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Urban Propagation Measurements and Statistical Path Loss Model at 3.5 GHz

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Abstract

This paper presents the results of a significant number of propagation measurements performed at 3.5 GHz in urban environments. Furthermore, the data collected is used to derive a statistical path loss model over the range 100 m to 2 km. This work offers valuable propagation measurements in a frequency range that is globally being allocated for broadband wireless systems.

Introduction

Over the period from December 2003 to June 2004, a large number of propagation surveys were conducted by Plextek and LCC UK on behalf of a client operating a radio network at 3.5 GHz. Measurements were performed in urban environments within major cities of the United Kingdom (London, Birmingham, Liverpool and Manchester amongst others).

Although numerous path loss models are available (including the Hata [1] and COST 231 Walfisch-Ikegami [2] models) that describe propagation in urban, suburban or rural environments, they tend to be limited to the lower frequency bands (up to 2 GHz) and to large ranges (1–20 km) in the case of the Hata model. This provided the motivation to use the measured path loss data at 3.5 GHz to derive a log-normal shadow fading model appropriate for the actual measurement environment. This was found to agree very well with published work at other frequencies [3].

Measurement Equipment and Technique

The propagation survey equipment and data acquisition software was developed to give system flexibility, thus allowing surveys at other frequencies to be readily undertaken should the need arise in the future. The survey system consisted of a base and a mobile station, using identical vertical half-wave dipoles as the antennas. Choke baluns were incorporated to prevent distortion of the radiation pattern owing to feed-line radiation. The base station was mounted at heights of typically 20 m ±5 m on either a rooftop or at the top of a trailer mast. Signal generation at the base station was provided by a variable frequency microwave signal generator driving a power amplifier. The total conducted RF transmit power delivered to the antenna was 2 W. The mobile station was mounted in a survey vehicle with its antenna at a height of 2.5 m above ground level. The mobile receiver comprised a low noise amplifier with appropriate band pass filters connected to a spectrum analyser. PC based acquisition software controlled the spectrum analyser via GPIB and stored raw survey data (including GPS time and position co-ordinates) to hard disk. The received signal strength was sampled and averaged according to the Lee sampling criteria to remove fast-fading effects and obtain the mean signal strength [4]. Sampling parameters are dependent on the frequency of operation and the mobile station velocity.

Measurement Results

A straight line fit to each measured data set was performed using least squares approximation. Although measurement distances extended to about 5 km, the analysis ranges were limited to prevent excess bias of the least squares approximation. The lower limit (typically 100 m or more) reduced the effect of position measurement errors and to exclude data that suited an alternative model (i.e. two ray line-of-sight). At ranges greater than the upper limit (typically less than or equal to 2.2 km), data was excluded as the signal level approached the receiver noise floor.

The least squares approximation results in a log-normal shadow fading model that is given by [5]

$$PathLoss_{dB} = A + 10\gamma \log_{10}\left(d / d_0\right) + \chi \qquad (1)$$

$$A = 20\log_{10}\left(4\pi d_0 / \lambda\right) \qquad (2)$$

where A is the free space path loss at range d_0, λ is the operating wavelength, γ is the path loss exponent, d is the range variable and χ is the fading error. The fading error χ typically has a log-normal distribution with standard deviation σ_χ.

Figure 1 shows a typical measured path loss data set with the least squares approximation superimposed. The distribution of the fading error is shown in Figure 2 and can be seen to be log-normal. For the example data set, $d_0 = 64$ m, $\gamma = 4.2$ and $\sigma_\chi = 7.3$ dB.

The least squares approximations for all data sets (28 in total) are collated in Figure 3. For these, the mean log-normal shadow model parameters are:

$$d_{0\text{mean}} = 73 \text{ m}; \qquad \gamma_{\text{mean}} = 4.3; \qquad \sigma_{\chi\text{mean}} = 7.5 \text{ dB}; \qquad \text{A}_{\text{mean}} = 80.6 \text{ dB}.$$

Figure 4 shows the distribution of path loss exponent γ, which appears to be Gaussian in shape. A few values result in the mean path loss exponent being higher than the mode. The mode lies in the range of 3.5-4.0, which is typically the path loss exponent using the Hata model for large base station antenna heights and also observed frequently in other urban propagation measurements [3]. Shown in Figure 5 is the distribution of $\log_{10} d_0$, which also appears to be Gaussian. The mode lies in the range of 1.5-2.0, thus correlating with the mean of 73 m ($\log_{10} 73 = 1.86$). Figure 6 shows the distribution of the fading error standard deviation, with the majority lying in the range of 6-9 dB. Similar values have been observed in propagation surveys at 1.9 GHz [6]. Although not appearing Gaussian in shape, the standard deviation of this distribution is 1.4 dB, which is the same as that of $\sigma_{\chi\text{mean}} / \sqrt{N}$ (where N is 28). This suggests that the distribution might be Gaussian if more data sets had been included.

A further refinement to this model would be the inclusion of antenna height and terrain specific parameters as used in a similar 1.9 GHz model [6].

Summary

A log-normal shadow fading path loss model for urban propagation at 3.5 GHz over the range 100 m to 2 km has been presented. The model is based on a large number of measured data sets obtained in the United Kingdom and agrees very well with published work at other frequencies. This work offers valuable propagation measurements for a frequency range that is increasingly being allocated for broadband wireless networks internationally.

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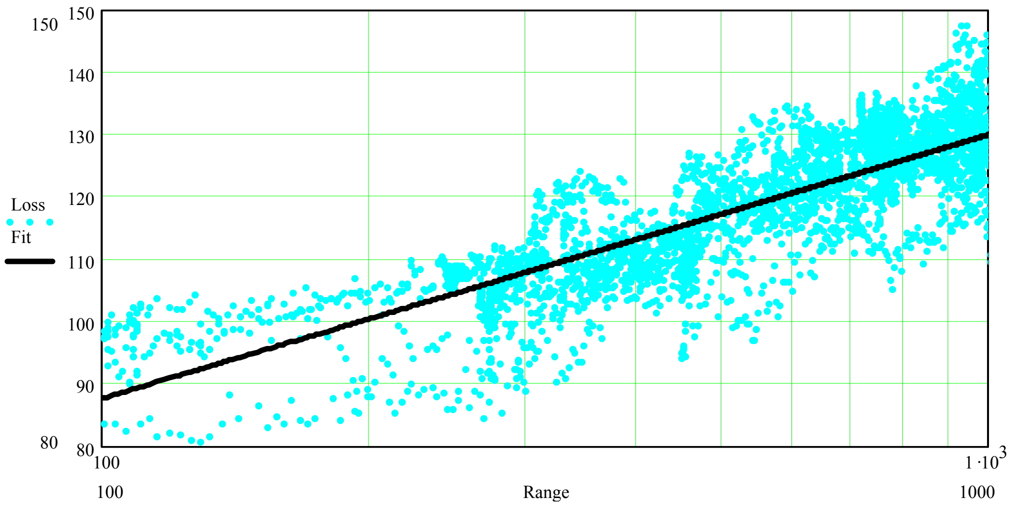

Figure 1: Measured path loss and least squares approximation versus range for sample data set

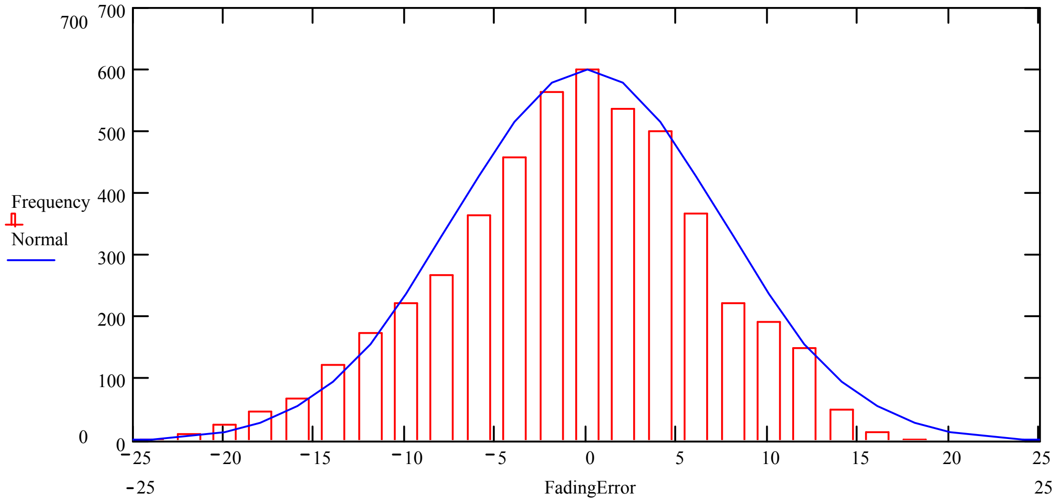

Figure 2: Distribution of measured fading error compared with normal distribution

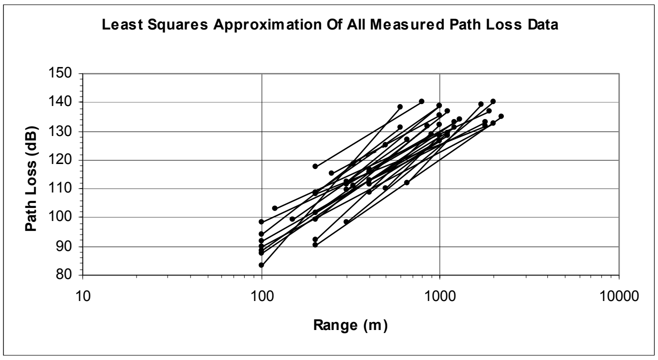

Figure 3: Least squares approximation of all measured path loss data sets

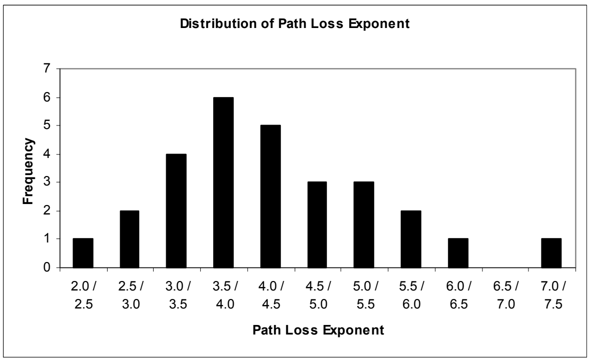

Figure 4: Distribution of path loss exponent from least squares approximation of all data sets

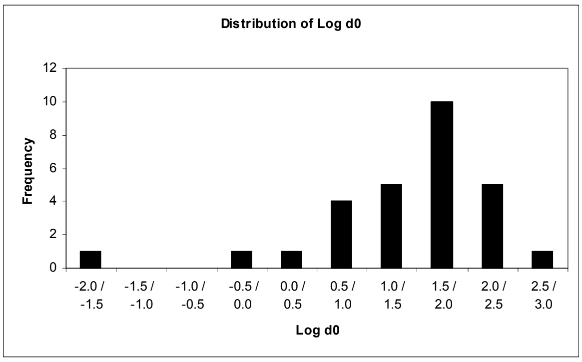

Figure 5: Distribution of $\log_{10} d_0$ obtained from least squares approximation of all data sets

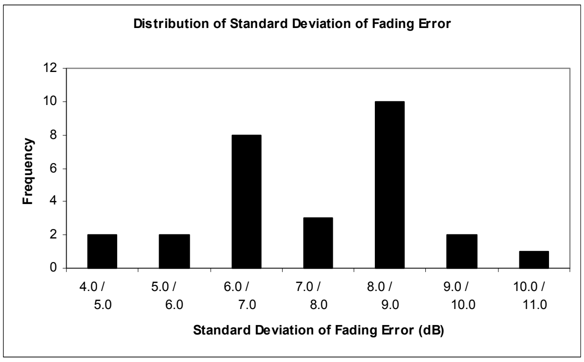

Figure 6: Distribution of standard deviation of fading error for all data sets