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Analysis of Wireless Sensor Network Topology and Estimation of Optimal Network Deployment by Deterministic Radio Channel Characterization

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Abstract: The design and development of a Wireless Sensor Network (WSN) on an indoor scenario, where multipath propagation has special relevance, is often a difficult task that requires a long and tedious fieldwork that is not reusable later. This paper focuses on the validation of 3D Ray Launching simulation as an efficient method for reducing the time and effort required to design and develop a WSN on a complex indoor scenario. The radioplanning procedure is validated in a prototype of a WSN MANET, implementing a chain configuration deployed in a real indoor scenario, providing assessment on radio level, signal quality and power consumption. The use of deterministic tools in WSN deployment phases can aid in providing optimal layouts in terms of coverage, capacity and energy efficiency of the network.

Keywords: Wireless Sensor Networks, 3D Ray Launching, IEEE 802.15.4, WSN system level simulation

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1. Introduction

The complexity of indoor scenarios characterization concern signal propagation, but also interferences caused by the coexistence of different communication systems working in the same frequency band or by the congestion due to abundant deployment of wireless devices. A seasoned designer of wireless sensor networks (WSN) usually quite easily identifies which are the most suitable sites to locate the nodes of the network, but a subsequent experimental validation is required in order to ensure that the decision is correct and that the network operates in accordance with the requirements set by the customer. For such reason, simulation, modeling and analysis of WSNS are required.

As it is well known, WSNs need to minimize the energy consumption of their nodes to ensure the longevity of the networks, and maximize service performance. For such reason, an inefficient design of the network may cause high energy consumption due to an inappropriate selection of the topology of the network and to an unsuitable location of the nodes. The different existing proposals for routing in WSNs focus on the use of clusters, chains or hybrid solutions. LEACH [1] is the reference proposal on cluster based WSNs, a cluster-head collects data from all other sensors in the cluster, aggregates the data, and then transmits the whole information to a base station also called sink. LEACH rotates the cluster-head in order to evenly distribute the energy consumption. PEGASIS [2] forms, by means of a greedy algorithm, a chain covering all the nodes in the network, ensuring that each node only communicates with its neighbors. The transmission of the aggregated information is performed by a node which is randomly selected each round to uniformly distribute the energy consumption. Chain based topologies follow a space filling curve that ensures a minimal consumption of battery nodes due to transmission and reception [3]. In this case nodes minimize the number of messages exchanged and then battery consumption decreases in both transmission and reception modes.

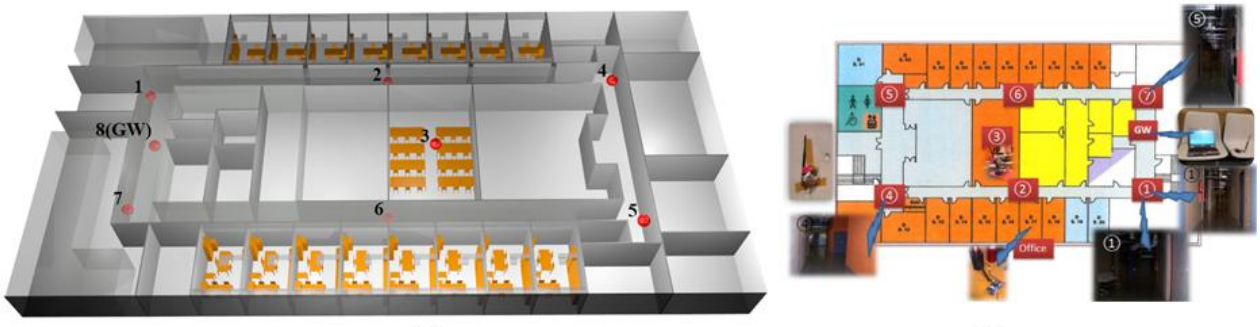
Indoor scenarios can be covered using chain based routing protocols, where an adequate radio planning ensures that the chain should be rarely redone. This is the case addressed on this paper, where the whole process of designing and deploying a chain based WSN by means of in-house 3D ray launching simulation is illustrated. The paper describes the results obtained by simulation and compares them with those obtained by real measurements, proving that in-house 3D ray launching simulation is an efficient method for reducing the time and effort required to design and develop WSNs on such scenarios.

2. Indoor scenario Simulation and Characterization

A 3D in-house developed RL algorithm has been used for the characterization of wireless propagation in the ground floor of a department of the Public University of Navarre (UPNA). The algorithm has been validated in the literature for different applications, like the analysis of wireless propagation in closed environments [4] interference analysis [5] or electromagnetic dosimetry evaluation in wireless systems [6]. It is based on Geometrical Optics (GO) and Geometrical Theory of Diffraction (GTD). GO approach consider only direct, reflected and refracted rays, bringing about abrupt areas, which correspond with the boundaries of the regions where these rays exist. Due to this constraint, the diffracted rays are introduced with the GTD and its uniform extension, the Uniform GTD (UTD). The entire floor of the UPNA department building has been considered for the simulations, taking into account all the furniture and infrastructures as chairs, tables or air ducts , as depicted in Figure 1(a). The total length of the scenario is 55.3m x 27.85m x 3.8m and it has been divided in 1m cuboids.

Eight antennas have been distributed all over the scenario considering the real antennas properties and the locations used in the measurement campaign. Their properties are given in the Table 1.

Figure 1 Simulated scenario (a) with all the antennas (Red points) and experimental scenario(b).



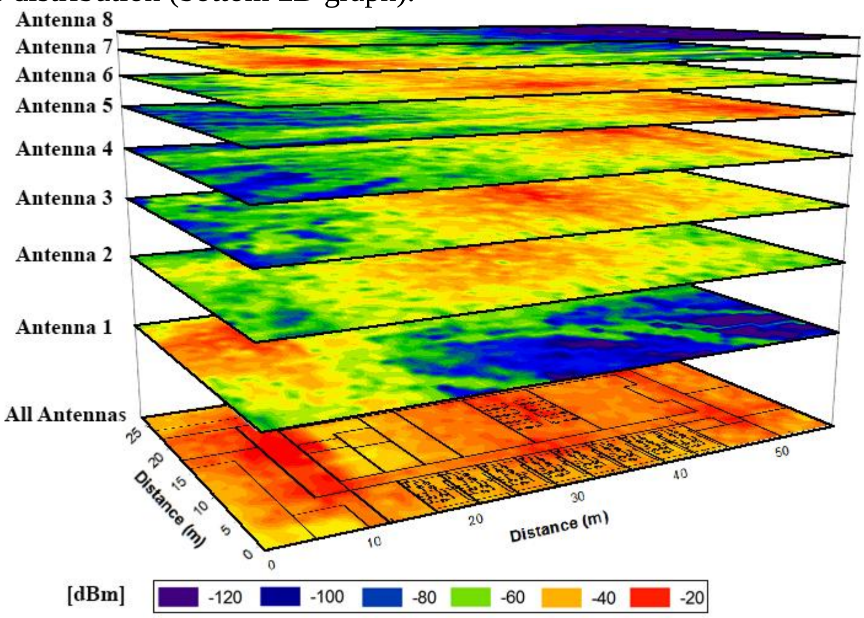
(a) (b)

Table 1 Considered parameters in the Ray Launching Simulation

Frequency	2.405GHz
Transmitter power	0dBm
Antenna gain	5dBi
Horizontal plane angle resolution (ΔΦ)	1º
Vertical plane angle resolution (Δθ)	1º
Reflections	5
Cuboids resolution	1m x 1m x 1m

The coverage given by a single antenna is not capable of providing service to the the complete scenario but an adequate RF power distribution is obtained by the sum of all of them placed properly. This behavior is shown in figure. 2 where the separate and joinlty contribution of all the antennas is depicted.

Figure 2 Contribution of all the simulated antennas for Z=1m, shown individually as well as the complete RF power distribution (bottom 2D graph).

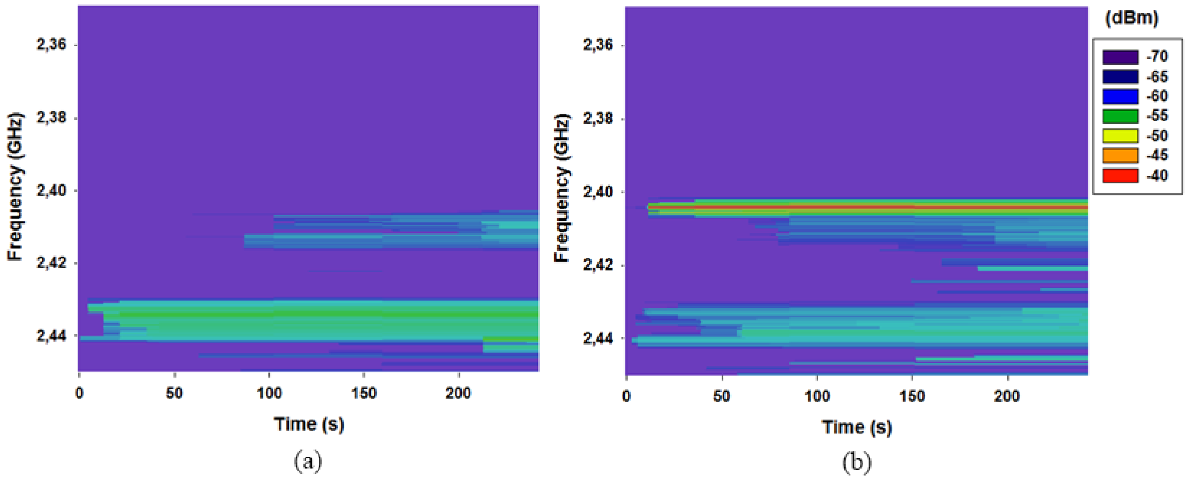


One of the most limiting factors in WSN performance is given by receiver sensitivity, determined basically by hardware limitations (such as noise factor) and employed modulation and coding schemes, which in turn determine maximum tolerable interference levels. The possible interference produced between transmitters must be considered in order to reduce packet loss and optimize the communication. Based on the results extracted from mathematical simulations, an efficient sensor mesh can be constructed.

3. Experimental results

Once the scenario has been characterized in terms of topological dependence of the wireless channel performance, experimental results are obtain to validate these previous estimations. Figure 1(b) depicts the experimental scenario where the WSN is deployed. We consider eight WSN nodes, that employ IEEE 802.15.4 standard where seven of them act as aggregators and the last one as gateway in charge of data collection. Due to the complexity of the environment, where several wireless signals could be propagating within it (e.g. WiFi), a spectrogram has been measured in order to gain knowledge about the radiofrequency pollution within the scenario, leading to an adequate and interference free wireless channel choice. Figure 3 shows the measured spectrogram for the scenario under analysis.

Figure 3 Measured spectrogram without (a) and with(b) operating WSN nodes.



Trying to avoid the interferences that can be seen in ISM 2.4GHz band, the IEEE 802.15.4 channel 11 (2.400-2.405 GHz) has been chosen. In Figure 3(b) the spectrum of the emitting nodes can be clearly seen, with a noticeable higher power level than the interferences.

The wireless sensor network is built by following a chain where each node receives a message form its predecessor, aggregates its information, and sends a message to its successor each 100 milliseconds without any acknowledgement or retransmission and at the end of the chain, node gateway (GW) collects all the information and stores it. Limitations may concern latency and packet fragmentation due to large payloads caused by data aggregation, but the reduced number of nodes (eight) involved in this WSN grants no packet fragmentation and an invaluable latency.

50,000 iterations have been performed, distributed in five experiments of 10,000 iterations and collecting the messages at two different locations: GW and Office (see Figure 4). Node #7 communicates directly (straight line) with node gateway, while it communicates by multipath with the office collector. This implies a high rate of losses as depicted in Figure 4. The fifth experiment has been conducted with the presence of several people moving freely through the halls without any movement pattern the first office experiment has been performed with the door closed obtaining a higher error rate(PER).

Figure 4 Packet error rate (PER) comparison between the hall and office base stations.

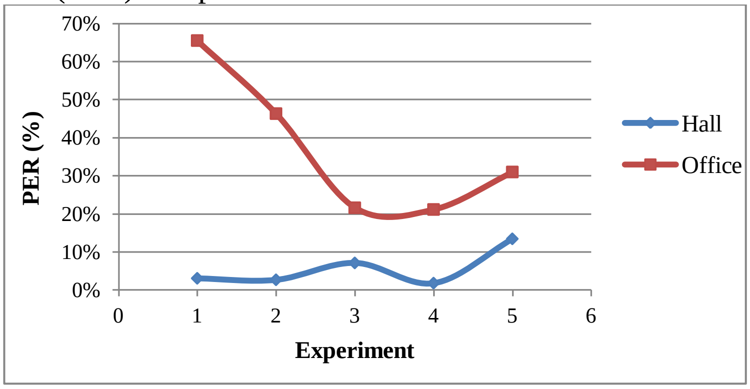


Table 2 summarizes the packet error rate of the WSN. We can observe a very small PER, lower than 6%. Given its condition of chain initiator, node #1 does not receive any message and hence it's PER is zero. and the higher values correspond to nodes #2 and gateway. Node #2 acts as a filter/stopper, ensuring a transmission rate that can be absorbed by the other nodes and the gateway has three times the PER of the node #2 mainly due the saturation of the receiver's buffer (and then the loss of some messages) caused by multipath propagation. However, the total amount of messages lost (2,806) is considerably low with respect to the total number of cycles initiated (50,000).

Table 2 Packet error rate (PER) by node.

Messages lost by node	#1	#2	#3	#4	#5	#6	#7	Gateway
Average	0,00%	1,21%	0,16%	0,42%	0,03%	0,08%	0,12%	3,58%

RSSI values (Table 3) for nodes #3, #6 and #7 are closer among them than those corresponding to nodes #2, #4 and #5. The higher RSSI average value corresponds to node #6 (-57.838 dB), while the lower average value corresponds to node #4 (-79.275 dB). The average values are far from the sensitivity threshold of the device (-95 dB) and node #4, which is the most conflictive point, has a reduced PER (0.42%).

Table 3 RSSI statistics for the indoor scenario.

Node	#2	#3	#4	#5	#6	#7
Average	-64.4467	-59.7705	-79.2746	-61.7483	-57.8385	-51.3382

In order to validate the estimations given by the radio channel, 3D Ray Launching code simulation and measurements results have been correlated (Table 4). In this case the value has been obtained in the radio link established from the preceding WSN node. A mean error of **1.4 dB** has been obtained in this comparison, validating the use of the 3D RL tool in order to adequately locate the proposed nodes of a WSN under design phases.

Table 4 Comparison between RSSI and simulation power values.

	#1 - #2	#2 - #3	#3 - #4	#4 - #5	#5 - #6	#6 - #7	#7 - GW
Measurements (dBm)	-65,62	-62,11	-79,13	-66,74	-57,11	-63,31	-57,99
Simulation (dBm)	-65,87	-58,53	-74,91	-66,07	-56,41	-62,13	-57,07

4. Conclusions

In this work, deterministic radioplanning techniques have been applied in order to fully determine the characteristics of the wireless channel for each one of the nodes of a Wireless Sensor Network in an indoor scenario. By taking into account all of the elements of the scenario, detailed information on the topological dependence of the network layout can be obtained. This influences not only the expected values of coverage of each individual node, but also determines maximum capacity performance, due to the fact that interference levels are also dependent on the network topology. Estimations have been obtained with the aid of deterministic 3D Ray Launching code implemented in-house at Public University of Navarre and validated with a real WSN, Signal to Noise ratio and Packet Error Ratio have been compared numerically and with measurement results, showing good agreement. The use of deterministic planning tools in the design phases of WSN in complex indoor scenarios can lead to cost efficient network designs, in which interference levels and energy consumption levels can be minimized, whilst maximizing overall WSN capacity.

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