# Integration of Wireless Communication Capabilities to Enable Context Aware Industrial Internet of Thing Environments

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**Abstract.** In order to provide interactive capabilities within the context of Internet of Thing (IoT) applications, wireless communication systems play a key role, owing to inherent mobility, ubiquity and ease of deployment. However, in order to comply with Quality of Service (QoS) and Quality of Experience (QoE) metrics, coverage/capacity analysis must be performed, in order to account for the impact of signal blockage as well as multiple interference sources. This analysis is especially complex in the case of indoor scenarios, such as those derived from Industrial Internet of Things (IIoT). In this work, a fully volumetric approach is employed in order to provide precise wireless channel characterization and hence, system level analysis of indoor scenarios. The proposed methodology will be tested against a real measurement scenario, providing full flexibility and scalability for adoption in a wide range of IIoT capable environments.

**Keywords:** Industrial Internet of Things · Wireless channel characterization · Coverage/Capacity estimations

## 1 Introduction

The implementation of scenarios with context-awareness capabilities is being progressively adopted with the aid of elements such as Internet of Things and novel heterogeneous communication networks. Multiple applications are envisaged within these scenarios, such as Smart Grids, Intelligent Transportation Systems or Smart Health, to name a few. Out of these, one of the most promising applications is related with Cyber Physical systems and Industry 4.0, giving rise to the paradigm of Industrial Internet of Things. In this sense, communication play a key role in order to enable data processing, inference, prediction or real time interaction, among others. Wireless communication systems are being employed in order to provide data exchange capabilities, owing to their flexibility, mobility and ubiquity. Moreover, the adoption of different types of wireless


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communication systems with variable coverage/capacity ranges provide a set of multiple options in order to provide different types of connectivity, as a function of node configuration, location and network topological requirements. In this way, different services such as logistic handling, maintenance, location, tracking or diagnostics can be provided by means of wireless personal area networks (e.g. Bluetooth, NFC, RFID, etc.), wireless sensor networks (ZigBee, Sigfox, LoRa-LoRaWAN), wireless local area networks or mobile networks (with emphasis on 4G and 5G systems, including specific networks for IoT based communications, such as NB-IoT or Cat M1-M2) [1–3].

Despite the advantages in the use of wireless communication systems in terms of rapid deployment, integration and high mobility, they also face multiple challenges, owing to highly vulnerable wireless channel characteristics. Wireless communication channels are subject to highly variable losses given by different mechanisms, such as fading due to blockage, absorption or multi-path propagation. Moreover, other effects are given by the existence of different types of interference sources, as well as by time related phenomena, such as Doppler shift or high levels of delay spread. In the case of indoor industrial environments, these effects are increased, mainly given by the predominance of non-line of sight links owing to high levels of clutter, as well as by strong multi-path components, owing to high density of metallic objects in the environment [4–9]. These phenomena lead eventually to degradation in terms of service level metrics, in which coverage areas tend to decrease given by degradation in signal to noise ratio values detected at the receiver side. In order to adequately address the deployment and design of wireless systems it´s therefore required to perform radio planning tasks in order to carefully assess transmitter signal levels, as well as distribution of non-desired interference sources. There are multiple methods in order to analyze wireless channel behavior, spanning from deterministic based techniques to empirical/statistical methods. The first ones solve Maxwell equations in a given simulation model of the Scenario Under Test (SUT), providing very accurate field estimation values. These methods, such as Full Wave electromagnetic simulation (e.g., FDTD, FITD, MoM, etc.) require precise scenario description as well as very large computational cost. The later methods exhibit much lower computational cost but exhibit large errors, requiring intensive measurement-based calibration. As a mid-term solution between these two there are techniques based on the approximation of field propagation based on GO-UTD, such as ray tracing and ray launching methods. These methods balance computational cost with accuracy, enabling the analysis of relatively large scenarios with complex scatterer distributions with feasible computational cost.

In this work, wireless channel characterization within complex indoor scenarios with large scatterer levels is presented, with the aid of an in-house implemented 3D ray launching code. The SUT is a large sized laboratory called Luis Mercader, at UPNA in Spain, which has been selected in order to emulate potential scatterer densities within industrial environments. The 3D RL simulation code has been extensively tested with multiple types of scenarios, in order to perform frequency/power calculations, time domain parameters extraction and with subsequent processing, quality of service (QoS)/quality of experience (QoE) metrics [10–12]. The code is implemented in Matlab and the SUT is recreated, considering the dimensions of all objects, as well as assignment of the frequency dispersive properties, in terms of dielectric constant as well as conductivity values, for each one of the elements within the scenario. In this work, the simulation scenario that has been implemented is shown in Fig. 1, where the detail of all the indoor elements within the scenario can be observed.

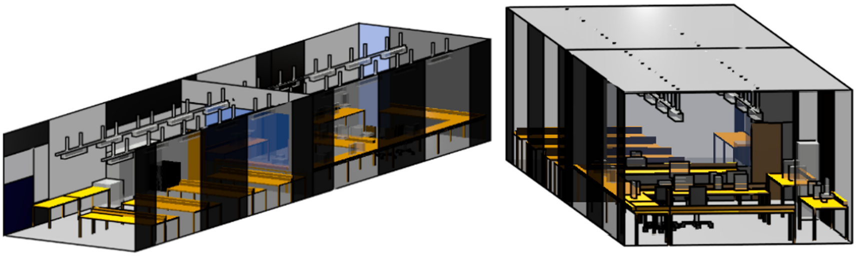

**Fig. 1.** Schematic representations of the Scenario Under Test for validation of volumetric wireless channel characterization.

## 2 Wireless Channel Simulation in the Scenario Under Test

Once the scenario has been defined, wireless channel estimation values corresponding to different network systems are obtained. Simulation parameters such as ray launching volumetric angular resolution ($\Delta\phi = \Delta\theta = 1^{\circ}$), maximum number of reflected rays until extinction (N = 6) or cuboid size resolution ($\Delta l$ = 10cm) are defined, following previous convergence analysis studies [12]. Potential transmitter/receiver sources have been located within the SUT, considering WBAN/WLAB/WSN/PLMN systems operating within the frequency bands of 433 MHz, 868 MHz, 2.4 GHz and 3.5 GHz (in order to include frequency range 1 5G network services). In this way, received power levels can be estimated within the total SUT volume. For the sake of clarity, specific cut-planes providing the bi-dimensional RX power level distributions have been depicted. The cut-plane height selected correspond to h = 0.6 m, h = 1.2 m, h = 1.8 m and h_2.4 m. The results obtained for each one of these cut-planes for all operational frequencies are depicted in Figs. 2, 3, 4 and 5. It can be observed, depending on the selected height and the operating frequency, received power level distributions vary, being strongly dependent on the specific location and material properties of the distribution of objects within the SUT. It's worth noting that the selected simulation sources can represent transmitters as well as any type of interfering source, including intra-system interference, inter-system interference or external interference sources, such as appliances, motors or other type of electro-mechanical devices. This is given by the fact the simulation code enables the use of hybrid simulation techniques as well as Huygens box emulation of equivalent radiating sources, in which full wave simulation techniques, like FDTD, can be employed to obtain the current sources of an equivalent array of transmitting sources, that can be embedded within the 3D RL code.

In order to validate the accuracy of the estimations obtained by means of 3D RL simulation, measurement results of receiver power level distributions have been obtained for the frequency bands under consideration. To this end, a wide band voltage controlled

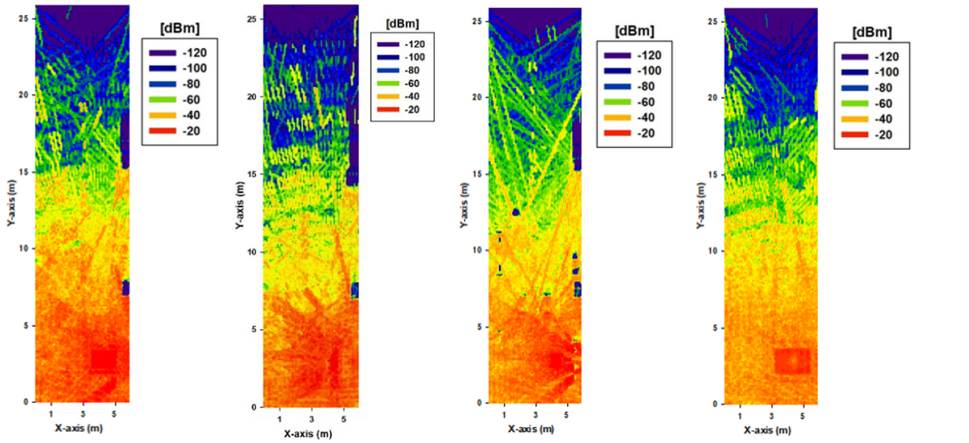


**Fig. 2.** Received power levels estimations for the SUT, corresponding to a frequency of operation of 433 MHz, and cut-plane heights of a) 0.6 m, b) 1.2 m, c) 1.8 m and d) 2.4 m respectively.

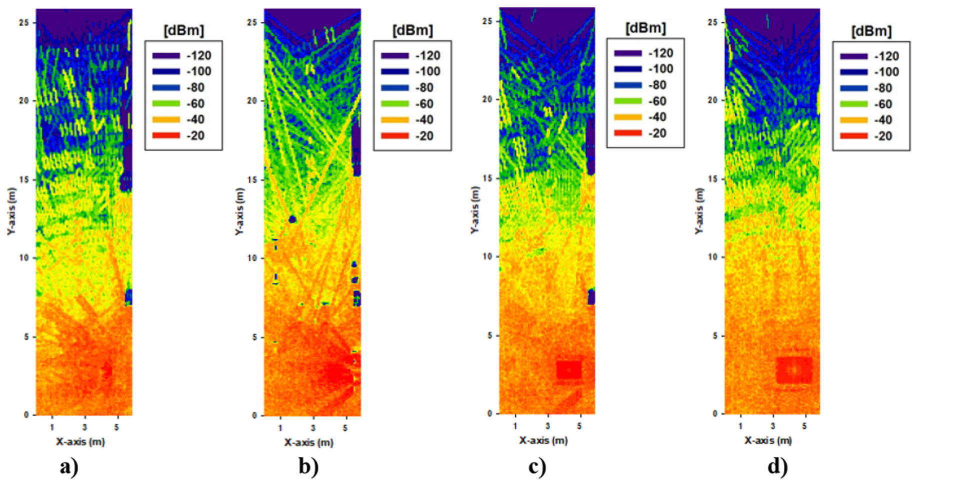


**Fig. 3.** Received power levels estimations for the SUT, corresponding to a frequency of operation of 868 MHz, and cut-plane heights of a) 0.6 m, b) 1.2 m, c) 1.8 m and d) 2.4 m respectively.

oscillator (Mini-Circuits ZX95 VCO) has been connected to a wide band transmitter antenna (Antenova Omni LOG up to 8 GHz) and measurement results have been obtained with the aid of a portable spectrum analyzer (Rohde Schwarz FSH20, up to 20 GHz). Images from the measurement setup employed are depicted in Fig. 6. The comparison between simulation and measurement results for linear TX/RX distributions are depicted in Figs. 7, 8, 9, 10 corresponding to the four frequency bands under consideration. It can be seen that in all cases, simulation and measurement results are in good agreement, with average errors in the order of 3–5 dB for all cases.

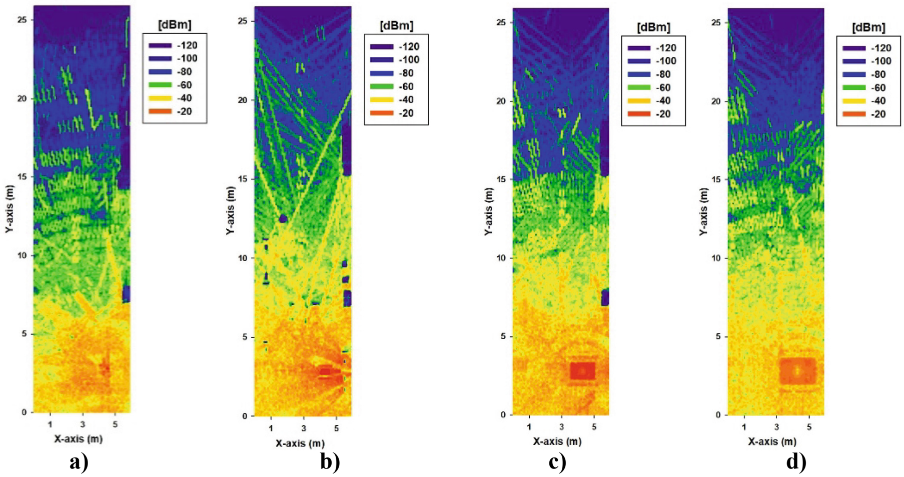


**Fig. 4.** Received power levels estimations for the SUT, corresponding to a frequency of operation of 2.4 GHz, and cut-plane heights of a) 0.6 m, b) 1.2 m, c) 1.8 m and d) 2.4 m respectively

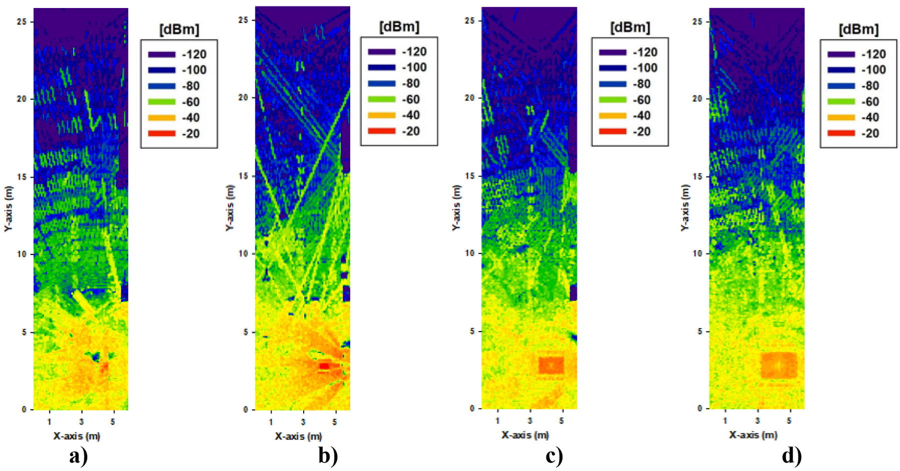


**Fig. 5.** Estimation of received power levels for the SUT, corresponding to a frequency of operation of 3.5 GHz, and cut-plane heights of a) 0.6 m, b) 1.2 m, c) 1.8 m and d) 2.4 m respectively

The results obtained show that received power levels are once again strongly dependent on the configuration of the scenario, as well as on the frequency of operation. As expected, path losses are higher as frequency increases. The proposed methodology can be readily extended to consider multiple aspects, such as transceiver design (in terms of antenna configuration, transmitter power range or receiver sensitivity thresholds), variations within the configuration of the scenario in terms of scatterer distribution, the configuration of the network topology as a function of node location or the existence and behavior of multiple interference sources, among others.

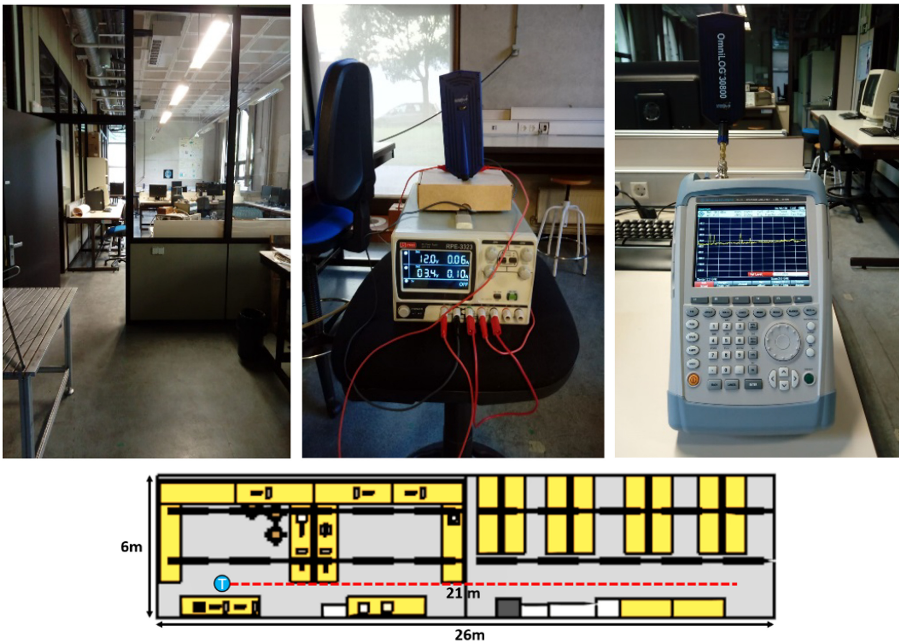


**Fig. 6.** Measurement scenario and schematic description of the measurement points within the Scenario Under Test, located at the Luis Mercader laboratory, at the Public University of Navarra.

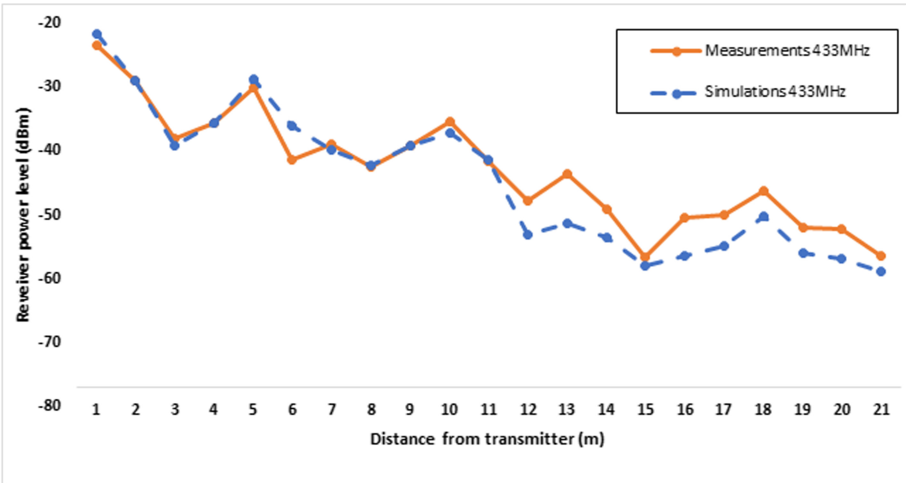


**Fig. 7.** Comparison of simulation vs measurement results for the Scenario Under Test, considering transceivers operating at a frequency of @433 MHz.

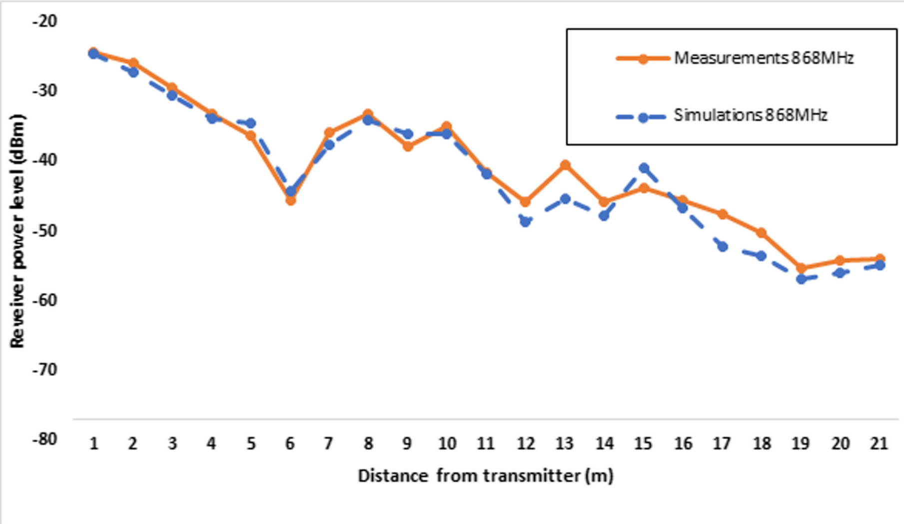


**Fig. 8.** Comparison of simulation vs measurement results for the Scenario Under Test, considering transceivers operating at a frequency of @868 MHz.

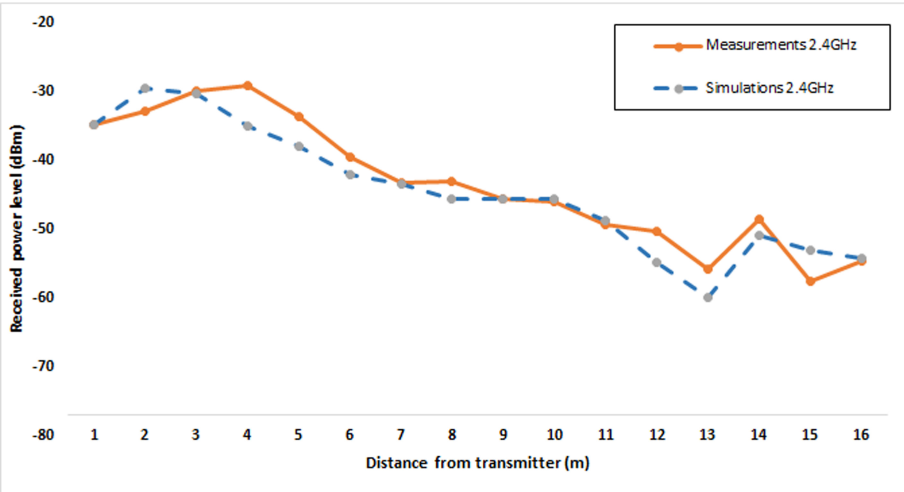


**Fig. 9.** Comparison of simulation vs measurement results for the Scenario Under Test, considering transceivers operating at a frequency of @2.4 GHz.

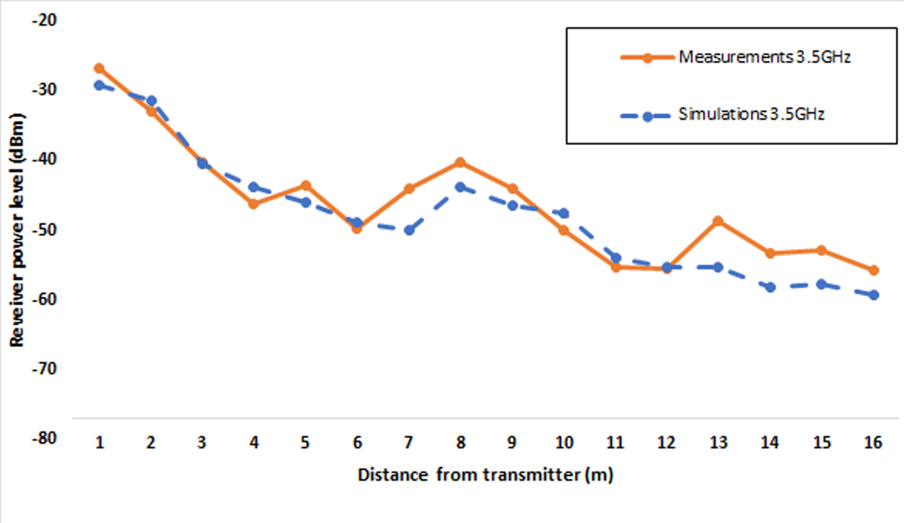


**Fig. 10.** Comparison of simulation vs measurement results for the Scenario Under Test, considering transceivers operating at a frequency of @3.5 GHz.

## References


1. Colombo, W., Karnouskos, S., Kaynak, O., Shi, Y., Yin, S.: Industrial cyber physical systems: A backbone of the fourth industrial revolution. IEEE Ind. Electron. Mag. **11**(1), 6–16 (2017)
2. Lu, C., et al.: Real-time wireless sensor-actuator net-works for industrial cyber-physical systems. Proc. IEEE **104**(5), 1013–1024 (2016)
3. Stenumgaard, J., Chilo, J., Ferrer-Coll, J., Angskog, P.: Challenges and conditions for wireless machine-to-machine communications in industrial environments. IEEE Commun. Mag. **51**(6), 187–192 (2013)
4. Candell, R.: Industrial wire-less systems: radio propagation measurements. In: NIST Tech. note 1951, NIST, Gaithersburg, MA, USA, January 2017
5. Cheffena, M.: Industrial wireless sensor networks: channel modeling and performance evaluation. EURASIP J. Wirel. Commun. Netw. **2012**(1), September 2012 https://doi.org/10.1186/1687-1499-2012-297
6. Cardieri, P.: Modeling interference in wireless Ad Hoc networks. IEEE Commun. Surv. Tuts. **12**(4), 551–572 (2010)
7. Savazzi, S., Rampa, V., Spagnolini, U.: Wireless cloud networks for the factory of things: Connectivity modeling and layout design. IEEE Internet Things J. **1**(2), 180–195 (2014)
8. Garcia, M., Tomas, J., Boronat, F., Lloret, J.: The development of two systems for indoor wireless sensors self-location. Ad Hoc Sens. Wirel. Networks **8**(3–4), 235–258 (2009)
9. Garcia, M., Martinez, C., Tomas, J., Lloret, J.: Wireless sensors self-location in an indoor WLAN. In: International Conference on Sensor Technologies and Applications. SENSORCOMM, Valencia, Spain, 14–20 October 2007
10. Azpilicueta, L., Rawat, M., Rawat, K., Ghannouchi, F.M., Falcone, F.: A ray launching-neural network approach for radio wave propagation analysis in complex indoor environments. IEEE Trans. Antennas Propag. **62**(5), 2777–2786 (2014)

11. Azpilicueta, L., Falcone, F., Janaswamy, R.: A hybrid ray launching-diffusion equation approach for propagation prediction in complex indoor environments. IEEE Antennas Wirel. Propag. Lett. **16**, 214–217 (2017)
12. Casino, F., Azpilicueta, L., Lopez-Iturri, P., Aguirre, E., Falcone, F., Solanas, A.: Optimized wireless channel characterization in large complex environments by hybrid ray launching-collaborative filtering approach. IEEE Antennas Wirel. Propag. Lett. **16**, 780–783 (2017)