Propagation Path Loss - A comparison between Ray-tracing Approach and Empirical Models

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Abstract— **The results obtained with a two-dimensional propagation model for wireless communications in an urban environment are compared against the results of other propagation models, such as COST-231 Walfisch-Ikegami, Hata's and Zhang's.**

Keywords— **Radio Propagation, Geometrical Theory of Diffraction, Ray Tracing.**

I. Introduction

RADIO waves arrive at a mobile station receiver from different directions with different time delays and polarization. As a result, a receiver at one location may experience a signal strength quite different from a similar receiver located only a short distance away. As a mobile station moves from one location to another, substantial amplitude and phase fluctuations may occur, and signals are subjected to fading.

Empirical propagation models are often used to determine how many cell sites are required to provide the coverage needed for a wireless network. The propagation model also helps to determine where cell sites should be located to achieve an optimal position in the network. If the propagation model used is not effective in providing a realistic path loss estimate, the probability of incorrectly deploying a cell site is high. The performance of the wireless network is affected by the propagation model chosen because the model is used for interference prediction. Based on traffic loading conditions, designing for high SNR could negatively affect financial feasibility. On the other hand, designing for a low SNR would degrade the quality of service.

Several empirical models based on limited experimental data have been used. No propagation model accounts for all variations experienced in practice, hence the limitations of these models must be known, in order to achieve a good RF engineering design of a wireless network. Also, calibrating the empirical models against analytical model and/or actual propagation environment is helpful in gaining confidence in these models. Therefore, a two-dimensional ray tracing simulator [1], [2], the polygonal line simulator, has been developed to compute the trajectories between arbitrary locations of the transmitter and receiver, and to provide results in terms of both path-loss and time-delay of each trajectory. The simulator has been validated by measurements on scaled models in an anechoic chamber [3-9].

Several well known empirical models for an urban environment are compared against the numerical results obtained from the two-dimensional ray-tracing approach.

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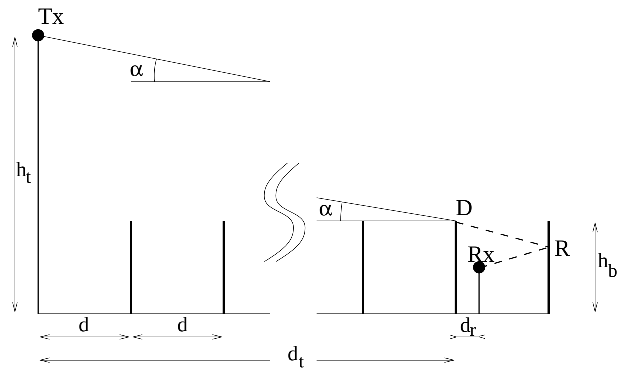

Fig. 1. Geometry for a simplified urban environment where buildings are replaced using knife edges. The continuous line represents a diffracted path, whereas the dashed line represents a diffracted-reflected path.

II. Comparisons

Many models for propagation in urban environment represent building obstructions using the knife edge approximation, as reported, for example, in [10-15]. The knife edge approximation is the simplest way to model a building obstruction but has some disadvantages that limit the number of actual practical situations that it can represent, as shown in [16]. Nevertheless, the knife edge approximation of buildings is still widely used. Therefore the geometry of Fig. 1 is considered herein to compare different propagation prediction methods because it represents an urban environment where parallel rows of buildings are modelled using knife edges. In the configuration of Fig. 1, the transmitter Tx is always above the rooftop height and the receiver is always in an obstructed area. This configuration was originally investigated by Walfisch and Bertoni [10], who applied a method based on physical optics. According to their method, the field transmitted by T_x propagates down to the street level by diffracting at D on the knife edge immediately to the left of R_x. Walfisch and Bertoni also considered a second contribution that is diffracted at D and undergoes a reflection at R on the knife edge to the right of R_x before reaching R_x. In order to account for the presence of the knife-edges between T_x and R_x, Walfisch and Bertoni introduced the concept of settled field. The settled field arises from the interaction of the wave that propagates above the knife edges with the knife edges. In particular, they found that if the number of knife edges is large enough, the field settles to a value that is what they apply in their computations. The models developed

TABLE I
PARAMETERS FOR THE GEOMETRY OF FIG. 1

Parameter	Value
frequency	f=2.154 GHz
transmitter height	$h_t = 12$ m
building separation	d=60 m
horizontal distance between T_x and D	d_t=1020 m
distance from mobile to left building	$5 \leq d_r \leq 55$ m
mobile height	h_r=1.6 m
building height	h_b=10 m
relative dielectric permittivity	ε_r=5
knife edges between T_x and R_x	n=17

by Walfisch and Bertoni, and Ikegami et al. [17] are at the base of the propagation model for macrocells developed by the European Committee COST-231. The Cost-231 Walfisch-Ikegami model provides a formula for the path-loss that contains empirical corrections to apply it to base station antenna heights below the average building height around the base station as well as other corrections derived from measurements.

A comparison of the prediction obtained with the polygonal line simulator and the COST-231 Walfisch-Ikegami model is shown in Fig. 2. For this comparison, as well as for those shown in Fig. 3, 4 and 6, the geometry of the environment under study is shown in Fig. 1 and the parameters for the simulation are shown in Table I. The comparison is carried out by computing the total electric field at the receiver, while the receiver moves horizontally and d_r measures its distance from the knife edge to its left. The total field is calculated assuming an isotropic source with transmitted power $P_t = 1$W and vertical polarization. Referring to Fig. 2, the prediction obtained using the COST-231 Walfisch-Ikegami model is in agreement with the one of the polygonal line simulator. In fact, the average value of the difference between the two curves is 1.46 dB and the standard deviation of this difference is 4.0 dB. In this comparison, the correction to the COST-231 Walfisch-Ikegami model described in [18] was introduced.

The concept of settled field of Walfisch and Bertoni was criticized by Saunders and Bonar [11] on the basis that:

- for very short distances between T_x and R_x it tends towards unity;
- for almost grazing incidence it predicts a zero field; and,
- it requires a large number of knife edges, which may not be the case in many instances.

Saunders and Bonar improved this concept of settled field by introducing an attenuation function that accounts for the presence of the knife edges and avoids the aforementioned limitations. Neve and Rowe [12] studied the same problem of Walfisch Bertoni but applied the uniform theory of diffraction, instead of relying on physical optics methods. Their equivalent formula for the attenuation function was later re-examined by Zhang [13], who further simplified it.

The next comparison is with the method of Zhang and the corresponding result are shown in Fig. 3. The parameters for this comparison are reported in Table I and correspond to the same ones used by Zhang in [13]. Using these parameters, the slope of the path $T_x \rightarrow D$ corresponds to an angle $\alpha = 2.25°$. For the simplified geometry under examination, there is good agreement between the two predictions; the average difference between the two curves is 0.75 dB and the standard deviation of this difference is 4.0 dB. This agreement is more apparent when one compares the averages of the local values of Fig. 3. In Fig. 4, the difference between the average values of the two predictions never exceeds 3 dB. The local averages are computed from the data shown in Fig. 3 by replacing

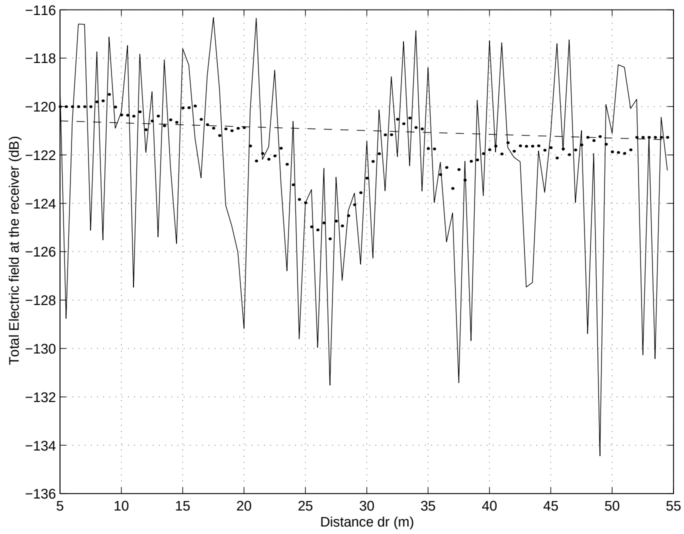

Fig. 2. Comparison with COST-231 Walfisch-Ikegami model. The solid line represents the polygonal line simulator; the dashed line is the COST-231 Walfisch-Ikegami model; and the dotted line represents the local average of the polygonal simulator results. Simulation data for this comparison are given in Table I. d_r varies at increments of 0.5 m, which corresponds to 3.6 wavelengths.

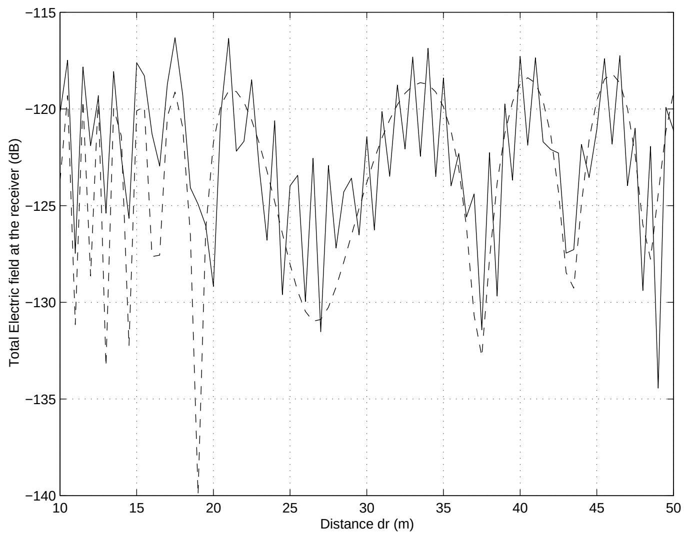

Fig. 3. Comparison between the polygonal line simulator (continuous line) and Zhang's method (dashed line) for the simplified geometry of Fig. 1. The values used in the computation are given in Table I. d_r varies at increments of 0.5 m, which corresponds to 3.6 wavelengths.

the local field magnitude $|E(x_i)|$ with the mean of the values $|E(x_{i+j})|$ chosen within a window centered at x_i and with half-width 5 m; for a frequency of 2.154 GHz this is equivalent to an average over 36 wavelengths. The values of Fig. 3 were computed by varying the distance d_r from 10 m to 50 m at increments of 0.5 m, which corresponds to 3.6 wavelengths. The electrical boundary conditions for the polygonal line simulator were chosen to resemble as much as possible Zhang's method. Therefore, a reflection coefficient $R = 0$ was assumed everywhere to avoid contributions from rays reflected from the ground level. All knife edges are perfect electric conductors except the knife edge to the right of R_x in Fig. 1 that has a dielectric constant $\varepsilon_r = 5$ to resemble the reflection coefficient of concrete walls.

It is worth to point out that the attenuation function used by Zhang to account for the multiple diffraction above the knife edges plays a role only when the slope α is less than 5°. In fact, when $\alpha > 5°$ the numerical value of the attenuation function approaches unity. The physical reason for this behavior is that when $\alpha > 5°$, the multiple diffraction mechanism becomes less important and the geometry of Fig. 1 reduces to the further simplified case shown in Fig. 5.

Finally a comparison is given with Hata's model [19] in Fig. 6. The average difference between the two curves is 12.6 dB and the standard deviation of the difference is 4.0 dB, a result that shows Hata's prediction being too pessimistic. The difference between Hata's prediction and the polygonal line simulator may be explained on the basis that Hata's model was obtained by fitting the experimental data measured by Okumura [20] and using only a few parameters to describe the environment. Specifically, Hata's model considers the frequency, the transmitter height, the receiver height and a correction factor that is a function of the coverage area. On the other hand, the polygonal line simulator accounts for the actual geometry of the environment. Therefore, it is not a surprise that the predictions obtained with the COST-231 Walfisch-Ikegami model and Zhang's model are closer to the result of the polygonal line simulator. In fact, the COST-231 Walfisch-Ikegami and Zhang's models were specifically developed for the configuration of Fig. 1, whereas Hata's model only accounts for averaged statistical parameters to characterize the environment under study.

III. Conclusion

These comparisons all involve the configuration of Fig. 1. The results show that there is agreement for the path-loss prediction obtained with the COST-231 Walfisch-Ikegami model, Zhang's method and the polygonal line simulator. Hata's method, instead, provides a more pessimistic prediction.

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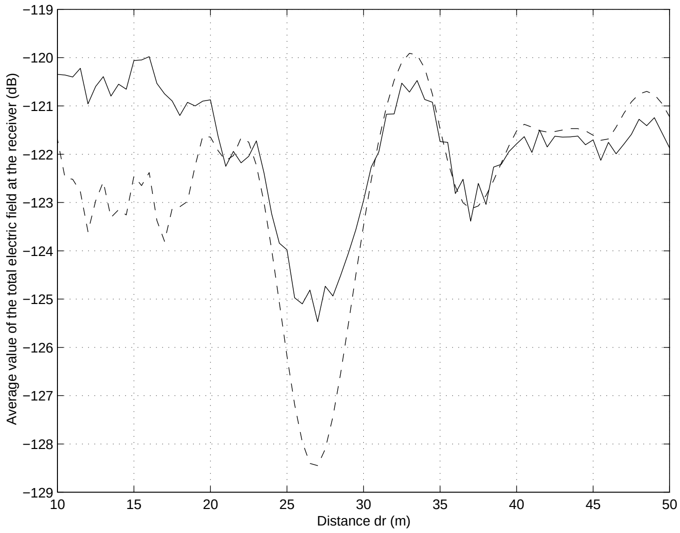

Fig. 4. Comparison between the average values of the polygonal line simulator (continuous line) and Zhang's method (dashed line).

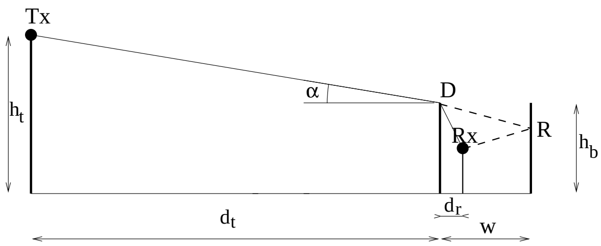

Fig. 5. Simplified geometry for $\alpha > 5°$.

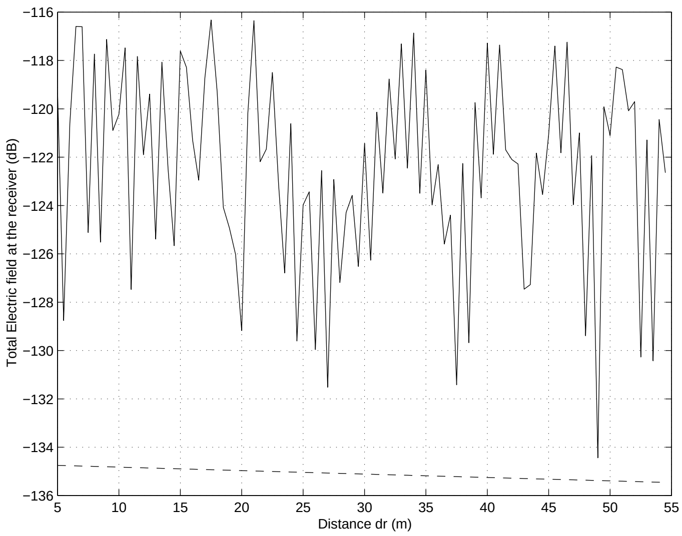

Fig. 6. Comparison with Hata's model. The solid line is the polygonal line simulator result; the dashed line is Hata's model result.

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