ICC®

IEEE GLOBECOM®

ECOC 2020

IEEE NETSOFT

IEEE INFOCOM™

IEEE pimrc

IEEE NFV-SDN

22nd ICTON2020
International Conference on Transparent Optical Networks
July 19th - 23rd, 2020 | Bari, Italy

EUCNC 2020
June 15-18
European Conference on Networks and Communications | Dubrovnik, Croatia

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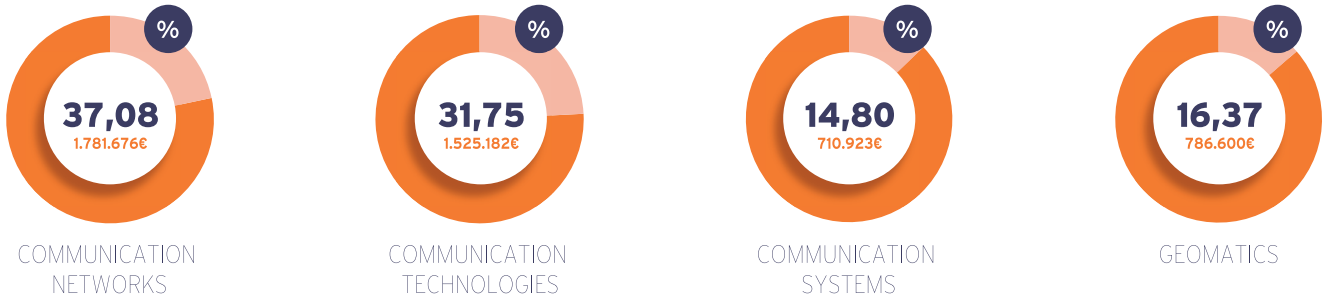
Projects

In the year 2020 CTTC was involved in 91 projects, 20 funded by the Spanish or Catalan administrations, 35 funded by the European Commission and 36 funded by national or international industry. The total income from these activities raised up to 4.8M€ euros per year.

As to the specific information relative to the 5G PPP program, during 2020 the CTTC has participated in 17 proposals in total: 5 for the call ICT-41-2020 (5G innovations for vertical with third party services) and 12 for the call ICT-52-2020 (Smart Connectivity beyond 5G). From which 4 have been selected for funding: 5GMediaHub (ICT-41-2020), 5GEPICENTRE (ICT-41-2020), MARSAL (ICT-52-2020), TeraFlow (ICT52-2020). CTTC coordinates two of them: MARSAL and 5GMediaHub.
CTTC has a leading role in a variety of research projects that lead the way in cutting-edge technologies such as 5G, AR, Cybersecurity, IoT, sensors, 4.0 Industry, Optical Networks, Communication Systems, Geomatics.

INCOME PROJECTS

INCOME FOR RESEARCH DIVISIONS



PROJECT RANKINGS

In terms of EC funding

22nd in H2020 in Spain

25th in LEIT-ICT (4th in Spain)

2nd in 5G-PPP (1st in Spain)

In terms of project participation

27th in H2020 in Spain

26th in LEIT-ICT (6th in Spain)

2nd in 5G-PPP (1st in Spain)

FEMIoT

Fostering Emergent Market Internet of things

FEM-IoT is a consortium of 12 Catalan research centers to boost the emerging sector of the Internet of Things. The main objective is to become a laboratory platform for the research and innovation of smart city infrastructure elements and all the resulting value-added services.

AURORAS

Autonomic and disaggregated optical networks leveraging edge computing and photonic technologies

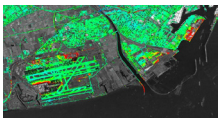
AURORAS aims at performing theoretical and experimental research relying on several key pillars. First, the use of Spatial Division Multiplexing (SDM), which has been proposed as the key technology to overcome the capacity crunch that the optical single-mode fibers (SSMFs) are facing, along with the integration of suitable photonic technologies and devices in novel transmission systems able to efficiently exploit the multiple dimensions at lower cost. Next, the systematic deployment of distributed computing and storage resources bound to transmission and switching nodes, the latter with partial or full disaggregation, across the underlying infrastructure for maximum service deployment flexibility.

ARISTIDES

Statistical Learning and Inference for High Dimensional Communication Systems

The ARISTIDES project aims to deepen the theoretical understanding and advance on the performance of data-driven learning and inference algorithms for high-dimensional data processing and wireless communications. A special focus is set on the enhancement of machine learning methods (incl. deep learning) and their application to the re-design of lower-layer functionalities of (beyond) 5G communication systems.

DEMOS



Deformation monitoring using Sentinel-1 data

DEMOS is an Earth Observation project based on Synthetic Aperture Radar (SAR) data and Differential Interferometric SAR (DInSAR) techniques. Its general objective is taking full advantage of the monitoring opportunities offered by the ongoing Sentinel-1A and 1B SAR missions. The project includes two main types of DInSAR activities.

5GCroCo

5G Cross-border Control

5GCroCo is a 5G-PPP phase III project, aimed at trialing 5G technologies for cooperative, connected, and autonomous driving in cross-border scenarios.

SEMANTIC

end-to-end Slicing and data-drivEn autoMAtion of Next generation cellular neTworks with moblle edge Clouds

SEMANTIC aims to answer the aforementioned performance and technological gaps by forming an innovative research and training network for multi-GHz spectrum communications, MEC-empowered service provisioning and end-to-end network slicing, all integrated and jointly orchestrated by forward-looking data-driven network control and automation exploiting the enormous amounts of mobile big data spurred into the mobile data network.

5GMED

Sustainable 5G deployment model for future mobility in the Mediterranean Cross-Border Corridor

5GMed will demonstrate advanced Cooperative Connected and Automated Mobility (CCAM) and Future Railway Mobile Communications System services (FRMCS) along the "Figueres – Perpignan" cross-border corridor between Spain and France.

DARLENE

Deep AR Law Enforcement Ecosystem

DARLENE aims to investigate means by which AR can be deployed in real time to aid in LEA decision-making by employing AR capabilities and combining them with powerful ML algorithms, sensor information fusion techniques, 3D reconstruction, wearable technology and personalized context-aware recommendations.

WINDMILL

Integrating wireless communication engineering and machine learning

This European Training Network aims at training Early Stage Researchers in the field of wireless communications and machine learning. With their evolution towards 5G and beyond, wireless communication networks are entering an era of massive connectivity, massive data, and extreme service demands. A promising approach to successfully handle such a magnitude of complexity and data volume is to develop new network management and optimization tools based on machine learning.

ONFIRE

Future Optical networks for Innovation, Research and Experimentation

The ONFIRE project will focus on exploiting, from both a hardware and software solutions perspective, the flexibility and modularity provided by two key topics: disaggregated optical networks and cognitive optical networks.

5GROWTH

5G-enabled Growth in Vertical industries

The vision of the 5Growth project is to empower verticals industries such as Industry 4.0, Transportation, and Energy with an AI-driven Automated and Sharable 5G End-to-End Solution that will allow these industries to achieve simultaneously their respective key performance targets.

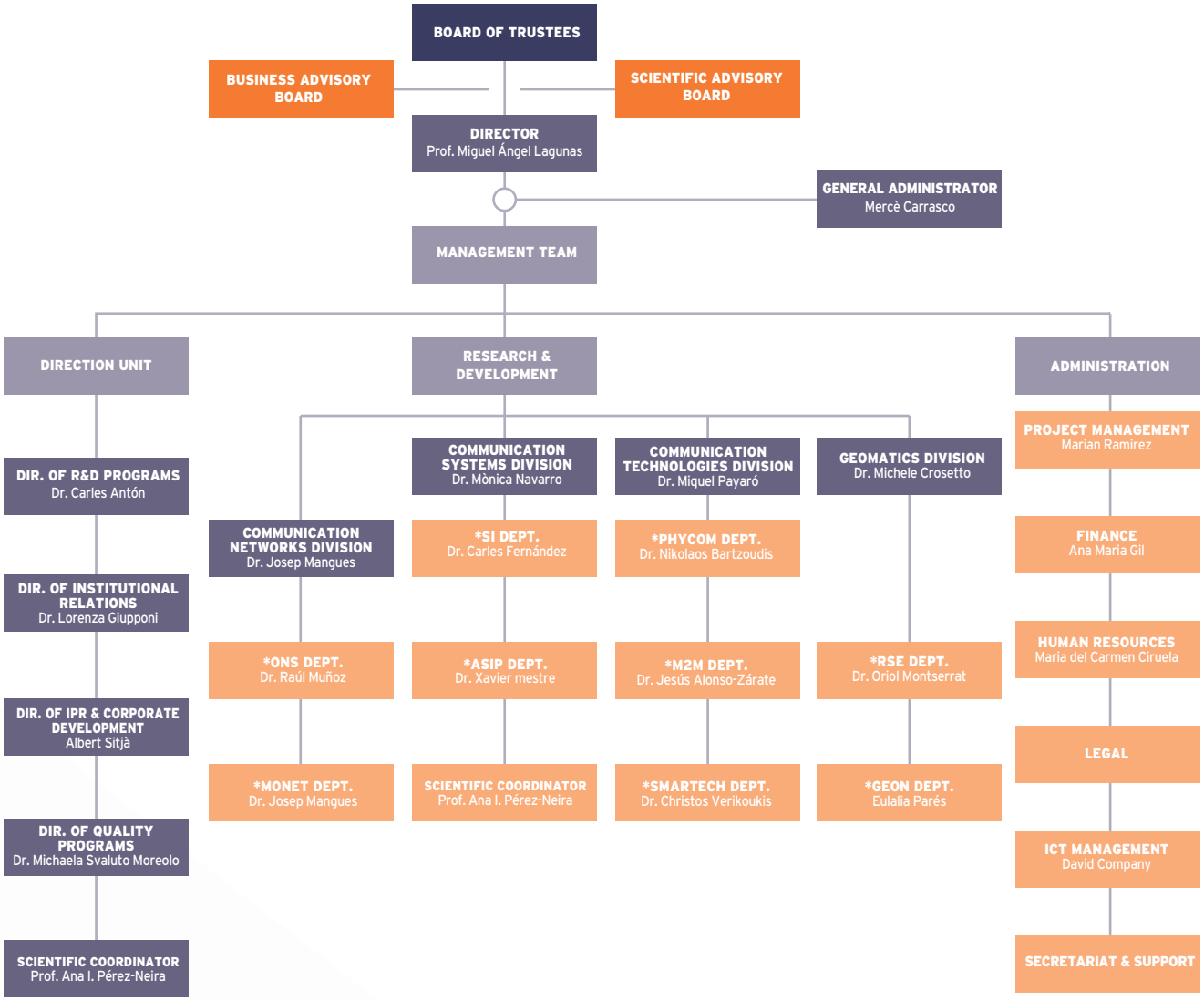
IOPES

Indoor-Outdoor Positioning for Emergency Staff

IOPES aims at strengthening the preparedness of civil protection and emergency teams (CPET) involved in disaster-related operations. The targets are (1) to provide continuous, time-tagged information about the location of CPETs, either indoors or outdoors (2) as a new feature of an already operational emergency management system (EMS), (3) relying in existing cartography, or new maps (fast mapping + Remotely Piloted Aircraft Systems (RPAS)) (4) using its own communication system to avoid the need of existing (possibly damaged/inoperative) infrastructures (5) to better the decision-making process.

People

Organization Chart



***ONS:** Optical Networks & Systems
***MONET:** Mobile Networks
***SI:** Statistical Interference for Communications and Positioning
***ASIP:** Advanced Signal and Information Processing
***A&MSP:** Array and Multi-Sensor Processing
***PHYCOM:** Phusical-layer Implementation of High Performance Communication Systems
***M2M:** machine to Machine Communication
***SMARTECH:** Smart Energy Eficient Communicaction Technologies
***RSE:** Remote Sensing
***GEON:** Geodesy and Navigation

Management Team

MIGUEL ÁNGEL LAGUNAS
Director

MERCÈ CARRASCO
General Administrator

CARLES ANTÓN-HARO
Director of R&D Programs

LORENZA GIUPPONI
Director of Institutional Relations

ANA I. PÉREZ-NEIRA
Scientific Coordinator

MICHELA SVALUTO
Director of Quality

ALBERT SITJÀ
Director of IPR & Corporate Development

MIQUEL PAYARÓ
Head of CTD

JOSEP MANGUES
Head of CND

MÒNICA NAVARRO
Head of CSD

MICHELE CROSETTO
Head of GMD

Researcher Team

COMMUNICATION NETWORKS DIVISION

JOSEP MANGUES **Head of Division**	ANDY QUISPE **Research Assistant**	ANKUSH MAHAJAN **Research Assistant**
BAHADOR BAKHSHI **Researcher (R2)**	BILJANA BOJOVIC **Researcher (R2)**	CARLOS HERRANZ **Researcher**
CARLOS MANSO **Research Assistant**	CARLOS HERNÁNDEZ **Research Assistant**	ENGIN ZEYDAN **Senior Researcher**
FABIANO LOCATELLI **Research Assistant**	FARHANA JAVED **Research Assistant**	FRANCESC WILHELMI **Researcher (R2)**
FRANCISCO JAVIER VILCHEZ **Researcher (R2)**	JORGE BARANDA **Researcher (R2)**	JOSEP M. FABREGA **Senior Researcher (R3)**
JUAN LUIS DE LA CRUZ CUEVAS **Research Assistant**	KATERINA KOUTLIA **Research**	LAIA NADAL **Researcher (R2)**
LUCA VETTORI **Research Assistant**	MANUEL REQUENA **Researcher (R2)**	MARCO MIOZZO **Senior Researcher (R3)**
NATALE PATRICIELLO **Researcher**	PAOLO DINI **Senior Researcher (R3)**	POL ALEMANY **Research Assistant**

RAMON CASELLAS
Senior Researcher (R3)

RAÜL MUÑOZ
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Highlights

Research Highlights

- First fully virtual organization of the 45th International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2020). The conference held over 22.000 registrants, increasing five time the highest number of ICASSP registration ever.
- Ana I. Pérez-Neira, Research Director, receives the ICREA academy award 2020 for her contribution and excellence research among the Catalan universities.
- METRO-HAUL project is featured by the 5G Infrastructure Public Private Partnership (PPP) experts as one of the ten most impactful 5G pilots.
- Participation in 17 5G-PPP proposals. 5G innovations for vertical with third party services and Smart Conectivity beyond 5G.
- Participation in a pilot demonstration with 5G technology at Mercabarna. 5G technology and advanced localization solutions have been successfully integrated to demonstrate their application to increase traffic safety in a highly challenging mobility scenario. The CTTC contributed to the development of the on-board unit hybrid positioning functionality. This pilot is an initiative of 5G Barcelona.
- CTTC participates in the project FEM-IoT to foster the Internet of Things sector, alongside with 12 Catalan universities and R&I centers. The project becomes a laboratory platform for research and innovation in smart city infrastructure.
- The 5G Infrastructure Association re-elects Carles Antón-Haro, Research Director, as a member of its board. The 5G IA is committed to the advancement of 5G in Europe and to building global consensus on 5G.
- CTTC has consolidated its position on the R&D satellite communications field by continue leading the largest ESA project on fundamental SatCom research (SatNEx V 1.2M€). Furthermore, its active collaboration with different satellite stakeholders, has led CTTC to the participation on the first AI-based SatCom H2020 project ATRIA. In addition, industrial grants are being promoted through dedicated contracts on industrial developments for beyond 5G and 6G NTN.
- The 34% of the European projects are led by the CTTC. 5G, 6G, Augmented Reality, Artificial Intelligence, M2M, Indoor Positioning, IoT, Cybersecurity technologies are part of our daily research.
- CTTC signs 36 project offers with industry (8 with Catalan industry) and represents 29.64% of the income.
- Constitution of the Spin-off Geokinesia, S.L. Geokinesia develops and markets the technology initiated and developed by the CTTC.

Awards

CTTC awarded with the NIST grant to study NR V2X for sub 6GHz and mmWave bands. The objective is to enable and accelerate New Radio (NR) Vehicular to Everything (V2X) communications, with special emphasis on Public Safety research.

Nikolaos Bartzoudis, Xavier Mestre and Miquel Payaró, researchers, receive the 2020 EURASIP JWCN best paper award. In this work, which featured an uncommon mixture of theoretical and practical aspects, the authors proposed a comparison of several 5G waveform candidates (OFDM, UFMC, FBMC and GFDM) under a common framework.

Hatim Chergui and Christos Verikoukis, researchers receive a best paper award in IEEE ICC2020. In this work, they investigate the concept of OPEXlimited resource provisioning as a key component in fifth generation (5G) radio access networks (RAN) slicing.

Jorge Baranda, Josep Mangues-Bafalluy, Engin Zeydan, Luca Vetorri and Ricardo Martínez, researchers, receive the best fast paper award in IEEE NFV-SDN. In this work, they present the the detailed architecture and first prototype of the 5Growth platform taking AI/ML-based network service autoscaling decisions to enforce the autonomous and automated assurance of vertical service level agreements.

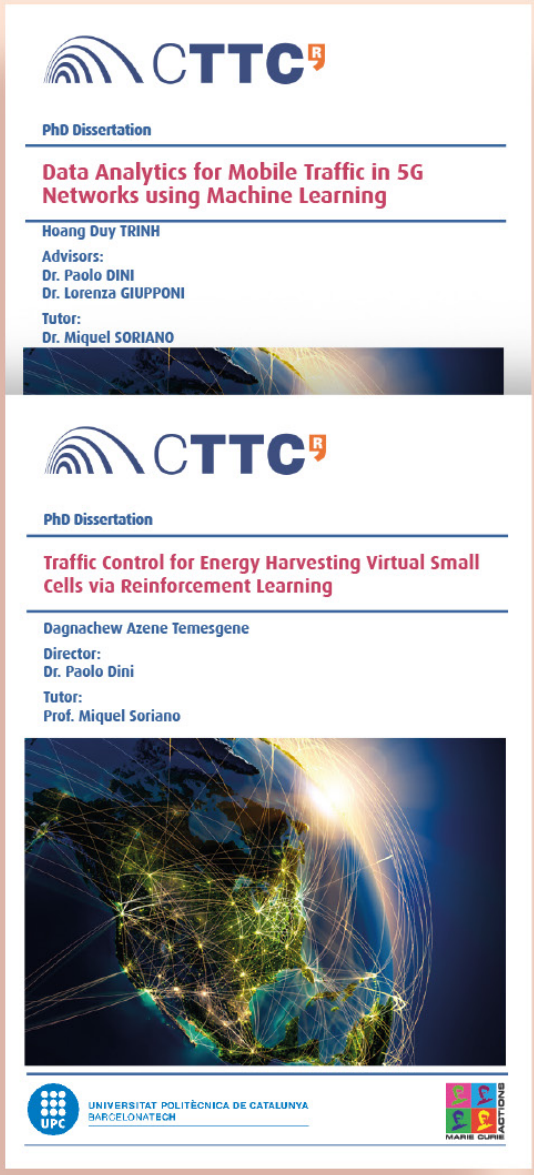
THESIS DEFENSE

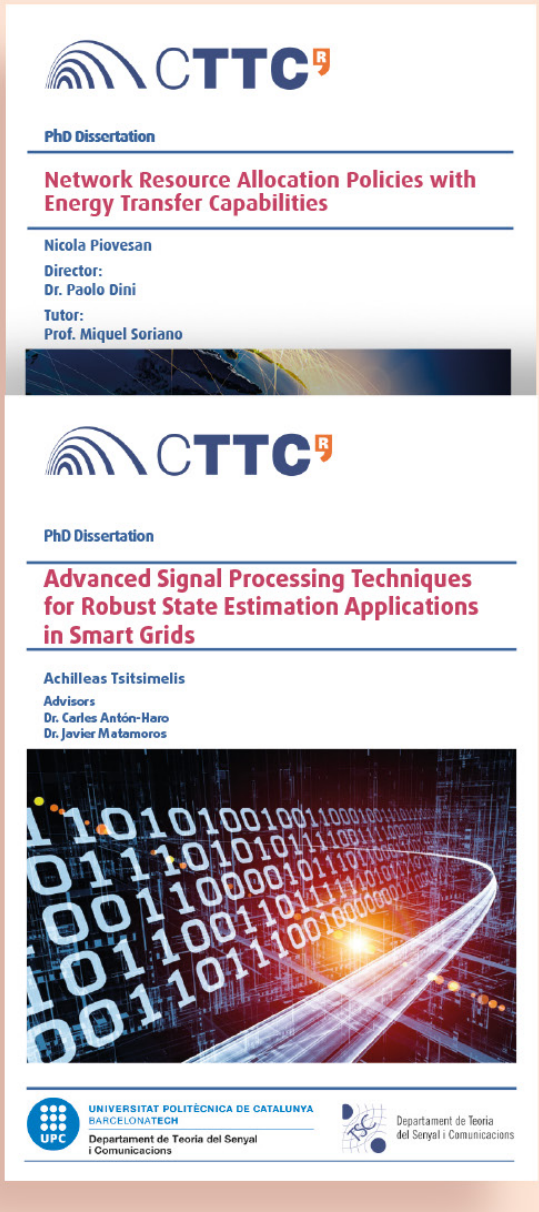
A.Tsitsimelis, Advanced Signal Processing Techniques for Robust State Estimation Aplications in Smart Grids , PhD Thesis Dissertation, Universitat Politècnica de Catalunya, October 2020.

D.Temesgene, Traffic Control for Energy Harvesting Virtual Small Cells via Reinforcement Learning , PhD Thesis Dissertation, Universitat Politècnica de Catalunya, July 2020.

N. Piovesan, Network Resource Allocation Policies with Energy Transfer Capabilities , PhD Thesis Dissertation, Universitat Politècnica de Catalunya, June 2020.

H. D. Trinh, Data Analytics for Mobile Traffic in 5G Networks using Machine Learning Techniques , PhD Thesis Dissertation, Universitat Politècnica de Catalunya, June 2020.





None of this would have been possible without our brillant team; the greatest asset of CTTC

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