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Analysis of Bluetooth-Based Wireless Sensor Networks Performance in Hospital Environments †

Peio Lopez-Iturri [1], Santiago Led [1], Erik Aguirre [1], Leyre Azpilicueta [2], Luis Serrano [1] and Francisco Falcone [1,*]

[1] Electrical and Electronic Engineering Department, Public University of Navarre, Pamplona 31006, Spain; peio.lopez@unavarra.es (P.L.-I.); santiago.led@unavarra.es (S.L.); erik.aguirre@unavarra.es (E.A.); lserrano@unavarra.es (L.S.)

[2] School of Engineering and Sciences, Tecnologico de Monterrey, Campus Monterrey, Monterrey, NL 64849, Mexico; leyre.azpilicueta@itesm.mx

* Correspondence: francisco.falcone@unavarra.es; Tel.: +34-948-169-741

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Abstract: In this work, a method to analyze the performance of Bluetooth-based Wireless Sensor Networks (WSN) deployed within hospital environments is presented. Due to the complexity that this kind of scenarios exhibit in terms of radio propagation and coexistence with other wireless communication systems and other potential interference sources, the deployment of WSNs becomes a complex task which requires an in-depth radio planning analysis. For that purpose, simulation results obtained with the aid of an in-house developed 3D Ray Launching code are presented. The scenarios under analysis are located at the Hospital of Navarre Complex (HNC), in the city of Pamplona. As hospitals have a wide variety of scenarios, the analysis has been carried out in different zones such as Boxes, where different medical sensors based on Bluetooth communication protocol have been deployed. The simulation results obtained have been validated with measurements within the scenario under analysis, exhibiting Bluetooth-based WSNs performance within hospital environments in terms of coverage/capacity relations. The proposed methodology can aid in obtaining optimal network configuration and hence performance of Bluetooth-based WSNs within medical/health service provision environments.

Keywords: Ray Launching; Bluetooth; Wireless Sensor Networks; hospital environment; Interference

1. Introduction

Information and Communication Technologies are key elements in the evolution of health provision. In this way, multiple elements can enhance health system efficiency as well as improving quality of service and hence citizen's quality of life, such as electronic health recorded, tele-medicine, mobile/wearable devices for remote diagnostics or the paradigm of Smart Health, as the provision of health services in the context of Smart City/Smart Region environments [1]. Several properties are desirable in the implementation of such context aware environments, such as high degree of mobility and interactivity or user-centric operation and interoperability capabilities, to name a few. One of the key elements within this framework are wireless communication systems, which in the majority of cases are the primary enablers in order to achieve mobility and service ubiquity, which is usually obtained by the combined use of multiple wireless systems (such as Body Area Networks, Wireless Local Area Networks and Public Land Mobile Networks, among others). This combined wireless system operation, capable of providing optimal quality of service as a function of user density and required transmission rate, leads to the concept of Heterogeneous Network, HetNet, and operation. In order to provide adequate service levels to each user, coverage/capacity relations must be considered, in which overall interference level is the main limiting factor [2]. Interference levels are given by intra-system users, inter-system users and external sources. It is worth noting that one of the most employed solutions is to deploy compact body area networks, based on WBAN/WLAN standards, with inherent energy limitations as well as available transmission power constraints [3]. Taking into account these limitations as well as the large variability in transceiver location and adverse wireless channel operation (given by non-line of sight operation and potentially large absorption losses), device and network planning and design is compulsory in order to guarantee adequate service levels whilst simplifying overall network architecture. In the specific case of hospital environments, several factors such as constructive complexity (given by the existence of multiple scatterers as well as enclosed environments) and potential interferences (given by the co-existence of multiple medical instruments and diagnostic elements, such as MRI), must be considered in order to estimate coverage/capacity relations specifically applied to low power compact devices.

In this work, the operation of WSNs employing Bluetooth devices is analyzed in the specific context of health services, with the aid of deterministic channel modelling based on in-house 3D Ray Launching code, enabling the consideration of scenario complexity and the influence of material properties within the scenario.

2. Experiments

A 3D Ray Launching algorithm has been used for the analysis of Bluetooth-based WSNs within hospital environments. This 3D Ray Launching algorithm is a deterministic methodology that has been implemented in-house and it is based on Geometrical Optics (GO) and Geometrical Theory of Diffraction (GTD), with its extension the Uniform Theory of Diffraction (UTD). The principle of the algorithm is that the considered whole 3D scenario, in this case the hospital environment, is divided into a grid of cuboids and each cuboid stores the information of the radio propagation analysis when rays are launched from the different transceivers. Parameters such as frequency of operation, transmitter power, number of reflections considered, considering diffraction or not, and the location of the transceivers are input parameters in the algorithm. The detailed description of the algorithm can be found in [4]. Moreover, it has been validated for different environments, such as indoor environments [5] and large complex environments [6].

Simulations have been carried out in different areas of the Emergency-department of the Hospital of Navarre, in the city of Pamplona. As an illustrative example, in Figure 1 the Boxes room zone scenario created for the 3D Ray Launching simulations is shown. The scenario has a size of 37 m × 13.4 m × 3 m and it is represents an area of the ground floor of the Emergency building of the HCN. The scenario consist of 12 rooms, called Boxes, where different medical staff cares for patients. This rooms are very similar and they have tables, chairs and shelves, in addition to the required medical stuff and devices. The constitutive materials of all the elements within the scenarios have been taken into account, introducing their dielectric properties in the simulator with the aim of obtaining accurate radio propagation estimations at the frequency of operation.

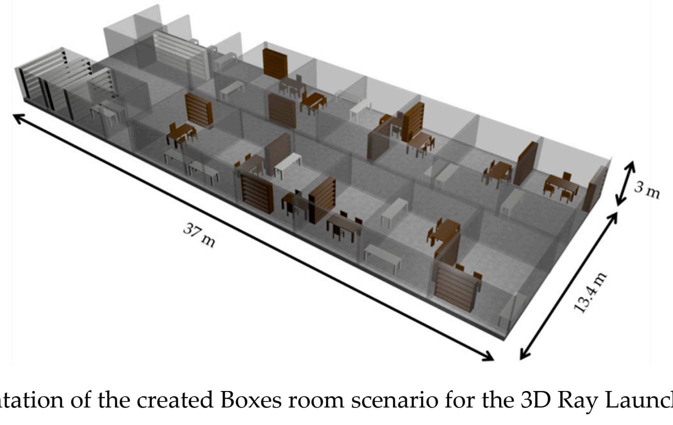


Figure 1. Representation of the created Boxes room scenario for the 3D Ray Launching simulations.

Once the scenario under analysis has been created for simulations, the wireless transceivers are placed within the scenario in order to obtain radio propagation estimations, which will be dependent on the morphology of the scenario as well as on the position of the transceiver itself and its radio characteristics such as transmitted power level and antenna type. For the study presented in this work, the medical devices based on Bluetooth wireless communication present on the Intelligent Point-of-Care (iPoC) of LQTAI. The iPoc include devices such as ECG, blood pressure monitor, thermometer, glucose meter, pulsioximeter, peak-flow, weight scale and a smart phone with Bluetooth 2.0. Figure 2 shows the iPoC of LQTAI.

Figure 2. iPoC medical device set.

For the simulations, the blood pressure monitor, the thermometer, the pulsioximeter and the glucose meter have been placed within each room, since they are common medical devices usually present in the real environment under analysis. The placement of the devices is depicted in Figure 3, where some devices are on the tables and others on the medical stretcher. An extra device (represented as a green point) has been placed within the aisle, which corresponds to a device used to validate the simulation results within this kind of environments. The main radio characteristics of the used Bluetooth devices both for simulations and validation measurements are summarized in Table 1.

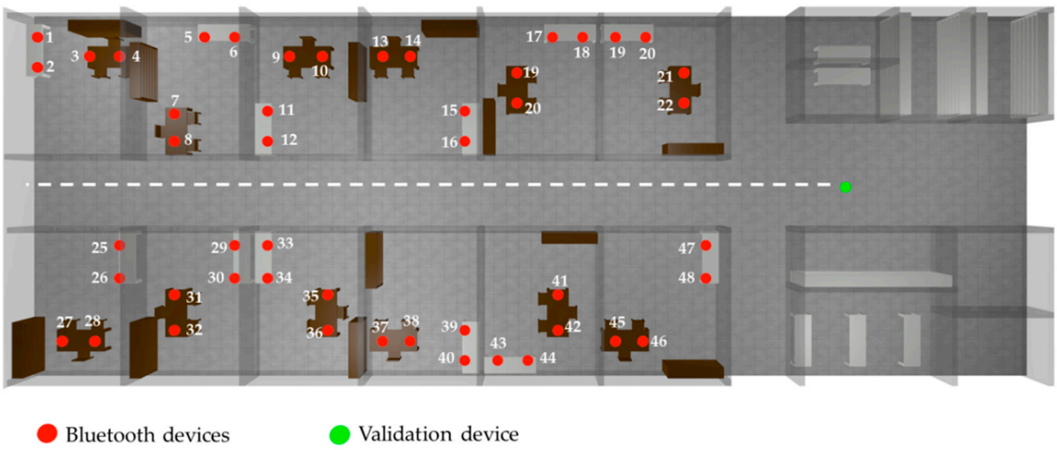


Figure 3. Localization of Bluetooth devices within the scenario under analysis.

Table 1. Radio characteristics for Bluetooth simulations.

Parameter	Value
Antenna type	Chip
Antenna gain	−1 dBi
Frequency	2.44 GHz
Transmitted power level	3 dBm

3. Results

Firstly, in order to validate the simulation results obtained by the 3D Ray Launching algorithm employed in this study, a specific simulation has been carried out to compare their results with measurements within the scenario under analysis. This simulation corresponds to the transmitter represented as a green dot in Figure 3. The white dashed line of the picture shows the linear path where measurements have been taken. Figure 4 shows the comparison between measurements and estimated results by means of the 3D Ray Launching method. The graph shows the typical variations of received RF power level due to multipath propagation, which is the most significant radio propagation phenomenon within complex indoor scenarios. The obtained results show good agreement between simulations and measurements.

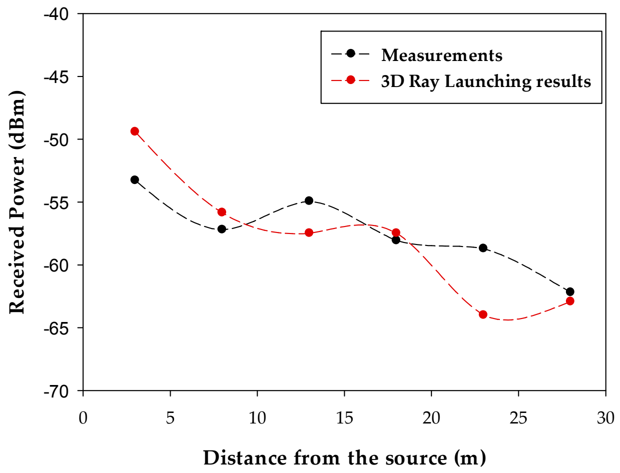
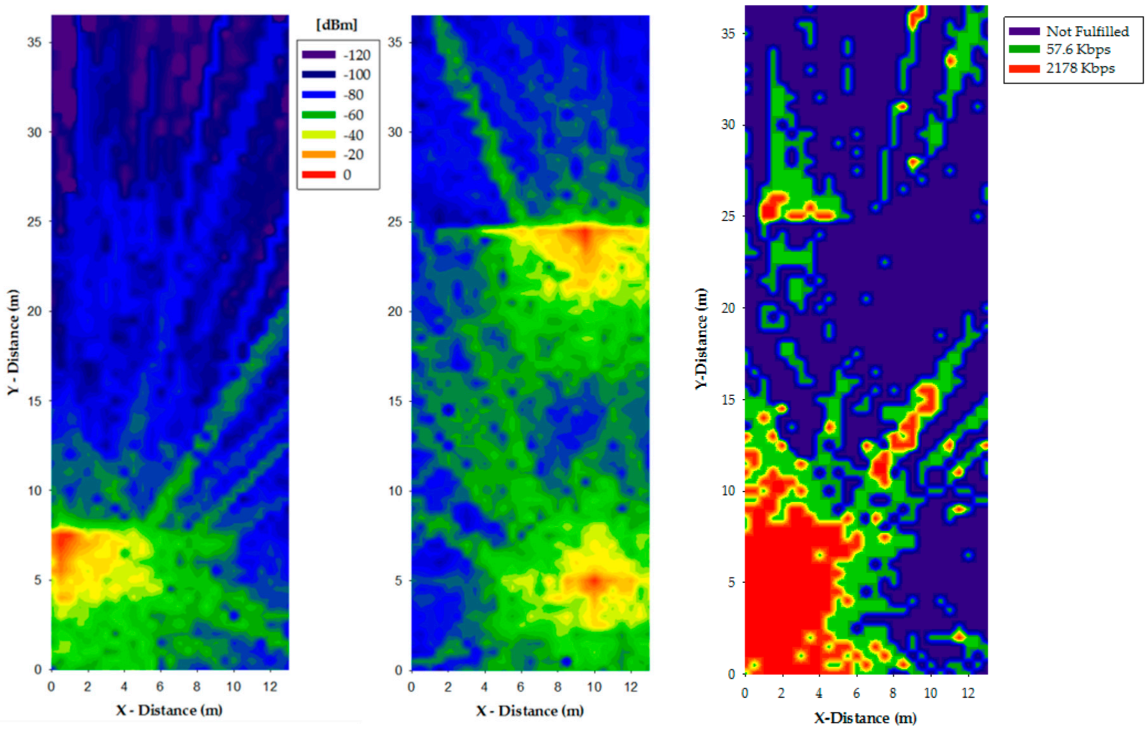


Figure 4. Measurements vs. 3D Ray Launching simulation results comparison.

Then, the rest of simulations have been performed. As an example, the bi-dimensional plane at height 1.5 m of the device #6 is depicted in Figure 5a, where the RF power distribution throughout the whole scenario can be seen. As one of the aims of this work is to study the performance of Bluetooth-based WSNs within this kind of environments, an important issue is the coexistence of several Bluetooth piconets and devices operating within the scenario. For that purpose, other three deployed devices (#31 and #48) have been chosen to consider them as interference to the communicating device #6. Note that this will happen only when a collision with the signal sent by the selected 2 devices happens. Figure 5b shows the RF power distribution for the 2 interfering devices for the height of 1.5 m. In order to show the effect of such potential interference, Figure 5c shows if the obtained SNR requirements are fulfilled for the situations of an asynchronous 8DQPSK communication at 2178 Kbps (red area), which corresponds to a high Bluetooth data rate, and for an asynchronous GFSK communication at 57.6 Kbps (extended green area). The required SNR values have been calculated by means of the well-known Shannon formula and they are 5.47 dB and −13.9 dB respectively. The dark blue colored area does not meet the requirements for a successful Bluetooth communication at those data rates.



(**a**) (**b**) (**c**)

Figure 5. (**a**) RF power distribution for device #6; (**b**) Interference level produced by devices #31 and #48; (**c**) Bluetooth device #6's coverage depending on different SNR value threshold.

4. Discussion

The results show that interference analysis in such environments where many Bluetooth devices could be deployed is a key issue, and mandatory for an optimized radio planning duties, since the interference will limit the performance of the deployed WSNs in terms of achievable data rates, coverage and power consumption (directly related to the transmission power level of devices). The presented Bluetooth interference analysis method by the 3D Ray Launching simulation algorithm is a novel accurate and useful tool for such analysis within complex hospital environments.

5. Conclusions

Non-desired interferences can affect negatively Bluetooth communications at ISM 2.4 GHz band, both for inter-system coexistence (such as Wi-Fi) and for intra-system coexistence. The results and the interference analysis methodology used in this work show the importance that this kind of analysis will have for the deployment of Bluetooth-based devices in such complex and critical environments like hospitals, more taking into account that the number of wirelessly connected medical devices and sensors is expected to grow exponentially with the advent of IoT and the development of Smart Health services.

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Conflicts of Interest: "The authors declare no conflict of interest." "The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results".

Abbreviations

The following abbreviations are used in this manuscript:

WSN	Wireless Sensor Network
iPoC	Intelligent Point-of-Care
GO	Geometrical Optics
GTD	Geometrical Theory of Diffraction
UTD	Uniform Theory of Diffraction
RF	Radio Frequency
SNR	Signal to Noise Ratio
DQPSK	Differential Quadrature Phase Shift Keying
IoT	Internet of Things

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