A SURVEY OF RF-PROPAGATION MODELS FOR WIRELESS SENSOR NETWORKS (WSNs)

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Introduction

- Wireless Sensor Networks are 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. Simulators require accurate and fast modeling of the radio propagation channel especially when considering large-scale networks.
- Here, we present a brief survey of the most famous physical and empirical outdoor propagation models suitable for WSNs along with their propagation environment, assumptions, and restrictions.

Most Used Radio Propagation Models For WSNs

Free Space Model

- Considers only the line-of-sight path loss.
- No obstacles nearby that could cause reflections or diffractions

$$L[\mathrm{dB}] = 20\log\left(\frac{4\times\Pi\, d}{\lambda}\right) - Gt - G$$

- L : path loss in dB.
- d : distance between the transmitter and the receiver.
- G_t, G_r : transmitter and receiver antenna gains in dBi.
- λ: wavelength.

Adapted Free Space Model

- Considers only the line-of-sight path loss.
- Uses an empirical value for the path loss exponent n according to the propagation environment[1].

$$L[\mathrm{dB}] = 10\log\left(\frac{4\times\Pi}{\lambda}\right)^2 d^n$$

- n : the path loss exponent of

Simplified Two-Ray Ground Reflection Model

- Considers the line-of-sight path + the ground reflected path.
- Assumes a large distance d between the transmitter and the receiver ($d \gg h_t\, h_r$), and perfect reflection coefficient (Γ = -1)[2].

$$L\,[\mathrm{dB}] = 20\log\left(\frac{d^2}{h_t h_r}\right)$$

Two-Ray Ground Reflection Model

- Considers the line-of-sight path + the ground reflected path.
- Considers the real ground reflection coefficient[3] .

$$\bar{P}r(d) = Pt\left(\frac{\lambda}{4\times\Pi\, d}\right)^2 \left|\frac{1}{r_1}\exp(-j\,k\,r_1) + \frac{\Gamma\,(\alpha)}{r_2}\exp(-j\,k\,r_2)\right|^2$$

Free Outdoor Model (FOM)

- Considers the line-of-sight path + the ground reflected path.
- Considers the real ground reflection coefficient.
- Adds a Gaussian random variable X_σ to represent the uncertainty of the estimated received level.
- Includes the factors (K1,K2) to represent the antenna radiation pattern gains along the direct and reflected paths[4] .

$$\bar{P}r(d) = Pt\left(\frac{\lambda}{4\times\Pi\, d}\right)^2 (K_1^2 + K_2^2\Gamma^2 + 2K_2\Gamma\cos(\frac{2\Pi}{\lambda}\Delta L) + X_\sigma(\bar{P}r)$$

- h_t , h_r : transmitter and receiver antenna heights
- P_r: received power.
- P_t: transmit power.
- d : distance between the transmitter and the receiver.
- λ: wavelength.
- Γ: ground reflection coefficient.
- K = 2∏f/c: wavenumber.
- r_1 , r_2 : direct and reflected path lengths.
- α : angle of incidence of the ground ray
- ΔL: path difference between direct and reflected paths,
- K_1, K_2: coefficients to represent the difference in the antennas' gain, along the direct and reflected paths respectively, due to the antennas' radiation pattern.
- $X_\sigma(\bar{P}r)$: a Gaussian distribution with a mean of $\bar{P}r$ and a variance of σ.

Two–Slope Log Normal Shadowing Model

- One-slope Log-Normal shadowing model is a general extension to the free space model. It estimates the path loss for a wide range of environments using some typical values of path loss exponents and shadowing deviations σ .
- When nodes are placed close to the ground, it was proven that using the log-normal model with two different slopes and deviation values gives more accurate estimations [5].

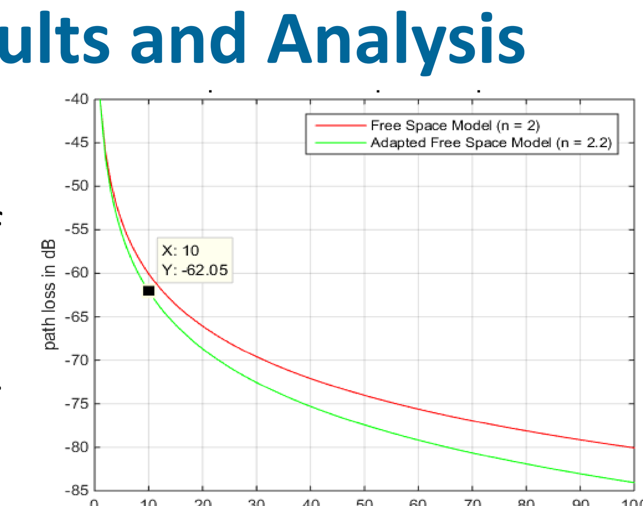
$$L(d_i) = \begin{cases} L(d_b) + 10\,n_1\log(\frac{d_i}{d_b}) + X_{\sigma_1}, d_i \le d_b \\ L(d_{b+1}) + 10\,n_2\log(\frac{d_i}{d_{b+1}}) + X_{\sigma_2}, d_i > d_b \end{cases}$$

$$d_b = \frac{4h_r h_t}{\lambda}$$

- d_b: breakpoint distance that separates the two slopes.
- $L(d_b)$: path loss in dB at a distance d_b .
- $L(d_i)$: path loss in dB at a distance d_i .
- n_1 , n_2 : path loss exponents before and after the breakpoint distance.
- X_σ: a zero-mean Gaussian random variable with a standard deviation of σ.

Simulation Results and Analysis

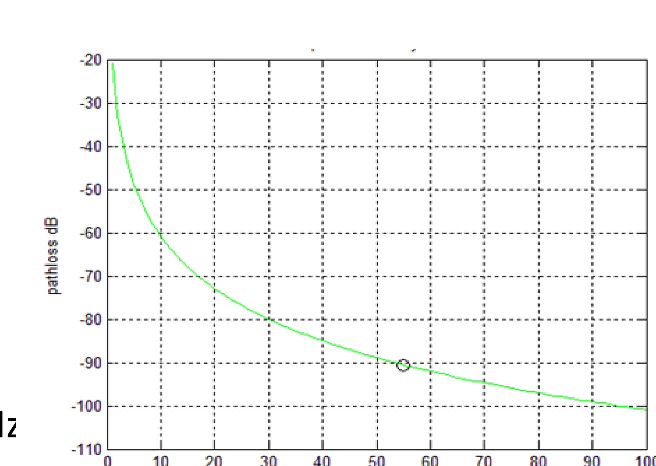
- Figure 1 compares between the free space model and the adapted free space model, the adapted model introduces 2 more dB/decade of loss because of the higher value of the path loss exponent.
- Figure 2 shows the simulation results for the simplified two-ray model, the results confirm that for near ground scenarios, it is expected to have higher attenuation.
- Figure 3 shows the simulation results for the Free Outdoor Model where the direct and the reflected rays add up constructively when the two rays are in phase, or destructively When the two rays are out of phase. The red points around the Free Outdoor Model curve represent the uncertainty range or the margin of error that was introduced by the Gaussian distribution.
- Figure 4 shows the simulation results of the two-slope model (the first slope value = 15.2 dB/decade, while the second slope value = 37.4 dB/decade). The two slopes are separated at the breakpoint distance = 32 m. The red points represent the variations of the received power for the first piece of the model while the black points represent the variations of the received power for the second piece of the model.



n =2.2

f = 2.4 GHz

Figure 1 : Free space model vs Adapted Free Space model

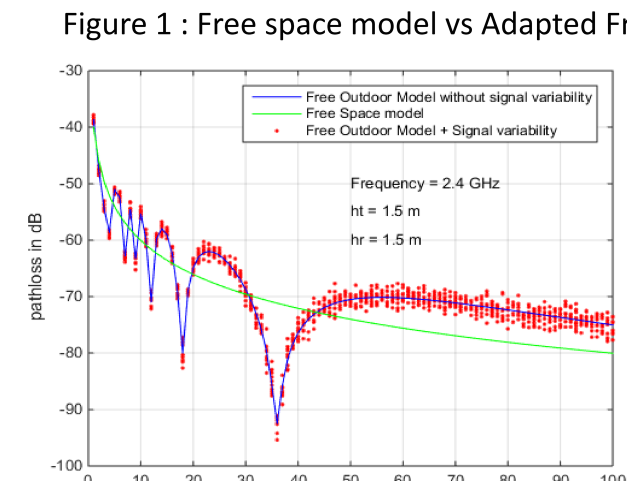


h_t=0.3 m

h_r=0.3 m

f = 2.4 GHz

Figure 2: Simplified two-ray ground reflection model



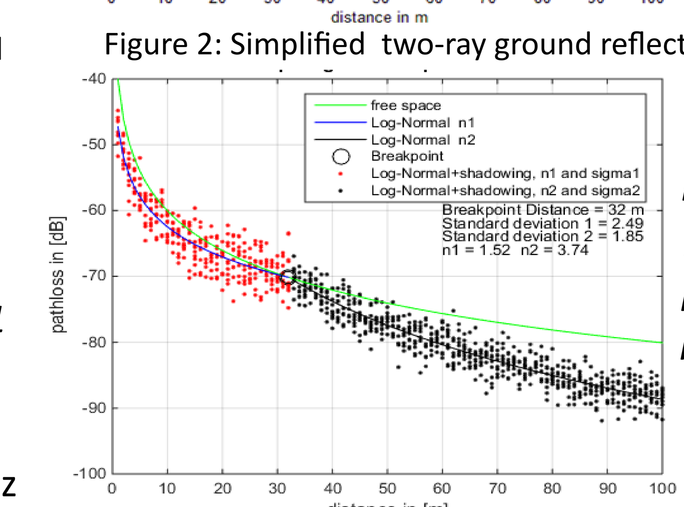
$K_1 = K_2 = 1$

h_t=1.5 m

h_r=1.5 m

f = 2.4 GHz

Figure 3 : Free Outdoor Model



h_t=1.0 m

h_r=1.0 m

n_1=1.52 ; σ_1 = 2.49

n_2=3.74 ; σ_2 = 1.85

d_b = 32 m

f = 2.4 GHz

Figure 4: Two-slope log-normal shadowing model

Conclusion

1. We have presented a survey of the most commonly used propagation models for WSNs.
2. Simulation results showed different behaviors for each model. Comparing the results of the presented models would be somehow inaccurate because each model assumes particular propagation conditions.

ACKNOWLEDGMENTS

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