A Survey of RF-Propagation Models for Wireless Sensor Networks for Smart City Applications

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ABSTRACT

This document presents a survey of the most famous outdoor radio propagation models suitable for Wireless Sensor Networks (WSNs) for smart city applications. The work presented here has already been published in an international conference.

1. Introduction

WSNs are networks formed by a large number of sensor nodes where each node is equipped with a sensor to detect environmental or physical phenomena. Simulators are fundamental tools for designing and simulating WSNs. Among the challenges in this field is the accuracy of the radio propagation models. This document presents the most famous outdoor physical and empirical propagation models, for WSNs. The objective of this paper is to list those models along with the related conditions, assumptions, and restrictions in order to use them correctly.

2. Radio Propagation Models for WSNs

WSNs for smart city applications have some constraints imposed by the nature of WSN in terms of the radio aspects, these constraints can be summarized as follows [1], [2], [3]:

- Low transmit power: The nominal transmit power defined by the IEEE 802.15.4 physical layer - 2003 is 1 mW (0 dBm).
- Low antenna heights: in most of the WSN scenarios in smart cities, sensor nodes are relatively close to the ground level.

Here, we will present the most commonly used outdoor propagation models:

2.1 Free Space Model

The fundamental reference path loss model is the free space model. The free space model is one of the most widely used propagation models for WSN. This model calculates the attenuation of an electromagnetic wave in free space for the line-of-sight path (LOS), taking account of the distance and the frequency, with no obstacles nearby to cause reflections or diffractions. Free space path loss is usually expressed in dB, and given by:

$$L\,(dB) = 20\log\left(4\pi\frac{d}{\lambda}\right) - Gt - Gr \qquad (1)$$

L : is the path loss in dB.
d : is the distance between the transmitter and the receiver.
λ : is the wavelength.
Gt, Gr: are the transmitter and receiver antenna gains in dBi.

2.2 Adapted Free Space Model

Path loss exponent in the free space model equals 2 (α = 2), but the adapted free space model makes it possible to use an empirical value for the path loss exponent according to the propagation environment. For example, in [4], for an urban unobstructed scenario, it was found that the measurements match the model if a path loss exponent of α = 2.2 is assumed.

2.3 Simplified Two-Ray Ground Reflection Model

Free space model does not consider any obstacle. When the nodes are placed close to the ground, we have an unavoidable obstacle, which is the ground. Wireless sensors are usually placed near to the ground, thus we have to take into account the ground reflected ray because it carries significant power. Two-ray model estimates the path loss of the received signal considering the two predominant paths in near-ground scenarios, which are the direct path (LOS) and the ground reflected rays. The calculation of the interaction or the interference between the direct path and the reflected path is simplified [5], by assuming a large distance d between the transmitter and the receiver, and perfect reflection (so, the reflection coefficient, $\Gamma = -1$). Thus, the simplified Two-Ray Ground equation is given by:

$$L\,(dB) = 20\log(\frac{d^2}{h_t h_r}) \qquad (2)$$

$h_t h_r$:are the transmitter and receiver antenna heights respectively.

2.4 Two-Ray Ground Reflection Model

The simplified version assumes some simplifying hypotheses such as perfect reflection coefficient which is not really true because the ground is not a perfect conductor, for this reason we have to consider the ground reflection coefficient. The receiver side sees the sum of all the existing signal paths. Considering only the direct and the reflected rays, we obtain the following equation [6]:

$$\overline{Pr}(d) = Pt(\frac{\lambda}{4\pi d})^2 \left| \frac{1}{r_1} exp(-jkr_1) + \frac{\Gamma_2(\alpha)}{r_2} exp(-jkr_2)\right|^2 \qquad (3)$$

$\overline{Pr}$: is the received power.
Pt : is the transmit power.
d : is the distance between the transmitter and the receiver.
λ : is the wavelength.
Γ : is the ground reflection coefficient given in [1].
$k = 2\pi f/c$: is the wavenumber.
r_1, r_2: are the direct and reflected path lengths.
α : is the angle of incidence of the ground ray.

2.5 Free Outdoor Model (FOM)

This model combines the four most significant path loss factors for WSN [1]. These factors are: free space path loss, ground reflection path loss, it adds a Gaussian random variable to represent the uncertainty of the estimated received signal level due to multiple less significant paths, and finally it includes two factors $K_1 K_2$ to represent the antenna radiation pattern gains along the direct and reflected paths respectively. The received power is, therefore, given by the final equation as:

$$\overline{Pr}(d) = Pt\left(\frac{\lambda}{4\pi d}\right)^2 \left(K_1^2 + K_2^2\Gamma^2 + 2K_2\Gamma cos\left(\frac{2\pi}{\lambda}\Delta L\right)\right) + X_{\sigma(\overline{Pr})} \qquad (4)$$

ΔL : is the path difference between direct and reflected paths,
$K_1 K_2$: are coefficients to represent the difference in the antennas' gain, along the direct and reflected paths respectively, due to the antennas' radiation pattern.

$X_{\sigma(\overline{Pr})}$: is a Gaussian distribution with a mean of $\overline{Pr}$ and a variance of σ [1].

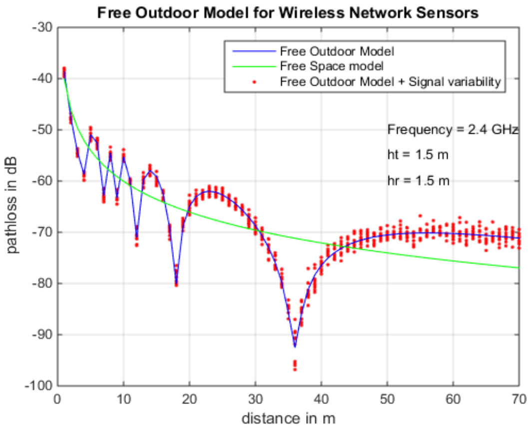

Figure 2. Simulation results for Free Outdoor Model.

Figure 2 shows the simulation results of this model. The blue curve shows the path loss using this model. It shows that the direct and the reflected rays add up constructively or destructively giving the energy holes. When the two rays are out of phase, they add up in a destructive manner, but on the other hand, when they are in phase they add up in a constructive manner [7]. The red points around the free outdoor model represent the uncertainty range or the margin of error that was introduced by the Gaussian distribution. The green curve in figure 2 shows the path loss of the direct ray without considering the reflected ray.

2.6 Log Normal Shadowing Model

Log-Normal shadowing model is a general extension to the free space model. It estimates the path loss for a wide range of environments, whereas, the free space is restricted to unobstructed path. The log-normal shadowing model consists of two parts; the first one is the adapted free model that uses a path loss exponent determined by field measurements. The second part is the shadowing model to reflect the variation of the received power. Some typical values of path loss exponent and shadowing deviation are given for each environment. The overall relation between the path loss and the distance is expressed as follows:

$$L(d_i) = L(d_0) + 10nlog\left(\frac{d_i}{d_0}\right) + X_\sigma \qquad (5)$$

$L(d_i)$: is the path loss in dB at a distance d_i, $d_i > d_0$.
$L(d_0)$: is the path loss in dB at a distance d_0 .
n : is the path loss exponent.
X_σ : is a zero-mean Gaussian random variable with a standard deviation of σ.

In [8], the authors proposed to use the log-normal model with two different slopes and deviation values. The breakpoint distance d_b (given in [8]) separates the two slopes of this model. The two-slope model is expressed as follows:

$$L(d_i) = \begin{cases} L(d_b) + 10n_1 log\left(\frac{d_i}{d_b}\right) + X_{\sigma 1} & d_i \le d_b \\ L(d_{b+1}) + 10n_2 log\left(\frac{d_i}{d_{b+1}}\right) + X_{\sigma 2} & d_i > d_b \end{cases} \qquad (6)$$

The simulation parameters are for a plaza side taken from [8] and the simulation results for this configuration are given in figure 3, which shows the two slopes of this model separated at the breakpoint distance = 32 m. The red points represent the variations of the received power of the first piece of the model and the black points represent the variations of the received power of the second piece of the model.

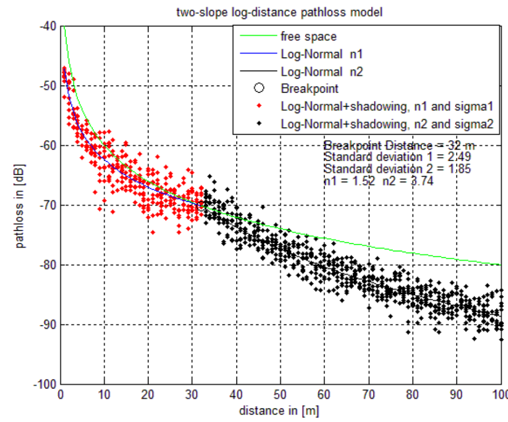

Figure 3. Simulation results for the two-slope log-normal model.

3. Conclusion

In this document we presented a survey of the most commonly used propagation models for WSNs with some simulation results. It would be pointless to compare the results of the presented models because each model assumes particular propagation conditions, assumptions, and restrictions. Furthermore the simulations were conducted using different simulation parameters.

4. Acknowledgements

Our thanks to the French National Research Agency ANR which financially supports the research project “PERSEPTEUR”.

5. References

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