Signal processing and Communications Group

ROUTE56 - Newsletter June 2022

Radio technologies for ubiquitous communications in the evolution from 5G to 6G

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Project Overview

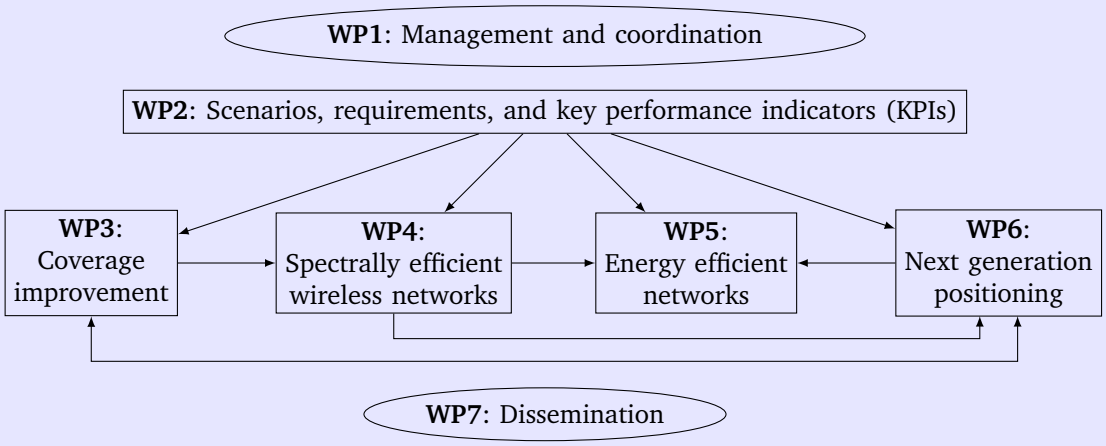
The ROUTE56 project proposes to make sensible progress in several promising technical approaches that might contribute to define the next generation of mobile communication systems:

- Blocking and statistical coverage analysis
- Spectrally efficiency boosting with advanced technologies
- Energy-efficient networks
- Artificial intelligence and reinforcement learning (RL) strategies
- Next generation positioning

The project will also promote results in international forums, like 5GPPP, 6G Flagship Initiative, 5GBarcelona, and world-class conferences, and will position the research team in a competitive place towards the forthcoming EU workprogramme.

Work Plan Structure

The structure of the project is shown below and its core (**WP3-WP6**) focuses on the three following key areas:



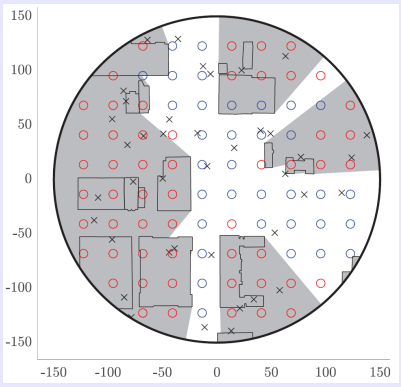
- **WP3:** Design of new tools to model and predict the coverage at very high frequencies (by better fitting reality), and new strategies to manage in an optimal way hybrid communication technologies.
- **WP4:** Improvement of spectral efficiency, which will allow to increase significantly the number of users that can be served simultaneously and the rates that can be achieved. This will translate into a more efficient use of resources and the provision of a better quality of service to users.
- **WP5:** Reduction of energy consumption, which will imply a reduction of the CO2 footprint and an increase of the lifetimes of the batteries.
- **WP6:** Development of new advanced positioning strategies that will give support to location-aware user applications and contribute to enhance location-aided communication technologies.

Second Year Work

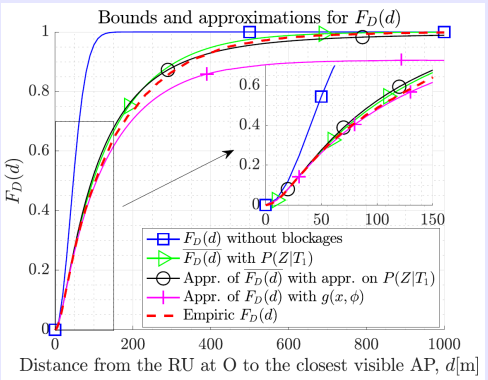
Task 3.1: Blocking analysis, coverage prediction, and network planning in mmWave networks

This task has been completely finished during the second year of the project. The core of the task has consisted in the application of stochastic geometry and random shape theory to describe blocking effects in mmWave networks. These tools have been used to characterize statistically buildings in urban areas with random positions, shapes, and sizes.

In particular, during the second year of the project, two main applications have been developed. The first one is the development of several coverage estimators, i.e., line of sight (LOS)/non-LOS (NLOS) estimators, based on a finite set of simple measurements provided by user terminals in a given geographical area. These estimators are inspired by the optimum Bayesian estimation and have different complexities and performances. One of the main uses of these estimators is the advanced prediction of non-coverage regions to assist in handover processes.

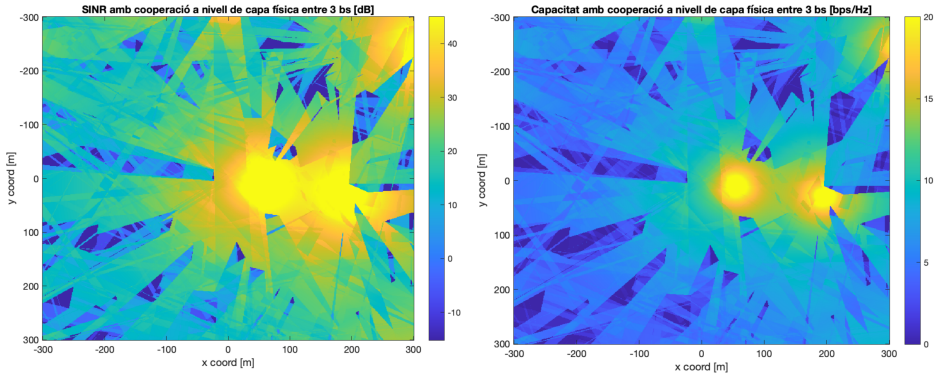


The second application has been the statistical characterization of the distance to the closest base station (BS) with no blocking (with the corresponding impact on the rate). Some almost-analytic expressions of the probability density functions of the distance and the achievable rate have been derived. These expressions could be used to design proper channel coding schemes or to assist in the development of network-level simulators.



Task 3.2: Techniques for blocking mitigation in mmWave networks

During the second year we have started to work in the evaluation of several macro-diversity schemes to mitigate the blocking effects in mmWave transmission. In particular, the effects of the blocking effects have been considered not only on the desired signal, but also on the interfering ones. The macro-diversity schemes that have been taken into account are based either on signal-level or multiplexing-level.



Task 3.3: Coverage boosting through hybrid cooperation in heterogeneous communication networks

Current work is devoted to the development of non-linear contextual MAB (Multi Armed Bandit) with the aim of improving the selection of the best accessible network by each device. The usual key performance indicators (KPIs) related to the regret and to the probability of choosing the best network will be measured.

Task 4.1: Channel model for the near-field propagation conditions

In this task we have studied the propagation channel models in the near-field of the antenna arrays (spherical wave vs. plane wave propagation), including polarization effects. We have departed from the electrical field expressions to obtain channel gains for extremely large antenna arrays (ELAAs). These methods have been applied in scenarios that include intelligent reflecting surfaces (IRS) to derive channel models in LOS conditions. In a second phase, we have started to study the implications of near-field in the delay spread of multiple-input multiple-output (MIMO) channels in near-field conditions. The objective is to derive the bandwidth limit for non-frequency selective transmissions.

Task 4.2: Cell-free implementation of LIS/ELAAs in wireless systems

We have been studying the coverage areas of ELAAs for uplink (UL) and downlink (DL) transmissions in the near-field area of the array, depending on the precoder and decoder types. For a large number of antennas at the BS and single antenna terminals, the coverage areas are ellipsoides, not cones as in far-field transmission conditions. This particularity allows a higher density packing of terminals in multiuser transmission, an aspect that will be exploited in the next phase of the project, using the models derived in task 4.1.

Task 4.3: IRS versus active antennas and conventional relays

The goal in this task is to devise methods to increase the spectral efficiency by artificially transforming the propagation channel properties using IRS. We have studied the capacity enhancement in single user links where IRS devices are present. We have checked the capacity increase when one or several IRS are deployed to enhance the rank of the MIMO channel between transmitter and receiver. We have elucidated the most appropriate configurations (number of antennas, relative position of transmitter, receiver and IRS, etc) as well as the design of the phases in the IRS elements that increase the spectral efficiency. Receive spatial modulation techniques will benefit from the presence of one or several IRS in the scenario.

On the other hand, during this second year, we have also been working on the use of IRS to support parameter estimation in mMTC networks. Considering a scenario where a set of sensors transmit their correlated measurements to a serving BS on a non-orthogonal basis, we have presented an estimation scheme based on the minimum mean squared error (MMSE) criterion. The resulting estimate is derived taking into account communication and imperfect channel state information errors. Accordingly, to overcome the lack of channel knowledge, we have studied different methods for acquiring that information feasibly (e.g., on/off protocol, DFT, etc.). In addition, to cope with the interference among devices, we have also considered the use of successive interference cancelation and optimized the decoding order. Based on that, the IRS is optimized to minimize the average mean squared error (MSE) under channel variation (i.e., coherence time) constraints.

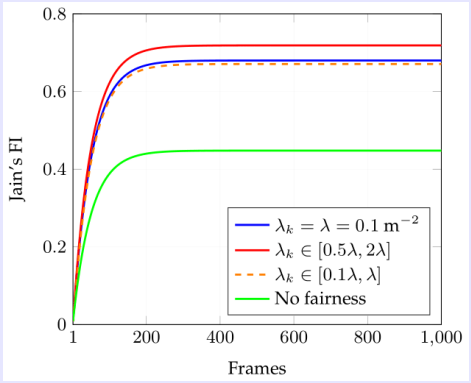
Task 5.1: Spatial modulation

During this second year, we have been working on the evaluation of spatial modulation techniques in mmWave environments where the far-field assumption is incorrect. In particular, performance differences between a realistic near-field evaluation and one based on the incorrect far-field assumption are being evaluated.

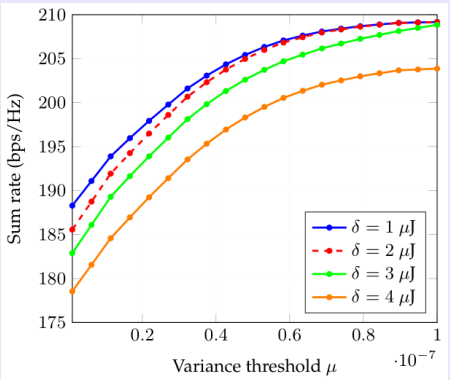
Task 5.2: Wireless power transfer for efficient energy transmission and reuse in mMTC networks

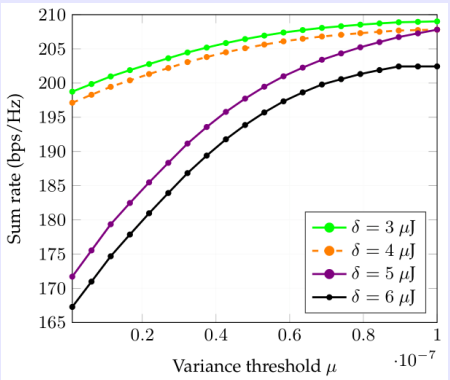
This task has been completely finished during the second year of the project. The core of the task has consisted in the application of stochastic geometry and binary random variables to describe wireless power transfer (WPT) and energy harvesting (EH) in mMTC networks. These tools have been used to characterize the mean and variance of the energy collected from these processes.

In particular, during the second year of the project, two main applications have been developed. The first one is the distribution of energy in a pure mMTC network based on proportional fairness. Simulation results have shown that, over time, most mMTC devices can recharge their batteries with a (more) fair amount of power. In fact, this behavior is more notorious in highly dense setups, where the contribution of EH is higher.



The second application is the transfer of information to human-type-communications (HTC) users and power to mMTC devices. The goal has been to maximize the data rate of the users while limiting the amount of depleted batteries of the devices. To do so, we have considered block diagonalization processing, which mitigates the interference in the DL, and convex approximations of the constraint set, which allow us to find a sub-optimal solution. Simulation results have shown that there is a trade-off between the sum rate and received energies. Higher and non-dispersed collected powers compromise the data transmission. As before, larger concentrations of sensors can improve the total throughput of the users.

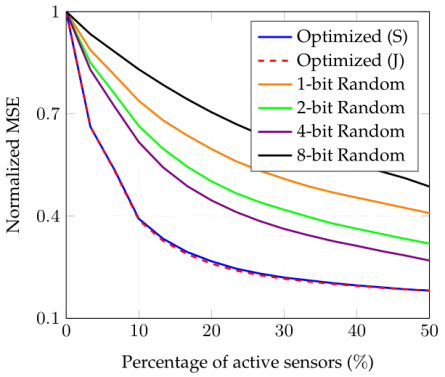


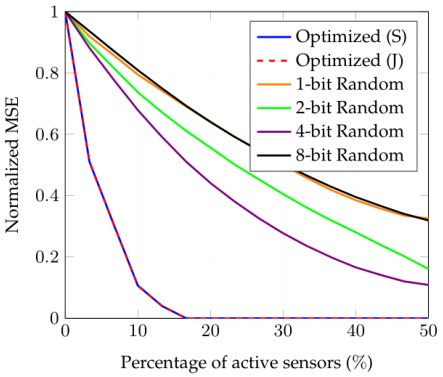


Task 5.3: Energy-efficient multiple access strategies in multiuser/MTC communications

During this second year, we have derived the analytical expression of the optimal Access Class Barring (ACB) parameter as standardized by the Third Generation Partnership Project (3GPP). We have proposed using Neural Networks (NNs) to predict the type and number of accessing devices through the acquisition of measurements available at the BS. These estimates are used to effectively implement the optimal barring scheme, achieving performance results close to the theoretical bound. Currently the algorithm proposed and developed for multiple MTC access is being compared with state-of-the-art techniques based on QL and Deep QL. The usual KPIs related to the delay and the probability of connection success will be also measured.

On the other hand, we have also been working on the design of an estimation scheme within the framework of an UL mMTC network. Numerical simulations have shown that in the case of synthetically generated data, our scheme can reduce the power consumption by 50 % (i.e., the number of silent sensors) without a significant increase in the normalized MSE (NMSE). This behavior is more notorious in the case of real data measurements, where the spatial correlation is significantly higher. With only 10 % of active sensors, we have attained a performance in NMSE of 0.1. In both cases, better performance is observed when including temporal correlation.





Task 6.1: Multipath-assisted localization

In this task we have started to work in localization assisted by IRS. We have analyzed the channel in scenarios with IRS and studied the required modifications of the NYUSIM simulator to incorporate IRS considering near field propagation. The optimization criterion for the design of the IRS phases should be based on localization KPIs. In other words, the IRS phases have to maximize the location accuracy, that means that they have to minimize the Cramér-Rao bound (CRB) of the position estimation. Machine learning approaches are being considered to efficiently reconfigure the IRS by adapting its phases to the user position.

Task 6.2: Location-aided communication

In this task we will analyze how location can be used for communication purposes by enhancing efficiency and radio network management. Concerning the use of IRS, we will optimize the IRS phases jointly maximizing the location accuracy and the communications KPI.

Publications

Journals

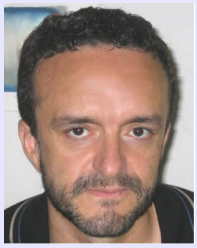
- Sergi Liesegang Maria, Olga Muñoz Medina, Antonio Pascual Iserte, "Sensor Selection and Distributed Quantization for Energy Efficiency in Massive MTC," *IEEE Transactions on Communications*, vol. 69, no. 12, pp. 8518-8533, ISSN 0090-6778, December 2021. DOI: 10.1109/TCOMM.2021.3112206
- Tomàs Ortega, Antonio Pascual Iserte, Olga Muñoz Medina, "LOS/NLOS Estimators for mmWave Cellular Systems with Blockages," *IEEE Wireless Communications Letters*, vol. 11, no. 1, pp. 121-125, ISSN 2162-2337, January 2022. DOI: 10.1109/LWC.2021.3122090
- Cristian García Ruiz, Olga Muñoz Medina, Antonio Pascual Iserte, "Effect of Correlated Building Blockages on the Ergodic Capacity of mmWave Systems in Urban Scenarios," *IEEE Transactions on Vehicular Technology*, vol. 71, no. 5, pp. 5633-5638, ISSN 0018-9545, May 2022. DOI: 10.1109/TVT.2022.3155356

Conference Proceedings

- Sergi Liesegang Maria, Olga Muñoz Medina, Antonio Pascual Iserte, "Modeling and Optimization of Wireless Powered MTC Networks with Stochastic Geometry," *Poster presented at 2021 IEEE Communications Theory Workshop (CTW)*, Virtual Conference, June 2021, **3rd Place Best Paper Award**.
- Sergi Liesegang, Olga Muñoz Medina, Antonio Pascual Iserte, "Stochastic Geometry Analysis and Design of Wireless Powered MTC Networks," *Video presented at 2021 Signal Processing, Information Theory and Communications Webinar (SIC)*. Virtual Webinar, July 2021.
- Martí Llobet Turró, Margarita Cabrera Bean, "Correlated Binary Data For Machine Learning," *Paper presented at 2021 29th European Signal Processing Conference (EUSIPCO)*, Virtual Conference, August 2021, pp. 1411-1415, DOI: 10.23919/EUSIPCO54536.2021.9616346.
- Sergi Liesegang Maria, Antonio Pascual Iserte, Olga Muñoz Medina, "Energy Driven Transmission Schemes for Coexistence between HTC and MTC," *Paper presented at 2021 26th European Wireless Conference (EW)*, Verona (Italy), November 2021, pp. 1-9, ISBN: 978-3-8007-5672-8.
- Adrian Agustin de Dios, Josep Vidal Manzano, Margarita Cabrera Bean, "Hierarchical Beamforming in Random Access Channels," *Paper presented at 2021 IEEE Global Communications Conference (GLOBECOM)*, Madrid (Spain), December 2021, pp. 1-6, DOI: 10.1109/GLOBECOM46510.2021.9685896.
- Lluís Martínez Casanovas, Margarita Cabrera Bean, Josep Vidal Manzano, "A Multi-Armed Bandit Model for Non-Stationary Wireless Network Selection," *Paper presented at 2021 IEEE GLOBECOM Workshops*, Madrid (Spain), December 2021, pp. 1-6, DOI: 10.1109/GCWkshps52748.2021.9681963.

Participants

Antonio Pascual Iserte (IP1) (Senior Member, IEEE) was born in Barcelona, Spain, in 1977. He received the degree in electrical engineering and the Ph.D. degree from Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, in 2000 and 2005, respectively. From September 1998 to June 1999, he was a Teaching Assistant in the field of microprocessor programming with the Department of Electronic Engineering, UPC. From June 1999 to December 2000, he was with Retevision R&D, working on the implantation of the DVB-T and T-DAB networks in Spain. In January 2001, he joined the Department of Signal Theory and Communications, UPC, where he was a Research Assistant until September 2003. He received a predoctoral grant from the Catalan Government for his Ph.D. studies during this period. He became Assistant Professor in September 2003 and since April 2008 he is Associate Professor. He currently teaches undergraduate courses on signal theory and communications. He also teaches postgraduate courses on advanced signal processing with the Department of Signal Theory and Communications. He has been involved in several research projects funded by the Spanish Government and the European Commission. He was the author or coauthor of several papers in international and national conference proceedings and journals. His research interests include array processing, robust designs, orthogonal frequency-division multiplexing, multiple-input multiple-output channels, multiuser access, optimization theory, energy-efficient networks, massive machine-type-communications, and stochastic geometry.



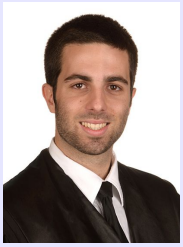
Josep Vidal Manzano (IP2) (Senior Member, IEEE) received the Ph.D. degree in telecommunication engineering from the Universitat Politècnica de Catalunya (UPC) in 1993. He is currently a Professor of the Signal Theory and Communications Department. His research interests are in statistical signal processing, information and communication theory, and machine learning, areas in which he has authored more than 200 journals and conference papers. Since 2002, he has coordinated collaborative EC-funded projects ROMANTIK, ROCKET, FREEDOM, TROPIC, TUCAN3G, and 5GSmartFact belonging to the FP5, FP6, FP7 and H2020 programmes, in different areas of MIMO relay communications, self-organization, cooperative transmission, and heterogeneous networks. He has held research appointments with EPF Lausanne, INP Toulouse, and the University of Hawaii. He has organized several international workshops. He has served as an Associate Editor of the IEEE TRANSACTIONS ON SIGNAL PROCESSING and as reviewer of several national and international research agencies. He belongs to the IEEE ComSoc Signal Processing for Communications and Electronics Technical Committee.

Olga Muñoz Medina (Member, IEEE) received M.S. and Ph.D. degrees in electrical engineering from the Universitat Politècnica de Catalunya (UPC), Spain, in 1993 and 1998, respectively. In 1994, she joined the Department of Signal Theory and Communications, UPC, where she teaches graduate and undergraduate signal processing and communications courses. She has been a Visiting Associate Professor at Stanford University in September–November 2014 and January–June 2015, respectively. She has served as a Reviewer for the Spanish Research Council. Besides, she has also served as a Reviewer in numerous journals and conferences. She accumulates substantial experience in relaying and cooperative upgraded networks backed by her work on European Commission projects ROMANTIK (5thFP), FIREWORKS (6thFP), and ROCKET (7thFP). She also has experience in heterogeneous and femtocell-based networks backed by her work in the project FREEDOM (7thFP) and the Spanish Government funded project MOSAIC (call 2010). She has participated in TROPIC (7thFP), pushing the idea of merging cloud computing with femtocell networking, and in TUCAN3G (7thFP), focused on providing connectivity to rural areas through new wireless technologies for the access network and WiLD (WiFi for Long Distances)-WiMAXVSAT heterogeneous backhauling. More recently, she has been designing, analyzing, and evaluating radio technologies in ultra-dense networks to meet the requirements for capacity and quality of service, distributed intelligence, and flexibility needed for the 5G and beyond. She has published over 70 papers in books, international conferences, and journals in the areas of signal processing and communications.

Margarita Cabrera Bean received the MSc degree and the PhD degree in Electronic Engineering from the Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, in 1986 and 1991, respectively and the MSc degree in Mathematics from the Universidad Nacional de Educación a Distancia (UNED), Madrid, Spain in 2013. Currently she is a Tenured Associate Professor at the Department of Signal Theory and Communications at UPC, where she teaches in the areas of Analog and Digital Communications and Signal Processing. Her research interests are in Signal Processing and include Mobile Communication Systems and Machine Learning techniques applied to medical applications where she has published around 60 papers in books, international conferences and journals. She has been serving as Vice-Dean at the School of Telecommunications Engineering of Barcelona at the UPC (2009-2015) and as expert in the Evaluation committees in verification program (Bachelor's and Master's) of the Andalucian Agency of knowledge, Spain (2016-).

Montse Nájar Martón received the electrical engineering and the Ph.D. degrees from the Polytechnic University of Catalonia (UPC), Barcelona, Spain, in 1991 and 1996, respectively. In 1992, she joined the Department of Signal Theory and Communication, UPC. Since 1997, she is an Associate Professor at UPC, where she teaches and coordinates undergraduate and graduate courses in digital communications and signal processing. From 2003 to 2006, she was member of the Board of Directors of the Telecommunications School of Barcelona, ETSETB. From 2005 to 2013, she was Research Associate in the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC). Her current research interests include signal processing with application to communication systems, array signal processing and location in wireless systems. She has participated in several EU projects as well as national public and private funded projects. She has been a Guest Editor of the EURASIP Signal Processing journal. She is reviewer of the IEEE and the EURASIP Signal Processing journals.

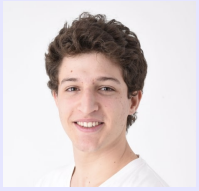
Juan A. Fernàndez Rubio (Live Senior Member, IEEE) received the PhD degree from the Universitat Politècnica de Catalunya (UPC) in 1982. He has been developing his teaching and research activities in the UPC since 1974. He taught Electromagnetic Fields from 1974 till 1985 and he has been teaching Signal Processing in Communication since 1986. He has also taught Mathematical Methods for Communications, Array Signal Processing and Communication Systems for graduated students. He started his research activities in the topic of Electromagnetic Propagation in Ferrite Materials in the Signal Theory and Communications Department. In 1985 he joints the Signal Processing Group belonging to the same department. His current research interests include Array Signal Processing, Wireless Communications, Global Navigation Satellite Systems, Audio Signal Processing, Multiuser Detection in CDMA Systems and Wavelets. He has collaborated in many research projects with Spanish public and/or private funds and he has directed some of these projects. He has also collaborated and directed some research projects funded by the European Community and the European Space Agency. He has been adviser of 10 PhD theses and he has published more than 100 papers in journal and international conferences. He was director of the Telecommunication School of Barcelona from 2000 until 2006 and president of the Spanish Institute of Navigation from 2004 until 2007. He was coordinator in the Evaluation and Prospective Spanish Agency (ANEP) for the IST program from 2000 until 2003.



Sergi Liesegang Maria (Graduate Student Member, IEEE) received the bachelor's degree in telecommunication engineering from ETSETB, Universitat Politècnica de Catalunya (UPC), in 2015, and the master's degree in telecommunication engineering from ETSETB, UPC, in collaboration with the Technical University of Munich in 2017. He is currently pursuing the Ph.D. degree with the Department of Signal Theory and Communications, BarcelonaTech (UPC). From March 2022 to July 2022 he was with the Università degli studi di Cassino e del Lazio Meridionale under the supervision of Prof. Alessio Zappone. He served as a Research Assistant for UPC from 2015 to 2018. He has participated in the project 5G&B RUNNER-UPC and is working in the project ROUTE56, both funded by the Spanish Ministry of Science and Innovation. His areas of interest include signal processing, and information and communication theory, with special concern on 5G technologies and MTC systems.

Cristian García Ruiz was born in Badalona, Spain, in 1996. He received the Telecom Bachelor (B.E., 2018), Master of Engineering (M.E., 2020) degree from the Universitat Politècnica de Catalunya (UPC), Barcelona, and the Master's Degree in Railway System and Electrical Drive (2021) from the UPC School. He is currently working at the operations department of Ferrocarril Metropolità de Barcelona (FMB). His current research interests include railway signalling, mmWave propagation modeling, stochastic geometry, signal propagation in tunnels and mobile communications for railway systems. He is set to take his Ph.D studies on new architectures for communications and signalling for railways.

Martí Llobet Turró received the BSc degree in Engineering Physics in 2021, and the MSc in Advanced Telecommunications Technologies in 2022, both from the Barcelona School of Telecommunications (ETSETB), Universitat Politècnica de Catalunya. He produced his BSc thesis on Unsupervised Ensemble Learning, which led to publishing a paper in the 2021 EUSIPCO conference. He worked as a Research Assistant in the SPCOM research group for the ROUTE56 project between September 2021 and May 2022. His role mainly consisted in adapting Deep Reinforcement Learning (DRL) agents and Neural Network (NN)-predictions to optimize access demand of Machine Type Communications (MTC) devices in next-generation mobile networks.



Lluís Martínez Casanovas received the bachelor's degree in telecommunication engineering from the Universitat Politècnica de Catalunya (UPC) in 2021. He is currently coursing a master's degree in cybersecurity at UPC. He is currently working in the project ROUTE56, funded by the Spanish Ministry of Science and Innovation. His current research interests include reinforcement learning with application to communication systems, with special concern on Multi-Armed Bandits and cellular networks.