# The Instrumentation and Measurement Society Technical Committee TC-37: Measurements and Networking

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TC-37–Measurements and Networking (current Chair Prof. Domenico Capriglione, University of Cassino and Southern Lazio, Italy) began six years ago as a proposal of Prof. Leopoldo Angrisani (University of Napoli Federico II, Italy) and Prof. Claudio Narduzzi (University of Padova, Italy) with the main purpose of increasing awareness and interest in networking and to encourage Instrumentation and Measurement Society (IMS) members to apply their skills and extend their knowledge of networking-related problems in the field of Instrumentation and Measurement (I&M) applications.

Indeed, given the complexity of modern networks and related systems, a multidisciplinary approach has to be followed for correctly addressing the technological challenges and issues that are arising and will arise in the future in the field of telecommunication systems and networking. So, the TC-37 tries to promote the international cooperation and integration of researchers belonging to the IMS with ones coming from other areas of the telecommunication and information technologies. In particular, efforts are made to highlight the important contribution of a metrological approach within different areas of networking, looking also to emerging fields such as IoT, software defined radio, software defined networks, coexistence and interference problems in wireless networks, 5G systems, to cite a few. To these aims, TC-37 is in touch with several other bodies in the networking world, such as the IP Performance Metrics working group (WG) of the Internet Engineering Task Force (IETF), the SIGMETRICS special interest group of Association for Computing Machinery (ACM) and the Antenna Measurement Techniques Association (AMTA).

The main fields of expertise include measurement for networking, networking for measurements, measurements for network performance assessment, measurements in/and for IoT, measurements for security in networks. Recently, new emerging topics have been included such as "measurements on 5G systems" and "antenna measurements for modern telecommunication systems."

The TC cooperates with the technical committees of the IEEE International Instrumentation and Measurement Technology Conference about the topics of expertise of TC-37, and it also is massively involved in the organization of the biennial IEEE Symposium on Measurements and Networking and the IEEE Sensors Applications Symposium.

As for the standardization activity of IEEE, the TC-37 supports WGs involved in the development of standards sponsored or co-sponsored by IMS.

The TC-37 has links with other IMS technical committees, e.g., TC-13–Wireless and Telecommunications in Measurements and TC-36–Industrial Inspection, and also tries to keep in touch with other IEEE societies such as the Communication Society and Computer Society. Today, TC-37 comprises 26 members mainly belonging to the IMS, and these researchers and their affiliations are listed on the TC website (http://tc37.ieee-ims.org/tc-contacts-cc).

In the following, a more detailed description of the main recent relevant activities of TC-37 is given.

## Main Fields of Expertise and Recent Relevant Activities

The main fields of expertise of TC-37 members include measurement for networking (methods and techniques for network performance assessment, quality of experience (QoE) and quality of service (QoS) in computer networks, traffic and protocol analysis, in-service testing), networking for measurements (wireless sensor network (WSN) design, implementation and performance assessment of WSNs, indoor positioning, synchronization issues, vehicular networks, cognitive radio), measurements for security in networks (anomaly and intrusion detection, application level trust and security, wireless and mobile network security, coexistence and interference problems in networks and sensor networks). Within such topics, some recent and relevant activities carried out by the members of TC-37 are described in the following.

### *Design and Development of SNs for Assistive Technology*

Assistive technology (AT) is a term with a very broad meaning that groups all of those devices, objects, hardware and


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software solutions intended for people with disabilities and/or elders and whose purpose is to improve the performance of all those daily activities that otherwise would be very difficult or even impossible for them, with consequent benefits on their independence, well-being, social inclusion and quality of life in general. AT counts on a variety of enabling ICT technologies, ranging from electronics and sensors to computer science, to develop reliable solutions with a high degree of acceptability that improve the life quality of frail people.

In the framework of AT, Prof. Bruno Andò (University of Catania, Italy) and his research group working at the SensorLab of the University of Catania, Italy are strongly involved in the NATIFLife project, "A Network of Assistive Technology for an Independent and Functional Life," funded in 2018 under the PC-Interreg Italia-Malta program.

Under the common challenge of the two regions tackled by the project, which is to provide effective technological solutions to the growing needs of independency and autonomy of elderly and people with impairments, the NATIFLife Project aims to define a new network infrastructure to develop valuable solutions in the field of AT for elderly willing to live autonomously.

The architecture developed through this project is based on a wide sensor network, which includes solutions for indoor localization, bio-physical user monitoring, assessment of users' habits and interaction with the living environment. Two joint living labs are under development in Catania and Malta that foster a strong link between user needs and technology. Living labs are strategic environments where new solutions can be developed by involving end-users, during the user-centered design and the final assessment [1].

### Development and Performance Assessment of SNs Based on IoT Protocols

Activities of the group coordinated by Prof. Leopoldo Angrisani (University of Naples Federico II) followed three main research lines. The first one focused on sensor networks based on IoT protocols for measurement and distributed monitoring. The most relevant examples are the networks for: (*i*) monitoring environmental radioactivity mainly tailored for disused nuclear power plants, (*ii*) monitoring structural health of reinforced concrete structures [2], and (*iii*) measuring domestic electrical power in order to improve consumer awareness. The second line involved the implementation of a remote laboratory based on augmented reality and IoT communication protocols. To achieve this objective, an appropriate hardware/software interface was created which allows communication with traditional measurement instrumentation (exploiting GPIB) through the message protocol most commonly used in IoT applications (i.e., MQTT). The third activity has dealt with methods of assessing the performance of IoT protocols; in particular, two methods for estimating the performance and parameters of LoRa protocol in the presence of noise were defined and characterized [3].

### New Experimental Methodologies for Industrial Distributed Measurement Applications

The research activities are in the field of wireless sensor networks and cyber-physical systems within the framework of industrial distributed measurement applications. One objective of Prof. Federico Tramarin (University of Modena, Italy) and his research group has been to provide innovative experimental methodologies to increase the robustness and determinism of the transmission time of measurement and control data over recent IEEE 802.11 MIMO systems. A model of the system was defined through experiments on real devices, which led to an appropriate tuning of the protocol parameters that allow it to achieve redundancy at the physical layer and significantly decrease data loss. An innovative technique for a dynamic transmission rate control, based on a cross-layer approach, has been proposed. The algorithm receives an indication of the deadline corresponding to the application data to be sent, and the measurement of the transmission channel status in terms of the signal to noise ratio. The choice of the speed is then made through the solution of a constrained minimization problem, where the packet error probability is minimized and conditioned with respect to maximum delivery time [4].

### Industrial Internet of Things: Solutions and Performance Evaluation

The Internet of Things (IoT) paradigm had a disruptive impact on many different application fields. The industrial domain has been affected as well, as confirmed by the definition of the Industry 4.0 initiative, aiming to improve overall efficiency in manufacturing processes. The IIoT (Industrial IoT) acronym has been coined to address the application of IoT technologies in the industrial domain. In particular, wireless IoT-like communication solutions have been widely applied in the recent past due to the flexibility and scalability they offer.

In light of these considerations, Prof. Emiliano Sisinni (University of Brescia, Italy) and his research group investigated the most diffused low power wide area networks (LPWANs), identifying the LoRa radio technology and the LoRaWAN communication protocol stack as an effective solution for building public and private cellular-like wireless networks for IIoT. The star-of-stars architecture the LoRaWAN networks offer, mimicking the mobile communication approach, requires well-defined metrics for performance evaluation. Despite being originally designed for sporadic communications, in which time awareness is not of main concern, LoRaWAN can be enhanced by simple but effective time dissemination strategies, including a-posteriori time synchronization [5]. Additionally, the very simple protocol, designed to minimize overall cost and computation requirements, permits the implementation of a transparent repeater that allows it to overcome limitations of a single-hop wireless tier, extending the coverage in harsh environments like those found in industrial buildings and premises [6].

### *Design and Validation of Sensing Network Architectures for Smart Measurement*

The design of networking environments for effective support of smart measurement systems is among the research aims of Prof. Giada Giorgi and Prof. Claudio Narduzzi (University of Padua, Italy) with their WG. The main interest is the analysis and optimization of measurement performances under typical network requirements such as data compression, energy saving and protocol tuning.

Personalized health monitoring services and telemedicine applications rely on the availability of dependable networks of low-cost energy-efficient wearable devices. The design of these networks involves communication protocol analysis and optimization and the development of dedicated data compression algorithms and event-based signaling mechanisms to reduce the huge amount of data generated in these applications. Furthermore, innovative signal processing algorithms need to be developed and their performances, strictly related to a new definition of QoE for e-health applications, must be studied in relation with the QoS provided by the network infrastructure [7], [8].

Cyber-physical systems are becoming ubiquitous in a great variety of applications, i.e., smart cities, smart factory smart grids and smart systems in general. In these contexts, it is essential to distribute a common time and/or frequency reference among system components. Network-based synchronization protocols provide an interesting solution. Prof. Giada Giorgi has been working for several years on accurate, robust and resilient statistical signal processing algorithms for precision network synchronization, [9], [10].

### *Design and Tuning of Self-driving Networks through Measurements*

The WG of Prof. Pere Barlet (Barcelona Neural Networking Center of Universitat Politècnica de Catalunya, Spain) is working on the application of the most recent advancements in artificial intelligence (AI) and machine learning (ML) to build self-driving networks. Although recently there has been significant research in this area, existing proposals are still unable to generalize to other network scenarios (i.e., they cannot operate efficiently in networks not seen during training). Designers argue that the lack of generalization is the main obstacle for the development of novel commercial products based on deep reinforcement learning (DRL) and their deployment in production networks.

In this context, network measurements and monitoring are crucial to integrate AI/ML techniques into the network control plane. In particular, our ongoing research is focused on the combination of DRL, with graph neural networks (GNN) and network measurements, to develop autonomous network agents that can operate efficiently in unseen network scenarios. The most recent results in this direction include RouteNet, the first GNN for computer networks, the development of a DRL-based agent for routing in optical transport networks [11], and the first work to combine DRL and GNN for network optimization [12].

### *Short-range Positioning Techniques*

Prof. Antonio Moschitta (University of Perugia, Italy) and his WG are currently involved in the topic of short-range positioning techniques based on multiple interconnected magnetic sensors. Accurate short-range positioning is currently a field of research that, depending on the targeted accuracy, can enable several applications, like remote telemanipulation, posture monitoring and biometrics for ambient assisted living, simultaneous localization and mapping applications, location-based services and line traceability. This research activity was recently focused on systems capable of real-time estimation of both position and orientation of multiple small devices, with subcentimeter accuracy and a measurement rate of 30 measurements per second or more. The proposed solutions are mostly based on low frequency inductively coupled ac magnetic fields and as a spin-off activity, on ultrasound waves. Current developments involve increased scalability of the developed prototype, to simultaneously track a few tens of moving devices, and for the ultrasound part, improved resilience to multipath phenomena and optimal placement of the system's anchors [13], [14].

Prof. Luigi Ferrigno (University of Cassino and Southern Lazio, Italy) and his research group have deeply worked on the same research topic due to the joint Project of Relevant National Interest (PRIN) that focuses on a six degrees of freedom scalable finger tracking system, along with the teams at the University of Perugia, Italy, University of Cassino and Southern Lazio, Italy and University of Brescia, Italy. In particular, the work has focused on the characterization of the localization system proposed by the University of Perugia, Italy to evaluate its robustness in an electromagnetic environment affected by disturbances, and on the proposal of a biomedical and an industrial application. As for the evaluation of the effect of electromagnetic disturbance, a novel method to mitigate the environmental noise effect has been developed. The biomedical and industrial applications have tracked the tremor and the finger trajectory of Parkinson's disease affected patients and the localized an eddy current probe during non-destructive test execution for defect detection on a planar surface [15], respectively.

### *Indoor Localization of Moving Agents*

The research activities of Prof. David Macii and Prof. Daniele Fontanelli (University of Trento, Italy) are focused on the development of sensor data fusion algorithms for indoor positioning and tracking of moving agents, particularly (but not only) service robots. The proposed estimators are conceived to be robust to outliers and multiple non-Gaussian uncertainty contributions to keep positioning uncertainty within given boundaries. Multiple experiments in the field were conducted by using different kinds of sensors. The underlying common idea is to merge the data from proprioceptive sensors that are able to track continuously the relative displacement of an agent moving indoors (e.g., by using ad-hoc inertial measurement units or odometers in the case of wheeled robots) with the sporadic position information measured from a limited amount of reference devices deployed in the environment. The ultimate goal is to maximize positioning performance and robustness at a reasonable cost and with adequate scalability when multiple agents move within the same environment. The reference devices can be either active (e.g., Wi-Fi access points or Bluetooth Low Energy anchor nodes) or passive, such as passive radio-frequency identification (RFID) tags or visual landmarks such as the QR-code labels. The passive reference devices are much less expensive, and the distance between an agent and each of them can be estimated with higher accuracy. However, the detection range of the adopted onboard sensors (e.g., an RFID reader or a camera) is typically much shorter (in the order of a few meters). As a consequence, a large number of passive devices is generally needed to ensure localization under given uncertainty constraints in large indoor environments. Fortunately, this problem and the related deployment costs of passive devices can be greatly mitigated if optimal placement strategies are adopted [16]. The most recent works of the group of the University of Trento, Italy in the field of indoor positioning deal with: the use of phase measures of backscattered RFID signals for enhanced agent tracking [17] and the performance evaluation of short-range 60-GHz radar systems based on antenna arrays for accurate multi-target positioning.

### *Spectral Measurements for Efficient Dynamic Spectrum Access*

Prof. Gianfranco Miele (University of Cassino and Southern Lazio, Italy) and his WG have been involved for several years in researching the topic of spectral measurements, especially focused on the design, characterization, and implementation on physical devices that involve spectrum sensing schemes for the cognitive radio world, in the framework of opportunistic dynamic spectrum access.

In this context, several spectrum sensing techniques belonging to a wideband class have been proposed and experimentally characterized to verify their applicability in blind scenarios [18], [19]. Suitable signal conditioning approaches able to enhance signal-to-noise ratios [20] have been also proposed and tested. The proposed methods have been implemented on real devices and tested in a distributed environment.

Such experience has been very important for contributing to the development of "IEEE 802.15.22.3: TV White Space Spectrum Characterization and Occupancy Sensing," where Prof. Gianfranco Miele and his WG are working to provide a framework to standardize the operations of spectrum monitoring, by defining devices, interfaces, message formats, and system architecture to standardize this activity and provide reference practices for secondary users to access the spectrum opportunistically. In detail, the role of IMS members inside this task group is very relevant to highlight all issues related to measurement tasks and devices to develop a system which is reliable also from the measurement point of view.

### *Measurements for Electric Field Human Exposure Evaluation*

The measurement of human exposure to electromagnetic fields (EMFs) is an important topic in today's scenarios. Indeed, the even more pervasive diffusion of cellular networks (also with incoming of 5G technology), as well as short-range and personal wireless devices, makes human exposure issues continuously growing. Focusing the attention on cellular systems, although regulators and normative committees are conveying specific guidelines for the measurements of EMFs generated by second-generation (2G), third-generation (3G) and fourth-generation (4G) mobile communication systems, there are still several issues to be addressed regarding the most reliable measurement procedures and evaluation of the related measurement uncertainties. In particular, the high variability of voice and data traffic make it very difficult to achieve reliable forecasting of human exposure to 3G and 4G systems in both narrowband and dosimetric measurements.

In this framework, Prof. Domenico Capriglione (University of Cassino and Southern Lazio, Italy) and his WG have been involved in this topic for several years, with particular reference to the employment of electric field extrapolation techniques on 3G and 4G systems [21]. The experimental results confirm how the reference measurement procedures should be refined for avoiding both undesirable electric field underestimation and high uncertainty.

### *Emerging Challenges with DSOs' Ultra-wide Bandwidth Requirement*

Most radiofrequency (RF) circuits in communication, radar, and high-end instrumentation require test and measurement instrumentation, such as digital storage oscilloscopes (DSOs), with extremely wide real-time electrical bandwidth. On the wave of this challenging requirement, oscilloscope technologies have evolved and differentiated into a variety of alternative solutions that permit, in different ways, bandwidths up to 100 GHz and sampling rates up to 240 GS/s to be achieved. The core architectures of top-end DSOs exploit time-interleaving and/or heterodyning strategies and rely on the massive use of digital signal processing (DSP) circuits. They can be grouped into three different technologies: time-interleaving, digital bandwidth interleaving (DBI), and asynchronous time interleaving (ATI).

DBI and ATI technologies are a different realization of a general strategy based on front-end analog transformations, i.e., filtering plus modulation or sampling plus filtering, and massive digital signal processing operations. Both strategies can be identified by means of the acronym MFP, which stands for mixing-filtering-processing, and can be implemented by means of both parallel and hierarchical architectures. In this context, even more challenging is the identification of the streamline calibration approaches to counteract channel mismatches and flatten the frequency response of the DSO. In this framework, the intense research activity of Prof. Mauro D'Arco (University of Napoli Federico II, Italy) is focused on the definition and implementation of innovative calibration strategies, which represent an asset of manufacturers' know-how, since the performance of the DSO largely depends on the calibration effectiveness [22], [23].

### *Development of Learning Sensors for Environmental Monitoring*

The measurement research group coordinated by Prof. Luigi Ferrigno (University of Cassino and Southern Lazio) has been recently involved in the study and application of novel monitoring techniques, able to detect the presence of contaminants in different environments (air, water) and to estimate, in real-time, the residual life of safety devices such as protection masks endowed with activated carbon filters. Such techniques are based on the novel concept of a "learning sensor," a small-scale, low-cost, low-power object that comprises one or more sensors (sensor array) and a processing platform (typically a microcontroller) able to both sense and process, by means of AI/ML techniques that directly run on the microcontroller. In this way, while the physical activity of the sensors is not changed during time, the processing algorithms learn how to use the raw measurements to understand the presence of a contaminant in the environment [24] or to mitigate the effect of sensor aging that in some environments is very fast. Such a platform is also able to perform impedance measurement (a small scale LCR meter), and based on such capabilities, it estimates the residual life of activated carbon filters by evaluating the time evolution of their impedance [25].

Both of these activities are really interesting because the adopted platform also has IoT capabilities, and it can transfer to a fusion center the obtained data, both in raw and processed form. Furthermore, due to their low-cost and high flexibility, such devices can easily be distributed in several measurement locations, thus building up a pervasive measurement system.

### *Sensor Networks for Structural Health Monitoring Applications*

Nowadays, structural health monitoring (SHM) addresses a wide area of research that aims to assess damages and risks for aerospace, civil and mechanical engineering infrastructures by means of advanced sensing and data processing techniques. The capability to monitor, also from remote stations, the working conditions of industrial plants or the structural integrity of civil buildings is widely requested in many application fields. At the same time, the deployment of SHM systems is often a challenging task, involving research contributions from sensing networks, measurement acquisition and management, and data analytics.

In this framework, Prof. Marco Di Felice (University of Bologna, Italy) and his working group can value a consolidated experience researching wireless and mobile networking, with a special emphasis on Internet of Things (IoT) monitoring systems and on sensor data acquisition and analytics. Within the BRIC 2018 MAC4PRO project [26], founded by INAIL and involving three Italian universities besides UNIBO (Polytechnic of Milan, Rome Tor Vergata, University of Messina), the teams of Prof. Alessandro Marzani (PI of the project), Prof. Luca De Marchi and Prof. Marco Di Felice are jointly investigating low-power and multi-source sensing technologies for structural characterization and vibration engineering. In addition, novel data acquisition solutions based on the emerging Web of Things standard [27] are under investigation for the seamless integration and remote management (as well as for the autonomous reconfiguration) of heterogeneous SHM sensor networks. The results of these activities can be of interest for practitioners and can further highlight the need for novel layered, sensor-to-cloud architectures for SHM systems that leverage the competences of interdisciplinary research teams.

## Involvement in Standards Development

Some members of TC-37 belong to working groups involved in the development of IEEE standards sponsored or co-sponsored by the IMS. The development of standards requires several formal steps and significant efforts, and due to the complexity of modern systems, it requires the cooperation of many researchers to build a WG with wide cross-skills. To these aims, some members of TC-37 closely cooperate with researchers belonging to other Technical Committees for coordinated development of the standards.

As an example, Prof. Antonio Moschitta (University of Perugia, Italy) is involved in the development of P 2414 ™/D02.2 Draft Standard for Jitter and Phase Noise. This draft standard, currently under evaluation, aims to improve the uniformity of definitions of related jitter while identifying and modeling the jitter components. The standard presents a new definition and modeling framework, with the aim of maximizing consistency with preexisting standards while providing unambiguous definitions. The provided models and definitions include: jitter, timing jitter, timing error, time interval error, period jitter, cycle-to-cycle jitter, random jitter, wander, deterministic jitter, data-dependent jitter, periodic jitter, bounded uncorrelated jitter, DJ model total jitter, RMS and peak-to-peak jitter; bit error rate, and phase noise.

Another example is the P21451-002–Recommended Practice for Low-Power Smart Transducers Applications that is being developed by a WG supported by the IMS/TC9–Sensor Technology (IM/ST) and the IEEE Industrial Electronics Society/Industrial Electronics Society Standards Committee (IES/IES). The purpose of this standard is to define the necessary methods and specifications to support the operation of low-power smart transductors, such as the ones powered by energy harvesting or by a battery, to be integrated and accepted in the IEEE1451 family of standards [28], [29]. The WG is chaired by Prof. António Espírito-Santo (Universidade da Beira Interior, Portugal) and co-chaired by Prof. Vincenzo Paciello (University of Salerno, Italy), and to support the WG, an open source for validation and test is under development.

## Promoting Links with Industry

TC-37 also tries to create links with industry by involving industry players within conferences and events organized or co-organized by the TC-37. As examples, more recent editions of IEEE International Symposium on Measurements and Networking included specific oral sessions for researchers who belong to industry and instrument manufacturers who operate in the field of "Measurements and Networking" with the aim of fostering their links with researchers from academia and those who belong to IMS. In particular, the oral presentations were made by experts of Teledyne LeCroy, Tektronix, Rhode & Schwarz, DELO Instruments, and ST Microelectronics, and ranged from IoT testing to measurements related to WSN and in modern wireless and 5G systems.

In the same way, in 2018, TC-37 invited a researcher of industry (Dr. Michael Fogelle, Director of Technology Department of ETS-Lindgren, Inc.) to open the special session titled "Measurements for Modern Networks and Telecommunication Systems," at the IEEE International Instrumentation and Measurement Technology Conference 2018 (I2MTC 2018) by presenting the position paper "RF Measurements in a 5G World." The special session was attended by several researchers really interested in the presented topic, and this could become a good practice for the future to encourage and increase more links between industry and academia. That is particularly true in the topic of measurements and networking, where cross-skills are really needed to properly address issues and challenges that will arise from modern systems.

## Development of Initiatives and TC Operating Plan

TC-37 will continue to promote the integration of researchers who belong to the IMS with ones coming from other areas of communication and information technologies. In particular, efforts will be made to highlight the important contributions within the IMS in different areas of networking, and also those in emerging fields as IoT, software defined radio, software defined networks, coexistence and interference problems in wireless networks, 5G, to cite a few. To this aim, TC-37 will continue to recruit new members for increasing international cooperation and to promote the role of IMS inside these research areas.

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