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Analysis of Radio Wave Propagation for ISM 2.4GHz Wireless Sensor Networks in Inhomogeneous Vegetation Environments

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Abstract: The use of wireless networks has been extended in an exponential growing due to the improvement in terms of battery life and low consumption of the devices. However, it is highly important to conduct previous radio propagation analysis when deploying a wireless sensor network. These studies are necessary to perform an estimation of the range coverage, in order to optimize the distance between devices in an actual network deployment. In this work, the radio channel characterization for ISM 2.4GHz Wireless Sensor Networks (WSN) in an inhomogeneous vegetation environment has been analyzed. The impact of topology as well as morphology of the environment is assessed by means of an in-house developed 3D Ray Launching code, to emulate the realistic operation in the framework of the scenario. Experimental results gathered from a measurements campaign conducted by deploying a ZigBee Wireless Sensor Network, are analyzed and compared with simulations in this paper. The scenario where this network is intended to operate is a combination of buildings and diverse vegetation species. To gain insight in the effects of radio propagation, a simplified vegetation model has been developed, considering the material parameters and simplified geometry embedded in the simulation scenario. The use of deterministic tools can aid to know the impact of the topological influence in the deployment of the optimal Wireless Sensor Network in terms of capacity, coverage and energy consumption, making the use of these systems attractive for multiple applications in inhomogeneous vegetation environments.

Keywords: Wireless Sensor Network; vegetation environment; 3D Ray Launching

1. Introduction

Wireless sensor networks (WSNs) are emerging as a significant technology and they are attracting applications in variety of fields, such as industrial sensing, health monitoring, sports applications, consumer and military applications [1]. With the adequate developments in design and fabrication technologies for ubiquitous wireless connectivity, monitoring of physical and environmental parameters in vegetation environments are gaining importance in the recent years. The functioning of WSN is clearly dependent upon having adequate signal levels at the distributed nodes, and thus designing effective WSN requires accurate propagation modelling capabilities for complex environments. Because of that, it is highly important to conduct previous radio propagation analysis when deploying a WSN. Traditionally, empirical methods were used (such as COST-231, Walfish-Bertoni, Okumura Hata, etc.) for initial coverage estimation. They are rapid but not as much accurate as deterministic methods, which are based on numerical approaches to the resolution of Maxwell's equations. Deterministic methods, such as ray launching and ray tracing (based on geometrical optics) or full-wave simulation techniques (method of moment (MoM), finite difference time domain (FDTD), FITD, etc.), are precise but are time-consuming to inherent computational complexity. As a midpoint, deterministic methods based on geometrical optics, offer a reasonable trade-off between precision and required calculation time. [2-3].

In this work, the characterization of the physical channel for radio planning purposes has been made for a vegetation environment. The main purpose is to model the radio wave propagation adequately in order to optimize the distance between devices in an actual network deployment.

2. Ray Launching Technique

A deterministic method based on an in-house developed 3-D Ray Launching code has been used to analyze the radio electric behavior of an inhomogeneous vegetation environment [4-5]. The software has been implemented in-house based on Matlab programming environment. It is based on geometrical optics (GO) and the uniform geometrical theory of diffraction (UTD), taking into account electromagnetic phenomena like reflection, refraction and diffraction. The main principle of the algorithm is that power is modeled as a finite number of rays launched within a solid angle. Parameters such as frequency of operation, radiation patterns of the antennas, number of multipath reflections, separation angle between rays, and cuboid dimension can be taken into account. Besides, all the material properties for all the elements within the scenario can also be considered, given the dielectric constant and the loss tangent at the frequency range of operation of the system under analysis. Figure 1 shows the schematic view of the inhomogeneous vegetation scenario which has been considered for simulation. The scenario consists of an outdoor environment, with trees of different heights, and grass in the floor. A simplified vegetation model has been developed for this purpose. The streetlights have also been taken into account, as well as the material properties of all the elements within the scenario.

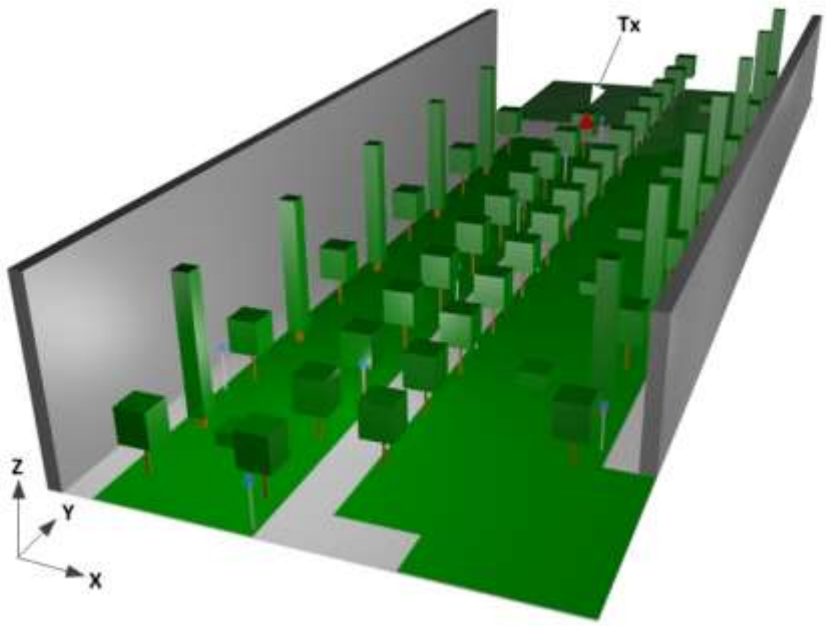

Figure 1. Vegetation scenario under consideration for simulation in the 3D Ray Launching algorithm.

For the simulations, an antenna has been placed at the point (X=11.95m, Y=70.8, Z=1.2), depicted with a red triangle in Figure 1. The radiating element is a wireless ZigBee mote which has been configured as a dipole, transmitting 18dBm at 2.41GHz. Simulation parameters are shown in Table 1.

Table 1. Parameters in the ray launching simulation.

Frequency		2.41GHz
Vertical plane angle resolution	$\Delta\theta$	0.5º
Horizontal plane angle resolution	$\Delta\varphi$	0.5º
Reflections		6
Transmitter Power		18dBm
Cuboids resolution		0.5m

3. Results and Discussion

Figure 2 shows the power distribution within the considered scenario for different heights. As it can be seen, the influence of the obstacles (like the trees and streetlights) can be easily appreciated. It is shown that the morphology as well as the topology of the considered scenario has a noticeable impact on radio wave propagation.

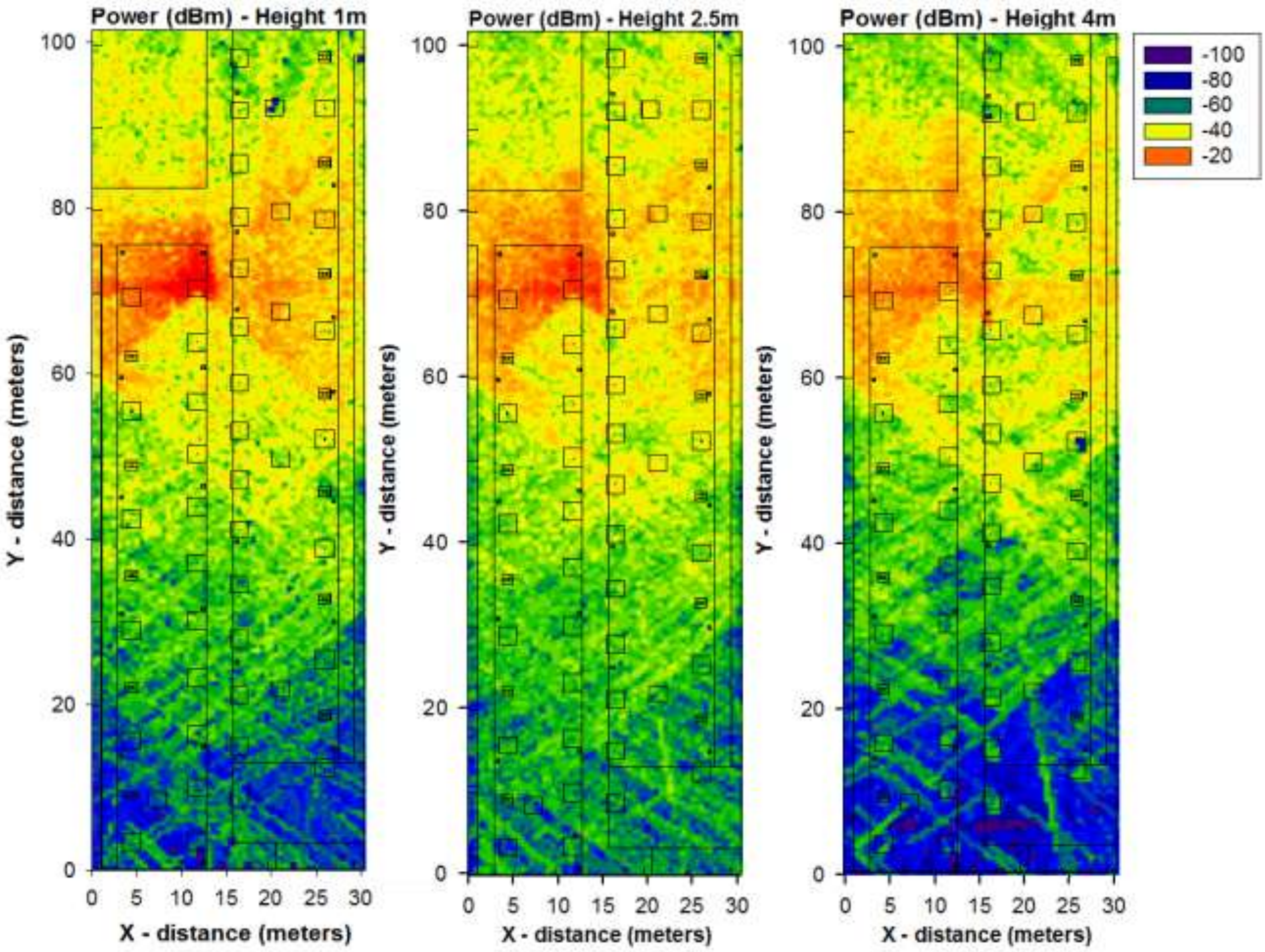

Figure 2. Estimation of received power (dBm) on the vegetation environment for different heights obtained by the 3D Ray Launching algorithm.

Figure 3 depicts the radials of power along the Y-axis of the considered scenario, for two different values of X, for different heights. It is observed that the distribution of power has a lot of variability due mainly to the strong influence of multipath components.

An important radioelectric phenomenon in this type of environment is given by multipath propagation. To illustrate this fact, the power delay profile for the central location of the scenario has been obtained and it is shown in Figure 4. As it is observed, there are several echoes in the scenario due to this behavior of multipath channel.

An experimental setup has been set with the aim of validating the simulation results obtained previously. ZigBee technology has been chosen for emulating a WSN. Specifically, the wireless devices used for the measurements have been the XBee Pro motes from Digi International Inc. The received power values estimated by simulation have been obtained for the same spatial samples as the real measurements, considering the corresponding cuboid in the three-dimensional mesh of cuboids in which the scenario have been divided. Figure 5 shows the comparison between simulation and measurements results, showing good agreement between them with a mean error of 1.67dB.

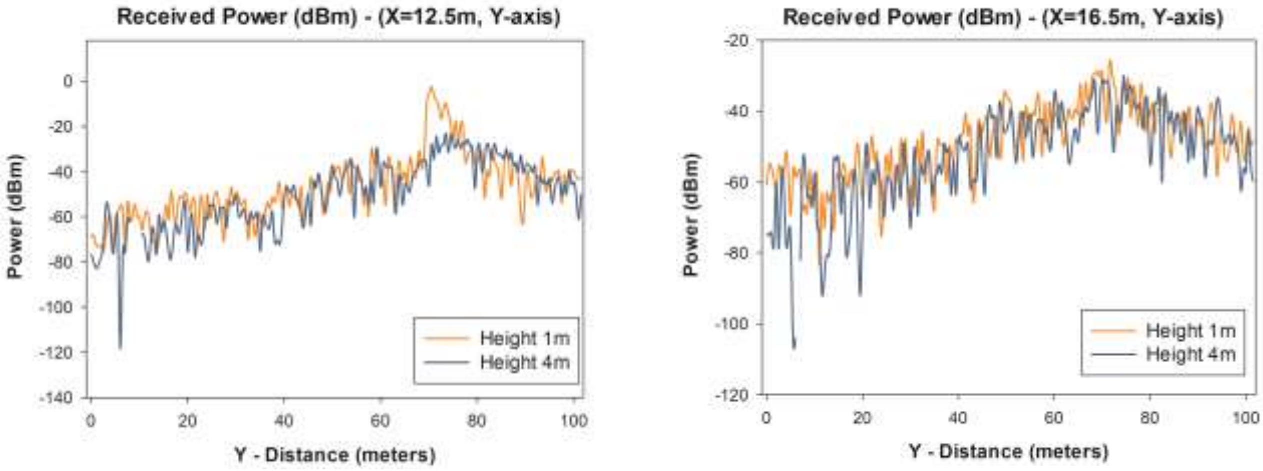

Figure 3. Estimation of radials of received power (dBm) along the Y-axis for X=12.5m and X=16.5m for different heights.

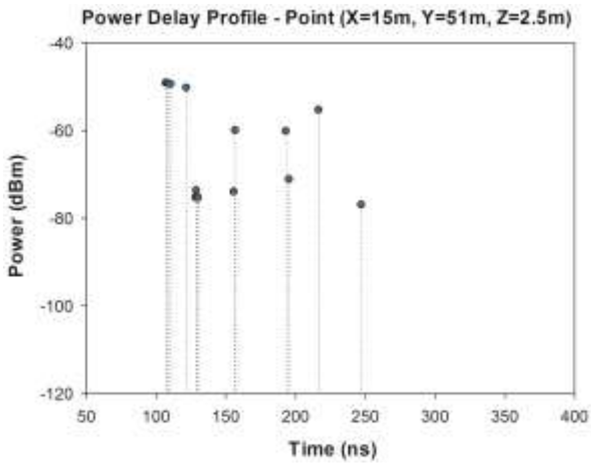

Figure 4. Power Delay Profile at a given cuboid, located at the central location in the considered scenario.

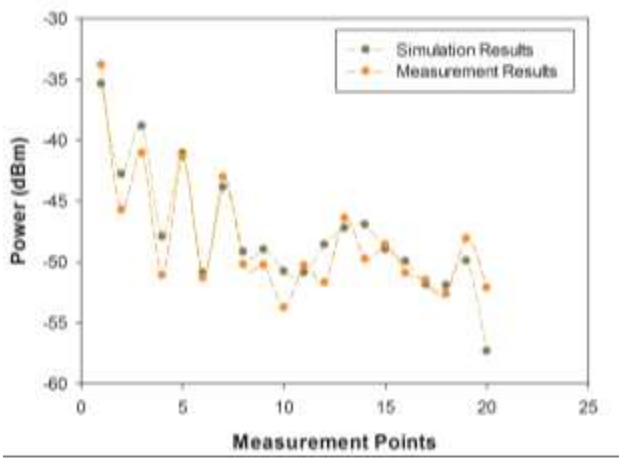

Figure 5. Comparison Simulation versus Measurements.

4. Conclusions

In this work, the demands for modeling the radio channel in inhomogeneous vegetation environments are presented. The obtained results show the complexity of vegetation scenarios. It is concluded that the morphology as well as the topology of the scenario plays a key role in the estimation of radio signal propagation, due to the strong impact of multipath components in the overall loss mechanism of the propagating radiowave. The agreement between simulation and measurement results validates the 3D ray launching algorithm, making it adequate for radioplanning analysis with the aim of deploying WSN within this type of environments.

Author Contributions

Leire Azpilicueta, Erik Aguirre, Peio López-Iturri, Ignacio Mateo and Francisco Falcone conducted the characterization of wireless propagation mechanisms in the outdoor scenario, as well as the WSN campaign of measurements. José Javier Astráin and Jesús Villadangos participated in the development of the WSN for such scenario.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

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