Implementation of Wireless Sensor Network Architecture for Interactive Shopping Carts to Enable Context Aware Commercial Areas

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***Abstract*—An interactive shopping cart to enable context aware environments within large commercial areas is presented. A wireless sensor network was designed, with specific nodes embedded within the shopping carts and infrastructure nodes in the shopping area. Due to the complexity of wireless propagation, given the large amount of obstacles and the inclusion of users, an in house deterministic method based on 3D Ray Launching was employed, providing results in terms of adequate transceiver deployment to minimize interference, energy consumption and maximize data throughput. The proposed system was tested in a real commercial scenario, with the implementation of an ad-hoc monitor shopping application, exhibiting successful detection rates in order of 99%. The proposed systems provides an interactive shopping experience for users as well as for commercial managers.**

***Index Terms*—Shopping Carts, 3D Ray Launching, Large Commercial Areas, Wireless Sensor Networks**

I. INTRODUCTION

THE use of information and communication technologies has revolutionized the way in which commercial transactions take place, from e-commerce, m-commerce to location based marketing [1]. In the case of on-site commerce in retail shops, the introduction of information technologies has aided in logistical processes, stock tracking, automated cashier systems and consumer analysis, among others [2]. It is worth noting that analysis of user interaction in commercial areas takes into account multiple variables, such as user movement patterns or potential user mood [3].

The inclusion of wireless technologies has provided new means of enhancing procedures related with commercial areas, such as the introduction of RFID in product tracking, development of mobile apps linked with retailer websites and the inclusion of Near Field Communication (NFC) in mobile terminals in order to enhance payment process [2,4]. New functionalities can be envisaged with the advent of wearable technology as well as the steady adoption of Wireless Personal Area Network and Wireless Body Area Network, coupled to Wireless Sensor Networks (WSNs), such as mobility support [5]. Moreover, the evolution of mobile networks, the extension of Internet of Things and the adoption of 5G networks, with Device to Device (D2D) capable connectivity will increase user/environment interaction levels [6-10]. In this way, traditional information exchange in retail and commercial areas, usually employed for periodic stock management and sales procedures at cashiers, can now be de-centralized and employed for a wider range of applications. Consequently, full advantage of cooperative networking techniques can be used (e.g., CoopMAC protocol, QoS provision via 802.11aa standard, etc.), as well as the possibility of enabling full interaction between the commercial infrastructure (e.g., shelves in which merchandise is contained, exhibition stands, information points). This leads to Context Aware environments, which can be seen as a subset in a larger framework of Smart City/Smart Regions scenarios, in which larger levels of user/systems interaction are achieved, involving multiple systems and functionalities, such as energy generation and distribution, waste management, Intelligent Transportation Systems or Smart Health, among others [11]. In the specific case of large commercial areas, work has been performed in order to provide context-aware scenarios which lead to ubiquitous shopping malls [12-21]. In many of the cited works, a higher functionality is provided to shopping carts, as it is an active element within the shopping process.

The wave propagation or the performance of a wireless network within shopping malls has been already analyzed for 320 MHz, 17 GHz and 28 GHz [22-24]. In this work, wireless sensor nodes, based on Wireless Body Area Network/Personal

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Area Network were embedded within a shopping cart and the infrastructure of a large commercial center in order to achieve a context aware shopping environment at 2.4 GHz. Wireless propagation analysis was performed with the aid of in house deterministic 3D Ray Launching code, in order to account for complex channel characterization, given by the presence of a dense array of multiple obstacles and scatterers (such as merchandise in different container types, materials and volumes), as well as the presence of users within the scenario. This provides information in terms of performance of optimal node configuration in the specific shopping cart/commercial area scenario under analysis. The node configuration allows the analysis of optimal aggregation schemes, as a function of network topology, which will be analyzed for the several cases of interaction between shopping carts and commercial area infrastructure (nodes within shelves or located in diverse access points). Full user interaction is provided by an ad-hoc monitoring system, composed by an Android app employed by the users, as well as by a System Architecture, interconnecting the diverse information elements. The complete system was tested in a real commercial environment, providing assessment in the interaction capabilities of the proposed solution.

The paper is organized as follows: Section II presents briefly the chosen scenario under analysis, where both the measurements and simulations were performed. In Section III the 3D Ray Launching algorithm used for the simulations is presented. Then, Section IV shows the obtained simulation results. In Section V measurements with the aim of finding the best wireless node deployment within the scenario are presented, followed by the developed shopping monitoring application in Section VI. Finally, the conclusions are discussed in Section VII.

II. COMMERCIAL SCENARIO UNDER ANALYSIS

The scenario where the system analysis was carried out is within the E.Leclerc supermarket, located in Pamplona, Navarre, being the largest commercial area in the region. Due to the large size inherent to these kind of commercial areas usually have, the scenario under analysis was limited to a single aisle with its corresponding shelves of the supermarket, as a first approximation to the problem. The characteristics of the chosen aisle are similar to those that can be easily found in large commercial areas, thus being able to extend the obtained results to any commercial area of this kind. Fig. 1 shows the real scenario. The antenna used as transmitter can be seen deployed in the shopping trolley. The dimensions of the limited scenario are 25.94 m (length) × 11.7 m (width) × 3m (height) (see Fig. 2). The aisle width is 2.9m and the shelves dimensions are 19.5 m (length) × 1.5 m (width) × 2.25 m (height). For the radiopropagation study, the trolley was placed at one end of the aisle, between the shelves, as seen in Fig.1.

Fig. 1. Real scenario. Note that the shelves on the left are filled mainly with products in glass jars, and the shelves on the right with products in metallic cans. Numbered red dots represent the measurement points.

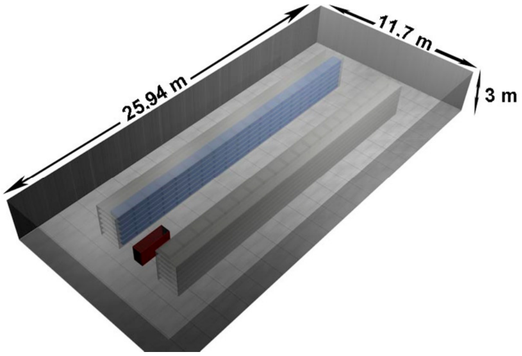


Fig. 2. Schematic view of the scenario generated for the 3D ray launching simulations.

III. SIMULATION PROCEDURE

The first step was to analyze the impact of the scenario in the physical layer performance of the wireless sensor network nodes. In the literature, radio-propagation within a shopping mall at 1.9 GHz was performed, comparing measurements, estimations by a statistical method and results obtained by a ray tracing algorithm. The work concludes that the ray tracing method is the most adequate in order to analyze the propagation in this kind of environments [25]. In order to characterize the radio channel in the presented scenario, an in-house developed deterministic 3D ray launching code was used. This simulation tool has been previously used and validated for the same purpose in different indoor complex environments [26,27], including preliminary radio-propagation analysis within a commercial environment [28]. Electromagnetic propagation phenomena such as reflection, refraction and diffraction are taken into account. The in-house developed simulation algorithm allows configuring radio propagation parameters within the scenario, such as operation frequency, angular resolution of launching and diffracted rays, maximum number of reflections permitted and the size of the cuboids in which the whole scenario is divided. The principle of the algorithm is that each ray propagates in the space as a single optic ray, and the electric field E created by the transmitter with a radiated power P_{rad}, and $D_t(\theta_t, \Phi_t)$ directivity, and $(X^{\perp}, X^{\parallel})$ polarization ratio, at a distance d, is calculated by:

$$E_i^{\perp} = \sqrt{\frac{P_{rad} D_t(\theta_t, \phi_t) \eta_0}{2\pi}} \frac{e^{-j\beta_0 r}}{d} X^{\perp} L^{\perp} \quad (1)$$

$$E_i^{\parallel} = \sqrt{\frac{P_{rad} D_t(\theta_t, \phi_t) \eta_0}{2\pi}} \frac{e^{-j\beta_0 r}}{d} X^{\parallel} L^{\parallel} \quad (2)$$

where $\beta_0 = 2\pi f_c \sqrt{\varepsilon_0 \mu_0}$, $\varepsilon_0 = 8.854 * 10^{-12}$, $\mu_0 = 4\pi * 10^{-7}$ and $\eta_0 = 120\pi$. $L^{\perp\parallel}$ are the path loss coefficients for each polarization.

The diffracted field is calculated by [29]:

$$E_{UTD} = E_0 \frac{e^{-jks_1}}{s_1} D^{\perp\parallel} \sqrt{\frac{s_1}{s_2(s_1+s_2)}} e^{-jks_2} \quad (3)$$

where s_1, s_2 are the distances from the source to the edge and from the edge to the receiver point. $D^{\perp\parallel}$ are the diffraction coefficients given by [29].

Table I shows the configuration of the most relevant parameters used for the simulations of this scenario.

TABLE I
PARAMETER CONFIGURATION FOR 3D RAY LAUNCHING SIMULATIONS

Frequency of operation	2.4 GHz
Transmitted power level	-10 dBm
Horizontal angular resolution (ΔΦ)	1º
Vertical angular resolution (Δθ)	1º
Permitted maximum reflections	5
Cuboids size	10cm x 10cm x 10cm

Besides the mentioned parameters, this in-house simulation method allows defining the dielectric constant and the conductivity of the materials included in the scenario. As can be seen in Fig. 1, the left shelves are mainly full of glass jars, and the right shelves have a lot of metallic cans. Therefore, in order to obtain more accurate simulation results, apart from the materials for the floor and walls (concrete), the shelves (aluminum) and the trolley (aluminum), the objects on the shelves were also defined in accordance with the products found in the real scenario. Table II shows the material properties used in the scenario. The obtained estimated results were calculated at each point of the whole scenario taking into account the losses of propagation through the medium at a distance d, with the attenuation constant α (Np/m) and the phase constant β (rad/m). The received power was calculated with the sum of incident electric vector fields in an interval of time Δ_t inside each cuboid of the defined mesh.

TABLE II
MATERIAL PROPERTIES FOR 3D RAY LAUNCHING SIMULATIONS

Material	Conductivity (S/m)	ε_r
Aluminum	$37.8*10^6$	4.5
Glass	0.11	6.06
Concrete	0.02	25

The schematic representation of the scenario created for the 3D Ray Launching simulations can be seen in Fig. 2. The shopping trolley is represented by a brown parallelepiped and the antenna was placed at the same position as the transmitter antenna used for measurements (0.4 m height, in the trolley). In the next section, the obtained simulation results and their validation are presented.

IV. RESULTS AND VALIDATION

In order to validate the simulation results obtained by the presented 3D Ray Launching algorithm, 32 different points were chosen within the scenario under analysis to measure the received power level and compare the obtained values with simulation estimations. The distribution of the 32 measurement points can be seen in Fig. 1, represented by numbered red dots. As can be seen, they are distributed in two different heights (0.6m and 1.8m) and in both sides of the aisle in order to analyze the effect of different materials on the shelves, as one side contains mainly glass jars and the other side metallic cans. The measurements were carried out with the aid of an Agilent CSA N1996A to generate the RF signal and an Agilent FieldFox N9912A portable spectrum analyzer, both connected to a 5dBi monopole antenna. The transmitter antenna was placed in the trolley, at a height of 0.4m, configured to transmit -10dBm at 2.4GHz. The received power for each of the 32 measurement points was measured placing the 5dBi antenna connected to the portable spectrum analyzer. These measurements were made without the presence of human beings within the scenario. Fig. 3 shows RF power distribution simulation results for the planes at the heights of the measurement points (0.6m and 1.8m). The transmitter antenna is represented by a white dot inside the trolley. Besides the expected power drop with the increase of the distance (from the transmitter), rapid power variations due to the multipath propagation can be observed. It is also observed how obstacles (shelves) affect the radio-propagation, receiving lower power level behind them.

When the ray launching approximation is used in large scenarios, such as the one presented in this work, divergence takes place. It is directly related with the size of the scenario, the angular resolution of the launched rays and the resolution (cuboids size) set by the user. For small cuboid sizes, large errors occur for big distances, as cuboids without received rays appear. In this scenario under analysis, the divergence phenomenon can be seen for distances larger than 11m approximately. In order to avoid these errors and obtain accurate results, new simulations with lower spatial resolution (higher cuboid size) are required for the mentioned bigger distances. In this case, the new cuboid size was incremented to 50cm × 50cm × 50cm. The final valid simulation results for both metallic cans and glass jars shelves can be seen in Fig. 4, where the comparison with measurements is also shown. A vertical dashed line divides the simulation results obtained with cuboids of 10cm and 50cm. In this graphs, the effect of the multipath propagation is more clearly seen, as there are points further which receive lower power levels than closer ones. The results depicted in Fig. 4 show the validity of the 3D

Ray Launching results, with good agreement between measured values and simulation results. The mean error taken into account the 32 measurement points is 0.13 dB, with a standard deviation of 0.72 dB.

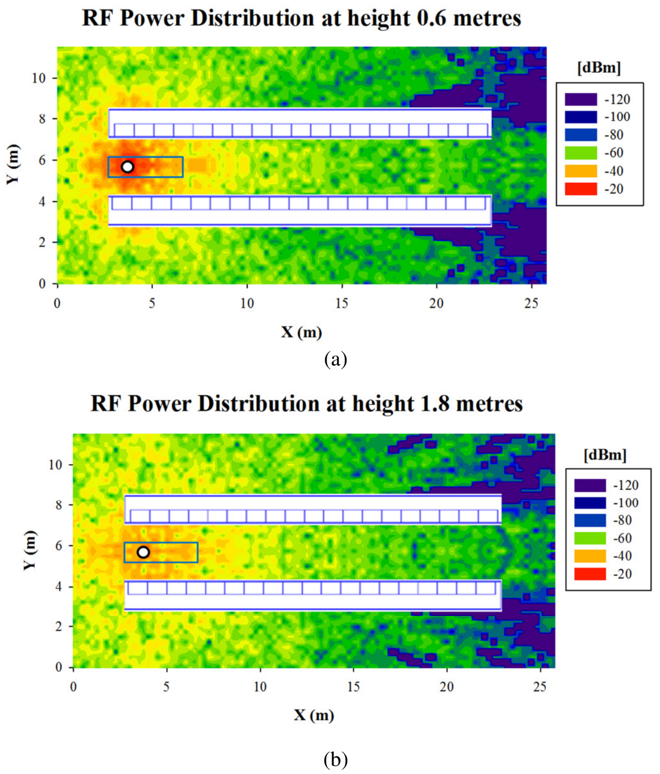


Fig. 3. RF power distribution planes obtained by the 3D Ray Launching method for two different heights: (a) 0.6m and (b) 1.8m.

Once the validation of the in-house Ray Launching simulation tool for this kind of scenarios was done, a new simulation analysis is presented with the aim of studying the presence of human beings, as it is the common situation in this kind of scenarios. Although the number of persons in an aisle of these characteristics varies, for this analysis 10 human beings, all of them adults, were placed randomly throughout the scenario. The used human body model was developed in-house and was previously used and validated [30]. Fig. 5 shows the schematic representation of the simulated scenario with the person distribution along the aisle. The simulation parameters were the same that those used in the previous simulations, shown in Table I. In order to show clearly the effect of the presence of persons, in Fig. 6 the difference between the results with persons and without them is shown, for the planes at heights 0.6m and 1.8m.

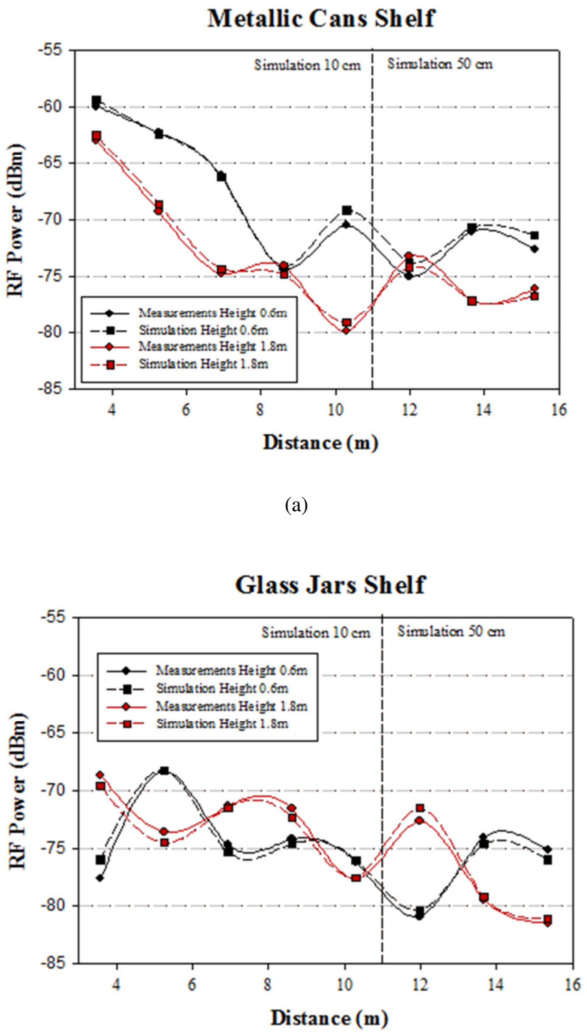


Fig. 4. Measurements and 3D Ray Launching simulations results comparison for: (a) Metallic cans shelf and (b) Glass jars shelf.

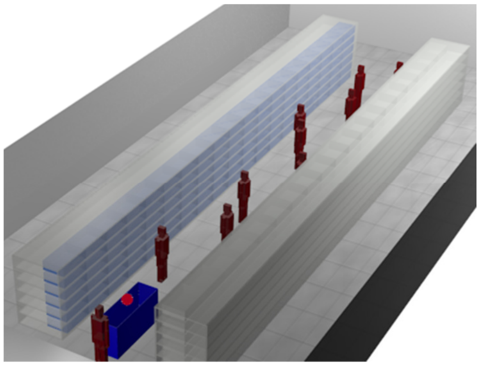
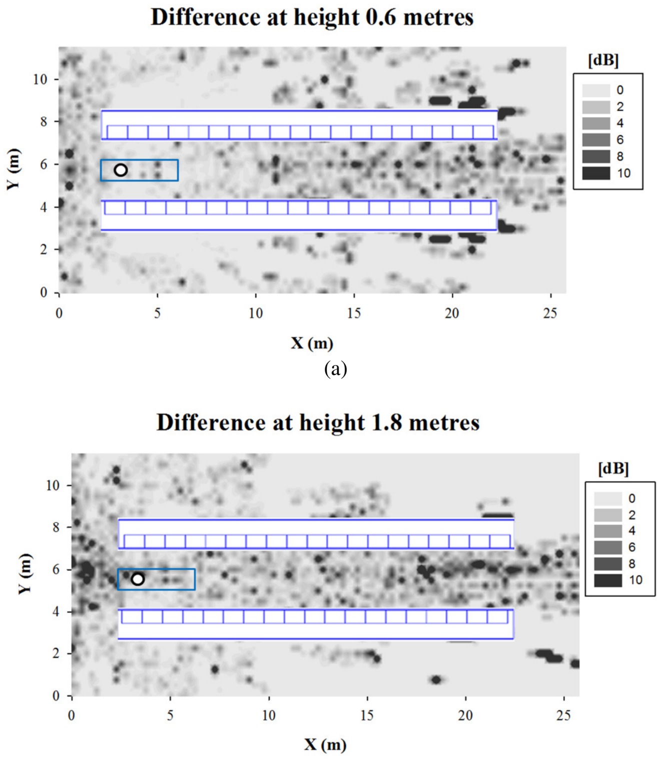


Fig. 5. Schematic view of the simulated scenario with the presence of 10 human beings.



(a)

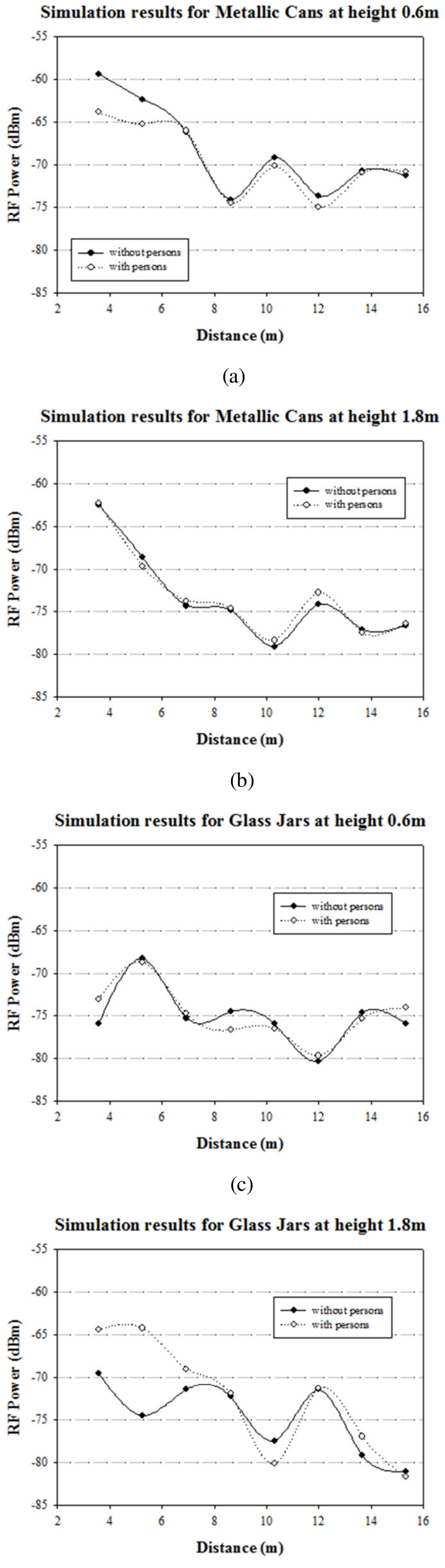
(b)

Fig. 6. Received power difference between 3D Ray Launching simulation results with the presence of 10 persons and without persons for the planes at height (a) 0.6m, and (b) 1.8m.

As expected, the results of Fig. 6 show that the presence of human beings affect the radio-propagation of the transmitted wireless signal. In some cases, in specific points, the received power level when 10 users are included in the simulation is very close to the value of the case without persons. In other points, the power level difference can be up to 10dB approximately, but in most of the cases it is of a few dB. In order to gain more insight, in Fig. 7 the comparison between the simulation results without persons and with persons for the 32 measurement points is presented. Specifically for these 32 points, the mean difference is 0.38dB, with a standard deviation of 2.50dB. Although the received power level difference is small in most cases, it can have a huge impact in the performance of wireless motes in terms of energy efficiency, even more if we consider a bigger density of human beings. In order to show this, a SNR graph for the fourth point (8.6m distance) at height 0.6m of the Glass Jars shelf (see Fig. 7c) is depicted in Fig. 8 as an example. Taken this point as a potential placement for a wireless mote, from Fig. 7c the received power levels for both the case without persons and the case with persons can be obtained, which are -74.53dBm and -76.67dBm respectively. Fig. 8 shows the SNR values for different noise levels at this specific point, when the output power of the transmitter is -10dBm. The dashed red lines represent the minimum SNR value required for a successful data transmission for the indicated data rates. These values have been calculated with the following well known formula:

$$C = BW \times \log_2\left(1+\frac{S}{N}\right) \tag{4}$$

where C is the channel capacity in bps, S and N the received signal power level and noise level in Watts respectively and BW is the Band-Width of the channel (3MHz for ZigBee-IEEE 802.15.4 devices).



(a)

(b)

(c)

(d)

Fig. 7. Comparison between 3D Ray Launching simulation results with the presence of 10 persons and without persons for points at (a) Metallic cans

shelf at height 0.6m, (b) Metallic cans shelf at height 1.8m, (c) Glass jars shelf at height 0.6m and (d) Glass jars shelf at height 1.8m.

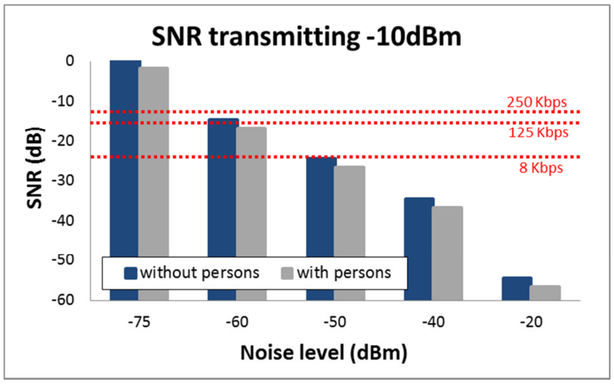


Fig. 8. SNR values for a specific point within the scenario when the wireless transceiver placed in the trolley transmits -10dBm and different noise levels are present.

The noise levels were assumed from -75dBm, which is approximately equal to the received signal at the point under analysis, to -20dBm, which could be the noise produced by a nearby wireless source such as WiFi or another 802.15.4 device. Under these boundary conditions, the transmission cannot be successfully achieved for any of the shown transmission data rates until the noise level is lower than -50dBm. It is worth noting the case for -60dBm of noise level, where the transmission at 125Kbps will be possible when the scenario is empty of persons, but the transmission will fail for the presence of the 10 persons shown in Fig. 5.

Thus, apart from the transmitted power level, which can be controlled by the network designer, there are critical issues such as the presence of people and the morphology of the scenario that could affect critically the received power at the receiver position, whatever it is. Therefore, an in-depth radio-planning analysis is required for this kind of scenarios in order to find an optimal wireless network deployment in terms of cost (reducing the number the wireless motes) and energy efficiency (reducing transmitting energy as well as data rates).

V. WIRELESS SENSOR NODES DEPLOYMENT

The simulation results presented in the previous section show the relevance of the layout of the scenario under analysis in the RF power distribution and therefore the potential deployment of WSNs, without the expected detected power level errors in low cost transceivers. As one of the main issues when deploying WSNs is the optimization of power consumption and therefore the lifetime of wireless motes [31-33], in this section a wireless mote deployment analysis based on experimental results within the scenario under analysis is presented. Due to the performance in terms of unit cost, power consumption and spectrum availability, IEEE 802.15.4 based devices were employed for the measurements. We embedded a Waspmote[2] node on each trolley and we placed a Meshlium[3] device (Linux-based router) which works as the gateway of the WSN of Waspmote nodes. Each Waspmote node manages, at least, one RFID transceiver. The used Meshlium device supports four different radio interfaces: WiFi 2.4GHz, WiFi 5GHz, Bluetooth and XBee. Fig. 9 shows the devices used on the development of the system. The Waspmote includes an RFID reader, which obtains the code of each of the products introduced on the trolley and transmits them to the Meshlium gateway.

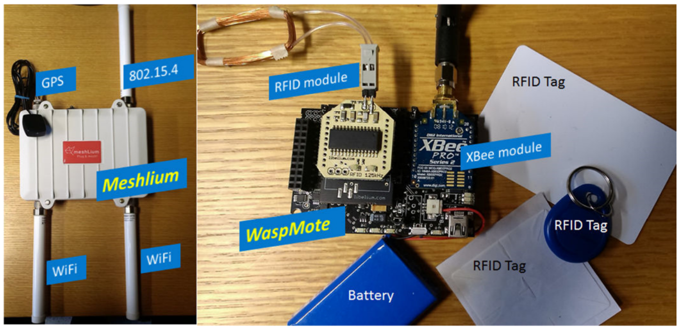


Fig. 9. Hardware used.

Notification-back implies that communication from trolley to gateway is postponed until the list of products of the trolley is about to be modified/replaced by new products. Notification-through is performed synchronously both to the node and to the gateway. Final notification performs the communication just when the trolley arrives to the checkout, and delayed-notification implies the periodic transmission of shopping information from trolley to gateway. The system can switch among these four notification strategies depending on the needs during operation.

The WSN considered in this paper includes the placement of sensors equipped with RFID readers on the shelves and inside the trolleys. Sensors located on the shelves aggregate the information of the detected tags along the mall's aisles. The last node of each aisle transmits the aggregated information to the central node for its integration into the logistic system of the company (ERP). The goal of this network is to conduct the inventory, which can be performed as a periodic pre-scheduled task, or on demand. Since the detection of many elements (cans, bottles, boxes…) produces an overload in the network, this activity must be performed during mall's downtime periods (opening and/or closing of the mall, or during the stock replacement process). On the other side, sensors located inside the trolley (their number and location depends on the size and material of the trolley) are devoted to determine what items are placed inside the trolley. In this case, the main issue is to discriminate between those products located inside or outside the trolley. The proper location of RFID transceivers and the proper selection of the number of sensors and their coverage areas allow minimizing the rate of false positives. Fig. 10 shows the communication schema followed, where the nodes placed inside the trolley and the sink nodes of each aisle communicate directly with the central node of the system via WiFi connection, while the rest of nodes communicate among them using IEEE 802.15.4. The nodes located inside the trolley communicates with the nodes located on the shelves in order to provide user localization. According to the nodes reachable by the trolley, the system can infer the localization of the trolley.

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[2] Waspmote, http://www.libelium.com/products/waspmote/
[3] Meshlium, http://www.libelium.com/products/meshlium/

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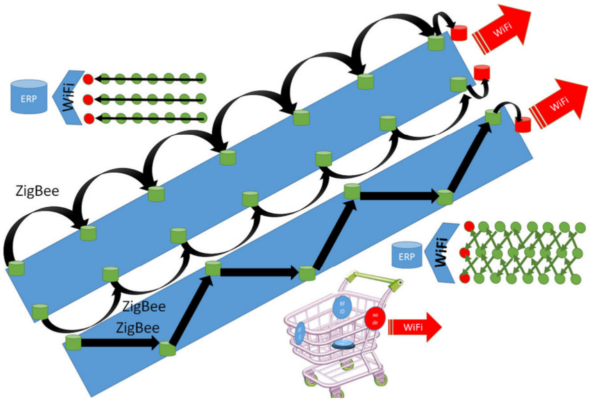


Fig. 10. Communication description. The trolley includes a Waspmote node (in red) with three different RFID transceivers (in blue) and a WiFi transceiver.

Two different networks of nodes within the scenario under analysis were deployed, following two different topologies: linear and zigzag (see Fig. 11). Each network consists on seven nodes, and a gateway (GW) in charge of data collection on a laptop. Both networks imply the transmission of messages from node i to node i+1 following a (linear or zigzag) chain. Communication starts at node 1 and ends at the GW. Data concerning information about products (temperature, luminosity, humidity, units, prizes…) is aggregated from a node to its successor until arriving to the GW, which is in charge of data collection and management. We performed more than 23,000 iterations, where 98.627% and 99.670% of the iterations are successfully achieved for the linear and zigzag configurations, respectively.

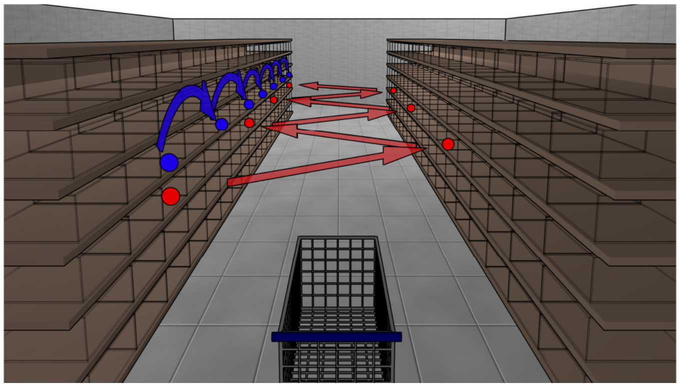


Fig. 11. Node distribution for the linear configuration (blue) and zigzag configuration (red).

Fig. 12 illustrates the received signal strength indicator (RSSI) values obtained at each node according to the node distributions depicted in Fig. 11. Note that $RSSI_i$ denotes the RSSI value measured at node i, which refers to the message received from its predecessor (node i-1). For such reason, node #1 has a zero value. Fig. 13 shows the variation of the RSSI values observed for each node. One can note that nodes #2 and #3 present high variations between the maximum and minimum values observed for both topologies, while the linear schema also presents a high variation on node #7. Fig. 13 shows lower values of RSSI for the linear configuration, values that get worse as we approach the end of the chain. Nodes 7 and GW are to blame for 60% of losses. As opposite, zigzag configuration provides its worst performance at node 3, which is the guilty of one third of the total losses. As it can be appreciated, the linear configuration provides worst results than the zigzag configuration, since connectivity between consecutive nodes is more difficult due to the diffraction and reflection of waves.

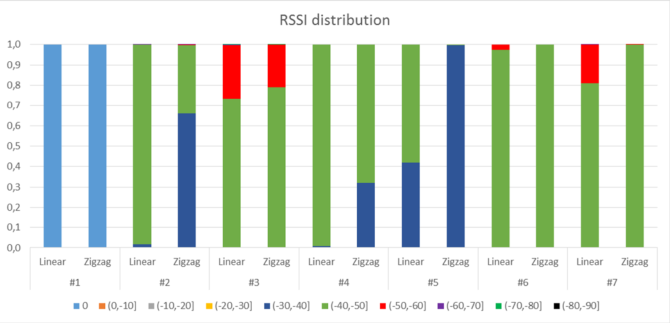


Fig. 12. Distribution of RSSI values measured at each node for the linear and zigzag configurations.

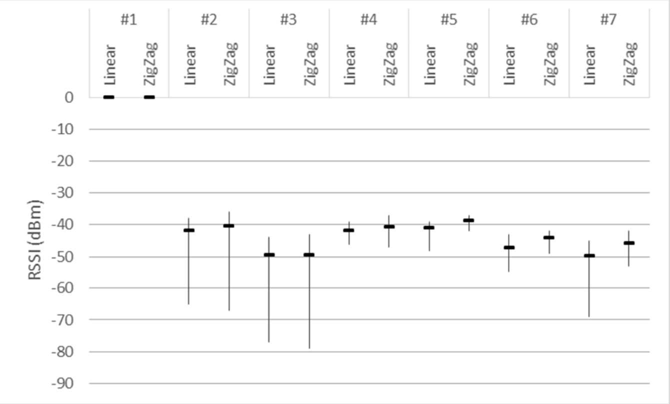


Fig. 13. RSSI variation. Maximum, average and minimum RSSI values measured for both configurations.

Related to this behavior, one can note that energy consumption of nodes is determined by the communication process, so that, linear configuration requires a higher power consumption by iteration. Fig. 14 illustrates the average power consumption of nodes according to the number of both initiated and successfully accomplished iterations. Message loss along the chain means that the number of iterations successfully accomplished is lower than this of the iterations initiated. The linear configuration involves higher power consumption, ranging from the 76% of node #4 to the 154% of node #6, than that required by the zigzag. The average power saving obtained when using the zigzag configuration is up to 122%. Taking into account the relevance of minimizing energy consumption when extending the lifetime of the WSN, it is clearly advantageous to choice the zigzag configuration.

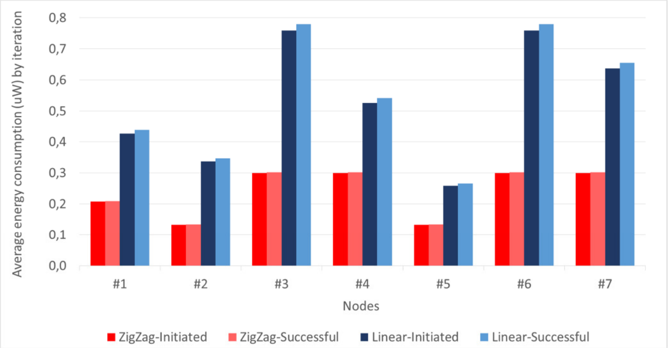


Fig. 14. Average power consumption (μW) by node, iteration and topology.

VI. APPLICATION

We have developed an application in charge of shopping monitoring. This application is used, first, on the customer side to achieve timely and detailed information of the current and previous purchases, and secondly, on the shopping mall management side to know the needs of product replacement on the shelves, the trend shopping, forecasting marketing campaigns, the path followed by the customers at the mall, and many others. Customers can know, in real time, the amount of products in the trolley, the expiration date of each product, the ingredients of each product (specially indicated for celiac, diabetic or lactose intolerant customers), its storage conditions, whether products require or not refrigeration, environmental conditions of the mall, etc. On the mall management side, the application allows to know the occupancy of the mall, to display a map of the displacement followed by customers with their trolley, to learn buying patterns of customers, to anticipate the number of checkouts to optimize the shopping flow, to compare trends and also the impact of marketing campaigns.

Communication between gateway and node is bidirectional since nodes may notify the server, and the server may interrogate the trolleys. Nodes communicate among them following the IEEE 802.15.4 protocol (XBee module), and the nodes located on the trolley and those in charge of data collection at each aisle communicate with the gateway using WiFi. The node transmits the information concerning the products introduced into the trolley by the customer to the gateway (PUSH model), but it also may be interrogated by the server (PULL model) in order to obtain its location or to actualize the product list. Communication between the smartphones of the customers (or other portable devices) and the system, or between the system and the stock clerks use WiFi (IEEE 802.11a/b/g). System communication with the office is wired due to security reasons. Fig. 15 illustrates the communication technologies involved.

Fig. 16 depicts the mobile application deployed at the customer size, which allows it to obtain all the nutritional information about the products by asking the server (PULL). This application also allows making the shopping list before going to the mall and then contrasting it with the content of the trolley as the purchase is made, analyzing the log of purchases made over a period of time, etc. Making use of augmented reality, the mobile app provides user guidance to the product indicated by the purchaser.

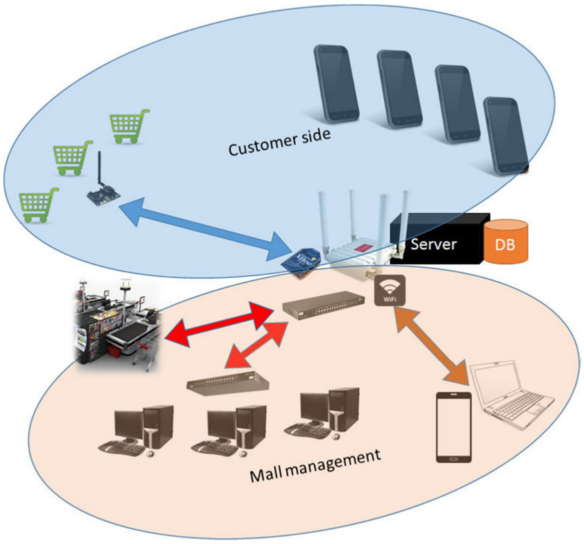
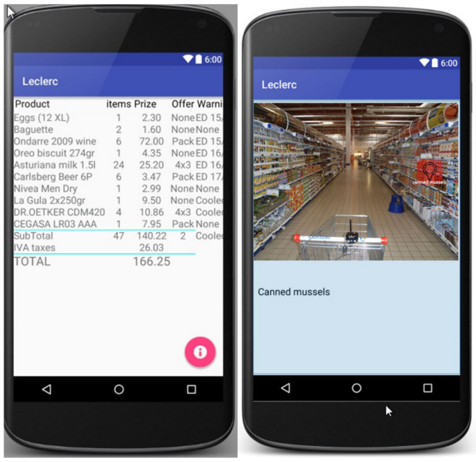


Fig. 15. Communication schema of the System Architecture implemented for the Context Aware shopping scenario.



Product	items	Prize	Offer	Warni
Eggs (12 XL)	1	2.30	None	ED 15
Baguette	2	1.60	None	None
Ondarre 2009 wine	6	72.00	Pack	ED 15
Oreo biscuit 274gr	1	4.35	None	ED 16
Asturiana milk 1.5l	24	25.20	4x3	ED 16
Carlsberg Beer 6P	6	3.47	Pack	ED 17
Nivea Men Dry	1	2.99	None	None
La Gula 2x250gr	1	9.50	None	Coole
DR.OETKER CDM420	4	10.86	4x3	Coole
CEGASA LR03 AAA	1	7.95	Pack	None
SubTotal	47	140.22	2	Coole
IVA taxes		26.03		
TOTAL		166.25		

Fig. 16. Android mobile app implemented for shopping cart monitoring within the commercial area.

The products introduced on the trolley are sensed by the node of the trolley, which transmits the corresponding information to the Meshlium gateway following four different strategies (notification-back, notification-through, delayed-notification & final notification) according to traffic congestion and to information requirements. Notification-back implies that communication from trolley to gateway is postponed until the list of products of the trolley is about to be modified/replaced by new products. Notification-through is performed synchronously from the node to the gateway. The node notifies the gateway as soon as it detects the presence/absence of a product on the trolley. Final notification performs the communication just when the trolley arrives to the checkout, and delayed-notification implies the periodic transmission of shopping information from trolley to gateway. The system can switch among these four notification strategies depending on the needs during operation. The election of the notification mode is determined by the management system. On the notification-back mode, the user has previously defined his/her shopping list, and the trolley compares this list with the products introduced into the trolley. The interaction with the user refers to the products of the shopping list. When the notification-through is selected, the node located inside the trolley notifies in real-time the presence/absence of a product as soon as it occurs. This communication mode may cause a higher communication flow than others since it allows to the marketing and sales managers of the mall to communicate directly to the users and offer them alternative products or sales. The delayed mode is similar to the previous one, but relaxing the real-time communication requisites. In this mode, communication between a trolley and the gateway is performed periodically, with a period that can be selected by the management system. This mode is indicted to reduce the traffic flow or whenever the direct interaction with the user is not desired or recommended. Lastly, the final notification mode is indicated when the checkouts are congested and the mall managers want to speed up the payment, or whenever they want to verify that the amount indicated by the cashier agrees with that indicated by the trolley. The notification modes do not entail relevant different performance at the communication layer and do not require any different underlying WSN topology; they mainly affect to the application layer, and specifically to the management part of the system. The normal flow between a node and the gateway, or among the nodes, remains unaffected by the notification mode selected. As future work lines, integration with wearable technologies, interaction with external mobile networks and distributed network capabilities will be analyzed in order to increase system functionality.

VII. CONCLUSIONS

In this work, a Context Aware environment for large commercial areas was implemented and tested, by means of combining WSN nodes to shopping carts, infrastructure nodes and an ad-hoc developed monitoring application. Intensive wireless channel analysis was performed in order to validate system functionality, considering inherent complexity given by the presence of multiple obstacles and scatterers, as well as by the inclusion of users within the commercial scenario. A fully functional system, including an ad-hoc application designed and implemented for large commercial areas was tested, providing full user interactivity when operating in a set of shopping carts in a real commercial center. The proposed system can be adapted and scaled in order to operate in a wide range of commercial environments. The proposed solution is capable of enhancing user shopping experience with new functionalities, such as indoor guidance, real time cart inventory or location based product alert, as well as providing valuable consumer analysis information to commercial operators in terms of marketing trends as well as optimized logistical and stock procedures.

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