Empirical Path Loss Models for 802.11n Wireless Networks at 2.4 GHz in Rural Regions

Jean Louis Fendji Kedieng Ebongue(✉), Mafai Nelson,
and Jean Michel Nlong

Computer Science, University of Ngaoundéré,
P.O. Box 454, Ngaoundéré, Cameroon
{jlfendji,mnelson,jmnlong}@univ-ndere.cm

Abstract. The prediction of the signal path loss is an important step in the deployment of wireless networks. Despite the plethora of works on this field, just a little is addressing rural environments at 2.4 GHz. In this work, we consider empirical path loss models in wireless networks at 2.4 GHz, using off-the-shelf 802.11n. We define three scenario usually observed in rural environment: free space, raised space and built space. Afterwards, we do a measurement campaign and compare results to selected prediction models. After analysing the results, Liechty model provides a better precision than the others. This model is further improved by considering the distance between the transmitter and the first breakpoint. We obtain predictions with mean errors less than 2.4 dB which is inferior to 4.00 dB predicted using Liechty model.

Keywords: Path loss · Empirical model · 802.11n · Rural area

1 Introduction

In rural regions, wireless networks appear as a suitable solution to bridge the digital divide between rural and developing regions. Although they can be more easily setup, especially in hostile environments, wireless networks can provide very bad performance if they are not well planned. The difficulty is to predict the quality of links by estimating the attenuation of the signal. To predict the quality of the signal, empirical path loss models are generally used. But empirical models are usually tied to particular environment with particular conditions such as the type of equipment, the frequency of the signal, the height of tower and the range of the signal. Despite the plethora of empirical models on signal path loss [1–8, 10], just few are considering rural environment at 2.4 GHz [9]. But with off-the-shelf technologies like IEEE 802.11b, g and n, wireless networks at 2.4 GHz and 5 GHz represent currently an appealing solution to connect rural regions. Therefore, there is a need to predict the signal path loss at these particular frequencies in rural environment.

In this work, we try to provide a more precise empirical model for predicting signal path loss at 2.4 GHz using off-the-shelf 802.11n in outdoor. Therefore, we do a measurement campaign in three different scenarios: free space, raised space and built

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space. Afterwards, we compare the results to the path loss predicted by selected empirical models. Liechty model [9] shows itself as the more precise empirical model with a mean error of 4.22 dB in raised space and 4.35 dB in built space. Finally, we improve this model to obtain a better prediction model by considering the distance to the first breakpoint. Finally we obtain a mean error of 2.33 dB in raised space and 2.36 dB in built space.

The rest of the paper is organised as follows: Sect. 2 presents relevant empirical models for this study; in Sect. 3, we present our methodology, material, scenario and data collection. Section 4 is for the numerical analysis of data and Sect. 5 presents the proposed new model.

2 Related Work on Prediction Models for Wireless Networks

There exists numerous works trying to predict path loss in wireless network and they are split into two groups: deterministic models also called theoretical methods and empirical models. Because of their complexity, deterministic models are usually set discarded in favour of empirical models which are based on statistics and probability.

There are several empirical loss models presented in literature. Each of them is designed for a particular environment, in Line Of Sight (LOS) and/or Non-Line Of Sight (NLOS), in indoor or outdoor propagation, at different frequencies. Table 1 provides a list of most common empirical path loss models.

Table 1. Most common empirical path loss models:

Models	Condition
|-Free space	
|-Egli	$f \in]30; 3000[$
|-One-slope	
|-Log Normal Shadowing	
|-Dual-slope	
|-Partitioned	
|-Liechty	$f \approx 2400$
|-Okumura	$f \in]150; 1920[\,;\, d \in]1; 100[;\ htx \in]30; 200[\,;\, hrx \in]3; 10[$
|-Okumura-Hata	$f \in]150; 1500[\,;\, d \in]1; 10[;\ htx \in]30; 200[\,;\, hrx \in]1; 10[$
|-COST 231 Hata	$f \in]150; 2000[\,;\, d \in]1; 20[;\ htx \in]30; 200[\,;\, hrx \in]1; 10[$
|-Hata-Davidson	$f \in]150; 1500[\,;\, d \in]1; 300[;\ htx \in]30; 200[\,;\, hrx \in]1; 10[$
|-Rural	$f \in \{160; 400; 900\}$
|-ITU-R	$1.5 < f < 2;\ 1 < d < 10;\ 30 < htx < 200;\ 1 < hrx < 10$
|-ECC-33	$700 \leq f \leq 3500;\ 1 < d < 10;\ 20 < htx < 200;\ 1 < hrx < 10$
|-Erceg	$f \approx 2000;\ 1 < hrx < 2$
|-SUI	$2500 < f < 2700;\ 0.1 < d < 8;\ 20 < htx < 80;\ 2 < hrx < 10$

f: frequency (MHz); d: distance between the transmitter and the receiver (Km)
htx: height of transmitter antenna (m); hrx: height of the receiver antenna (m)

In general, all these empirical models attempt to predict the propagation attenuation of the signal as the ratio in decibels between the transmitted power and the received power. The basic equation is the one of Friis:

$$PL_{fs} = 10log_{10}\frac{(4\pi d)^2}{G_t G_r \lambda^2} \tag{1}$$

With PL_{fs}: Signal attenuation in free space (dB)

d: distance between the transmitter and the receiver (Km)
Gr: Gain of the receiver antenna (dBi)
Gt: Gain of the transmitter antenna (dBi).

When considering the antennae as isotropic (Gt = Gr = 1) we obtain (2)

$$PL_{fs} = 20log_{10}\frac{(4\pi d)}{\lambda} \tag{2}$$

With c = λf, f frequency in Hz and $c = 3.10^8 m.s^{-1}$, we finally obtain (3)

$$PL_{fs} = -147.56 + 20log_{10}d + 20log_{10}f \tag{3}$$

Basic empirical path loss models are based on (3) taking into consideration the distance between transmitter and receiver and the frequency of transmission. Some models also consider the obstacles between transmitter and receiver and the height of antennae.

In this work, we compare five models:

(1) One Slope Model:

$$PL_{1slope} = PL(d_0) + 10nlog\left(\frac{d}{d_0}\right) \tag{4}$$

$PL(d_0)$: attenuation of the signal in free space at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: distance of reference (m)
n: path loss exponent of the environment.

(2) Dual-slope Model:

$$PL_{2slope} = PL(d_0) + \begin{cases} 10n_1log_{10}d & with\ 1m < d \leq d_{bp} \\ 10n_2log_{10}\frac{d}{d_{bp}} + 10n_1log_{10}d_{bp} & with\ d > d_{bp} \end{cases} \tag{5}$$

$PL(d_0)$: attenuation of the signal at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: reference distance (m)
d_{bp}: distance between the transmitter and the first obstacle (m)
n_1: path loss exponent for $d \leq d_{bp}$
n_2: path loss exponent for $d > d_{bp}$.

(3) Log Normal Shadowing Model:

$$PL_{sha} = PL(d_0) + 10n log \frac{d}{d_0} \chi_\sigma \tag{6}$$

$PL(d_0)$: attenuation of the signal at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: reference distance (m)
χ_σ: shadowing effect (dB)
n: path loss exponent of the environment.

(4) Partitioned Model:

$$PL_{parti} = PL_{fs}(d_0) + \begin{cases} 20 log d & with\ 1m < d \leq 10m \\ 29 + 60 log \frac{d}{20} & with\ 20m < d \leq 40m \\ 20 + 30 log \frac{d}{10} & with\ 10m < d \leq 20m \\ 47 + 120 log \frac{d}{40} & with\ d > 40m \end{cases} \tag{7}$$

$PL(d_0)$: attenuation of the signal at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: reference distance (m).

(5) Liechty Model:

$$PL = PL(d_0) + 10n log_{10}\left(\frac{d}{d_0}\right) + \sum_i nbre_i * a_i \tag{8}$$

$PL(d_0)$: attenuation of the signal at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: reference distance (m)
$nbre_i$: number of obstacle of type i
a_i: attenuation of obstacle of type i (dB)
n_1: path loss exponent for $d \leq d_{bp}$
n_2: path loss exponent for $d > d_{bp.}$

In all these models, the reference distance is the minimal distance for measuring the signal and the path loss exponent is the attenuation factor indicating how quickly the signal attenuation increases with the distance.

3 Methodology

3.1 Environment and Tools

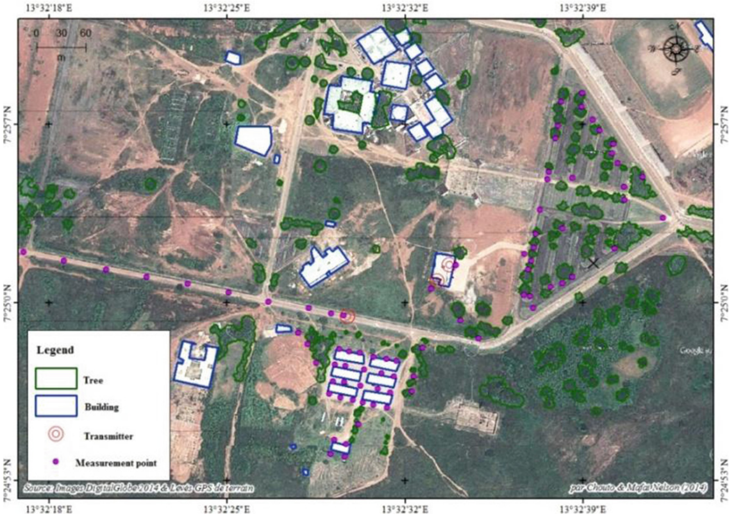
Figure 1 present the environment of study. From this environment, we define three scenarios: Free space, Raised space shown in Fig. 2 and Built space shown in Fig. 3.

- Free space: This environment covers a distance of 600 m. Measurements of signal strength are taken straight to each interval of 50 m.

- Raised space: In this space, all trees have an average height of 6.5 m. Measurements of the signal strength are taken at different points as shown in Fig. 2.

- Built space: In this space, the heights of the houses are 3.5 m (the average height of the houses). Measurements of the signal strength are taken at different points as shown in Fig. 3.

In all scenarios described above, measurements are made with an USB wireless 300 Mbps Dodocool SL-1504N (Chipset Realtek 8191, driver RTL8188SU/8191FEB28 antenna gain 2 dBi) compliant to the IEEE 802.11n standard. An ALFA Network N2 compliant to the IEEE 802.11n standard (power 30 dBm, integrated antenna 12 dBi) serves as access point. A laptop, to which the USB wireless adapter is connected, is driven away from access point to geographical coordinates (latitude and longitude) determined using a USB GPS (Navilock NL-464US 60122, sensibility: −159 dBm). The signal intensity at each point is measured using Vistumbler version 9.8.



Source: Images DigitalGlobe 2014 & Levés GPS de terrain

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Fig. 1. Environment of study

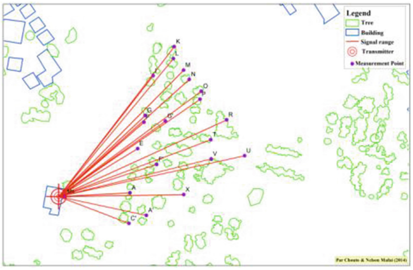

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Fig. 2. Raised space scenario

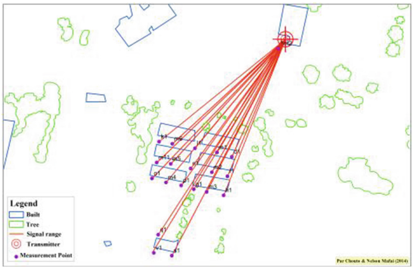

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Fig. 3. Built space scenario

3.2 Data Collection

During the measurements, the USB wireless adapter was connected to the USB port of the laptop. Throughout the measurements, the antenna of the wireless USB adapter is oriented towards the sky. In this study, the positioning mode used is the Single Marker Measurements [9]. In this method, measurements are made at each location chosen randomly. So with the help of Vistumbler software, this method has been used in all the different scenarios previously described.

3.3 Numerical Analysis

The analysis is done in five steps: 1. Calculate the mean loss of signal measured in the field. 2. Use the least squares method to determine the fitting curve. 3. Evaluate the attenuation exponent n, using the fitting curve. 4. Calculate the σ parameter of Log Normal Shadowing Model. 5. Compare the mean loss measured with the loss calculated by the selected models.

1. Using the curve fitting to evaluate the path loss exponent n for the models One-slope, Dual slope, Log-normal shadowing and Liechty. This is done using the least squares methods (9).

$$y = ax + b$$
$$\text{so that} \begin{cases} \sum_i (A_i P_i)^2 = \sum_i (e_i)^2 \quad \text{is minimal} \\ A_i P_i = e_i = y_i - (a x_i + b) \quad 1 \le i \le n \end{cases} \tag{9}$$

2. Determining the value of the attenuation of the obstacle i for Liechty model: the difference between the mean loss of signal obtained before and after the obstacle.
3. Evaluating the value of parameter σ of Log-normal shadowing model. It is determined using (10):

$$\sigma^2 = \frac{\sum_i (\overline{P_m} - \overline{P_r})^2}{k} 1 \le i \le k \tag{10}$$

With:

$\overline{P_m}$: power of measured received signal
$\overline{P_r}$: strength of estimated received signal
k: number of measurement point.

4 Results and New Model

4.1 Analysis Results

Comparative results of selected models are illustrated in Figs. 4, 5 and 6.

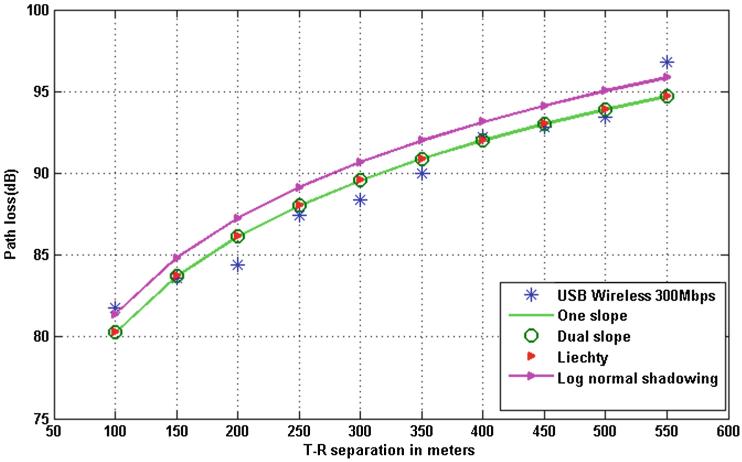

Fig. 4. Comparison of path loss in free space between selected models

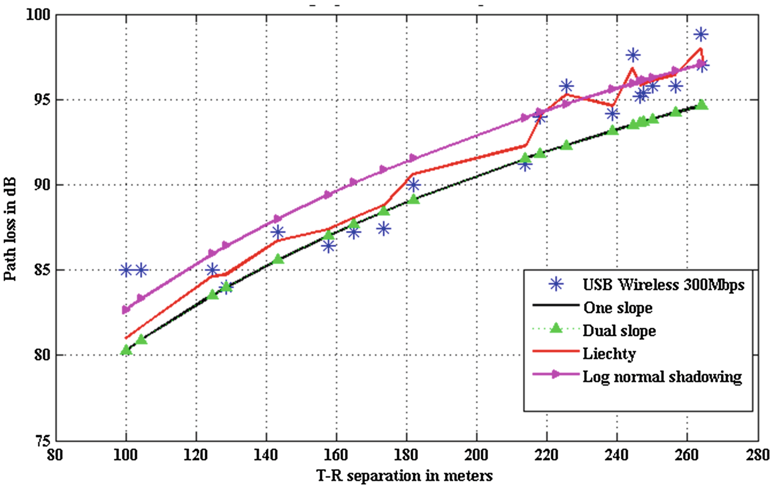

Fig. 5. Comparison of path loss in raised space between selected model

In Table 2 we have the path loss prediction of selected models. From this table, Lietchy model provide the less path loss. This is provable by looking Figs. 4, 5 and 6. In these Figures, Lietchy model is more close to measured points.

4.2 New Empirical Path Loss Model

Liechty model takes into account the number of obstacle between the transmitter and the receiver and their attenuation on the signal. But, the distance of each attenuation point also influence the quality of the signal. So considering the distance from the

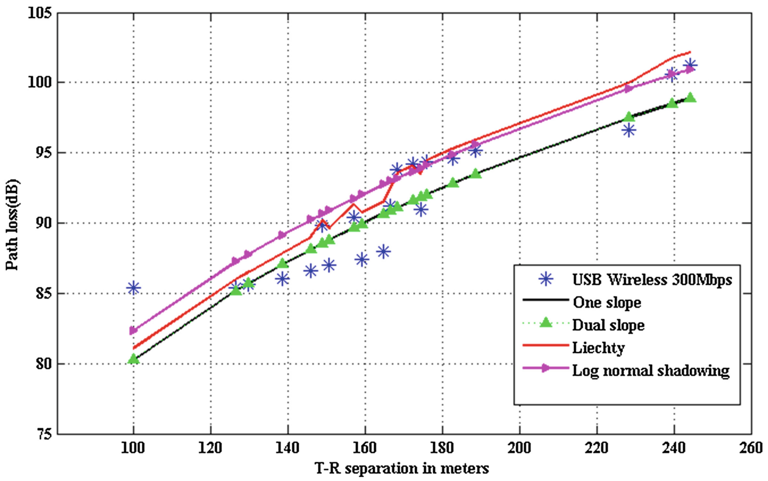

Fig. 6. Comparison of path loss in built space between selected models

Table 2. Comparative results between selected Models:

Models		Mean error (dB)	Standard deviation (dB)
Free space	One slope	0.90	1.12
	Dual slope	0.90	1.12
	Lietchy	0.90	1.12
	Log normal	1.54	1.68
	Partitionned	141.03	142.89
Raised space	One slope	1.97	2.41
	Dual slope	1.97	2.41
	Lietchy	0.94	1.35
	Log normal	1.54	1.81
	Partitionned	116.73	117.32
Built space	One slope	1.73	2.10
	Dual slope	1.73	2.10
	Lietchy	1.60	2.03
	Log normal	1.97	2.49
	Partitionned	109.71	109.93

transmitter to those points during the prediction could improve the prediction of the signal. However, since it is difficult to consider the distance from the transmitter to all those points, we just consider the distance to the first obstacle, the so-called breakpoint. We assume that the attenuation at this point has the greatest impact on the signal.

The optimization is done by adding to Liechty model the parameters of the Dual slope model. This results in Eq. 10:

$$PL_{new} = PL(d_0) + \begin{cases} 10n_1 log_{10} d & with \ \ 1m < d \leq d_{bp} \\ 10n_2 log_{10} \dfrac{d}{d_{bp}} + 10n_1 log_{10} d_{bp} + \sum_i num_i * a_i & with \ d > d_{bp} \end{cases} \tag{11}$$

Where:

$PL(d_0)$: attenuation of the signal at the distance d_0 (dB)
d: distance between the transmitter and the receiver (m)
d_0: reference distance (m)
d_{bp}: distance from the transmitter to the first obstacle (m)
$nbre_i$: number of obstacle of type i
a_i: attenuation of obstacle of type i (dB)
n_1: path loss exponent for $d \leq d_{bp}$
n_2: path loss exponent for $d > d_{bp.}$

Figures 7 and 8 show a comparison between the two models on measured data respectively in built space and raised space. From these Figures it is clear that the new model is more close to measured data than Liechty model both in raised space and in built space.

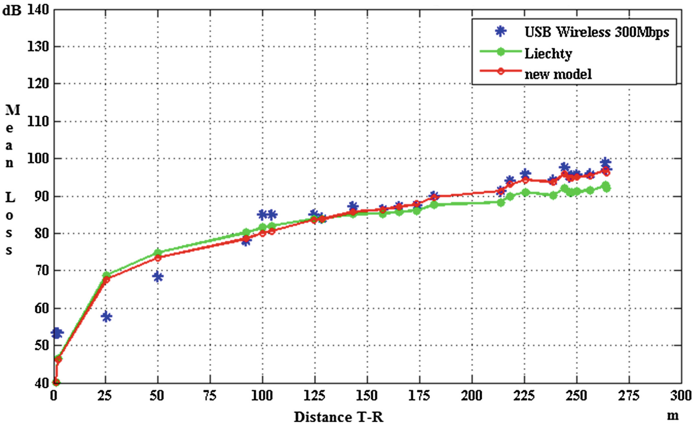

Fig. 7. Path Loss in built space Lietchy and new model

From Table 3 the new model provide a better prediction of the path loss of the signal. In raised space we obtain a mean error of 2.33 dB and a standard deviation of 4.02 dB and in built space a mean error of 2.36 dB and a standard deviation of 4.01 dB.

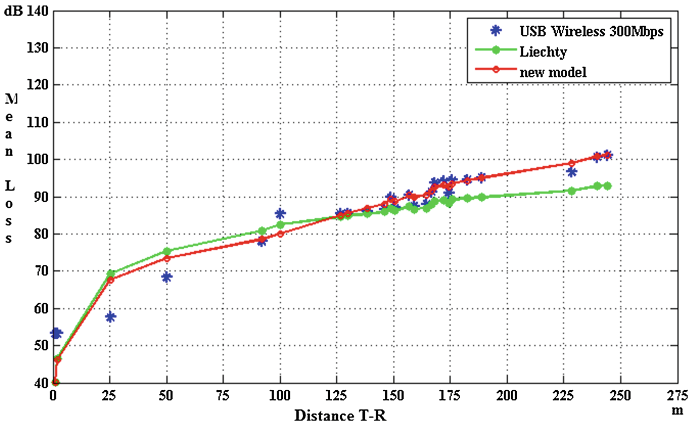

Fig. 8. Path Loss in raised space Lietchy and new model

Table 3. Comparative results between Lietchy Model and the new model

Models		Mean error (dB)	Standard deviation (dB)
Raised space	Lietchy	4.22	5.12
	New model	2.33	4.02
Built space	Lietchy	4.35	5.46
	New model	2.36	4.01

5 Conclusion

In this work, we defined three scenario tied to rural regions and we conducted a measurement campaign. We compared five selected models and we found that Liechty model is the more precise with a mean error of 4.22 dB and 4.35 dB and standard deviation of 5.12 dB and 5.46 dB respectively in raised space and in built space. Further, we improved this model by considering the distance to the first breakpoint. We obtained a better prediction model with a mean error of 2.33 dB in raised space and 2.36 dB in built space, and a standard deviation of 4.02 in raised space and 4.01 dB in built space.

Usually, between the transmitter and the receiver, we observe more than one breakpoint. To be more precise, all those different breakpoints should be taken into consideration. But thinking like this should make the model more complex and difficult to handle. The next step of this work is to study the impact of other breakpoints on the precision of the path loss model. And we will also compare the new model to more other empirical path loss models in more different scenario.

References

1. Sumit, J.: Outdoor propagation models : a literature review. IJCSE **12**(2) (2012)
2. Egli, J.: Radio propagation above 40 mc over irregular terrain. Proc. IRE (IEEE) **45**, 1383–1391 (1957)
3. Alam, D., Khan, R.H.: Comparative study of path loss models of WIMAX at 2.5 GHz frequency band. Int. J. Future. Gener. Commun. Netw. **6**(2), 11–23 (2013)
4. Rakesh, N., Srivatsa, S.K.: A study on path loss analysis for GSM mobile networks for urban, rural and suburban region of Karnataka state. Int. J. Distrib. Parallel. Syst. (IJDPS) **4**(1), 53–66 (2013)
5. Chebil, J., et al.: Comparison between measured and predicted path loss for mobile communication in Malaysia. World. Appl. Sci. J. **21**, 123–128 (2013). (Mathematical Applications in Engineering)
6. Kumari, M., et al.: Comparative study of path loss models in different environments. Int. J. Eng. Sci. Technol. **3**(4), 2945–2949 (2011)
7. Erceg, V., Greenstein, L.J., Tjandra, S., Parkoff, S.R., Gupta, A., Kulic, B., Julius, A., Jastrzab, R.: An empirically based path loss model for wireless channels in suburban environments. In: GLOBECOM 1998, vol. 2, pp. 922–927 (1998)
8. Medeisis, A., Kajackas, A.: On the use of the universal Okumura-Hata propagation prediction model in rural areas. IEEE. Veh. Technol. Conf. Proc. **3**, 450–453 (2000)
9. Liechty, L.C.: Path loss measurements and model analysis of 2.4 GHz wireless network in an outdoor environment. Master's thesis, Georgia Institute of Technology (2007)
10. Hata, M.: Empirical formula for propagation loss in land mobile radio services. IEEE Trans. Veh. Technol. **1**(29), 317–325 (1980)
11. Tummala, D.: Indoor propagation modeling at 2.4 GHz for IEEE 802.11 networks. Master's thesis, University of North Texas (2005)