Signal processing and Communications Group

ROUTE56 - Newsletter June 2021

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

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Project Overview

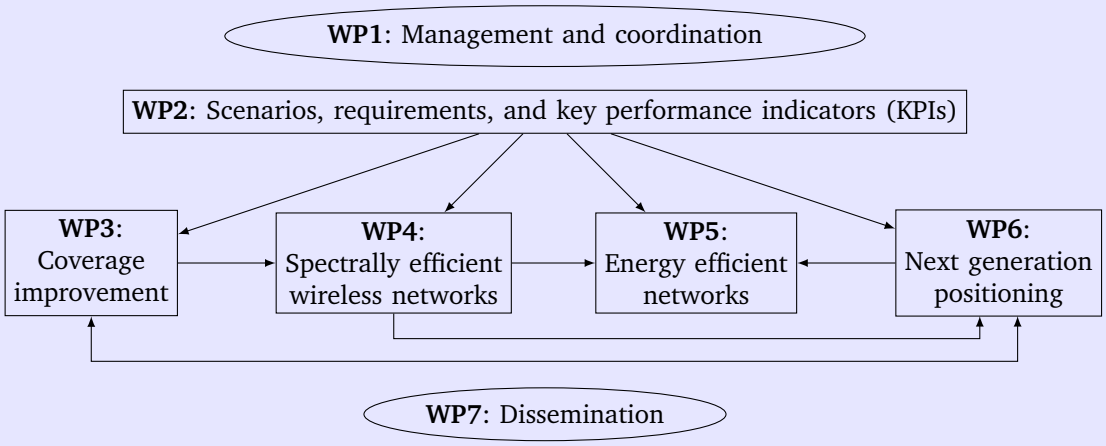
The ROUTE56 project proposes to make sensible progress in several promising technical approaches that might contribute to define the next generation of mobile communication systems:

- 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:



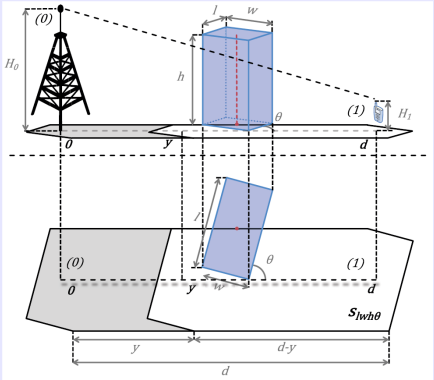
- **WP3:** Design of new tools to model and predict the coverage at very high frequencies (by better fitting reality), and new strategies to manage in an optimal way hybrid communication technologies.
- **WP4:** Improvement of spectral efficiency, which will allow to increase significantly the number 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.

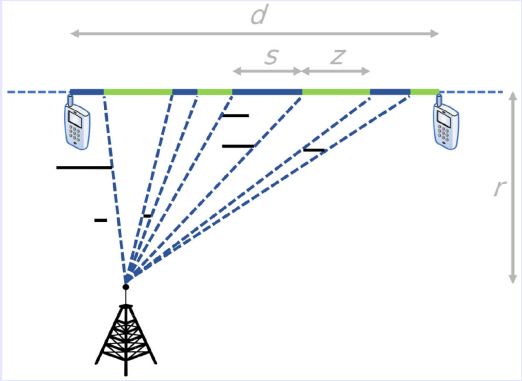
First Year Work

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

In this task, we have been developing models based on 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, these models have been exploited to develop analytical expressions for the blocking probability and the lengths of shadows regions. The validity of the developed models has been checked using Barcelona and Chicago as reference cities.

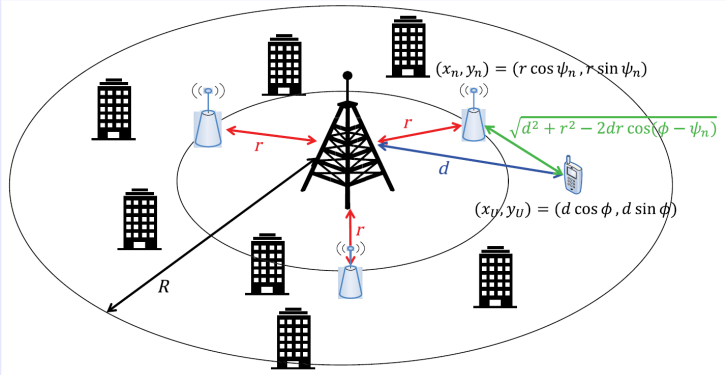




Additionally, we have started to work on two other issues, namely the statistical characterization of the distance to the closest BS with no blocking (with the corresponding impact on the rate), and a tool to predict LOS/NLOS regions based on a limited number of simple measurements.

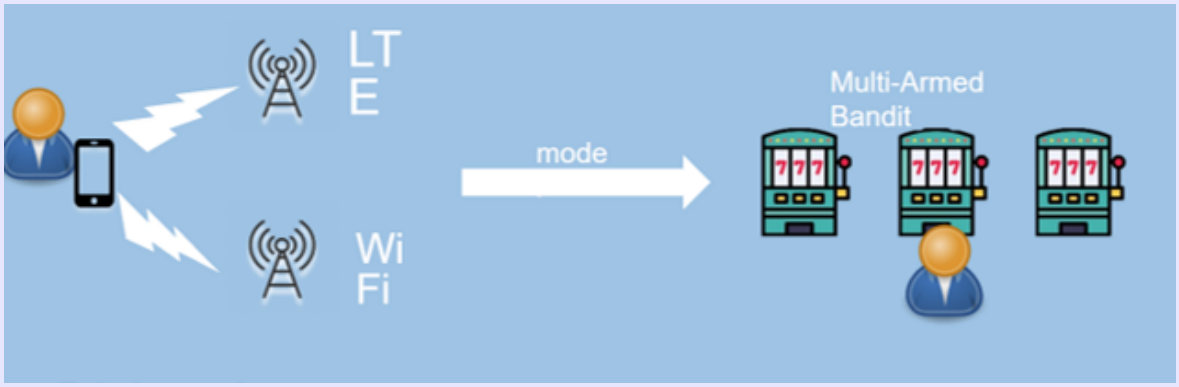
Task 3.2: Techniques for blocking mitigation in mmWave networks

In this task, we have used the models developed in the previous task to design strategies to mitigate the impact of the blocking and, therefore, increase the coverage of 5G networks. Specifically, we have optimized the position of a set of relays within the cell to reduce the blocking probability.



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

In this task, we have addressed a scenario where multiple radio access technologies (multi-RAT) coexist, and user terminals have to select the one providing best quality of experience, and do a subsequent handoff. The RL based model multi-armed bandit (MAB) has been applied. We have proposed a new model that uses real network parameter values that change over time, that is, a nonstationary scenario. We have designed a new set of MAB algorithms intended to work in non-stationary and more realistic environments. These new algorithms are able to measure the non-stationarity of the environment and adapt accordingly and show excellent performance in terms of the number of correct decisions over time and hence of user throughput.



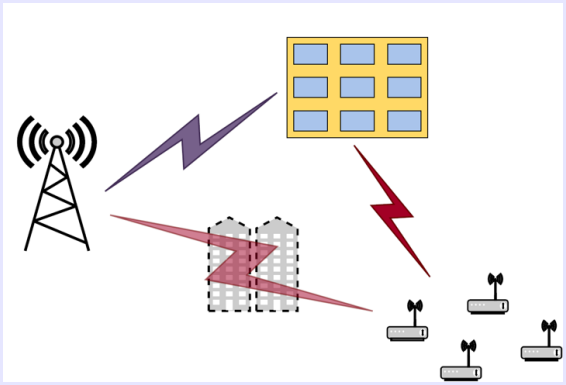
Some open challenges are being addressed: the theoretical characterization of adaptive techniques, the optimization of the ratio between exploration and exploitation of the knowledge of different RATs, and the use of deep contextual MAB as a way to predict QoE for every type of RAT and improve handoff decisions.

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

In this task, we have been working on the identification and integration of multipath channel models based on planar waves for mmWave communications. In addition, we have also captured the requirements and equations associated to near-field based transmissions. Some open challenges are being addressed: the implementation of channel models for spherical waves in near-field transmissions, and the study of the number of channel transmission modes.

Task 4.3: IRS versus active antennas and conventional relays

In this task, we have been working on the use of IRS to support parameter estimation in mMTC networks. Considering the lack of channel knowledge, we have started to analyse different methods for acquiring this information in a feasible way (e.g., on/off protocol). This is of special interest in the case of IRS-aided communications given their passive nature and the large number of reflecting elements, which make channel estimation a challenging task. On the other hand, assuming a non-orthogonal multiple-access scheme, we have been studying the use of successive interference (SIC) decoding to enhance the transmission between devices and the BS. Based on that, our goal is to design the IRS to minimize the average error in the parameter estimation by adapting the wireless environment to the SIC procedure and considering both, communication and channel estimation errors.



Task 5.1: Spatial modulation

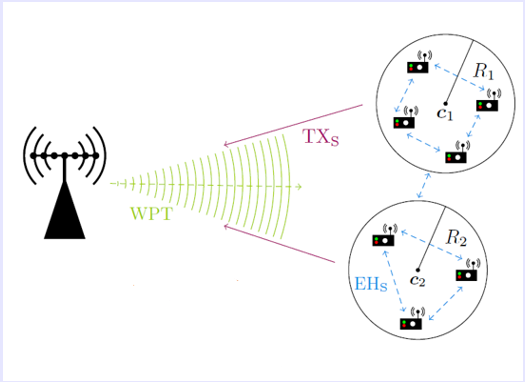
In this task, we have started to work in a scheme where the transmitter at the BS is equipped with a basic RF generator so that the generated wave impacts on a passive IRS. This IRS is controlled locally by the BS, so that the reflected waves depend on the weights of the individual reflectors of the IRS producing a spatial modulated signal. The high dimensionality of the IRS is expected to allow to create a versatile signal that allows a simultaneous transmission to several users at the same time. The main benefit is that this locally-controlled IRS does not need multiple RF chains and has a low energy consumption.

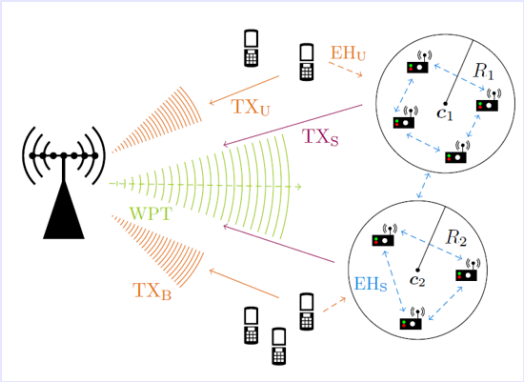
Task 5.2: Wireless power transfer for efficient energy transmission and reuse in mMTC networks

In this task, we have been working on the characterization of the statistics (mean and variance) of the energy collected from wireless power transfer (WPT) and energy harvesting (EH) in a mMTC network. In that sense, WPT is provided by the transmit signal of the BS while EH is obtained when recycling the power of other transmit signals in the environment. Accordingly, we have modeled the random position of the devices and their sporadic activity with the help of stochastic geometry tools and binary random variables.

Depending on the type of devices involved, we have studied two different scenarios: (i) pure mMTC setup and (ii) setup where mMTC and human-type-communications (HTC) coexist. Accordingly, in (i) we have designed the BS transmit signal to maximize the average energy collected over time under a proportional fairness policy, whereas in (ii) this signal is constructed to maximize the DL data rate of the HTC users while ensuring that the mMTC devices receive a sufficient amount of energy. Both schemes enable wireless powered mMTC networks.

Besides, for the latter, we have also considered the use of separate signals to transfer energy and information, as well as simultaneous wireless power and information transfer signals. In both cases, we have constrained the dispersion of the collected energy in order to limit the number of depleted batteries.



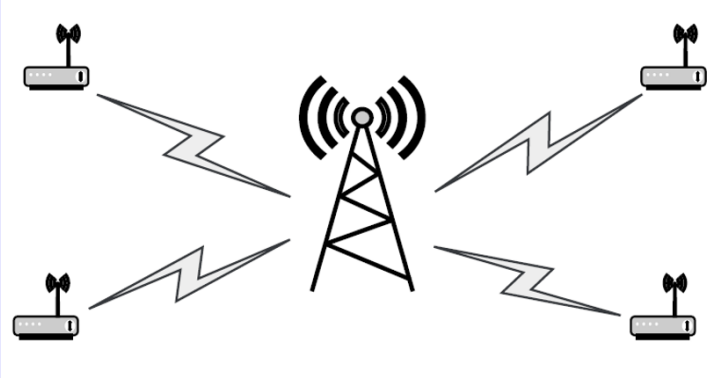


Task 5.3: Energy-efficient multiple access strategies in multiuser/MTC communications

Managing a massive number of terminals in a contention-based multiple access is challenging due to its intrinsic limited efficiency. Several time-based protocols are normally applied to redistribute the overload under high terminal activity regime, thus avoiding the congestion. In this task, we have explored the use of the spatial domain by means of a hierarchical codebook-based beamforming, where the BS selects the appropriate beams as a function of the number of non-collided and collided preambles. Since the activity and placement of terminals may be dynamic over time, the sequential selection of parameters can benefit from a RL framework. Our deep Q learning (DQL) based algorithm exploits both domains, temporal and spatial, with the goal of reducing collisions and enhancing transmission delay. Our approach is able to efficiently learn whenever there is a non-homogeneous spatial distribution of terminals and adapt the spatial beams accordingly.

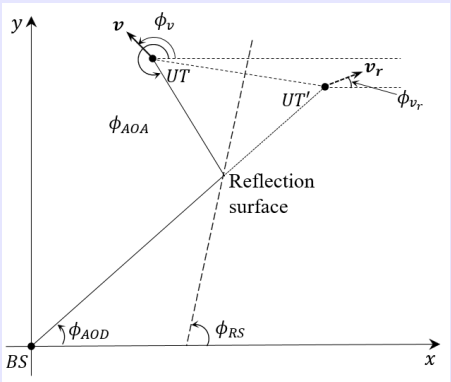
Some open challenges are being addressed: the use of DQL to predict the number of active users, the beamforming implementation aspects associated to hierarchical codebooks and the benefits of time-reversal transmission in the segregation of colliding users. Blending these techniques might drastically enhance the throughput and reduce delay for URLLC-based services.

On the other hand, we have also been working on the design of an estimation scheme within the framework of an UL mMTC network. Considering sensors transmitting their spatio-temporally correlated observations to the BS, we have derived an approach based on the MMSE estimate and Kalman filters that considers the energy limitations of the sensing devices. In that sense, given that communication errors may compromise the estimation performance, we have averaged the MSE over the different decoding error probabilities and proposed a device selection scheme and quantization approach that minimize the resulting MSE. As a result, since the number of active sensors and the information to be transmitted are significantly reduced, we have been able to decrease the data traffic and constrain the power consumption. The validity of this strategy has been checked using synthetic and real data. For the latter, we have employed the database collected by the Intel Berkeley Research Lab.



Task 6.1: Multipath-assisted localization

Multipath information can be exploited for positioning and environment mapping thanks to the high degree of resolvability of propagation paths in mmWave channels. In this task, we have considered realistic channels combining specular and scattered components by using the NYUSIM simulator. Taking advantage of the mmWave channel sparsity in angle domain, both compressive sensing approaches and tensor decomposition have been proposed for detection of dominant signal paths and estimation of its AOAs, AODs and TOA for positioning estimation. Multipath assisted localization improves accuracy in NLOS scenarios and even allows positioning in OLOS, however in LOS the best performance is obtained avoiding multipath interference. For this reason, we have proposed to classify channels into LOS, NLOS and OLOS by clustering classification or applying support vector machine algorithms.



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.

Publications

Journal Papers

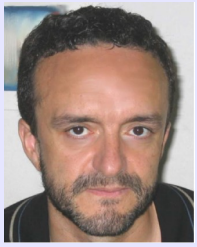
- Cristian García Ruiz, Antonio Pascual Iserte, Olga Muñoz Medina, "Analysis of Blocking in mmWave Cellular Systems: Characterization of the LOS and NLOS Intervals in Urban Scenarios," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 12, pp. 16247-16252, ISSN 0018-9545, December 2020. DOI: 10.1109/TVT.2020.3037125
- Cristian García Ruiz, Antonio Pascual Iserte, Olga Muñoz Medina, "Analysis of Blocking in mmWave Cellular Systems: Application to Relay Positioning," *IEEE Transactions on Communications*, vol. 69, no. 2, pp. 1329-1342, ISSN 0090-6778, February 2021. DOI: 10.1109/TCOMM.2020.3038177
- Sergi Liesegang Maria, Olga Muñoz Medina, Antonio Pascual Iserte, "Sensor Selection and Distributed Quantization for Energy Efficiency in Massive MTC," *Submitted to IEEE Transactions on Communications*, March 2021.

Conference Papers

- Sergi Liesegang Maria, Olga Muñoz Medina, Antonio Pascual Iserte, "Modeling and Optimization of Wireless Powered MTC Networks with Stochastic Geometry," *Accepted to be presented at IEEE CTW 2021 (Communications Theory Workshop)*, Virtual conference, June 2021.
- Martí Llobet Turró, Margarita Cabrera Bean, "Correlated Binary Data For Machine Learning," *Accepted to be presented at 29th EUSIPCO (European Signal Processing Conference)*, Virtual conference, August 2021.
- Sergi Liesegang Maria, Antonio Pascual Iserte, Olga Muñoz Medina, "Energy Driven Transmission Schemes for Coexistence between HTC and MTC," *Accepted to be presented at EW 2021 (European Wireless)*, Verona (Italy), November 2021.
- Adrian Agustin de Dios, Josep Vidal Manzano, Margarita Cabrera Bean, "Hierarchical Beamforming in Random Access Channels," *Submitted to IEEE GLOBECOM 2021 (Global Communications Conference)*, Madrid (Spain), December 2021.

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.



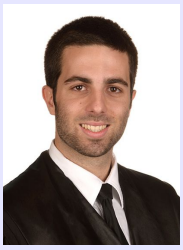
Josep Vidal Manzano (IP2) (Senior Member, IEEE) received the Ph.D. degree in telecommunication engineering from the Universitat Politècnica de Catalunya (UPC) in 1993. He is currently a Professor of the Signal Theory and Communications Department. His research interests are in statistical signal processing, 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). 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.