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Effects of Airy Buildings to Micro-cell Path Loss Prediction on 2-D Maps

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1. Introduction

In modern communication, network planning is very important for high quality service both coverage area and QoS including outage probability reduction. These require a tool, which is easy to use in planning the cellular network with high accuracy not only between base station and a mobile unit but also multi-hop network. There are many tools or models for cellular network planning such as semi-deterministic model, Xia et al. [1] proposed path loss formulas for micro-cells in low-rise and high-rise building environments. Additionally, COST 231 Walfisch-Ikegami model [2] is also a popular prediction tool for micro cell environments. The models need the environment data base in details such as an average height of building rooftop, street width etc. However in the case of the airy building which has no full concrete walls and/or windows, the dominant wave does not diffract at the roof edge but it propagates through the building and diffracts at the edge of a railing. Therefore the height of building rooftop can not be used. To solve this problem, we propose a airy building effect in the Xia model. A preliminary test provided a better solution compared with measured path losses.

2. Path Loss Prediction

When waves propagate in urban or sub-urban environments, there are various propagation effects such as diffraction over rooftops and around building corners, scattering on buildings, and penetration through vegetation *etc*. The original Xia model for low-rise environments with one-five story buildings was applied to predict path loss because it needed 2-D maps of buildings for calculation. There are three routes for prediction namely, staircase route, transverse route and lateral route as shown in Fig. 1. A transmitter (Tx) was located on street in the middle of a building block. The original Xia path loss formulas for regular buildings [1] were written as

Staircase route:

$$\begin{aligned} P_L(d) = {} & [137.61 + 35.16 \log f_G] \\ & - [12.48 + 4.16 \log f_G]\mathrm{sgn}(\Delta h)\log(1+|\Delta h|) \\ & + [39.46 - 4.13\mathrm{sgn}(\Delta \mathrm{h})\log(1+|\Delta h|)\log d \end{aligned} \quad (1)$$

Transverse route:

$$\begin{aligned} P_L(d) = {} & [139.01 + 42.59 \log f_G] \\ & - [14.97 + 4.99 \log f_G]\mathrm{sgn}(\Delta h)\log(1+|\Delta h|) \\ & + [40.67 - 4.57\mathrm{sgn}(\Delta h)\log(1+|\Delta h|)\log d \end{aligned} \quad (2)$$

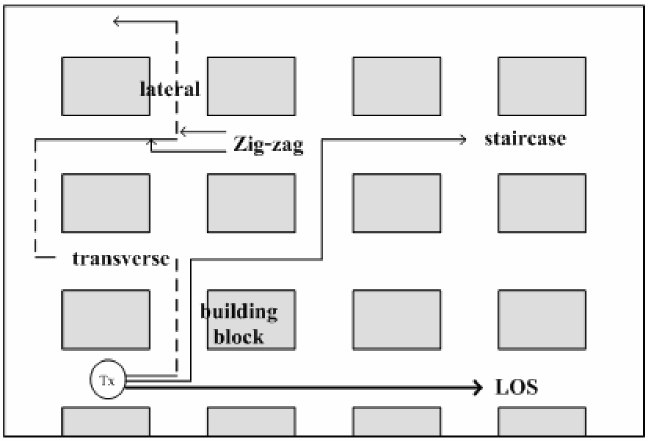

Fig. 1. Geometry of Xia model

Lateral route:

$$\begin{aligned} P_L(d) = {} & [127.39 + 31.63 \log f_G] \\ & - [13.05 + 4.35 \log f_G]\mathrm{sgn}(\Delta h)\log(1+|\Delta h|) \\ & + [29.18 - 6.70\mathrm{sgn}(\Delta h)\log(1+|\Delta h|)\log d \end{aligned} \tag{3}$$

All non-LOS routes:

$$\begin{aligned} P_L(d) = {} & [139.01 + 42.59 \log f_G] \\ & - [14.97 + 4.99 \log f_G]\mathrm{sgn}(\Delta h)\log(1+|\Delta h|) \\ & + [40.67 - 4.57\mathrm{sgn}(\Delta h)\log(1+|\Delta h|)\log d \\ & + 20\log(\Delta h_m/7.8) + 10\log(20/d_h) \end{aligned} \tag{4}$$

Where

d is the mobile distance from transmitter (m). $[0.05 < d < 3]$,
f_G is the frequency (GHz). $[0.9 < f_G < 2]$,
Δh is the relative height of transmitter to average building height (m). $[-8 < \Delta h < 6]$,
Δh_m is the height of the last building relative to the mobile (m),
d_h is the distance of mobile from the last rooftop (m),
h_b is the transmitting antenna height from ground level (m),
h_m is the mobile antenna height from ground level (m),and
λ is the wavelength (m).

In the case of airy buildings which have no any walls, the dominant wave does not diffract over the roof tops but it diffracts at the edges of the railings as shown in Fig. 2. This is because the vertical length of the railing is larger than the wavelength. The equation (4) is also applied, but the average building height of rooftop is modified to be

$$\begin{aligned} h_{\mathrm{BD(airy)}} &= \sum_{i=1}^{n-1} H_i + h_r \quad \text{if } h_b < h_{BD} \\ &= h_{BD} \qquad\qquad\quad \text{if } h_b \geq h_{BD} \end{aligned} \tag{5}$$

Where

H_i is the ceiling height of i^{th} floor (m),
n is the floor's number which the dominant wave propagates through an airy building,
h_r is the railing height (m) and
h_{BD} is the average building height of rooftop (m).

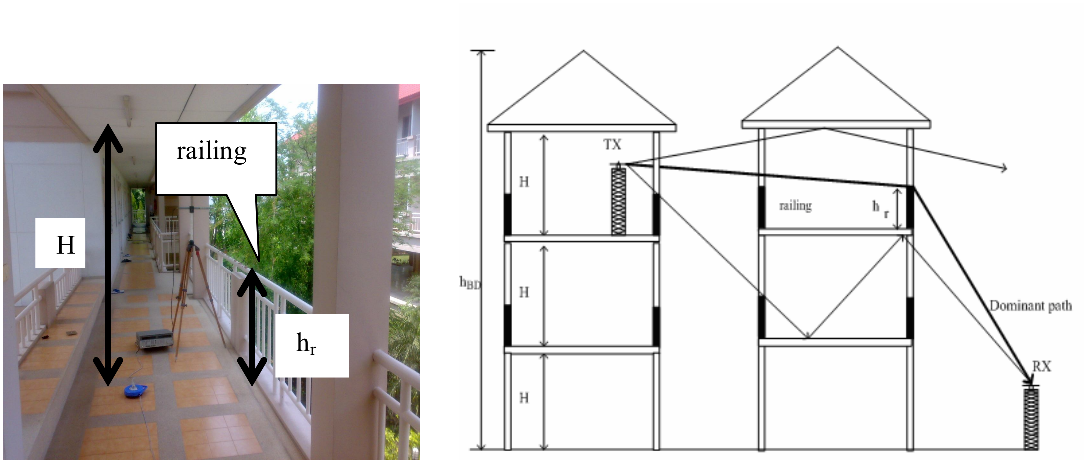

Fig. 2. Geometry of airy building model

Fig. 3 Measurement locations

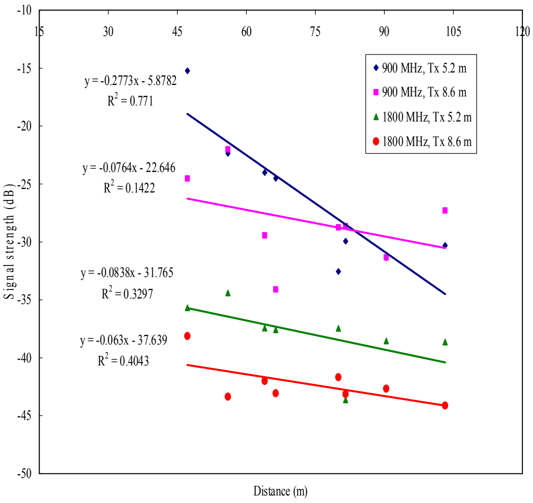

Fig. 4 Regression of measured signal

If the buildings between the transmitter and the receiver are both the airy and regular buildings, the average building height must be calculated. It is an average between the height of h_{BD}(airy buildings) in (5) and the height of rooftop of h_{BD} (regular buildings). This average value is used in (4).

3. Measurement Procedure and Sites

The measurements were performed at frequencies of 900 and 1800 MHz. The equipment for propagation measurement consisted of a fixed CW transmitter and a portable spectrum analyzer. The transmitter consisted of HP 83732B signal generator (with 18 dBm output) and a quarter wave antenna. We used HP 8593E spectrum analyzer with a 30 dB low noise amplify (LNA) and a quarter wave dipole antenna for signal strength measurement. All measurements are co-vertical polarization.

We selected the dormitory for a measurement site, It consists of 3 main building with three stories buildings and 6 small single story buildings for offices, a cafeteria and an auditorium in this area. The average height and % of buildings in the area are 9.5 m and 23 % respectively. There are two marshes and vegetation in the area.

The transmitting antenna heights was fixed at 5.2 and 8.6 m above ground on second and third floors of a dormitory buildings as shown by rectangular dots in Fig. 3, while the receiving antenna height is fixed at 1.6 m above ground. The receiver unit was moved to the measurement points as shown by circular dots in Fig. 3. For each measurement point, at least 36 samples taken over 40 wavelengths were averaged to the local average power. Therefore the distance between two adjacent samples is 0.8λ in order to fulfill Lee's criteria [3].

4. Prediction Results

Table 1. Comparison of the models at measurement points for all locations and frequencies

Measurement Point Number	Distance (m)	RMSE	
		Original model	Proposed model
1	47	12.83	2.16
2	56	12.46	2.49
3	64	11.25	1.69
4	66	9.95	3.12
5	80	12.02	2.46
6	82	10.90	3.05
7	90	12.59	1.81
8	103	15.25	2.73
	Average	12.16	2.44

The proposed model is evaluated in term of Root Mean Square Error (RMSE) comparing with the original building model. The results of the comparison are given in Table 1. We found that the proposed model in (5) provided better accuracy than the original model because of the airy building effect.

The linear fits of measured path loss are shown in Fig.4. We found that signal strength at the transmitting antenna height of 5.2 m and frequency of 900 MHz tended to rapid decrease as shown in Fig. 4. This is because of the first Fresnel zone region. The breakpoint distance d_{bp}, for the wavelength λ, can be calculated by $4h_bh_m/\lambda$ or 99.84 m which is in the range of the measurement point. This makes the signal strengths at distance after breakpoint become low quickly. Additionally, the diameter of the first Fresnel zone region is $Z_f \approx \sqrt{\lambda d_{bp}}$ or 5.77 m.. This zone is mostly interfered by obstructions therefore the signal propagates in case of NLOS is rapidly attenuated. The R^2 of 0.771 confirms this phenomenon. While the other regression lines in Fig. 4 provide low slopes since their d_{bp} are in the range of 165 – 330 m from the transmitter which are far from the measurement points and the diameters of the first zone are in the range of 5.77 – 7.42 m. This make the zones are about kept free from obstructions. Therefore, the waves can propagate via the zones to the receiving antenna with low attenuation.

4. Conclusion

A radio wave propagation prediction has been proposed. We have modified the original Xia model with the effects of airy buildings. We found that the dominant wave propagates through the airy buildings and diffracts at the edges of the railings To verify the proposed model, the measurements were performed in realistic areas at two frequencies: 900 MHz and 1800 MHz. From the results it is found that the proposed model provides a good agreement compared with the measured path loss.

Acknowledgments

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References

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