# COST Action CA15104
# First Scientific Annual Report


COST Action CA15104 (IRACON) aims to achieve scientific networking and cooperation in novel design and analysis methods for 5G, and beyond-5G, radio communication networks.

The scientific activities of the action are organized according to two types of Working Groups: disciplinary and experimental Working Groups. In total, IRACON consists of 6 working groups: Radio Channels (DWG1), PHY layer (DWG2), NET Layer (DWG3), OTA Testing (EWG-OTA), Internet-of-Things (EWG-IoT), Localization and Tracing (EWG-LT) and Radio Access (EWG-RA). A sub-working group of EWG-IoT was also recently created: IoT for Health.

This report details the achievements of IRACON as a whole and of its Working Groups during the first grant period, summarizing the main activities and scientific results, and providing perspectives for the next period.



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# List of acronyms

| | |
|---|---|
| BER | Bit Error Ratio |
| BPSK | Binary Phase Shift Keying |
| CoMP | Cooperative Multi Point |
| D2D | Device-to-Device |
| DTT | Digital Terrestrial Television |
| DWG | Disciplinary Working Group |
| ECI | Early Career Investigator |
| EMF | Electro-Magnetic Field |
| ETSI | European Telecommunications Standards Institute |
| EWG | Experimental Working Group |
| GNSS | Global Navigation Satellite System |
| GP | Grant Period |
| HeNB | Home eNode B |
| HW | Hardware |
| IEEE | Institute of Electrical and Electronical Engineers |
| IET | Institute of Engineering and Technology |
| IoT | Internet-of-Things |
| ITS | Intelligent Transportation Service |
| ITU-R | International Telecommunication Union – Radio |
| LSA | License Shared Access |
| LT | Localization and Tracking |
| LTE | Long-Term Evolution |
| MAC | Medium Access Control (layer) |
| MIMO | Multiple-Input Multiple-Output |
| MOSG | MIMO OTA Sub-Group |
| MRC | Maximal Ratio Combining |
| MTC | Machine Type Communication |
| NET | Network (layer) |
| NFV | Network Functions Virtualization |
| OTA | Over-the-Air |
| PHY | Physical (layer) |
| PLNC | Physical Layer Network Coding |
| RA | Radio Access |
| RAT | Radio Access Technology |
| RAN | Radio Access Network |
| RRM | Radio Resource Management |
| SC-FDMA | Single Carrier Frequency Division Multiple Access |
| SDN | Software Defined Network |
| SDR | Software Defined Radio |
| SG | Study Group |
| STSM | Short Term Scientific Mission |
| TD | Temporary Document |
| URSI | Union Radio Scientifique Internationale |
| V2X | Vehicle-to-Infrastructure |
| VNO | Virtual Network Operator |
| WG | Working Group |
| ZF | Zero-Forcing |

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# 1. Introduction

## 1.1 Scientific objectives of IRACON

The demand for mobile connectivity is continuously increasing, and by 2020 Mobile and Wireless Communications will serve not only very dense populations of mobile phones and nomadic computers, but also the expected multiplicity of devices and sensors located in machines, vehicles, health systems and city infrastructures. The ***Inclusive Radio Communication Networks*** concept defines the technologies for supporting wireless connectivity for any rates, type of communicating units, and scenario. It is expected to be implemented in and beyond the fifth generation (5G) of radio communication networks. Spectral and spatial efficiency are key challenges, in addition to constraints like energy consumption, latency, mobility, adaptability, heterogeneity, coverage, and reliability, amongst others. While many of these aspects are not especially new, the wireless Internet of Things (IoT) beyond 2020 will in particular require revolutionary approaches in Radio Access Technologies (RATs), networks and systems in order to overcome the limitations of the current cellular deployments, the layered networking protocols, and the centralised management of spectrum, radio resources, services and content. Theoretical foundations have to be fully revisited and disruptive technologies are to be discovered during the coming decade.

In this context, IRACON, aims to achieve scientific breakthroughs, by introducing novel design and analysis methods for 5G, and beyond-5G, radio communication networks. IRACON aims at proposing solutions for inclusive and multidimensional communication systems with a wide variety of devices, practical constraints and real-world scenarios, addressing systems ranging from very simple transceivers and sensors, to smartphones and highly flexible cognitive radios. Challenges include: i) modelling the variety of radio channels that can be envisaged for inclusive radios; ii) capacity, energy, mobility, latency, scalability at the physical (PHY) and Medium Access Control (MAC) layers; iii) network automation, moving nodes, cloud and virtualisation architectures at the MAC and Network (NET) layers; iv) experimental research on the practicality of the proposed techniques, addressing Over-the-Air (OTA) testing, IoT, localisation, tracking and radio access.

## 1.2 Objectives of the first grant period

For the first grant period, IRACON's objectives have been defined at the kick-off meeting as follows:

1. agree on specifications and requirements in terms of channel models for inclusive radios;
2. define requirements and applications scenarios for Physical (PHY) and Medium Access Control (MAC) layer techniques;
3. define requirements and applications scenarios for MAC and network (NET) layer techniques;

4. list and organize pan-European laboratory facilities and networks for shared experimental research addressing Over-the-Air (OTA) testing, IoT, localization, tracking and radio access;
5. facilitate the collaboration between ECIs through STSMs, with at least 6 missions over the Grant Period (GP);
6. establish or maintain liaisons with international standardization bodies, via the identification of liaisons and invited speakers at each IRACON technical meeting: the MIMO OTA Sub-Group (MOSG) of CTIA, the 3GPP RAN4, the ETSI Technical Committee on ITS;
7. establish procedures for continuing cooperation with International Scientific Associations, mainly to URSI and IEEE;
8. establish links with existing H2020 projects, exploring the possibility of organizing one joint workshop during the grant period;
9. train ECIs through the organization of one training school;
10. disseminate IRACON position and results via the publication of a newsletter and one position paper (white paper) on 5G; the organization of special sessions and workshop at international conferences.

### 1.3 Working Groups: structure and coordination

The development of 5G-and-beyond systems requires the joint consideration of all aspects related to the exploitation of radio resources: from the radio channel to the PHY, MAC and Network layers. The techniques envisioned for future wireless standards are in fact so revolutionary that they have impact on many separate aspects of the Radio Access Network (RAN). Massive MIMO and beamforming are good examples of this, as these techniques, implemented at the PHY layer, will heavily impact the strategies implemented for radio resource control at MAC and Network layers, and in turn are strongly dependent of the characteristics of the radio channel. Therefore, research developments on radio channel characterisation, PHY, MAC and NET layers need to be suitably coordinated. IRACON is organised into three Disciplinary Working Groups (DWGs) respectively dealing with the radio channel, PHY as well as MAC/NET layers. Meetings will be organised in such a way that a proper coordination of activities among the three DWGs is achieved, namely via joint sessions regrouping documents with overlapping interests. This coordination will ensure that new techniques developed within IRACON will be jointly devised and assessed from all viewpoints.

Moreover, this coordination of research efforts is further demonstrated within IRACON by the creation of four Experimental WGs (EWGs) that will address specific topics through a transversal approach; experimental facilities will be made available by institutions to IRACON participants in order to test new algorithms, techniques and protocols in real-world contexts, enabling a coordinated effort among experts of separate disciplines, as complex test beds need a variety of suitably joint and coordinated competences. Coordination

among theoretical and experimental activities will be ensured through a back-and-forward principle: new ideas, novel techniques envisioned within the DWGs will be considered as candidates for their testing on the experimental facilities made available within the EWGs. At the same time, real-world experiments conducted within the EWGs will provide useful databases of measurements for the theoretical activities brought forward within the DWGs.

### 1.4 Working Groups: practical implementation

As mentioned, IRACON technical content is organised in Working Groups (WGs) to facilitate the coordination and networking between participants. During technical meetings many of the sessions deal with several of the WGs' interests, being identified as "joint" sessions in such sense.

Every IRACON participant is at least interested in two types of WG: One disciplinary WG, on the basics of (WG1) Radio Propagation and Channel Modelling, (WG2) Communications Physical Layer and (WG3) Radio Network Aspects; plus one Experimental WG related to application scenarios and testbeds: (EGW-LT) Location and Tracking, (EWG-IoT) Internet of Things, (EGW-RA) Radio Access Systems, (EGW-OTA) Over-the-Air Testing.

Essentially, the relationship between the Disciplinary WGs (DWGs) and the Experimental WGs (EWGs) is based on the fact that every of the new algorithms, techniques and protocols developed in the context of a DWG is suitable to be tested in some of the application scenarios described by the EWGs, and on this basis the technical meetings and the discussions are organised. On the other way round, experiments conducted within the EWGs will provide useful feedback and databases of measurements for the theoretical activities brought forward within the DWGs.

# 2. DWG1: Radio Channels

## 2.1 General aspects of DWG1 work

The goal of DWG1 is to develop more accurate radio channel models for inclusive deployment scenarios (including but not limited to heterogeneous cells, body area networks and vehicular communications), using carrier frequencies above UHF up to Terahertz as well to co-develop antenna systems that can cope with the inclusive aspects of the targeted deployments.

DWG1 is chaired by Sana Salous and Katsuyuki Haneda.

## 2.2 Technical progress

In the area of **channel sounding**, the following major technical trends have been observed.

- Novel radio channel sounding campaigns in various scenarios, including dynamic body-centric, outdoor-to-indoor and train-to-infrastructure and in-tunnel scenarios at below- and above-6 GHz.
- Novel channel sounding techniques, e.g., angularly highly-resolved massive MIMO indoor measurements at various radio frequencies, and reflections and scattering measurements from various wall materials at 60 GHz.
- New channel sounding campaigns including outdoor 52 GHz channels, train-to-train channels, indoor ultra-wideband 70 GHz channels, rescue scenarios in a forest from aircraft and self-interference channels of in-band full-duplex radios in a train. Plans for long-term measurements of mm-wave channels were also mentioned.
- Characterization of measured channels, such as multipath cluster and diffuse scattering properties at 11 GHz and frequency dependency of indoor channels.
- Several new channel sounding campaigns in different propagation environments such as maritime container environments at 2 GHz, multi-frequency measurements of outdoor-to-indoor insertion loss measurements (3, 10, 17, 28 and 60 GHz), outdoor measurements with massive antenna array at 15 GHz, and 300 GHz short-range indoor line-of-sight link measurements with antenna misalignment effects.

Concerning **radio channel modelling theory**, the following trends can be mentioned.

- Studies of improved channel modelling methods and frameworks. An extension of high-resolution propagation path parameter estimation methods for ultra-wideband signals was presented for example.

- Discussions on radio propagation models and frameworks. Physical-statistical models of radio channel propagation were proposed. Suitability of the 3GPP channel model for 5G simulations and generality of the map-based model was addressed. Frequency dependency of large-scale channel parameters, time-correlation of mobile-to-mobile links, over-the-rooftop radio wave propagation and improved models of diffuse scattering were also reported.
- Theory of characteristics modes for terminal antenna design that provides superior decoupling of antenna elements in an array and hence improved multi-antenna link performance.
- New activities of channel characterization, including the frequency dependency of de-polarization effects in radio waves at millimetre-waves, indoor multipath clustering at 11 GHz and multi-modal modelling of dense multipath components.

Finally, in the area of **channel simulation and prediction**, the main results are as follows.

- Propagation channel simulations, which are mainly implemented through optical approximation of radio propagation called ray-tracing, including the use of graph-theory, the radiosity method and the point cloud ray-tracing for frequencies below- and above-6 GHz.
- Proposals for an improved standard channel model, e.g., inclusion of two-path ground reflection at millimetre-waves.
- Performance analysis of antennas and systems, such as a reconfigurable MIMO antenna mounted on a car roof and self-interference cancellation in time-varying scenarios for in-band full-duplex radios.
- New simulation methods of radio propagation and coverage, such as un-equi-spaced Laplacian transform based physical optics, volume electric field integrate equations.
- Improved tools of radio coverage analysis. Cloud-computing-powered ray-tracing platform with library of different radio environments, e.g., train carriage and outdoor hotspots was introduced. Other TDs report a radio coverage simulator including human body and bus blockage models for millimetre-waves, and also a massive antenna array at the base station.

The following are the main highlights of DWG1 during the first year:

- as a continuation from the COST IC1004, WG1 published a white paper on “Channel measurement and modelling for 5G networks in the frequency bands above 6 GHz”;

  http://www.iracon.org/wp-content/uploads/2016/03/SanaSalous.pdf.

- three contributions to the ITU-R SG3 with the name of United Kingdom, concerning clutter loss, rms delay spread and path loss in residential areas all in the millimetre wave band for future 5G systems in March

2017 as well as contributing to the site general path loss model submitted to the ITU as input from Correspondence Group CG 3K-6;

- organization of a convened session in the 11th European Conference on Antennas and Propagation (EuCAP2017), Paris, France;
- presentation of an invited paper in EuCAP2017 on 'Towards a channel model for 5G';
- organization of a workshop on 'Radio Propagation and Technologies for 5G', Durham University, United Kingdom, on 03 October 2016, with about 58 participants;
- liaison with the General Assembly of URSI Commission C on Radiocommunication systems and signal processing, and with the European Union Horizon 2020 projects mmMAGIC and 5G X-haul;
- a number of collaborative publications made by participating institutions about joint radio channel sounding and modelling;
- contribution to the 5G Alliance -Measurement White Paper.

# 3. DWG2: PHY Layer

## 3.1 General aspects of DWG2 work

DWG2 focuses on a very wide area of PHY layer related aspects in wireless communication networks. It includes all issues related to coding, signal processing, estimation and decoding, HW imposed constraints and solutions, distributed processing in wireless networks. This huge diversity of areas together with a limited number of researches involved affects the form and the focus of the research results.

The areas and some selected achievements that were addressed during the first period are in the next section. DWG2 is quite diverse and in principle quite universally applicable and the results form rather tools than 'turn-key' solutions.

DWG2 is chaired by Hanna Bogucka and Jan Sykora.

## 3.2 Technical progress

The technical contributions can be broadly divided into

- advanced waveforms, coding, signal processing, detection/ estimation/synchronization,
- distributed and cooperative PHY processing in wireless networks (including physical-layer network coding (PLNC)),
- HW related problems.

In the area of **advanced waveforms, coding, signal processing, detection/ estimation/synchronization**, results were obtained in advanced waveform design and generic modulation description formats, finite alphabet constrained multiuser interference cancellation, impulsive noise modelling, interference aware and cancelling receivers, processing and interference modelling in large stochastic networks, iterative equalization in MIMO system, effects of the estimation errors in MRC/ZF M-MIMO processing solved by user grouping;

Regarding **distributed and cooperative PHY processing in wireless networks**, contributions of DWG2 covered: estimation of channel and network state information in large PLNC networks under specific waveform/signal-space (non-orthogonal) constraints, PLNC coding design (the nonlinear map designs and also lattice-based quantization and forward approaches, Compute and Forward in massive MIMO type of cell-free scenario, evaluation of the analytic approximation of BER in PLNC coded BPSK scenario), computation over the networks with aggregation algorithm at nodes;

Results in **HW related problems** range from advanced radio access HW design (full duplex terminals, high dynamics range receiver architectures) to HW hybrid full-duplex self-interference cancellation.

# 4. DWG3: NET Layer

## 4.1 General aspects of DWG3 work

The goal of DWG3 is to investigate the NET layer aspects that will characterise the merger of the cellular paradigm and the IoT architectures, in the context of the evolution towards 5G-and-beyond. In particular, the following objectives will be pursued : 1) identifying and assessing the network architecture of 5G-and-beyond systems; 2) studying the impact of the “fog” networking/computing approach foreseen for 5G, on the evolution of the RATs; 3) evaluating radio resource management approaches compatible to the new requirements set by future mobile radio networks (e.g. on latency); 4) proposing new concepts and paradigms to take account of the plethora of new applications arising from the IoT context.

During the first Management Committee Meeting, DWG3 attendees agreed in the main keywords of the working group. Considering the research papers discussed at the sessions, but also the research activity of the members, as well as topics from the Radio Networks Group of the past COST IC1004 action, we grouped into six main “umbrella” topics:

- 5G and beyond Networks architecture
- RRM & scheduling
- Protocols
- Spectrum management and sharing
- SDN and NFV
- Scenarios

A second list of subtopics was also approved: 4G + cellular, Beamforming, Cloud RAN, Green Networks, Network architecture, Network optimization, Network planning, Network deployment, Network simulation, Network virtualization, Relaying, Scenarios, Scheduling and RRM, Small cells, Spectrum management, Spectrum sharing, Standards, Ultra-low latency, Internet of Things, Network failure management and trouble shooting.

DWG3 is chaired by Silvia Ruiz Boqué and Hamed Ahmadi.

## 4.2 Technical progress

Both chairs and DWG3 members discuss about joint research activities and publications, Short Term Scientific Missions (STSM), training schools and workshops that could be organized under the umbrella of the action, as well as about the possibility to organize special sessions related with DWG3 topics at International Conferences and Journals.

DWG3 had the opportunity to discuss about different **network aspects of Small-Cell Network deployments**. The effects on coverage and interference of Hyper-Dense Small-Cell Network deployments on an urban environment were studied using a realistic 3D scenario to model buildings and to calculate ray-optical pathloss predictions. Optimization of the dynamic allocation of resources is obtained by defining a new auction-based allocation mechanism

through which virtual network operators (VNOs) can bid for a combination of resources, specifically the cloud-based antennas and the spectrum. Details of the first world's License Shared Access (LSA) pilot in the 2.3-2.4 GHz band to manage spectrum sharing in future 5G wide area cells were given describing the testbed architecture and showing results from measurements and simulations, as well as the sharing framework and the rules currently defined to protect the incumbent users. EMF exposure under the context of the same real dense indoor femtocell environment deployed for the LSA, with 2 outdoor nodes and 4 femtocell indoor nodes were analysed showing through measures that indoor electric field level is much lower than the thresholds commonly adopted worldwide.

**LTE HetNets performance** was also one of the key topics of the meeting, focusing on the implementation of Carrier Aggregation operating at 800 MHz and 2.6 GHz including realistic interference constraints, or in the performance comparison in terms of goodput, packet loss ratio and delay of six different packet schedulers using open source LTE-Sim simulator that includes HeNBs as well as heterogeneous traffic. Massive MIMO was introduced for future seamless high-data rate wireless connectivity for railways, defining the architecture for several scenarios including inter and intra-wagon, station, train-to-infrastructure and infrastructure-to-infrastructure communications.

Advances in **MTC and IoT** was the third topic discussed by DWG3 members, as for example the definition of the technical restrictions in the maximum power that could be transmitted by a narrwoband LTE (IoT) network when it shares TV-White-Spaces with DTT, or the definition of a new distributed and fast algorithm to allow each Delay Tolerant Network node to identify if the sensors are producing faulty data. Other interesting works define algorithms to enable traffic steering between IEEE 802.11p and LTE for V2X communications or showing strategies to reduce energy consumption from the traditional energy grid of a wireless access network and its trade-off with respect coverage and capacity.

In the area of **network virtualization:**

- the possibility of auctioning the spatial streams in a co-located or distributed massive MIMO system was explored: this model enables the infrastructure operator to maximize it revenue by assigning the spatial streams to the virtual network operators who value the resources the most;
- a model of virtual radio resource management was proposed to provide quality of service guarantee for different classes of services in a heterogeneous cloud-based radio access network (C-RAN): this work solved a nonlinear optimization problem aiming for proportional fair solution for allocation of data rate to different services according to their QoS requirements;
- a customizable resource virtualization algorithm for multi-user data scheduling in Long term evolution (LTE) C-RAN deployment was also discussed;
- an analysis of a new RRM scheme for Virtualized RAN was based on modified Proportional Fair when there is not enough capacity to serve all

subscribers, delaying some users to free capacity for high priority services;
- a system level evaluation in a realistic scenario of a new Dynamic Base Station clustering for CoMP with Joint Transmission for DL was performed, comparing the performance with respect no CoMP or static clustering.

In the area of **device-to-device (D2D) communication,** an interference graph-based approach for LTE D2D resource allocation with multi-user sharing of resource blocks considered the single carrier frequency division multiple access (SC-FDMA) constraint of assigning continuous resource blocks to user equipment. The presented results show potential gains with increasing amount of D2D pairs per cell.

For **smart grid communications**, the feasibility of using LTE cellular networks for real-time smart grid state estimation, which is receiving the measurement reports from different nodes installed in the smart grid, was investigated. The work selected the uplink LTE radio delay performance as the key performance indicator for the collection of desired measurements. Different types of measurement nodes and different resource allocation techniques have been studied in this work and their results have been compared. This work was a part of SUNSEED project and the presenter also introduced the project.

**4G+ networks** topics covered: a new Linear Downlink Power Control Algorithm for Cellular Networks suitable for distributed networks was analysed through simulations. A new methodology was investigated to balance the load in LTE HetNet urban networks, with throughput gains up to 8%, based on Inter-Frequency Handovers for 900, 1800 and 2600 MHz bands. New LTE features to be used for PPDR (Public Protection and Disaster Relief) networks replacing TETRA were also introduced.

Regarding the use of **drones**, an explanation of how femtocell Base Stations mounted on drones could help in creating Ad-Hoc networks in emergency scenarios, combined with BTSs installed on public transport and emergency service vehicles. The concept of moving networks is introduced by using base stations mounted on UAVs and moving according to traffic and network needs. An explanation of capacity improvements achieved in an urban area is given. Another work investigated the potential of mounting LTE femtocell base stations on drones to offer an alternative for the saturated existing wireless infrastructure. In this work, the authors studied the number of required drones considering the coverage area, flight altitude and drone type.

For **Licensed Shared Access**, the details of the first world large scale Licensed Shared Access (LSA) pilot applied to a live LTE network at 2.3-2.4 GHz band have been explained, in terms of technical feasibility and regulatory compliance.

For **MTC and IoT:** a dynamic Resource Partitioning scheme between Massive Broadband and Machine Type Communication traffic in 5G networks was defined, to avoid collisions between both traffic types, using a control loop to calculate the average collision probability and to estimate traffic load.

Regarding dissemination activities, Professor Roberto Verdone (University of Bologna) and member of DWG3 organized a tutorial on “Integrating the internet of things into 5G and beyond networks”. The idea of organizing a workshop or a training school in one of the topics of DWG3 was discussed, with possible topics such as Spectrum Management, or Virtualized Networks.

# 5. EWG-OTA: Over-The-Air Testing

## 5.1 General aspects of EWG-OTA work

The goal of this EWG is to investigate and validate new OTA testing methods, channel models (in coordination with DWG1) for implementation in advanced OTA testing set-ups for inclusive networks (large objects, small ad-hoc networks, adaptive networks, etc.).

EWG-OTA is chaired by Wim Kotterman and Moray Rumney.

## 5.2 Technical progress

A few important new themes emerged in the Experimental Working Group on Over-the-Air testing. Compared to the standardization of MIMO OTA testing of handheld user equipment, the contributions to the IRACON Action concentrated on OTA testing (electrically) large objects and the emergency created by the advent of the fifth generation mobile communication systems. With respect to the latter, two aspects are prominent.

The first is the intended **incorporation of millimetre wave bands** with their own peculiarities w.r.t. the propagation channel posing large problems. Channels models are at the very heart of every Over-the-Air testing procedure and it is fair to say that the development of realistic channel models for mm-waves did not get the attention channel modelling received during the development of former generations of mobile communication systems. As a result, developing tests for full functional compliance will be delayed. This has to be seen in the context of the second aspect, the very tight time schedule for 5G. Information about the system is supplied at the very last moment. This too, hampers development of OTA testing for 5G. Now, one approach is simply extending testing procedures for 3G/4G to components of the 5G system design as far as these are defined

The aforementioned **electrically large objects** are either vehicles, in the context of cooperation between automated vehicles through ITS (dedicated communication systems), or large Base Station antennas. The latter can be divided into Massive MIMO base station or beam-steering bases station for mm wave communication. Although, in principle, the same approaches can be applied to OTA testing as for small equipment, scaling up the set-ups is economically not viable. This scaling involves the dimensions of the equipment-under-test in wave lengths and going from devices of one or two wavelengths as dominant dimension to constructs of hundred wavelengths across or more, results in a similar scaling in costs (mainly made up by the large-bandwidth signal processing and high-performance RF hardware).

In the EWG, different approaches were tentatively presented. However, for Base Station array antennas with large numbers of antenna elements, it is highly unlikely that test set-ups, of whichever method, with a smaller number of antenna elements than that of the Base Station array will suffice, simply because the required number of degrees of freedom is not available.

# 6. EWG-IoT: Internet-of-Things

## 6.1 General aspects of EWG-IoT work

The goal of EWG-IoT is to support the evolution of 5G networks through the inclusion of the IoT component, via the investigation and assessment of the network architectures, the comparison among the many approaches currently devised for the development of an ecosystem of the IoT platforms and applications in terms of operating systems, and the experimental validation of different protocols for large scale applications of the IoT.

EWG-IoT is chaired by Erik Ström and Chiara Buratti.

## 6.2 Technical progress

During the first year, EWG-IoT had TDs (13 in Lille, 8 in Durham and 19 in Lisbon). This WG being focused on the experimental facilities, the first year was dedicated to identifying, present and categorize the experimental facilities made available by the COST Action Institutions. The main facilities identified are the following:

- **FIT/CorteXlab,** INRIA SOCRATE INSA Lyon, France. It is a large facility in a 200 m² room, entirely faradised and covered with EM, absorbers, equipped with 22 USRPs (National Instruments), 16 PicoSDRs, (MIMO 2x2 and 4x4, from Nutaq) and 42 WSN nodes (Hikob). All these equipments are remotely accessible and programmable through the Internet to launch experimentations
- **iMinds w-iLab.t,** Ghent University, Belgium. It is a generic wireless testbed equipped with 60 wireless nodes with IEEE 802.11a/b/g/n, IEEE 802.15.4 and IEEE 802.15.1 interfaces. In addition, the lab offers mobile nodes to the experimenters. These mobile nodes consist of a Roomba vacuum cleaning robot with the same wireless node configuration mounted on top of it. The location also hosts software defined radio platforms (URSP, WARP) and spectrum scanning engines developed by IMEC.
- **EuWIn@Bologna,** Bologna University, Italy. It is composed of two platforms: i) a network composed of 52 radio devices compliant with the IEEE 802.15.4 standard, flexible enough to allow the development and testing of any routing algorithm compatible with such a standard, and deployed in fixed positions at the University of Bologna; 2) a platform composed of 100 devices battery charged and having different sensors on board.
- **Resource for Vehicle Research (ReVeRe),** Chalmers University of Technology, Sweden. It enables full vehicle control for various real-traffic test scenarios on public roads or on test tracks.

Many others have been presented and they are all included into a webpage of the IRACON website (see http://radiokom.eti.pg.gda.pl/IRM/), hosting a short description of all these available facilities.

The main research topics and trends of this EWG are briefly summarized below.

- **Vehicular Communications**. This research regards the study of communication network architecture for future railway, aiming at developing high-data rate wireless connectivity, such as the investigation of IEEE 802.11p/LTE hybrid solutions for vehicle-to-X communications. An extensive real-world measurement campaign conducted along Austrian railways, using 3G/4G user equipment located on-board, has been performed.
- **Energy-efficiency**. Research topics are: experimental characterization of energy consumption in wireless sensor networks working in the 2.4 GHz band, when affected by interference coming from Wi-Fi; experimental validation of wake-up radio receiver; design of energy efficient routing protocol for WSNs.
- **SDN-based IoT networks**. Novel architectures for enabling the SDN paradigm into the IoT world have been proposed. One solution is based on Locator Identifier Separation Protocol (LISP), while another one is based on a proprietary design integrated into an OpenFlow-based SDN network. Experimental results show the validity of these solutions.
- **Routing and MAC protocols**. A novel joint scheduling and routing algorithm for centralised IoT networks has been proposed and integrated into the 6TiSCH (IPv6 over the TSCH mode of IEEE 802.15.4e) protocol stack. The solution has been tested via experimentation in the framework of a joint research activity between UNIBO and UNIBL. Other research regards the study of joint routing and scheduling algorithms based on backpressure and incorporating energy harvesting constraints.
- **Low Power Wide Area Networks**. The research regards the study via experimentation of new solutions for the IoT, such as LoRa and NB-IoT.
- **IoT for Health.** The main topics addressed are: path-loss modelling for off-body channel; methodology to construct an accurate UWB phantom for in-body to on-body propagation; broadband measurement of electromagnetic tissue phantoms using open-ended coaxial systems; antenna system design for wireless capsule endoscope application; nano-communications and routing mechanisms through in-body nano-networks; IEEE 802.15.6-based body area networks.

Given the interest in Health-related topics, a Sub-WG on “IoT for Health” (EWG-IoT-Health) has been formally created and approved during the meeting in Lisbon, and the following Sub-WG Co-Chairs, Slawomir Ambroziak and Kamran Sayrafian, were elected.

Finally, we underline that in this first year this EWG organized:

- Tutorial on “Integrating the Internet of Things into 5G and Beyond Networks”, gave by Roberto Verdone in Lisbon on January 31st 2017;
- Joint Workshop with EWG-Loc on “Dependable Wireless Communications and Localization for the IoT” which will take place in Graz on September 2017.

# 7. EWG-LT: Localisation and Tracking

## 7.1 General aspects of EWG-LT work

The goal of this EWG is to follow the development of 5G standardisation, taking advantage of the new techniques implemented and defined (millimetre waves, massive MIMO, etc.) to design and test new localisation and tracking techniques for devices, working both in outdoor and indoor environments.

EWG-LT is chaired by Carles Anton-Haro and Klaus Witrisal.

## 7.2 Technical progress

During the first year, the EWG-LT has organized several sessions at the Lille, Durham and Lisbon meetings. The number of TDs presented were three, three and six, respectively. Besides, one joint session with EWG IoT was organized in Lisbon. In general, sessions were well attended and a number of interesting and lively discussions took place.

This experimental working group has also made a substantial effort to identify and bring to the attention of WG participants a number or research infrastructures owned by IRACON participants. The ultimate goal is to foster joint research activities among IRACON participants and, also, to stimulate Short Term Scientific Missions (STSMs). A non-exhaustive list of platforms includes:

- **UWB high-end indoor positioning testbed** (Graz University of Technology, Austria): Testbed for UWB indoor positioning based on a high-performance channel sounder for the 3-10 or 0-3 GHz frequency ranges and flexible MIMO antenna configurations up to 4 x 6. This Research Infrastructure is willing to exchange of data to drive joint research on indoor positioning.
- **GESTALT®** (Centre Tecnològic de Telecomunicacions de Catalunya, Spain) includes a set of commercial of-the-shelf hardware and an open source software, constituting a state-of-the-art platform for research and development of next-generation GNSS receivers. The core of the platform is the GNSS-SDR receiver which has been extended to support multi-band and multi-system operations. As a relevant case of use to validate the research facility, CTTC presented a triple band GNSS-SDR customization capable of receiving four GNSS signals in real-time: GPS L1 C/A, GPS L2CM, Galileo E1b, and Galileo E5a.
- **w-iLab.t testbed** (UGent/iMinds, Belgium): This testbed is equipped with 60 wireless nodes, with IEEE 802.11a/b/g/n, IEEE802.15.4 and IEEE802.15.1 (Bluetooth) interfaces. In addition, the w-iLab.t Zwijnaarde offers mobile nodes to the experimenters which are particularly relevant for research indoor localization techniques. These mobile nodes consist of a Roomba vacuum cleaning robot with the same wireless node configuration mounted on top of it. The location also hosts software

defined radio platforms (USRP, WARP) and spectrum scanning engines developed by IMEC. The iMinds w-iLab.t allows flexible testing of the functionality and performance of wireless networking protocols and systems in a time-effective way, by providing hardware and the means to install and configure firmware and software on (a selection of) nodes, schedule automated experiments, and collect, visualize and process results.

- **FemtoCell Indoor testbed** (U. of Malaga, Spain): This testbed comprises +10 femtocells deployed in a indoor/lab environment in the University of Malaga. It is an outcome of the MONOLOC project. As an application example, the testbed can be used to develop location-based methods for the identification of coverage gaps in femtocell environments.

These testbeds have been/are in the process of being incorporated in the so-called IRACON's registry of Research Infrastructures. The ultimate purpose is to raise awareness and/or conduct dissemination activities via its publication in the IRACON website.

As far as research activities are concerned, in the first year of IRACON priority has been given to the following areas:

- **Localization and positioning techniques for 4G and 5G communication networks**: This includes the design of accurate and robust positioning techniques for 5G systems, and the analysis of how accuracy scales with signal bandwidth and diversity gain in dense multipath environments. It is foreseen that mm-wave 5G systems, employing both, large bandwidths and antenna-array beamforming, will provide the radio frontends needed for highly accurate and robust indoor positioning. Complementarily, the impact of frequency-hopping schemes for narrowband-IoT positioning in 4G and 5G networks has been investigated, as well. Results indicate the feasibility to achieve a position accuracy below 50 meters, by covering a system bandwidth of 10 MHz with two consecutive hops. Also, several techniques have been developed to detect coverage gaps in femtocell networks by leveraging on the signal received by geo-located user terminals.
- **Channel modelling, propagation and positioning**: Here, some EWG members have employed a geometry-based stochastic channel model to analyze and characterize the ranging error variance as a function of the bandwidth, covering the narrowband up to the UWB regimes in dense multipath environments. Other authors have analysed the achievable ranging and positioning performance in an RFID system for two design constraints: (i) the bandwidth of the transmit signal and (ii) the use of multiple antennas at the readers. The ranging performance has been derived for correlated and uncorrelated constituent channels by utilizing a geometry-based stochastic channel model for the downlink and the uplink. Complementarily, other participants to this EWG has also developed an emitter location technique using game engines 3D ray-based tools and Power Difference of Arrival (PDOA) information.

- **Synchronization, tracking and data fusion techniques** are of utmost importance for this EWG too**.** Hence, topics such as (i) the real-time localization of a moving target with mobile sensors using hybrid RSS and angle of arrival information; (ii) the derivation of methods for estimating time-difference-of-arrival in a network of receiver nodes not requiring explicit synchronization between such nodes: or (iii) the use of virtual multi-antenna array for estimating the angle-of-arrival of a RF transmitter, have been investigated in several works. Research has been conducted at the analytical, simulation and/or experimental levels.

- **Experimental validation and platforms:** Here, on the one hand, efforts have been devoted to experimentally validate the use of off-the-shelf DecaWave UWB Transceivers for high-accuracy multipath-assisted indoor positioning. Specifically, it has been shown that the positioning algorithm, requiring information from a single anchor only, achieves reliable and robust positioning at an accuracy below 0.5 m. On the other, GNSS-SDR, an open source software-defined GNSS receiver/platform for experimentation in satellite-based positioning techniques has been presented to EWG participants too.

Finally, the EWG-LT has organized several dissemination activities. In particular, a workshop on “Localization and Tracking: Indoor, Outdoor and Emerging Networks” was organized and held in Globecom 2016. Currently, the EWG leaders are working towards the organization of a joint workshop with the EWG-IoT on “Dependable Wireless Communications and Localization for the IoT” which will be held in Graz on September 2017.

# 8. EWG-RA: Radio Access

## 8.1 General aspects of EWG-RA work

The goal of this EWG is to experimentally validate the many techniques that will be implemented at the PHY and MAC layers of the radio access part of 5G, especially those developed within DWG2. New waveforms, cognitive radio approaches, or massive MIMO, are possible examples.

EWG-RA is chaired by Florian Kaltenberger and Mark Beach.

## 8.2 Technical progress

During the first three technical meetings, a total of 18 technical documents were presented. The majority of the documents can be attributed to two main topics: massive MIMO and full duplex radio.

**Massive MIMO** is one key concept for 5G, especially (but not only) for frequency bands above 6GHz. It allows to increase the spectral efficiency of the system by using a large number of antennas at the base station to spatially multiplex signals to multiple users concurrently.

In a strategic partnership with Lund University (Sweden) and National Instruments (NI), have made significant contributions to the evolution of a key enabling technology for 5G wireless connectivity. They have jointly advanced the state-of-the-art of massive MIMO, using experimental hardware provided through the joint venture between Bristol City Council and the University of Bristol (Bristol-Is-Open (BIO)). In their experiments they were able to serve 22 user clients simultaneously in the same 20 MHz band which, with a total throughput of nearly 3 Gbps and a spectral efficiency of 145.6 bits/s/Hz, a world record.

Another massive MIMO testbed has been implemented at Eurecom, France. This testbed focuses more on a holistic massive MIMO approach, using existing 4G technology based on OpenAirInterface. Using this testbed, researchers at Eurecom managed to get a connection to a commercial phone served by a 64 element antenna array base station using reciprocity-based massive MIMO precoding.

**Full duplex radio**, where devices can send and receive signals at the same time, is as old as radio itself, but only recently significant breakthrough has been achieved to make such systems practically feasible. Some of this work carried out within the IRACON EWG-RA has been conducted by Bristol university: First, novel low-complexity algorithms have been devised to quickly measure and adjust the balance network impedance, so that an adaptation loop can easily track changes in antenna impedance. Second, a novel adaptive method of generating a signal to cancel the self-interference has been devised, based on the frequency-domain equalizer which is relatively trivial in an LTE system. Together with the adaptive impedance balancing, over 80 dB suppression of the local transmitted signal in the receiver can be achieved. Third, a further reduction of 20dB has been obtained by applying non-linear signal processing,

based on Volterra kernels, which can be implemented in the digital domain. Fourth, field tests in hand-held device use-cases, and high speed (road and rail) deployment scenarios, have also demonstrated performance in demanding dynamic radio propagation conditions.

Finally, **testbeds** are an important part of EWG-RA. Together with the other experimental working groups it was decided that a list of testbeds that are actively used within the action should be created. Each testbed has to be presented at least once in a TD to be included in that list. The initial list of testbeds is

- the Lund massive MIMO testbed
- the Bristol massive MIMO testbed (TD(16)02031)
- the Eurecom massive MIMO testbed (TD(16)02044)
- the METIS-II 5G visualization tool (TD(16)02016)
- CASTLE: A user-friendly platform to test, evaluate and develop contemporary wireless communication standards (TD(17)03027)
- Experimenting Cognitive Radio Communication with GNU Radio on CorteXlab (TD(17)03077)
- Update on Electrical Balance Duplexer Performance in High Speed Rail Applications (TD(17)03033)
- Link Performance Evaluation and Channel Propagation for mmWave Systems (TD(17)03047)

# 9. Conclusions and Perspectives

## 9.1 Conclusions

During its first year, IRACON has successfully launched its Working Groups and started working towards its objectives. As described in the previous sections, all WGs are progressing according to plan and have completed the assigned objectives for the first grant period.

The following table illustrates the achievements over the first GP as compared to the GP objectives detailed in Section 1.

| | | |
|---|---|---|
| 1 | Agree on specifications and requirements in terms of channel models for inclusive radios | Covered by DWG1 (see Section 2) |
| 2 | Define requirements and applications scenarios for Physical (PHY) and Medium Access Control (MAC) layer techniques | Covered by DWG2 (see Section 3) |
| 3 | Define requirements and applications scenarios for MAC and network (NET) layer techniques | Covered by DWG3 (see Section 4) |
| 4 | List and organize pan-European laboratory facilities and networks for shared experimental research addressing Over-the-Air (OTA) testing, IoT, localization, tracking and radio access | First issue of the list now online<br>➔ http://radiokom.eti.pg.gda.pl/IRM/ |
| 5 | Facilitate the collaboration between ECIs through STSMs, with at least 6 missions over the Grant Period (GP) | 10 STSMs funded |
| 6 | Establish or maintain liaisons with international standardization bodies | • On-going action (members of IRACON are active members of the MIMO OTA Sub-Group of CTIA and the 3GPP RAN4)<br>• Contribution to ITU-R SG3 (see Section 2.3)<br>• IRACON liaisons:<br>➔ 3GPP – Aki Hekkala<br>➔ URSI – Sana Salous<br>➔ ITU-R – Sana Salous and Belen Montenegro<br>➔ IEEE 1900.6 – Kostas Katzis |
| 7 | Establish procedures for continuing cooperation with International Scientific Associations | IRACON liaisons:<br>➔ URSI – Sana Salous<br>➔ EurAAP – Claude Oestges |

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| | | ➔ EURACON – Roberto Verdone |
| 8 | Establish links with existing H2020 projects, exploring the possibility of organizing one joint workshop during the grant period | IRACON liaisons:<br>➔ H2020 METIS-II – Narcis Cardona<br>➔ H2020 mmMAGIC – Mark Beach<br>➔ H2020 5G X-haul – Mark Beach<br>➔ CommNet (EPSRC network) – Mark Beach<br>➔ ITN WiBEC – Narcis Cardona<br>➔ 5G initiative – Fernando Velez |
| 9 | Establish links with existing H2020 projects, exploring the possibility of organizing one joint workshop | Organization of one joint training school with ITN WiBEC (Antennas and Propagation for Body Communications), gathering xx participants |
| 10 | Train ECIs through the organization of one training school | Organization of one joint training school with ITN WiBEC (Antennas and Propagation for Body Communications), gathering xx participants |
| 11 | Disseminate IRACON position and results via the publication of a newsletter and one position paper (white paper) on 5G; the organization of special sessions and workshop at international conferences | • Publication of one white paper on 5G channel models<br>➔ http://www.iracon.org/wp-content/uploads/2016/03/SanaSalous.pdf<br>• Organization of one full-day workshop at PIMRC 2016<br>➔ http://www.iracon.org/workshops/pimrc-2016/<br>• Organization of one full-day workshop in cooperation with IET<br>➔ http://www.iracon.org/workshops/radio-propagation-and-technologies-for-5g/<br>• Organization of one special session at EuCNC2016<br>➔ http://www.iracon.org/special-session/special-session-at-eucnc-2016/<br>• Organization of two special sessions at EuCAP2017<br>➔ http://www.iracon.org/special-sessions/special-sessions-at-eucap-2017/ |

## 9.2 Success stories

A few success stories are outlined below:

- at each management committee and technical meeting, the attendance

is largely above the strict number of management committee members (around 100 attendants per meeting, including many ECIs): this illustrates that IRACON WGs are really seen as a natural biotope by many PhD students;

- a very large number of technical documents have already been produced (see the full list in annex), many of them by ECIs;
- IRACON has already published three Newsletters, highlighting a number of important scientific topics (each issue is downloaded more than 300 times);
- as a continuation from COST IC1004, IRACON published a white paper on “Channel measurement and modelling for 5G networks in the frequency bands above 6 GHz”,
- three contributions were submitted to the ITU-R SG3 in the area of millimetre wave channel modelling for future 5G systems,
- the structuring of pan-European laboratory facilities and networks for shared experimental research was carried out: the list can be consulted on IRACON website,
- two IRACON ECIs received the Best Propagation Paper Award and the Best Student Paper Award at EuCAP 2017 (both papers were presented in IRACON special session on “mm- and THz- wave propagation measurements and modelling for ultra-high data rate communications”).

## 9.3 Perspectives for the second grant period

In the next period, IRACON will intensify its activities, in particular with respect to scientific dissemination. The GP objectives have been set as follows:

1. discuss and submit contributions about concerted 5G radio channel models to international bodies (namely, ITU-R);
2. define IRACON Reference Scenarios and provide assessment of 5G radio access techniques through experimental platforms;
3. promote the use of pan-European laboratory facilities and networks for shared experimental research addressing Over-the-Air (OTA) testing, IoT, localization, tracking and radio access, using a shared web platform;
4. facilitate the collaboration between ECIs through STSMs (at least 6 missions over the GP);
5. establish or maintain liaisons with international standardization bodies, via the identification of liaisons and invited speakers at each IRACON technical meeting: the MIMO OTA Sub-Group (MOSG) of CTIA, the RAN4 of 3GPP that pursue standardized OTA tests for LTE User Equipment, the ETSI Technical Committee on ITS, and the URSI Commission C, among others;

6. maintain on-going links with existing H2020 projects, exploring the possibility of organizing one joint workshop in the grant period;
7. train ECIs through the organization of two training schools, with a focus on basic and advanced competences;
8. disseminate IRACON position and results via the ongoing publication of a newsletter, the animation of a blog and the issue of one position paper (white paper) on new localization techniques suitable for 5G and the Internet of Things; the organization of at least two special sessions at international conferences (EuCNC, EuCAP); the organization of one full-day IRACON workshop in conjunction with an MC meeting;
9. discuss COST gender policy through women-only meetings at MC meetings, with inputs to the newsletter or to the blog.

## Annex: List of Temporary Documents

| | TD number | Title | Authors |
|---|---|---|---|
| 1 | TD(16)01002 | Impact of antenna position on performances in relay-assisted network | Jean-Marc Conrat, Issam Maaz, Jean-Christophe Cousin |
| 2 | TD(16)01003 | Radio Channel Measurements in Body-to-Body Communications in Different Scenarios | Slawomir J. Ambroziak, Luis M. Correia, Kenan Turbic |
| 3 | TD(16)01004 | Initial Results from Millimeter-Wave Outdoor-to-Indoor Propagation Channel Measurements at 3, 10 and 17 GHz | Cheikh A. L. Diakhate, Jean-Marc Conrat, Jean-Christophe Cousin |
| 4 | TD(16)01005 | Constructive Interference through Symbol Level Precoding for Multi-Level Modulation | Maha Alodeh, Symeon Chatzinotas, Bjorn Ottersten |
| 5 | TD(16)01006 | Reducing the impact of solar energy shortages on the wireless access network powered by a PV panel system and the power grid | Margot Deruyck, Daniela Renga, Michela Meo, Luc Martens, Wout Joseph |
| 6 | TD(16)01007 | Impact of Electromagnetic Interference on Vehicular Antenna Performance | Irfan Mehmood Yousaf, Buon Kiong Lau, Björn Bergqvist |
| 7 | TD(16)01008 | On Characteristic Modes of MIMO Terminals With Real Components | Zachary T. Miers, Augustine Sekyere, John Ako Enohnyaket, Max Landaeus, Buon Kiong Lau |
| 8 | TD(16)01009 | Analysis of f-OFDM as a candidate waveform for 5G | Kun Chen Hu and Ana Garcia Armada |
| 9 | TD(16)01010 | Scenario Partitioning for High Speed Railway | Bo Ai, Ke Guan, Ruisi He, Yan Li, Jingya Yang, Qi Wang, Zhangdui Zhong, Hua Song |
| 10 | TD(16)01011 | Dedicated Social Network Architecture for Rail Traffic Systems | Bo Ai, Ke Guan, Yan Li, Ruiqi Zhang, Yue Zhao, Guoyu Ma, Zhangdui Zhong, Lei Xiong, Jianwen Ding, Hua Song |
| 11 | TD(16)01012 | Communications Network Architecture for Future Railway | Bo Ai, Ke Guan, Yan Li, Qi Wang, Ruiqi Zhang, Yue Zhao, Guo-Yu Ma, Zhangdui Zhong, Hua Song |
| 12 | TD(16)01013 | Dense Multipath Component Parameter Estimation in 11GHz-band Indoor Environment | Kentaro Saito, Takada Jun-ichi, Minseok KIM |
| 13 | TD(16)01014 | Testing OpenWSN and Contiki OSs Performances on OpenMote Platform | Gordana Gardašević, Dragan Vasiljević, Mladen Veletić |
| 14 | TD(16)01015 | Investigating the angular dependence of diffuse scattering correlation | Yang Miao, Quentin Gueuning, Claude Oestges |
| 15 | TD(16)01016 | Measuring and Modelling of Specular Reflections at mm-Wave Frequencies | Angelos A. Goulianos |

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| 16 | TD(16)01017 | Physical-Statistical Modeling of Dynamic Indoor Power Delay Profiles | Evgenii Vinogradov, Aliou Bamba, Wout Joseph, Claude Oestges |
| 17 | TD(16)01018 | Analysis of Deployment Options to Enhance Horizontal Information Sharing and Networking in Internet of Things | Andrej Mihailovic, Marko Simeunovic, Milica Pejanovic-Djurisic |
| 18 | TD(16)01019 | An Extension of the RiMAX Algorithm for Ultra-Wideband Channels | Brecht Hanssens, Emmeric Tanghe, Davy P. Gaillot, Martine Liénard, Claude Oestges, David Plets, Luc Martens, Wout Joseph |
| 19 | TD(16)01020 | Spectrum sharing in DTT band for IoT Services provission | Kevin Llamas, Gerardo Martínez, Narcis Cardona |
| 20 | TD(16)01021 | Virtual multi-antenna array for estimating the angle-of-arrival of a RF transmitter | Francois Quitin, Vivek Govindaraj, Xionghu Zhong and Wee Peng Tay |
| 21 | TD(16)01022 | On stochastically emulating continuous scattering structures by discrete sources for OTA testing of DuT with highly directive antennas | Wim Kotterman, Markus Landmann, and Giovanni del Galdo |
| 22 | TD(16)01023 | A Medical Cloud | Jurij Tasic, Marjan Gusev, Sasko Ristov |
| 23 | TD(16)01024 | Effects of Hyper-Dense Small-Cell Network Deployments on a Realistic Urban Environment | Dennis M. Rose, Thomas Kürner |
| 24 | TD(16)01025 | A Data Traffic Steering Algorithm for IEEE 802.11p/LTE Hybrid Vehicular Networks | Nils Dreyer, Andreas Möller, Zeeshan Hameed Mir, Fethi Filali, Thomas Kürner |
| 25 | TD(16)01026 | Spectrum sharing in 5G networks: the Italian first world's Licensed Shared Access pilot in the 2.3-2.4 GHz band | Doriana Guiducci, Claudia Carciofi, Valeria Petrini, Eva Spina, Pravir Chawdhry |
| 26 | TD(16)01027 | EMF exposure assessment in a real femtocell environment under 5G paradigm | Doriana Guiducci, Claudia Carciofi, Simona Valbonesi, Valeria Petrini, Marina Barbiroli, Eva Spina, Pravir Chawdhry |
| 27 | TD(16)01028 | Waveform Design Principles and Comparison of New Generation Waveform Candidates for 5G and Beyond | Berker Pek• oz, Ahmet Yazar, and H• useyin Arslan |
| 28 | TD(16)01029 | LTE-ADVANCED RADIO AND NETWORK OPTIMIZATION: BASIC COVERAGE AND INTERFERENCE CONSTRAINTS | Fernando J. Velez, Sofia Sousa, Jessica Acevedo Flores, Daniel Robalo, Albena Mihovska, Ramjee Prasad |
| 29 | TD(16)01030 | BASIC LIMITS FOR LTE-ADVANCED RADIO AND HETNET OPTIMIZATION IN THE OUTDOOR-TO-INDOOR SCENARIO | Fernando J. Velez, Sofia Sousa, Albena Mihovska, Ramjee Prasad |
| 30 | TD(16)01031 | Impact of Transmitter Power in Packet Schedulers Performance in LTE HetNets | Rui R. Paulo, Fernando J. Velez, Giuseppe Piro |
| 31 | TD(16)01032 | Experimental Characterization of WSNs Applied to Swarms of Aquatic Surface Drones | Fernando J. Velez, Aleksandra Nadziejko, Anders Lyhne Christensen, Sancho |

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| | | | Oliveira, Tiago Rodrigues, Vasco Costa, Miguel Duarte, Fernando Silva, Jorge Gomes |
| 32 | TD(16)01033 | Generality of Map–Based Model | Aki Hekkala, Pekka Kyösti |
| 33 | TD(16)01034 | MIMO Channel Reconstruction from Lower Dimensional Multiple Antenna Measurements | Rimvydas Aleksiejunas |
| 34 | TD(16)01035 | Joint Routing and Scheduling for Centralised Wireless Sensor Networks | Chiara Buratti, Roberto Verdone |
| 35 | TD(16)01036 | Performance Evaluation of LoRa Technology: Experimentation and Simulation | Luca Feltrin, Stefan Mijovic, Chiara Buratti, Andrea Stajkic, Enrico Vinciarelli, Roberto Verdone, Roberto De Bonis |
| 36 | TD(16)01037 | EuWin@UniBo: Experimental Facilities for the Internet of Things | Chiara Buratti, Roberto Verdone |
| 37 | TD(16)01038 | Analysis of in-Room mm-Wave Propagation: Ray Tracing Simulations and Directional Channel Measurements. | F. Fuschini, S. Häfner, M. Zoli, R. Müller, E. M. Vitucci, D. Dupleich, M. Barbiroli, J. Luo, E. Schulz, V. Degli-Esposti and R. S. Thomä. |
| 38 | TD(16)01039 | Three Dimensional (3D) Beamforming: An Application Example with Satellite-Terrestrial Spectral Coexistence Scenario | Shree Krishna Sharma, Symeon Chatzinotas, Joel Grotz and Björn Ottersten |
| 39 | TD(16)01040 | A Measurement Based Multilink Shadowing Model for V2V Network Simulations of Highway Scenarios | Mikael Nilsson with mail mikael.nilsson@volvocars.com |
| 40 | TD(16)01041 | A Semi-deterministic Method for Predicting Indoor Cellular Coverage in Dense Urban Areas | V. Degli-Esposti, J. S. Lu, J. N. Wu, J. J. Zhu, J. A. Blaha, E. M. Vitucci, F.Fuschini, M. Barbiroli |
| 41 | TD(16)01042 | Overview of the COST IC1004 white paper on 'Channel measurement and modelling for 5G networks in the frequency bands above 6 GHz' | S. Salous |
| 42 | TD(16)01043 | On Dimensions of OTA set-up for Base stations Radiated Testing | Pekka Kyösti, Wei Fan, Anders Karstensen |
| 43 | TD(16)01044 | Measurement Results and Simulation Based Channel Characterization For Outdoor Open Area Access Scenarios at 58.5 GHz | Minseok Kim, Tatsuki Iwata, Kento Umeki, Karma Wangchuk, Takada Jun-ichi, Shigenobu Sasaki |
| 44 | TD(16)01045 | Analysis of Outdoor Small-cell Path-loss and Propagation Channel from Ray-based Simulations in Sub-6GHz and mmWave Bands | Yoann Corre, Thierry Tenoux, Julien Stéphan, Florian Letourneux, Romain Charbonnier, Yves Lostanlen |
| 45 | TD(16)01046 | OTA testing challenges at mmWave frequeincies | Moray Rumney |
| 46 | TD(16)01047 | Indoor Highly Resolved Channel Measurements at 60 GHz | Jonas Medbo, Henrik Asplund, Niklas Jaldén |
| 47 | TD(16)01049 | An Advanced Graph-based Ray Tracing Method for Radio Propagation Modelling and Localization | Nicolas Amiot,Mohamed Laaraiedh, Bernard Uguen |

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| 48 | TD(16)01050 | Experimental validation of a wake-up radio architecture | Florin HUTU, David KIBLOFF, Guillaume VILLEMAUD and Jean-Marie GORCE |
| 49 | TD(16)01051 | A parallel unbalanced digitization architecture to reduce the dynamic range of multiple signals | Mathieu Vallérian, Florin Hutu, Guillaume Villemaud, Benoıt Miscopein and Tanguy Risset |
| 50 | TD(16)01052 | Experimental evaluation of interference impact on the energy consumption in wireless sensor networks | Viktor Toldov, Laurent Clavier, Nicolas de Araujo Moreira |
| 51 | TD(16)01053 | Attainable Capacity of Spatial Radio Channels: A Multiple-Frequency Analysis | Katsuyuki Haneda, Sinh Le Hong Nguyen and Afroza Khatun |
| 52 | TD(16)01054 | Passive Millimeter-Wave RFID using Backscattered Signals | Francesco Guidi and Raffaele D'Errico |
| 53 | TD(16)01055 | A Unified Generic Multicarrier Modulation Framework | Konstantinos Maliatsos, Eleftherios Kofidis, Athanasios Kanatas |
| 54 | TD(16)01057 | Accurate and Robust Positioning for 5G Systems: Bandwidth Scaling and Diversity Gain in Dense Multipath | Klaus Witrisal, Erik Leitinger, Stefan Hinteregger, Josef Kulmer, Paul Meissner, Katsuyuki Haneda, Carl Gustafson, and Fredrik Tufvesson |
| 55 | TD(16)01058 | Research activities at WiComTec-UPC research group | Sílvia Ruiz, Mario Garcia_Lozano, David Perez, José Luis Valenzuela, Joan Olmos and Lluis Alonso |
| 56 | TD(16)01059 | On frequency dependence of large scale channel parameters | Henrik Asplund, Jonas Medbo, Niklas Jaldén |
| 57 | TD(16)01060 | Specular Reflection Formulation for Point Cloud Modelling | Jean-Frederic Wagen, Usman Tahir Virk, Katsuyuki Haneda |
| 58 | TD(16)01062 | Indoor Channel Characterization in the E-band | Aliou Bamba, Francesco Mani, Raffaele D'Errico |
| 59 | TD(16)01063 | MU-MIMO Performances Analysis from Aggregated Measurement Channel in Indoor Environment. | Mamadou Dialounke Baldé, Bernard Uguen |
| 60 | TD(16)01064 | Study of Dominant Path Probability Models for 5G 3GPP Channel Model | Gerhard Steinböck, Tommi Jämsä, Mattias Gustafsson |
| 61 | TD(16)01065 | Performance evaluation of massive-MIMO systems in fading-emulator based setup | W. Fan, I. Carton, P. Kyösti, T. Jämsä, M. Gustafsson, G. F. Pedersen |
| 62 | TD(16)01066 | 3GPP 3D Channel Model for 5G | Tommi Jämsä, Gerhard Steinböck |
| 63 | TD(16)01067 | Wireless Network Design with Dynamic Interference | Malcolm Egan, Mauro de Freitas, Laurent Clavier, Alban Goupil, Gareth W. Peters and Nourddine Azzaoui |
| 64 | TD(16)01068 | Millimeter-wave Channel Modeling Using Graph theory Based on Digital Maps | Li Tian, Vittorio Degli-Esposti, Enrico M. Vitucci, Xuefeng Yin |

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| 65 | TD(16)01070 | An Efficient Ray-Tracing Method Based on Image Visibility Mapping for Propagation Prediction in Urban Environments | Sajjad Hussain and Conor Brennan |
| 66 | TD(16)01072 | Time Correlation in Mobile to Mobile Indoor Channels | Gloria Makhoul, Francesco Mani, Raffaele D'Errico, Claude Oestges |
| 67 | TD(16)01073 | On the Duality Between State-Dependent Channels and Wiretap Channels | David Kibloff, Samir M. Perlaza, Guillaume Villemaud, Leonardo S. Cardoso |
| 68 | TD(16)01074 | Substitutability of Spectrum and Cloud-based Antennas in Virtualised Wireless Networks | Hamed Ahmadi, Irene Macaluso, Ismael Gomez, Linda Doyle, Luiz DaSilva |
| 69 | TD(16)01075 | S. Fortes, A. Aguilar-García, J.A. Fernández-Luque, A. Garrido-Martín, R. Barco | Location-Based User Equipment Identification of Failures in Femtocell Networks |
| 70 | TD(16)01076 | Experimental Characterization and multipath clustering modelling for 13-17 GHz Indoor Propagation Channels | Cen Ling, Xuefeng Yin, Haowen Wang, Xiaomei Zhang, and Reiner S. Thomä |
| 71 | TD(16)01077 | Sensor Selection and Power Allocation Strategies in Energy Harvesting Frameworks | Miguel Calvo-Fullana, Javier Matamoros and Carles Antón-Haro |
| 72 | TD(16)01078 | Millimeter-wave Channel Prediction Using Point Cloud Data | Jan Järveläinen, Katsuyuki Haneda, Aki Karttunen |
| 73 | TD(16)01079 | A study on the performance of Over-Roof-Top propagation models in dense urban environment | E. M. Vitucci, F. Fuschini, M. Barbiroli, M. Zoli, V. Degli-Esposti |
| 74 | TD(16)01080 | An Empirical Random-Cluster Model for Subway Channels Based on Passive Measurements in UMTS | Xuesong Cai, Xuefeng Yin, Xiang Cheng, and Antonio Perez Yuste |
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