A New Generic Model for Signal Propagation in Wi-Fi and WiMAX Environments

Rana Ezzine
PRINCE Research Group
ISITC
Hammam Sousse, Tunisia
ezzine.rannou@gmail.com

Rafik Braham
PRINCE Research Group
ISITC
Hammam Sousse, Tunisia

Ala Al-Fuqaha
Computer Networks' Group
Engineering and Applied Sciences College,
Western Michigan University
Michigan, USA

Abdelfettah Belghith
Research Pole RIM ± CRISTAL Laboratory
ENSI
Mannouba, Tunisia

*Abstract*Ð **The ability to accurately predict radio propagation behavior for wireless communication systems, such as cellular mobile radio, is becoming crucial to system design. Since site measurements are costly, propagation models have been developed as suitable, low-cost, and convenient alternative. In this paper, we will propose a new generic signal propagation model for Wi-Fi and WiMAX environments. To develop this model we used existing models which are classified as: Free space models and land propagation models. This includes different types of loss: path loss, slow fading (shadowing) and fast fading. Our aim is to have a flexible model to be applicable in indoor and outdoor environments. Experiments carried out for indoor Wi-Fi and outdoor WiMAX cases have shown excellent results for the proposed model.**

Keywords-Curve fitting, fast fading, path loss, signal propagation models, slow fading, parameters estimation, Wi-Fi, WiMAX

.

I. INTRODUCTION

The success of wireless technologies has led to an important interest to predict radio propagation characteristics in urban, suburban and open areas. As the explosive growth of using wireless devices continues, it is essential to be able to determine optimum base stations and antennas locations and types. It is therefore important to develop signal propagation models for Wi-Fi and WiMAX environments in the aim to estimate the received signal power by the user. Existing models can be classified into two classes: models for free space propagation and models for land propagation.

II. FREE SPACE PROPAGATION

First space is an ideal propagation medium. The Free space model is the simplest one. It only assumes direct path between transmitter t and receiver r. The received power P_r depends on transmitted power P_t, transmitter and receiver antennas gain (G_t, G_r), wavelength λ and distance d between the two nodes. All parameters, except distance d, are system constant parameters. The Free space model is also known as Friis model. In this model received signal power, P_r is expressed by the following equation:

$$P_{r,FS} = \frac{G_t \times G_r \times \lambda^2}{(4\pi d)^2} \times P_t \qquad (1)$$

III. LAND PROPAGATION

Propagation in free space and without obstacles is the ideal case. But when radio waves encounter an obstacle, several propagation effects occur: reflection, diffraction and scattering. The phenomenon of reflection occurs when obstacles are larger than signal wavelength. Obstacles in this case can be earth surface, tall buildings, and large walls. Diffraction takes place when the obstacle is a surface with sharp irregular edges. Scattering occurs when obstacles are smaller than the wavelength, for example foliage or street signs. In this case we use land propagation equation and the received signal power is expressed as:

978-1-4244-2829-8/08/$25.00 ©2008 IEEE

$$P_{r,LP} = \frac{G_r \times G_t \times P_t}{L} \qquad (2)$$

where L represents the propagation loss (clearly $L > 1$). Wave propagation in wireless environments is characterized by three aspects: path loss (L_P), slow fading (L_S), and fast fading (L_F). We can therefore express L as:

$$L = L_P \times L_S \times L_F \qquad (3)$$

A. *Path Loss*

The path loss is the average propagation loss over a wide area. It depends on macroscopic parameters such as transmitter-receiver distance and land profile. We can express it as follow:

$$L_P = A \times d^{\alpha} \qquad (4)$$

where A and α are propagation constants. Based on Okumura curves and to predict propagation constants, Hata presented an empirical formula for L_P in three cases: urban area, suburban area and open area.

- *Urban area*

In this case, the path loss L_{PU} can be expressed as fellow:

$$L_{PU} = 69.55 + 26.16\log_{10} f_c - 13.82\log_{10} h_b - \alpha[h_m] + [44.9 + 6.55\log_{10} h_b]\log_{10} d \qquad (5)$$

where L_{PU} is in dB, f_c is carrier frequency in MHz, h_b is the effective base station antenna height, h_m is the mobile station antenna height and $\alpha[h_m]$ is a correction factor for the mobile antenna height. Values of $\alpha[h_m]$ are calculated differently for large cities or for medium and small cities [1].

- *Suburban area*

Suburban area path loss L_{PS} is given in the following way:

$$L_{PS} = L_{PU} - 2\left[\log_{10}\frac{f_c}{28}\right]^2 - 5.4 \qquad (6)$$

- *Open area*

Here, corresponding path loss L_{PO} is expressed by following equation:

$$L_{PO} = L_{PU} - 4.78[\log_{10} f_c]^2 - 18.33\log_{10} f_c - 40.94 \qquad (7)$$

B. *Slow fading*

Slow fading is caused by long term spatial and temporal variations over distances large enough to produce big variation path between base station and mobile station. Slow fading is also called Log-normal fading or shadowing because its amplitude has a log-normal pdf [1].

C. *Fast fading*

Fast fading is of short-scale nature due to fast spatial variations. A number of fast fading models exist, for example Rayleigh, Ricean, Nakagami and Weibull [2][9] [11].

IV. EXAMPLES OF SIGNAL PROPGATION MODELS

In this section we present two frequently used land propagation models.

A. *Okumura and al. model*

This is one of the most widely used models for propagation in urban areas. The model can he expressed by following expression:

$$L_{50}(dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA} \qquad (8)$$

where L_{50} is the median value of the propagation path loss, L_F is the free-space propagation loss, A_{mu} is the median attenuation in the medium relative to free space at frequency f, and d corresponds to the distance between the base station and the mobile station. $G(h_{te})$ and $G(h_{re})$ are the gain factors for the base-station antenna and the mobile antenna respectively. h_{te} and h_{re} are the effective heights of the base-station and the mobile antennas (in meters), respectively. G_{AREA} is the gain generated by the environment in which the system is operating. Both $A_{mu}(f,d)$ and G_{AREA} can be found from empirical curves.

The major disadvantage of Okumura et al.'s model is its slow response to rapid changes in terrain profile.

B. *Two-ray ground model*

The Two-ray Ground model is an improved version of the free space model. It considers the direct ray between sender and receiver, but also ground reflection. As with the free space model, both nodes are assumed to be in Line Of Sight (LOS).

Up to a crossover distance $d_{Th} = \dfrac{4\pi \times h_t \times h_r}{\lambda}$, the Two-ray Ground model is equal to the free space model. Suppose that the transmitter and receiver antenna heights, h_t and h_r respectively, are constants. Beyond the distance, the ground reflection destructively interferes with the direct ray and further reduces the field strength. The received signal strength grows then proportionally to d^{-4}.

Just like the free space model, the distance between transmitter and receiver is the only parameter in Two-ray Ground model. Equation 9 represents the Two-ray Ground model:

$$\text{If } d < d_{Th} : P_{r,TR} = \frac{G_t \times G_r \times \lambda^2 \times P_t}{(4\pi d)^2} = P_{r,FS}$$

$$\text{If } d \geq d_{Th} : P_{r,TR} = \frac{G_t \times G_r \times h_t^2 \times h_r^2 \times P_t}{d^4} \qquad (9)$$

C. Shadowing model

For both free space model and two-ray ground model, the sender-receiver distance is the only variable parameter. This forms a circular coverage around a sending node and a sharp range limit. Beyond this range, no further reception is possible. To introduce random events, the shadowing model utilizes a random variable X. The shadowing model requires a reference distance d_0 to calculate the average received free space signal strength $P_{r,FS}(d_0)$. In equation 10, X is normally distributed with an average of zero and a standard deviation σ (called shadow deviation).

$$P_{r,SH} = P_{r,FS}(d_0) \times \left(\frac{d}{d_0}\right)^{-\beta} \times 10^X \qquad (10)$$

where the exponent β depends on the propagation environment. For open-space area, like in the free space model, we have $\beta=2$. For urban areas with obstacles, β is between 2.5 and 3.5.

The shadowing model introduces some kind of unpredictability for data transmissions. Correct receptions are guaranteed for close proximities and impossible over long distances, whereas correct receptions are unpredictable for medium distances. Nevertheless, the correct reception area still forms a disc when considering many transmissions [10]. The unpredictability is a severe disadvantage of this model. Signal strength variations are not direction-dependent and possible errors can occur during every transmission. It varies significantly between consecutive transmissions and even differs for the reception of the same transmission at different receiver.

D. COST-231-Walfisch-lkegami model

This model utilizes the theoretical Walfisch-Bertoni model and is composed of three terms :

$$\begin{aligned} &\text{If } L_{rts} + L_{msd} \succ 0 : L_b = L_0 + L_{rts} + L_{msd} \\ &\text{If } L_{rts} + L_{msd} \leq 0 : L_b = L_0 \end{aligned} \qquad (11)$$

Where :

- L_0 represents the free space loss,
- L_{rts} is the ªroof top to street diffraction and scattering lossº,
- L_{msd} is the ªmulti screen diffraction lossº.

The free space loss is given by:

$$L_0 = 32.4 + 20\log d = 20\log f \qquad (12)$$

where d is the radio path length (in km) and f is the radio frequency (in MHz).

L_{rts} is function of the street width (in m) and the difference between the height of the building on which the base station antenna is located, and the height of the mobile antenna.

More detailed discussions can be found in [2] and [11]. In the following section we present our model.

V. A GENERIC RADIO SIGNAL PROPAGATION MODEL

The models presented above are valid for specific environment and working conditions. So for a given situation we are not sure that we are using the appropriate model. Therefore, our idea is then to design a generic model which takes in to consideration most types of signal attenuation. In the model we propose, the signal power at the receiver $P_{r,GR}$ takes on the following expression:

$$P_{r,GR} = \frac{A \times P_t}{B \times d^{\alpha} + C \times (\log_{10} d)^{\beta} + D} \qquad (13)$$

As can be seen from (13), $P_{r,GR}$ (in mw) depends as usual on distance d (in m) between base station and mobile station. The transmitted signal power (in mw) at given base station is assumed fixed. A, B, C, D, α and β are propagation constants that have to be estimated. This way, the modeling problem has become a parameters estimation problem. A number of parameter estimation techniques exist. We have chosen to use Levenberg-Marquardt algorithm (LMA), which is a well known and popular curve-fitting algorithm [3].

LMA provides a numerical solution to the problem of minimizing a function, generally nonlinear, over a space of parameters of the function. These minimization problems arise especially in least squares curve fitting and nonlinear programming. The LMA is more robust than the Gauss-Newton algorithm (GNA), which means that in many cases it finds a solution even if it starts far off the final minimum. On the other hand, for well-behaved functions and reasonable starting parameters, the LMA tends to be a bit slower than the GNA [3].

A. *Measurement environments and scenarios*

We have taken measurements at the Engineering and Applied Sciences College in Western Michigan University, USA. The building where measurements were taken is composed of two floors and contains a dozen of access points. We have considered four scenarios: Wi-Fi measurements inside and outside the building and WiMAX measurements inside and outside the building. Actually we realised the two scenarios: Wi-Fi indoor the building and WiMAX outdoor the building.

In this zone we considered some measurement points so that we had an empirical data base. Each measurement point is defined by two sets. The first set is the set of distances between the measurement point and all access points which are in the building. The second set is the set of received signal powers by the measurement point from each access point. For the transmitted power we consider that $P_t = 100mw$.

B. *Results and Discussion*

To achieve our work and to reach our aim we implement the parameter estimation program for each access point. So we have (A, B, C, D, α , β) for each access point and we calculate received power by each measurement point from this access point.

Figure 1.a and Figure 1.b show the experimental data base curve and the curve obtained from calculated values of received power considering the new model.

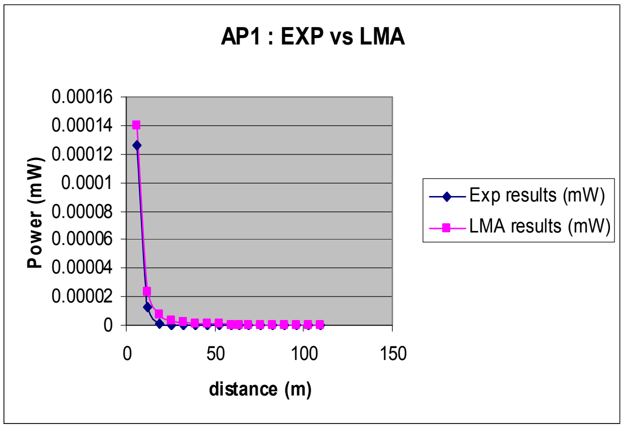

Figure 1.a

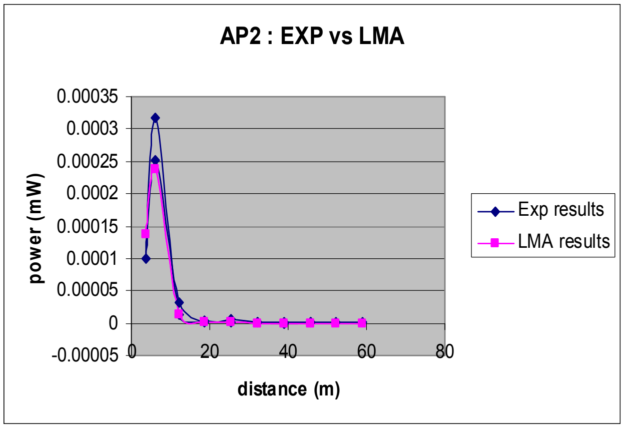

Figure 1.b

Figure 1. Experimental curves VS curves from the model

In two figures we remark that two curves are very close. We conclude that the estimate received power by the model is very close to the measured received power.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a new generic model for signal propagation in Wi-Fi and WiMAX environments. The model was validated for indoor Wi-Fi and outdoor WiMAX cases. Future work would be in a first step to validate this model for the two other cases which are outdoor Wi-Fi and indoor WiMAX cases. Then, as a second step, we will develop a simulator to have a random data base similar to the empirical data base and which will be used as input for the implemented program using LMA. Comparison between the two results should provide more validation for the new model.

ACKNOWLEDGMENT

Support for this work was provided by PRINCE research unit, ISITC-HS, University of Sousse, Tunisia. Part of this work was carried out during a stay of the first author (R. Ezzine) within the Computer Networks' Group, Engineering and Applied Sciences College, Western Michigan University, USA.

REFERENCES

[1] D. P. Argrawal and Q.-A. Zeng, “Introduction to wireless and mobile systems”, second edition, Brooks/ Cole (Thomson Learning), August 2002.

[2] T. K. Sarkar, Z. Ji, K. Kim, A. Medouri, and M. Salazar-Palma, “A Survey of Various Propagation Models for Mobile Communication”, IEEE Antennas and Propagation Magazine, Vol. 45, No. 3, June 2003, pp. 51 – 82.

[3] M. I. A. Lourakis, “A Brief Description of the Levenberg-Marquardt Algorithm Implemened by levmar”, February 11, 2005. Available: http://www.ics.forth.gr/~lourakis/levmar/levmar.pdf

[4] http://www.curvefit.com/

[5] “NLOS Optimization Outfits WiMax for Wide Coverage”, RTC Magazine, March 2005.

[6] IEEE 802.16-2004, IEEE Standard for local and metropolitan area networks, Air Interface for Fixed Broadband Wireless Access Systems, Oct 2004.

[7] H. Yaghoobi, “Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN”, Intel Technology Journal, August 2004, vol.8, no.3, pp.201–212.

[8] E. Grenier, “Signal propagation modeling in urban environment”, white paper, ATDI, June 2005.

[9] F. Belloni, “Physical Layer Methods in Wireless Communication Systems”, Fading models course, Helsinki University of Technology, November 2004. Available: http://www.comlab.hut.fi/opetus/333/2004_2005_slides/Fading_models.pdf

[10] I. Stepanov, D. Herrscher and K. Rothermel, “On the Impact of Radio Propagation Models on MANET Simulation Results”, Institute of Parallel and Distributed Systems (IPVS), Universität Stuttgart Universitätsstr. 38, 70569 Stuttgart, Germany.

[11] T. S. Rappaport, “Wireless Communications, Principles and Practice”, second edition, Prentice Hall, March 2008.