COST Action CA15104
Third 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 third 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 third grant period

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

1. discuss and review future architecture and protocols for the Internet of Things (including the production of one deliverable)
2. promote the use of pan-European laboratory facilities and networks for shared experimental research addressing Over-the-Air (OTA) testing, IoT, localisation, tracking and radio access, using a shared web platform.
3. facilitate the collaboration between ECIs through STSMs (12 missions over the GP)

4. establish or maintain liaisons with international standardisation 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 standardised OTA tests for LTE User Equipment, the ETSI Technical Committee on ITS, and the URSI Commission C, among others.
5. maintain on-going links with existing H2020 projects (Clear5G, 5G-car, etc.), by organizing one joint workshop in the grant period (at EuCNC 2018).
6. train ECIs through the organization of two training schools, with a focus on 5G waveforms and on the transmission of small information quantities in dense networks (both covering aspects going from theory to practice)
7. 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 experimental platforms for performance evaluation; the organization of at least two special sessions/workshops at international conferences (EuCNC, EuCAP, PIMRC).
8. define radio channel models to cover gaps in existing models, in particular for the mmWave band and for localization
9. propose new schemes at PHY and MAC layers for 5G, with a focus on interference mitigation, ultra low power and latency.
10. discuss COST gender policy through women-only meetings at MC meetings, with recommendations to the COST office.
11. discuss the content of the final book of the Action and identify key editors.

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 ensures that new techniques developed within IRACON are 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.

1.5 Final Book overview

This book will present the latest research results and remaining questions in the area of 5G (and beyond) networks. It will cover fundamental problems (e.g. radio propagation) as well as application-specific challenges (e.g. IoT in healthcare). After reading this book, the reader will have an up-to-date knowledge of the current progress and future directions of 5G wireless networks in their most inclusive aspects (and not only for cellular 5G). Topics discussed in this book include:

- Radio propagation modeling and tools
- Wireless channel measurements for 5G systems
- IRACON channel model for 5G
- Over-the-air testing for 5G
- Coding and signal processing for 5G systems
- 5G network architectures
- Internet-of-Things protocols, architectures and applications (including healthcare)
- Localization and tracking in 5G wireless systems.

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 and measurements**, the following major technical trends have been observed.

- New channel sounders are developed in different institutions, mainly for the purpose of dynamic, real-time and mm-wave channel sounding.
- Many MIMO and millimetre-wave channel sounding campaigns are reported to complement the measured evidence of radio links and their further improvement. The former includes massive MIMO, distributed MIMO and multi-user MIMO sounding. The latter covers scattering from walls, building entry loss, clutter loss and polarization.
- Extensive vehicular-to-X measurements were reported at various frequencies including millimetre-waves due to relevance to 3GPP channel modelling. The measurements cover highway and street intersection scenarios, among others.
- Channel sounding in industrial scenarios, including MIMO and ultrawideband measurements, attracted attention due to relevance to 3GPP channel modelling.
- Radar measurements of, e.g., cars and drones, are found of importance for intelligent transportation.

Concerning **radio wave propagation and channel modelling**, the following trends can be mentioned:

- Geometry-based stochastic channel models are one of the key approaches to generate realistic channel responses for radio system design. They are further developed to cover different scenarios, e.g., for a vehicular scenario and massive MIMO channels. The latter is based on the COST2100 channel model framework.
- Site-specific radio propagation simulations are another popular approach of channel modelling, realized mainly by ray-optical simulations of radio wave propagation. New physical models of wave propagation are devised such as human blockage losses, field scattering

on rough surfaces and penetration through vegetation.

- Improvement of several standard channel model, e.g., ITU-R short-range outdoor pathloss model (P.1411-9), cluster delay line model of 3GPP NR and terrain clutter loss models, are suggested.
- Many works report insights into wave propagation based on analytical, experimental and numerical studies. The insights cover diffuse scattering, signal blockage, shadowing and diffraction. Their mathematical and statistical models are also proposed through clustering, room reverberation, graph and transport theory.
- Several studies focus on frequency dependency of radio channel characteristics, e.g., pathloss, delay spread, power angular profile, diffuse scattering, showing no apparent frequency dependency except for pathloss.

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

- Radio link performance of new application scenarios was extensively studied based on computer simulations. The scenarios cover for example massive MIMO, air-to-ground, dynamic on-body, off-body, vehicular-to-infrastructure, intra-vehicular and backhaul long-range communications. The simulations also cover very wide range of frequencies up to sub-millimetre-wave frequencies.
- EMF exposure evaluation is also performed in addition to radio link performance evaluation.
- Various techniques are reported to improve efficiency and accuracy of radio channel simulations/predictions. The former includes computational acceleration techniques of ray-tracing while the latter addresses impacts of environmental database on the simulation accuracy.

The following are the main highlights of DWG1 reports and events during the third year.

- Organization of a joint IET/IRACON in EUCAP 2019 in Krakow.
- Two convened sessions have been proposed for the chairs of convened sessions in EuCAP 2020 (1) IRACON Spectrum Sharing: challenges and opportunities for 5G and beyond, (2) IET & IRACON Propagation measurements and modelling for 5G and beyond
- Contributions to the International Telecommunications Union, Radiocommunications, Study Group 3, ITU-R SG3 from the United Kingdom, regarding stationary distance (ITU-R P. 1407), rms delay spread (ITU-R P. 1238), and path loss in various indoor and residential environments (ITU-R P. 1238 and ITU-R 1411) all in the millimetre wave band for future 5G systems were submitted in March 2018 and 2019 and approved in 2019. Also input from the UK contributed to the site general path loss model submitted to the ITU as input from Correspondence Group CG 3K-6 for suburban environments for line of sight, non-line of sight, above and below rooftops. A document on measurements carried out at JRC in collaboration with Durham University on joint building entry

loss and clutter loss was was also submitted to the meeting in May 2019. A document on the impact of precipiation on mm wave propagation was also submitted to the meeting in May 2019. The various contributions which proposed modifications/additions to the recommendations were approved in the updated or new recommendations;

- ITU-R P.1238-10 https://www.itu.int/rec/R-REC-P.1238/en
- ITU-R P.1411-10 https://www.itu.int/rec/R-REC-P.1411/en
- ITU-R P.1407-7 https://www.itu.int/rec/R-REC-P.1407/en
- ITU-R P. 2109-0 https://www.itu.int/rec/R-REC-P.2109/en
- ITU-R P. 2108-0 https://www.itu.int/rec/R-REC-P.2108/en

Collected data in residential outdoor environments and rain statistics collected during one year in the UK were submitted to the data bank of the ITU.

- Three sessions and a tutorial have been proposed and approved for the General Assembly of URSI Commission C on Radiocommunication Systems and Signal Processing,
- Liaison with the European Union Horizon 2020 project WAVECOMBE;
- A number of opportunities for dissemination are organized in DWG1, e.g., special issues of radio science and ITU journal.

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 third 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 WG2 scope is very wide, so the actual research contributions form a large number of building blocks (generally applicable in many scenarios) rather than one solid piece of the research target. Despite the wide range of topic, there are clearly emerging two common principles present in the majority of WG2 work - massive MIMO and cooperative algorithms (signal processing, coding, decoding) The major achievements of the last reporting period are summarized here.

- *Cooperative coding and signal processing* - channel state estimation for wireless physical layer coded systems (non-pilot based channel state estimation in physical-layer network coded communications (PLNC)), throughput optimisation in relay based communication network (optimisation of BLER in relay based cooperative communication), iterative interference cancelation for non-orthogonal waveforms, application of machine learning approaches to PHY signal processing, low rank channel estimation for multi-antenna systems, various forms of HW aided processing (iterative analogue-HW aided detection, RF domain aided precoding), sparse channel matrix channel detection and estimation for PLNC, PLNC with bit-wise mapped H-SODEM and iterative dual-loop decoding.
- *Massive MIMO* - distributed beamforming for massive MIMO, capacity optimisation technique for uplink M-MIMO with distributed access points with quantised backhaul links.

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

The activity done during the third year in the technical meetings has been:

- Three technical sessions at Cartagena meeting, with 10 technical documents (TDs) that were discussed s as well as several joint sessions with other working groups and experimental working groups. 3 TDs were discussed in a joint session with Radio Access EWG, and 9 in a joint session with IoT EWG. Presented TDs on this meeting were grouped in Networks, Spectrum and Wireless sessions with research activity on predicting coverage maps, Virtual RANs, Radio Resource Slicing, Cloud-RAN, the use of date from social sources in cellular networks,

novel 5G frequency bands and spectrum sharing, resource allocation and sharing among cellular and NB-IoT, mesh networks.

- Two technical sessions at Podgorica meeting, with 8 TDs discussed as well as a joint session with Working Group 1 with 4 TDs and another with the Radio Access EWG with 3 TDs. Sessions were focused on Radio Resource Management and tools to monitor both Networks and Spectrum.

- Three sessions at the Dublin meeting, with 13 TDs to be jointly discussed. Additionally 2 TDs were discussed in a joint session with the Radio Access EWG and 4 in a joint session with IoT EWG. Presented TDs on this meeting were grouped in Cellular, WAN/MANET and Planning/Optimisation sessions, with research activity on 5G network deployment and optimisation, the prediction of moving interference sources and SIR variability, different techniques to decrease energy consumption, new SON techniques for load balancing or inter-frequency handover based on the optimisation of the QoE, measures to characterize the mutual interference of different networks working at the same frequency band, rules to improve spectrum efficiency when allocating orthogonal polarisation to nodes.

Technical progress of DWG3 was not only limited to its main areas of activities, but also had technological progress in interdisciplinary fronts too, by doing joint publications, Short Term Missions, organising special sessions at international conferences.

During this year one of the key responsibilities of the WG has been the definition of the final book structure, where WG3 has a full chapter, as well as short collaborations in other chapters. DWG3 members agreed in having the following sections, that reflect the main activity of the working group and summarize most of the 130 TDs that have been discussed so far in the WG:

0. Wireless connectivity. Editors: Gordana Gardašević (UNIBL) & Yoram Haddad (JCT)
1. Spectrum management and sharing. Editors: Paolo Grazioso (FUB) & Konstantinos Katzis (EUC) & Valeria Petrini (FUB)
2. Scheduling and RRM (12 TDs) Editors: Kemal Ozdemir (IMU) & Arie Reichman (RAC)
3. HetNet and UDN. Editors: Sergio Fortes (UMA) & Rui Paulo (UBI) & Fernando Velez (UBI)
4. CRAN Editors: Mojgan Barahman (IST-UoL) & Luis M. Correia (IST-UoL)
5. SDN and NFV Editors: Luis M.Correia (IST-UoL) & Behnam Rouzbehani (IST - UoL) & Hamed Ahmadi (UCD/UEX)
6. UAVs (15 TDs) (5 pages) Editors: Margot Deruyck (UGent) + Silvia Mignardi (UniBo) & Roberto Verdone (UniBo)+
7. Application domains/ solutions. Editors: Karim Nasr (UoG) & Haibin Zhang (TNO)

Chapter editors will be Hamed Ahmadi and Silvia Ruiz as WG3 chairs. It is important to remark that there are 20 WG3 members from 16 different institutions collaborating in the chapter writing, which reflects the strong relationship in research that has been developed during the Action.

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

Compared to the second year of the Action, despite all the progress 3GPP made in standardising 5G New Radio, in topics crucial to OTA testing, progress in 3GPP was limited to line-of-sight cable replacement methods, and the more challenging environments with multi-signal beamsteering remain unaddressed. In the context of channel models, especially in relation to mobility, developments in standardisation even seem to have stalled. They are part of the scope of current studies but unlikely to be addressed soon, that is, not before the end of the Action. The consequence without actual questions, similar to ones pertinent to LTE to address, is that the investigations remain of a conceptual nature.

This does not mean the EWG did not make any progress in OTA research. Given the fact that for 5G NR no RF interfaces are specified that would have allowed for cabled testing, apart from being close to pointless at millimetre-wave bands, attempts are made to test operation of especially antennas and antenna arrays. Aspects to be tested are among others the presence of faulty elements in large/massive arrays and the effective beam shape and beam angle agility of such arrays. Test practices themselves are improved and supplemented. The action has seen the presentation of a novel method for emulating dynamic angle of arrival for testing beamsteering which is hoped will be presented to 3GPP before the end of the action. Especially the influence of finite measurement chambers for antenna arrays with potentially large far-field distances, the specification of the number of RF channels in 3D channel emulation, and the metrics to evaluate the accuracy of different emulation strategies can be determined by simulations.

In that respect, the situation with lack of experimental millimetre-wave facilities, as noted in earlier reports, has not improved. It is worthwhile noting that most of the institutions participating in IRACON can only acquire equipment in the context of dedicated projects. Application for projects against the background of hesitating standardisation is not likely to be successful, although a recent contribution indicates dual use of a 5G reference radio system developed in-house.

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. The SWG: IoT-Health (Sub Working Group – Internet of Things for Health) as part of EWG-IoT aims to focus on the design, development, performance evaluation and experimentation of IoT in healthcare applications such as health monitoring and Telemedicine.

EWG-IoT is chaired by Erik Ström and Chiara Buratti, while the SWG IoT-Health is chaired by Kamran Sayrafian and Slawomir J. Ambroziak.

6.2 Technical progress

During the third year, EWG-IoT presented 7 TDs in Cartagena, 6 TDs in Podgorica and 8 TDs in Dublin. For Sub-WG IoT-Health there were 5, 4 and 7 TDs, respectively.

The main research topics and trends of the EWG-IoT briefly summarized below.

- **Vehicular Communications and UAV-aided Networks.** The research related to vehicular communications mainly focused on the performance analysis of the IEEE 802.11p standard in urban interference channels. By linking a network simulator to a software defined radio setup, communication performance measurements in the worst-case interference scenario caused by an urban traffic jam, are derived. As far as UAV networks is concerned, the research was devoted to the design of joint design of dynamic trajectories and Radio Resource Management strategies, such as to the definition of an Integer Linear Programming model aiming at maximizing the number of served users, while considering constraints on UAV battery, speed, data rate and radio resources that the UAV can provide to the users. Finally, beamforming has been proposed to improve mmWave link budget between the UAV and users and to decrease possible interference caused by the UAV on the terrestrial network.
- **SDR platform for IoT**. A fully functional prototype for a low-cost satellite gateway based on an embedded Software Defined Radio platform has been designed. The prototype is able to route data between the satellite and IoT devices using standard technologies like 802.11b/g/n, ZigBee, BLE, etc. Other research was dedicated to the development of a new real-time multi-threading operating system, implementing a microkernel architecture supporting a wide range of IoT devices.

- **Routing and MAC protocols for Industrial IoT**. The research was devoted to the implementation of Source Routing Minimum Cost Forwarding (SRMCF) protocol over IPv6 over the TSCH mode of IEEE 802.15.4e (6TiSCH). Different kind of experimental results related to packet losses and round trip time, obtained using the OpenMote-B platform, have been reported in different TDs.
- **Low Power Wide Area Networks**. Some works dealt with the experimental characterization of point-to-point LoRa links in different environments, such as the analysis of the LoRa capture effect and the performance of LoRa Geo-location for outdoor tracking purposes. For what concerns the research related to NB-IoT, a mathematical model of the access mechanism to predict the best performance obtainable in a given scenario with a specific configuration of some of the design parameters, has been proposed. The suitability of NB-IoT for smart grid applications was also investigated, concentrating on the reliable and timely delivery of outage restoration and management messages at the event of a local or regional power outage.

The EWG-IoT in this third year organised the following events:

- Workshop on “Vertical Industries & Services for 5G (VIS5G)”, EUCNC 2018, June 18-21, Ljubljana, Slovenia. Organizers: Woon Hau Chin, Erik G. Ström, Chiara Buratti, Laura Baracchi, Stephanie Parker, Mikael Fallgren, Belkacem Mouhouche.
- Workshop on “UAV Communications for 5G and Beyond”, PIMRC 2018, Sept. 9-12, Bologna, Italy. Organizers: Chiara Buratti, Adrian Garcia-Rodriguez, Gianluigi Ferrari, Ming Ding.
- Special Session on “UAVs for Future Wireless Networks”, PIMRC 2018, Sept. 9-12, Bologna, Italy. Organizer: Chiara Buratti
- A joint WG2 - EWG-IoT training school on “ITSP (Information Theory and Signal Processing) for IoT” took place in Lyon on November 18-22, 2018. The training school included a theoretical part, dealing with bursty multi-user communication and standard for the IoT, and lab activities, where students will have the possibility to use the FIT/CorteXlab facilities.

The main research topics discussed at the SWG IoT-Health are also summarized below.

- **Radio channel modelling in Body Area Networks**: Wearable and implantable sensors or actuators in body area networks are fundamental component of IoT-Health. This research focuses on statistical modelling of radio channels inside, on the surface and in the vicinity of the human body. During the second year, a dynamic channel model for off-body communications and a motion model for wearable antennas in body area networks have been developed. A simple model for body shadowing in off-body and body-to-body channels has also been proposed. New empirical results have been achieved for different static and dynamic scenarios in a ferry environment at 868 MHz and 2.45 GHz. The latter is the result of joint research activities between GUT and IST.
- **Adaptive energy detection threshold in Body Area Networks**:

Several low complexity strategies to adaptively control the energy detection threshold in IEEE802.15.6 have been proposed. These strategies can be used to enhance the QoS performance in scenarios with multiple adjacent Body Area Networks.

- **Localisation of UWB capsule endoscopy**: This research focuses on techniques based on the received signal strength for two-dimensional localisation of a capsule endoscopy using Ultra-Wideband (UWB) communication. The project also includes a novel two-layer experimental liquid phantom to obtain physical measurements and assess the achievable localisation accuracy.
- **RF Exposure & SAR Evaluation**: The objective of this research was validation of a computational model for SAR evaluation of wireless devices. Additionally, using a multi-band body-worn distributed exposimeter, the effect of human morphology on the measurement uncertainty was investigated. Also, the results of in-situ determination of downlink signal levels emitted by GSM 900, GSM 1800, UMTS, and LTE networks in urban areas and the corresponding body exposure were presented.
- **IoT-Health Supporting Services & Infrastructure**: A heterogeneous IoT-based architecture for remote monitoring of physiological and environmental parameters employing Bluetooth and IEEE 802.15.4 wireless protocols has been presented. Healthcare applications in the resulting crowdsensing environment have been discussed. In addition, an alternative methodology to create computationally efficient procedures for unsupervised processing of the data in resource-limited environments has been proposed. Finally, the idea of using TV white spaces to establish a healthcare network infrastructure for wide area remote monitoring has been discussed.
- **IoT-Health for Animals**: A wireless communication system based on an IoT architecture for tracking and monitoring dairy cows has been proposed. This research provides experimental results indicating the accuracy and efficiency of the proposed system.
- **Nanocommunications**: This research focuses on molecular communication using Foerster Resonance Energy Transfer (FRET) mechanism. Preliminary models of the communication system along with analysis of the achievable throughput and bit error rate have been provided. Molecular communication provides an alternative approach for in-body medical applications.

In the third year, the SWG IoT-Health organised a joint COST IRACON & H2020 WIBEC Project workshop titled „WIreless Body COMunications in Medicine (WIBCOMM)". The workshop was held along with the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Sept. 9-12, 2018, Bologna, Italy. In addition, a convened session titled "COST Action CA15104 (IRACON): Measurements and Simulations and Channel Modelling in Wireless Body Area Networks," was organised during EuCAP in Krakow, Poland, on 31.03.-05.04.2019, and one session titled: "IoE and Health Applications," was organised during 18th

International Symposium INFOTEH-JAHORINA, Jahorina, RS, B&H, 20-22.03.2019.

The following two STSMs were also completed during the third period: “Simulation of polarised off-body channels with dynamic users” (18.02.2019–01.03.2019, GUT to IST); and, " Communication interfaces for medical chips in patients’ bodies suitable for early detection of infections” (29.03.2019–10.04.2019, AGH to UPCT).

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 third year, the EWG-LT has organized several sessions at the Cartagena, Podgorica, and Dublin meetings. The number of TDs presented were eight, five and nine, respectively. Besides, a number of joint activities (special sessions, workshops, whitepapers, etc) were undertaken by several IRACON partners. The technical sessions were in general well attended (at least 30 participants at each meeting), regularly leading to interesting and lively discussions.

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

- **Localization and positioning techniques for 4G and 5G communication networks and the IoT**: Different wireless technologies have been investigated regarding their potential use for positioning. The presented papers include a system-level performance study for a vehicular environment looking at placement of roadside units for positioning, sensor fusion and tracking filters exploiting 3G / 4G cell measurements as well as LoRA measurements, and a machine-learning-based beam selection scheme working with AoA data. Novel scenarios and system approaches have been discussed, for instance the use of wireless communications systems for passive radar with an intended use in vehicular scenarios to detect vulnerable road users such as pedestrians and cyclists.
- **Channel modelling, propagation and positioning; modeling of measurements**: Several papers investigated measurement modeling and related positioning algorithms, strongly focused on the radio channel influence. Measurement parameters analyzed include ToA, AoA, and RSS and the scaling with respect to system parameters such as bandwidth and number of antennas and also radio channel parameters. Furthermore, measurement acquisition techniques have been presented, ranging from array-based multipath parameter estimation techniques for positioning, array-based RSS measurements using BLE,

to radar signal processing with 1 bit quantization.

- **Multipath-assisted positioning and data fusion techniques** have again been a topic in various contributions. Multipath assisted positioning would make use of the geometry of reflected, deterministic multipath components, leading to a potential reduction in the infrastructure needed and an enhancement of the robustness. The exchange of map information in SLAM algorithms has been discussed to exploit map information from users that already explored a certain environment previously. Another SLAM algorithm has been presented on the basis of current 4G LTE signals, demonstrating the applicability of the multipath-assisted localization approach to wireless technologies that are alread in use.

As for joint activities, a Seminar on Localization was organized jointly by the IRACON action and the Marie Curie ITN WiBEC (Cartagena; 29-5-2018), consisting of three extended presentations entitled “High-accuracy Positioning in Multipath Channels” by Klaus Witrisal (TU Graz, Austria); “Cooperative Positioning for Real Time Location Systems (RTLS)” by Monica Navarro (CTTC, Spain); and “Positioning and localization of mobiles in rich multipath scenarios” by Davy Galliot (U. Lille, France). Besides, a double special session on “Localization in Current and Emerging Networks” was organized at IEEE WCNC’18 (by UAB, Chalmers, and DLR).

In addition, a **White Paper** on “Localization Techniques for 5G and the IoT” was produced by the EWG-LT, as reported in Deliverable 5, and finally published in April 2018. The two EWG chairs acted as editors and it was authored by 43 IRACON members and non-members. The White Paper has been posted on IRACON’s website and in other repositories like Research Gate, where it has meanwhile received a good visibility within the scientific community. Specifically on Research Gate, the White Paper has achieved 2300 read and more than 700 downloads as of May 29, 2019. From the IRACON website, the White Paper has been downloaded a significant number of tmes.

Complementarily, substantial work has been done towards the preparation of the **book chapter in IRACON’s final book**. This has resulted into a stable table of contents with the following sections and appointed section editors:

1. Introduction (Carles Anton, CTTC; Klaus Witrisal, TU Graz)
2. Measurement acquisition, measurement modeling, and performance limits (Stefan Grebien, Thomas Wilding, both TU Graz)
3. Position estimation methods, data fusion, and tracking (David Plets, Joseph Wout, both U. Gent)
4. Multipath exploitation and modeling (Erik Leitinger and Xuhong Li, Lund U. and TU Graz)
5. System study, system-level performance analysis and performance limits (Jose del Peral, UAB; and Jordi Vilà-Valls, Supaero)
6. Testbed and prototyping activities (Carles Anton, CTTC; Klaus Witrisal, TU Graz)

and the preparation of an interim draft including the all the TDs presented in the meetings of the COST Action so far (Brussels, Lille, Durham, Lisbon, Lund,

Graz, Nicosia, Podgorica and Dublin). Selected parts of the whitepaper (introduction, testbeds and experimental platforms) have also been adapted and included in the book chapter.

Finally, a number of **papers jointly authored** by researchers from more than one IRACON partner have been published during this reporting period.

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

The activities of this EWG were in practice merged with other WGs, as the number of TDs did not warrant specific EWG-RA sessions. The members of the WG will also contribute to the various chapters of the Final Book, when experimental testbeds are to be discussed.

9. Conclusions and Perspectives

9.1 Conclusions

During its third year, the various Working Groups have continued working towards the objectives of the Action. As described in the previous sections, all WGs are progressing according to plan and have completed the assigned objectives for the third grant period.

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

1	Discuss and review future architecture and protocols for the Internet of Things (including the production of one deliverable)	Covered by EWG-IoT (see Section 6)
2	Promote the use of pan-European laboratory facilities and networks for shared experimental research addressing Over-the-Air (OTA) testing, IoT, localisation, tracking and radio access, using a shared web platform.	Updated list now online http://radiokom.eti.pg.gda.pl/IRM/
3	Facilitate the collaboration between ECIs through STSMs, with at least 6 missions over the Grant Period (GP)	16 STSMs submitted, 11 STSMs funded
4	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) • Contribution to ITU-R SG3 (see Section 2.3) • IRACON liaisons: ➔ 3GPP – Aki Hekkala ➔ URSI – Sana Salous ➔ ITU-R – Sana Salous and Belen Montenegro ➔ IEEE 1900.6 – Kostas Katzis
5	Maintain on-going links with existing H2020 projects (Clear5G, 5G-car, etc.), by organizing one joint workshop in the grant period (at EuCNC 2018).	• Joint EuCNC workshop with Clear 5G • IRACON liaisons: ➔ H2020 METIS-II – Narcis Cardona ➔ H2020 mmMAGIC – Mark Beach ➔ H2020 5G X-haul – Mark Beach ➔ CommNet (EPSRC network) – Mark Beach ➔ ITN WiBEC – Narcis Cardona

		➔ 5G-VINNI – Per Hjalmar Lehne ➔ 5G-HEART – Per Hjalmar Lehne ➔ 5G-EVE – Florian Kaltenberger ➔ EMPOWER – Per Hjalmar Lehne ➔ 5G initiative – Fernando Velez
6	Train ECIs through the organization of two training schools	Three training schools were organized during the second grant period ➔ http://www.iracon.org/training-schools/
7	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.	• Publication of quarterly newsletters ➔ http://www.iracon.org/newsletters/ • Animation of an online blog ➔ http://www.iracon.org/blog/ • Publication of two white papers ➔ http://www.iracon.org/whitepapers/ • Organization of workshops ➔ http://www.iracon.org/workshops/ • Organization of special sessions (e.g. at EuCAP2019) ➔ http://www.iracon.org/special-sessions/
8	Define radio channel models to cover gaps in existing models, in particular for the mmWave band and for localization	See Section 2
9	Propose new schemes at PHY and MAC layers for 5G, with a focus on interference mitigation, ultra low power and latency.	See Sections 3 and 4
10	Discuss COST gender policy through women-only meetings at MC meetings, with inputs to the newsletter or to the blog	The newsletters often highlight the role of women within the Action. IRACON also participated to the online action organized by the COST office (movie)
11	Discuss the content of the final book of the Action and identify key editors.	On-going (see Section 1).

9.2 Perspectives for the fourth 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. 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;
2. facilitate the collaboration between ECIs through STSMs (at least 6 missions over the GP);

3. provide technical inputs and liaison statements to Standardisation Groups on metrics for Over the Air (OTA) testing;
4. finalize a set of IRACON concerted radio channel models for 5G and beyond;
5. maintain liaisons with international standardisation 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 standardised 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 (Clear5G, 5G-car, etc.), by organizing one joint workshop in the grant period;
7. train PhD students through the organization of at least two training schools, with a focus on the network layer;
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 experimental platforms for performance evaluation; the organization of at least two special sessions/workshops at international conferences (EuCAP, PIMRC);
9. write the final book of the Action;
10. discuss COST gender policy through women-only meetings at MC meetings, with recommendations to the COST office.

Annex: List of Temporary Documents

	TD number	Title	Authors
1	TD(18)07001	An Empirical System Loss Model for Body Area Networks in a Passenger Ferry Environment	Pawel T. Kosz, Slawomir J. Ambroziak, Jacek Stefanski, Krzysztof K. Cwalina, Luis M. Correia, Kenan Turbic
2	TD(18)07002	An Off-Body Narrowband and Ultra-Wide Band Channel Model for Body Area Networks in a Ferry Environment	Krzysztof K. Cwalina, Slawomir J. Ambroziak, Piotr Rajchowski
3	TD(18)07003	Mobile Device for Generating Electromagnetic Curtain for Special Applications	Piotr Rajchowski, Slawomir J. Ambroziak, Krzysztof K. Cwalina, Jaroslaw Magiera, Pawel T. Kosz
4	TD(18)07004	Multipath Fingerprints Exploitation to Enhance Localization Performance in TDoA Systems	Marcelo Nogueira de Sousa, Reiner Thomä
5	TD(18)07005	LoRa-like CSS-based PHY layer, capture effect and Serial Interference Cancellation	Umber Noreen, Laurent Clavier, Ahcène Bounceur
6	TD(18)07006	Millimeter Wave Multi-User Performance Evaluation Based on Measured Channels With Virtual Antenna Array Channel Sounder	Allan Wainaina Mbugua, Wei Fan, Yilin Ji, Gert Frølund Pedersen
7	TD(18)07007	Assessment of the Suitability of NB-IoT Technology for ORM in Smart Grids	Varun Nair, Remco Litjens, Haibin Zhang
8	TD(18)07008	Modelling and Evaluation of Uplink and Downlink KPI Variations using Information Bottleneck and Non-parametric Hypothesis	Taulant Berisha and Christoph F. Mecklenbräuker
9	TD(18)07009	Theoretical and Experimental Study at 60 and 94 GHz in Indoor Environments	Maria-Teresa Martinez-Ingles, Davy Gaillot, Juan Pascual García, Jose-Maria Molina-Garcia-Pardo, José-Víctor Rodríguez, Leandro Juan Llácer
10	TD(18)07010	Evaluation of an antenna selection strategy for reduced massive MIMO complexity	F. Challita, M.Liénard, D.P. Gaillot, M-T. Martinez-Ingles, J-M. Molina-Garcia-Pardo

11	TD(18)07011	Flexible Multi-Numerology Systems for 5G New Radio	Ahmet Yazar, Huseyin Arslan
12	TD(18)07012	Study of coexistence between different services in novel 5G Frequency Bands	Claudia Carciofi, Paolo Grazioso, Francesco Matera, Valeria Petrini
13	TD(18)07013	A Map-Free Indoor Localization Method Using Ultrawideband Large-Scale Array Systems	Yilin Ji, Johannes Hejselbæk, Wei Fan, Gert F. Pedersen
14	TD(18)07014	Frequency Dependence of UWB In-Body Radio Channel Characteristics	Carlos Andreu, Concepcion Garcia-Pardo, Sergio Castelló-Palacios, Ana Vallés-Lluch and Narcís Cardona
15	TD(18)07015	PDOA Emitter Location Using Game Engines 3D Ray based Tools	Andres Navarro and William Cruz
16	TD(18)07016	Antenna Aperture Impact on Channel Delay Spread in an Urban Outdoor Scenario at 17 and 60 GHz	Cheikh Diakhate, Jean-Marc Conrat, Jean-Christophe Cousin, Alain Sibille
17	TD(18)07017	Predicting Wireless Coverage Maps Using Radial Basis Network	Yisroel Mirsky, Yoram Haddad, Orit Rozenblit, Rina Azoulay
18	TD(18)07018	Wireless Controller Placement Problem	Amit Dvir, Yoram Haddad, Aviram Zilberman
19	TD(18)07019	Implementation of Low-complexity Hybrid Analogue-digital Solutions in CAP-MIMO	Rooderson Martines de Andrade, Fernando J. Velez, Kun Chen, and Ana Garcia Armada
20	TD(18)07020	Insights on Spectrum Sharing in Heterogeneous Networks with Small Cells	Bruno C. Silva, Sofia C. Sousa, Emanuel Teixeira, Fernando J. Velez
21	TD(18)07021	FM Band Channel Modelling and Measurements	Omar Ahmadin and Mehmet Kemal Ozdemir
22	TD(18)07022	A Study of Polarimetric Diffuse Scattering at 28 GHz in an Urban Open Square	Pasi Koivumäki, Sinh L. H. Nguyen, Katsuyuki Haneda, Gerhard Steinböck
23	TD(18)07023	Measured Channel Hardening in an Indoor Multiband Scenario	Golsa Ghiaasi, Jens Abraham, Egil Eide and Torbjörn Ekman
24	TD(18)07024	UWB RSS-based Localization for Capsule Endoscopy using a Multilayer Phantom and In-Vivo Measurements	Martina Barbi, Concepcion Garcia-Pardo, Andrea Nevarez, Vicente Pons, Narcís Cardona
25	TD(18)07025	Hierarchical Decoding with Bit-Wise Soft-Aided H-SODEM and Iterative Double-Loop Processing	Jan Sykora

26	TD(18)07026	Initial UWB In-Body Channel Characterization Using a Novel Multilayer Phantom Measurement Setup	Sofia Perez-Simbor, Martina Barbi, Concepcion Garcia-Pardo, Sergio Castelló-Palacios, Narcís Cardona
27	TD(18)07027	Spatial Statistical Analysis for the Design of Indoor Particle Filter based Localization Mechanisms	Miguel Martínez del Horno, Ismael García Varea and Luis Orozco Barbosa
28	TD(18)07028	Experimental Demonstration of BLE Transmitter Positioning based on AOA Estimation	Shaghayegh Monfared, Trung-Hien Nguyen, Luca Petrillo, Philippe De Doncker, Francois Horlin
29	TD(18)07029	Characterizing and Modeling the Wideband Vehicle to Pedestrian Propagation Channels	Gloria Makhoul, Raffaele D'Errico, Claude Oestges
30	TD(18)07030	Network Design for Accurate Vehicle Localization	José A. del Peral-Rosado, Gonzalo Seco-Granados, Sunwoo Kim, and José A. López-Salcedo
31	TD(18)07031	Resource Allocation and Sharing for Heterogeneous Data Collection over Conventional 3GPP LTE and Emerging NB-IoT Technologies	Samouylov K. and Gaydamaka Y.
32	TD(18)07032	On Simple Scattering and Diffraction Models using Point Cloud Maps for Channel Model or Coverage Predictions	Jean-Frederic Wagen and Karol Kruzelecki
33	TD(18)07033	TAKE - Tactical Ad-Hoc Network Emulation	Simon Ruffieux, Christophe Gisler, Jean-Frederic Wagen, Francois Buntschu and Gerome Bovet
34	TD(18)07034	An SLA-Based Method for Radio Resource Slicing and Allocation in Virtual RANs	Behnam Rouzbehani, Luis M. Correia, Luísa Caeiro
35	TD(18)07035	Spatial Data Focusing: an alternative to Beamforming for geocasting scenarios	Julien Sarrazin, Michael Odhiambo, Sidney Golstein, François Horlin, Philippe De Doncker
36	TD(18)07036	Extended TDL Modeling for V2X Channels	Nina Hassan, Martin Kaske, Gerd Sommerkorn, Christian Schneider and Reiner Thomä
37	TD(18)07037	Simultaneous Multi-band Indoor Measurements from 6 to 60 GHz - a Study on System Influence on Channel Modelling	Diego Dupleich, Robert Müller, Sergii Skoblikov, Christian Schneider, Jian Luo, Giovanni Del Galdo, and Reiner Thomä
38	TD(18)07038	V2V/V2R Channel Measurements on a Highway at 2.53GHz: A Delay and Doppler Discussion	Gerd Sommerkorn, Daniel Czaniera, Martin Käske, Christian Schneider and Reiner Thomä

39	TD(18)07039	The hypervisor-based and container-based virtualization in IoT environment	Borislav Djordjević, Valentina Timcenko
40	TD(18)07040	Millimeter wave channel measurements in an intra-wagon environment	Vicent M. Rodrigo-Peñarrocha, Lorenzo Rubio, Juan Reig, Leandro Juan-Llácer, Juan Pascual-García and José María Molina-García-Pardo
41	TD(18)07041	Information transfer from FRET-based nanonetworks to nerve cells	Jakub Kmiecik, Pawel Kulakowski, Krzysztof Wojcik, Andrzej Jajszczyk
42	TD(18)07042	Elaboration of Simple Gel Phantoms for 5G/mmWave Communications	Sergio Castelló-Palacios, Reza Aminzadeh, Concepcion Garcia-Pardo, Günter Vermeeren, Narcís Cardona, Wout Joseph, Ana Vallés-Lluch
43	TD(18)07043	Hybrid virtual polarimetric Massive MIMO measurements at 1.35 GHz	F. Challita, P. Laly, M.Liénard, D.P. Gaillot
44	TD(18)07044	Specification of the Internet of Things platform for energy efficient living	Lazar Berbakov, Nikola Tomašević, Marko Batić
45	TD(18)07045	Correlation-based Clustering Procedure Towards Energy-Efficient Cooperative Spectrum Sensing	Krzysztof Cichoń, Adrian Kliks, Hanna Bogucka
46	TD(18)07046	Modelling Polarimetric Power Delay Spectrum for Indoor Wireless Channels via Propagation Graph Formalism	Ramoni Adeogun and Troels Pedersen
47	TD(18)07047	On Clustering in Multipath Channel Models	Alister Burr, Katsuyuki Haneda and Aki Karttunen
48	TD(18)07048	Conformal Automotive Roof-Top Antenna Cavity With Increased Coverage to Vulnerable Road Users	Gerald Artner, Wim Kotterman, Giovanni Del Galdo and Matthias A. Hein
49	TD(18)07049	Fixed link long term measurements	Sana Salous, Yusheng Cao, Xavier Raimundo
50	TD(18)07050	Modeling Human Blockage at 5G Millimeter Wave Frequencies	Usman Tahir Virk and Katsuyuki Haneda
51	TD(18)07051	Next steps in channel modelling and OTA test methods for 5G	Moray Rumney
52	TD(18)07052	Performance Evaluation of Source Routing Minimum Cost Forwarding Protocol over 6TiSCH applied to the OpenMote-B platform	Fernando José da Silva Velez; Gordana Gardašević; Anderson Rocha Ramos

53	TD(18)07053	Use of Digital Maps in Context of Radio Propagation Simulations	Marjo Heikkilä, Aki Hekkala, Ossi Saukko
54	TD(18)07054	Measurement based ultra-wideband channel model for mobile communications in tunnels	Andrej Hrovat, Klemen Bregar, Tomaž Javornik
55	TD(18)07055	Localization of Scatterers in Railway Environments for Train-to-Train Propagation	Paul Unterhuber, Michael Walter, Thomas Kürner
56	TD(18)07056	Spatial consistency of clusters in mm-wave ray-tracing results for 5G communications	Manijeh Bashar, Katsuyuki Haneda and Alister Burr
57	TD(18)07057	Relative Positioning and Velocity Component Estimation of Two Vehicles by using the Time-VAriant, Delay-Dependent Doppler Spectrum	M. Walter
58	TD(18)07058	Window loss measurements and Model Validation	Satyam Dwivedi, Jonas Medbo
59	TD(18)07059	Exchanging Transmitter Maps in Multipath Assisted Positioning	Markus Ulmschneider, David Calvo Luz, Christian Gentner
60	TD(18)07060	Joint Path and Radio Resource Management for UAVs Supporting Mobile Radio Networks	Silvia Mignardi, Roberto Verdone
61	TD(18)07061	Spatiotemporal Gait Variables using Wavelets for an Objective Analysis of Parkinson Disease	Yor Castaño, Juan Arango and Andres Navarro
62	TD(18)07062	Joint Aerial-Terrestrial Resource Management in UAV-Aided Mobile Radio Networks	Roberto Verdone, Silvia Mignardi
63	TD(18)07063	Wideband Channel Measurements for Polarised Indoor Off-Body Communications	Kenan Turbic, Slawomir J. Ambroziak, Luis M. Correia, Marko Beko
64	TD(18)07064	A Real-time Computational Resource Management in C-RAN	Mojgan Barahman, Luis M. Correia, Lúcio S. Ferreira
65	TD(18)07065	A Simple Method for Robust Vehicular Communication with Multiple Nonideal Antennas	Keerthi Kumar Nagalapur, Erik G. Stro¨m, Fredrik Bra¨nnstro¨m, Jan Carlsson, and Kristian Karlsson
66	TD(18)07066	System-Theoretical Modeling and Analysis of Phase Control in a Photonically Steered Terahertz Phased Array Transmitter	Kevin Kolpatzeck, Xuan Liu, Lars Häring, Andreas Czylwik
67	TD(18)07067	Data from Social Sources in Cellular OAM	Sergio Fortes, David Palacios, Inmaculada Serrano, Raquel Barco

68	TD(18)07068	Polarimetric Diffuse Scattering Channel Measurements at 60GHz and 26GHz	Alberto Loaiza, Timothy Pelham, Di Kong, Lawrence Sayer, Victoria Sgardoni, Fai Tila, Evangelos Mellios, Mark Beach, Andrew Nix, Gerhard Steinböck
69	TD(18)07069	Tri-Band Mm-wave Directional Channel Measurements in Indoor Environment	Enrico Vitucci, Marco Zoli, Ke Guan, Franco Fuschini, Marina Barbiroli, Thomas Kuerner, Vittorio Degli Esposti
70	TD(18)07070	Power delay profile modelling in indoor environments using the VEFIE	Ian Kavanagh and Conor Brennan
71	TD(18)07071	Cell-Free Massive MIMO with Limited Backhaul	Manijeh Bashar and Alister Burr
72	TD(18)07072	A unified channel model for terrestrial and non-terrestrial networks	Tommi Jämsä, Guo Bolun, Mingming Gan, Gerhard Steinböck
73	TD(18)07073	Impact of rough surface scattering on stochastic multipath component models	Josef Kulmer, Fuxi Wen, Nil Garcia, Henk Wymeersch, Klaus Witrisal
74	TD(18)07074	Resource Allocation in Wireless Mesh Networks	Arie Reichman, Shahaf Wayer, Miri Prieser
75	TD(18)08001	Novel Over-the-Air test method for 5G mmWave devices with beam forming capabilities	David Reyes, Mark Beach, Evangelos Mellios, Moray Rumney
76	TD(18)08002	Resilience of airborne networks	Hamed Ahmadi, Gianluca Fontanesi, Konstantinos Katzis, Muhammad Zeeshan Shakir, Anding Zhu
77	TD(18)08003	NB-IoT: Performance Estimation and Optimal Configuration	Luca Feltrin, Massimo Condoluci, Toktam Mahmoodi, Mischa Dohler, Roberto Verdone
78	TD(18)08004	A study of the effect and mitigation of wind turbines on telemetry links and digital TV reception	Karim M. Nasr
79	TD(18)08005	Indoor 1-40 GHz Channel Measurements	Maria-Teresa Martinez-Ingles, Juan Pascual-Garcia Davy, P. Gaillot, Concepción Sanchís-Borrás, Jose-Maria Molina Garcia-Pardo
80	TD(18)08006	Outdoor 3G Location Tracking of Mobile Devices in Cellular Networks	Jens Trogh, David Plets, Erik Surewaard, Mathias Spiessens, Mathias Versichele, Luc Martens and Wout Joseph

81	TD(18)08007	On the worst-case influence of atmospheric circumstances on microwave links	Emmanuel Van Lil, Roeland Van Malderen
82	TD(18)08008	Neural network approach for human activity recognition on smartphones and smartwatches	Martin Milenkoski, Kire Trivodaliev, Biljana Risteska Stojkoska Martin Milenkoski
83	TD(18)08009	TDoA-based Outdoor Positioning with Tracking Algorithm in a Public LoRa Network	Nico Podevijn, David Plets, Jens Trogh, Luc Martens, Pieter Suanet, Kim Hendrikse, Wout Joseph
84	TD(18)08010	H-MAC Channel Phase Estimator with Hierarchical Data Decision Aided Feed-Back Gradient Solver	Jan Sykora
85	TD(18)08011	A Channel Model for Polarised Off-Body Communications with Dynamic Users	Kenan Turbic, Luis M. Correia and Marko Beko
86	TD(18)08012	Performance Analysis of Mixture of Unicast and Multicast Sessions in 5G NR System	Konstantin Samouylov, Yuliya Gaidamaka
87	TD(18)08013	3D Map Implementation And Visualization for Radio Propagation Simulation	Ossi Saukko, Aki Hekkala, Ville Pitkäkangas, Anttoni Porri, Marjo Heikkilä
88	TD(18)08014	Efficient Detection and Clustering Mechanisms for Spectral-Activity Information Exchange	Krzysztof Cichoń, Hanna Bogucka
89	TD(18)08015	Internet of Things and Mobile Crowdsensing in Hypertensive Patients	Tamara Škorić, Slađana Jovanović, Milan Jovanovic, Branislav Milovanović, Konstantinos Katzis, Dragana Bajić
90	TD(18)08016	Clutter Loss in a Vegetated Residential Environment – Part-I	Saul A. Torrico and Roger H. Lang
91	TD(18)08019	An Energy Efficient Service-based RAN slicing Technique in Virtual Wireless Networks	Behnam Rouzbehani, Luis M. Correia, Luísa Caeiro
92	TD(18)08020	Conformal Automotive Antennas in the Roof for Vehicle-to-X Communications	Gerald Artner, Wim Kotterman, Giovanni Del Galdo, Matthias A. Hein
93	TD(18)08021	A Minimum Average-delay and Maximum Spectral Efficiency Configuration Algorithm for Relay-assisted HARQ Transmissions Under Reliability and Maximum-delay Constraints	Vasile Bota, Mihaly Varga
94	TD(18)08022	1-bit Localization Scheme for Radar using Dithered Quantized Compressed Sensing	Thomas Feuillen, Chunlei Xu, Luc Vandendorpe and Laurent Jacques

95	TD(18)08023	Path Optimization for Unmanned Aerial Base Stations with Limited Radio Resources	Silvia Mignardi, Chiara Buratti, Valentina Cacchiani, Roberto Verdone
96	TD(18)08024	Statistical modelling of short-range interference paths	Richard Rudd
97	TD(18)08025	Performance Evaluation and Packet Scheduling in HeNB Deployments	Rui R. Paulo, Fernando J. Velez and Giuseppe Piro
98	TD(18)08026	SIMO RSS Measurement in Bluetooth Low Power Indoor Positioning System	Stanislav Rozum, Jiri Sebesta, Martin Slanina, Ladislav Polak
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