RECEIVING ANTENNA HEIGHT DEPENDENCE OF RADIO PROPAGATION PATH LOSS IN FIXED WIRELESS ACCESS ENVIRONMENT

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Abstract

In Fixed Wireless Access (FWA) applications, the receiving antennas are usually placed at relatively higher level. The receiving antenna levels from 3 meters up to rooftop level are considered possible in FWA application. This paper shows the variation of radio propagation path loss at different receiving antenna heights. An radio propagation path loss model base on measurement was developed as a function of distance and receiving antenna's height.

I. Introduction

At present, the industry is looking on the possibility to provide the last mile wireless connection to fixed users. There are many attractive advantages of FWA over the conventional wireline network such as fast deployment, flexible capacity and lower maintenance cost. The focus of this paper is to investigate the variation of radio propagation path loss at different receiving heights in suburban areas. The results obtained are applicable for urban areas outside high rise core. Suburban areas are the highly potential areas for FWA applications. This is because of the fast growing demand for extra lines in suburban residential areas to support applications such as internet, facsimile and other multimedia applications.

The review of literature shows that a lot of analytical and experimental works have been done for radio propagation in mobile environment. Various analytical and empirical models have also been developed to provide highly accurate prediction. Most of the models assume the receiving height is between 1 m and 3 m with the base station height either below, near to or above average rooftop level. These models can perform well for LOS and non-LOS situation in both microcells and macrocells.

In FWA application the possible receiving heights are between 3 meters and rooftop level. The possible height of transmitting base on the other hand is about several meters above average rooftop level. The cell size is about 1 km due to the density of user in this area. In urban and suburban areas FWA capacity can reach up to hundreds and sometimes up to thousand of subscribers per square kilometer.

Factor affecting the height of both transmitting base and receiver is the quality of service required by fixed services. It is important for FWA to provide services with quality comparable with fixed line. Radio propagation in FWA environment is often blocked by rows of intervening buildings that are available in position perpendicular to the path between transmitter and receiver. The propagation mechanism in FWA environment is about the same with the vehicular and outdoor-to-indoor environments that involves mainly diffraction, scattering, and reflection of radio wave.

At higher receiving height, it is expected that the loss due to rooftop-to-street diffraction will become smaller. Furthermore, at certain higher receiving level, the radio propagation path between transmitter and receiver is the mix of LOS and non-LOS due to non-uniform buildings' height, which further reduce the overall propagation path loss. A measurement campaign has been conducted in order to investigate the variation of radio propagation path loss at different receiving heights. Basically, this paper consists of four sections, 1) introduction, 2) measurement, 3) analysis & discussion, and finally a conclusion.

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II. Measurements

The transmitter that is used in this measurement has been constructed using Hewlett Packard 8657B signal generator and power amplifier. The signal generator is capable of generating CW signal at 2 GHz. The selection of CW carrier frequency at 2 GHz was made as the initial aim of this measurement is to study the application of FWA in International Mobile Telecommunication-2000 (IMT-2000), where 2 GHz is about the center of IMT-2000 frequency band. Discone antennas with frequency range 1.7-2.3 GHz and gain 2.2 dBi were used at both transmitting and receiving side. The height of the transmitting antenna is 19 m.

The receiver is mounted on a mobile vehicle equipped with other facilities such as adjustable mast and AC power supply. The receiver is in fact a modified commercial receiver that consists of a down converter, field strength meter and a personal computer for data acquisition purpose. CW signal level was monitored at the field strength meter. The CW signal levels were then digitised at sampling rate 100 Hz and stored on hard disk.

A. Measurement environment

The selected test suburban area, Taman Universiti is located about 20 km from Johore Baharu City. It is a typical suburban area around major cities in Malaysia. Its terrain in general is flat and is homogenous in nature with average rooftop level, h_{roof} around 7.5 m. It consists of single and double story terrace houses with h_{roof} about 5.5 m and 8.5 m respectively. Up to ten terraces houses are organised in a row. The separation between two rows of houses, which are facing each other, is about 25 m.

In general, both single and double story residential houses have triangular roof. The building materials are basically similar such as cement plastered bricks wall, glass windows, concrete floor and concrete roof tiles. Trees are planted along major roads and their height can achieve up to 10 m or even higher. Trees that are planted in front of houses are much lower than those available along major roads. At the center of residential area, double story shop houses with average height about 9 m are available along both sides of the street. The main streets are wider and straight. They are organised in rows as for residential houses.

B. Field measurement

At each measurement location, the vehicle was parked in front of house that is facing to the transmitter. The vehicle was then moved straight and slowly along roadside. CW signal strength was recorded after achieving constant speed. The measurement path is about 5 m. The decision on 5 m measurement path is based on [1][2]. It is adequate in getting accurate average signal strength at 2 GHz frequency.

For each measurement location, the similar measurement procedures were repeated for receiving antenna height from 3 m to 7 m. The locations were properly chosen so that the produced results could represent the overall radio propagation environment of the selected residential area. The location selection also ensures that rows of intervening houses are available in position perpendicular to the path between transmitter and receiver. In other words, buildings are blocking the path between transmitter and receiver.

III. Data analysis and discussion

There are two interested parameters to be extracted from the obtained data namely, radio propagation path loss and receiving antenna height gain.

A. Path loss at different receiving heights

Radio propagation path loss is one of the important radio propagation parameters. A widely used model [3][4] indicates that path loss (*PL*) increases with distance (*d*), that is

$$PL(d) \propto \left(\frac{d}{d_o}\right)^n \qquad (1)$$

where n is the path loss exponent, d is the separation between transmitter and receiver in kilometer (km) and d_o is the reference distance. In this analysis, d_o=0.1 km is used since most of the collected data are between 0.1 km to 1 km. This decision is in line with the assumption that FWA coverage is about microcellular coverage for suburban residential area where most of the users are expected to be at location less than 1 km. This is because of the relatively higher user density in suburban residential area. The complete path loss model can be expressed as [5]

$$PL(d) = PL(d_o) + 10n\log_{10}\left(\frac{d}{d_o}\right) + X_\sigma \qquad (2)$$

where X_σ is the zero mean Gaussian random variable with standard deviation σ (dB), $PL(d_o)$ is the free space path loss at reference distance d_o=0.1 km which is 71.9 dB down from the transmitted power [6]. Fig.1 shows the obtained path loss against transmitter-receiver separation (T-R separation) in km for receiving height from 3 m to 7 m by using least square regression method. The value of each path loss exponent, n and standard deviation, σ are shown in Table 1.

The obtained results clearly indicate that σ is less than 5 dB for receiving height, h_r below or equal to 5 m. For h_r above or equal to 6 m σ is greater than 6 dB. This is due to the fact that the residential area consists of single and double story buildings with rooftop level 5.5 m and 8.5 m respectively. Therefore, received signal at single story area for h_r above 5.5 m experiences less loss as compared with received signal at double story area. As a result the radio propagation path loss is scattered around the regression line at greater deviation. However, the obtained σ are between 3-7 dB indicate that these regression lines are highly reliable [7].

Table 1 shows that n is between 2-4. The path loss exponent is reducing towards free space path loss, n_{fs}=2 as the receiving antenna's height, h_r is increased towards average rooftop level, h_{roof}. The h_{roof} is calculated by taking the average of buildings' height including single story, double story and shop houses for area covered by the measurements. In order to show the dependence of path loss on h_r equation (2) has been modified as

$$\overline{PL}(d,h_r) = PL(d_o) + 10n(h_r)\log_{10}\left(\frac{d}{d_o}\right) + X_\sigma \quad (3)$$

where $\overline{PL}(d,h_r)$ is the empirical path loss model for FWA environment in suburban residential area, $n(h_r)$ is the relationship between receiving antenna height, h_r and path loss exponent, n. The function $n(h_r)$ can be described as equation (4) where h_{roof} is 7.5 meters.

$$n(h_r) = n_{fs} - \ln\left(\frac{h_r}{h_{roof}}\right) + 0.551 \quad (4)$$

Equation (4) is only valid for h_t equal to 19 meters. According to [8] the transmitting antenna height gain is

$$\text{Antenna height gain} = 20\log_{10}\left(\frac{h_t'}{h_t}\right) \quad (5)$$

Transmitting antenna height gain factor (5) is included in (4) as shown in (6) where h_t' is transmitting antenna height at any level but above rooftop level and h_t is 19 meters.

$$n(h_r) = n_{fs} - \ln\left(\frac{h_r}{h_{roof}}\right) - 2\log_{10}\left(\frac{h_t'}{h_t}\right) + 0.551 \quad (6)$$

The developed empirical path loss model (6) is valid for all h_r below h_{roof} and near to h_{roof}.

IV. Conclusions

The obtained results show that the path loss exponents, n are within the range of 2-4. This range is acceptable because for free space propagation the n is about 2 and for mobile application where the h_r is less than 3 m, the n is about 3.8 to 4. An empirical path loss model was developed to include the effect of receiving height on path loss. This model is important in determining the cell coverage less than 1 km with respect to various receiving antenna heights in FWA application.

References

[1] M. Lecours, J. Y. Chouinard, G. Y. Delisle, and J. Roy, "Statistical modelling of the received signal envelope in a mobile radio channel", *IEEE Trans. Veh. Technol.*, vol. 37, pp. 204-212, Nov. 1998.

[2] V. Erceg, S. J. Fortune, J. Ling, A. J. Rustako, and R. A. Valenzuela, "Comparisons of a computer-based propagation prediction tool with experimental data collected in urban microcellular environments", *IEEE J. Select. Areas Commun.*, vol. 15, pp. 677-684, May 1997.

[3] M. J. Feuerstein, K. L. Blackard, T. S. Rappaport, S. Y. Seidel, and H. H. Xia, "Path loss, delay spread, and outage models as functions of antenna height for microcellular system design", *IEEE Trans. Veh. Technol.*, vol. 43, pp. 487-498, Aug. 1994.

[4] T. S. Rappaport and C. D. Mcgillem, "UHF fading in factories", *IEEE J. Select. Areas Commun.*, vol. 7, pp. 40-48, Jan. 1989.

[5] J. B. Andersen, T. S. Rappaport, and S. Yoshida, "Propagation measurements and models for wireless communications channels", *IEEE Communications Magazine*, pp. 42-49, Jan. 1995.

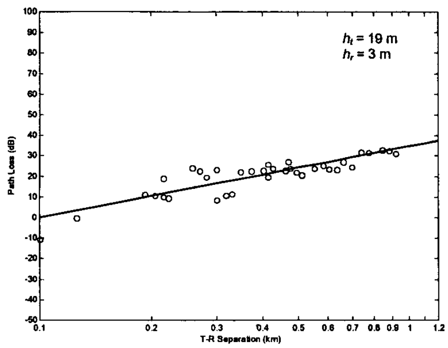
[6] S. Y. Seidel, T. S. Rappaport, A. J. Michael, and R. Singh, "Path loss, scattering, and multipath delay statistics in four European cities for digital cellular and microcellular radiotelephone", *IEEE Trans. Veh. Technol.*, vol. 40, pp. 721-730, Nov. 1991.

[7] H. H. Xia, H. L. Bertoni, L. R. Maciel, A. L.-Stewart, and R. Rowe, "Microcellular propagation characteristics for personal communications in urban and suburban environments", *IEEE Trans. Veh. Technol.*, Vol. 43, pp. 743-752, Aug. 1994.

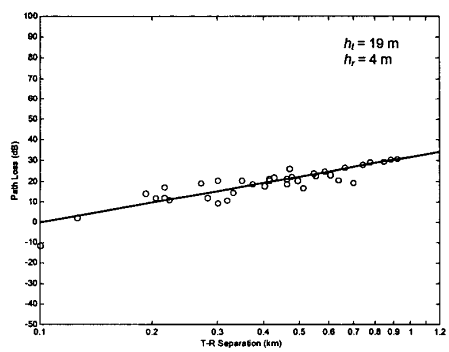
[8] W. C. Y. Lee, Mobile communications design fundamental, John Wiley & sons, 2nd edition pp. 60-61, 1993.

h_r (m)	n	σ (dB)
7	2.59	6.3
6	2.83	6.1
5	2.99	4.7
4	3.18	3.9
3	3.48	4.4

Table 1. Path loss exponent at different h_r.



(a)



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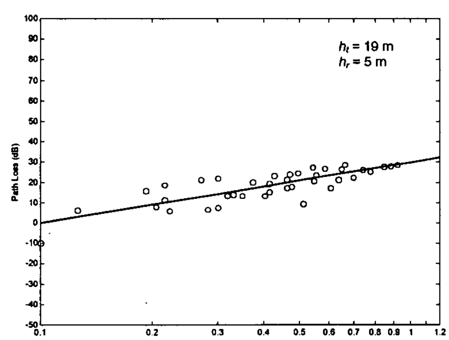

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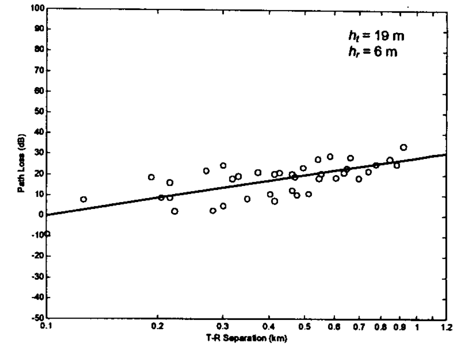

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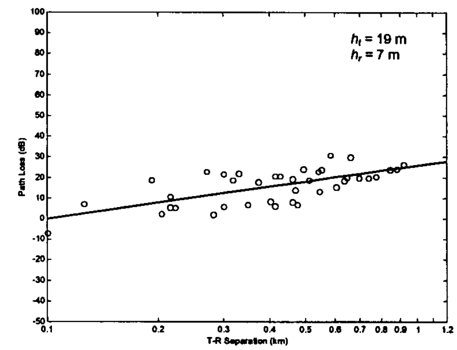

(e)

Fig.1. Radio propagation path loss for receiving antenna heights, h_r between 3 m to 7 m.