A Prediction Model of Signal Degradation in LMSS for Urban Areas

Takashi Matsudo, Kenichi Minamisono,
Yoshio Karasawa and Takayasu Shiokawa
KDD R&D Laboratories
2-1-15 Ohara, Kamifukuoka-shi, Saitama
356, Japan
Tel: +81-492-66-7877
Fax: +81-492-66-7510

ABSTRACT

A prediction model of signal degradation in LMSS for urban areas is proposed. This model treats shadowing effects caused by buildings statistically and can predict a Cumulative Distribution Function (CDF) of signal diffraction losses in urban areas as a function of system parameters such as frequency and elevation angle, and environmental parameters such as number of building stories and so on. In order to examine the validity of the model, we compared the percentage of locations where diffraction losses were smaller than 6dB obtained by the CDF with satellite visibility measured by a radiometer. As a result, it was found that this proposed model is useful for estimating the feasibility of providing LMSS in urban areas.

INTRODUCTION

Recently, proposals for a Land Mobile Satellite Service (LMSS) using handheld terminals have been advanced. In urban areas, signal degradation in LMSS is anticipated to be very large because of heavy shadowing effects caused by buildings. However, quality of service is still expected to be good even if users with handheld terminals are in urban areas.

Some propagation models for LMSS have been proposed [1],[2], however, it has become ambiguous to define environmental parameters in these models. It is therefore difficult to apply the models to areas where the urban structure is different.

In Japan, prediction methods for visibility in urban areas have been developed [3],[4]. These methods have used urban structure statistics such as a Probability Density Function (PDF) of building stories and building width as a function of the number of building stories, but they can not estimate signal fading.

In this paper, we propose a new type of prediction model of signal degradation in LMSS for urban areas. The proposed model treats shadowing effects caused by buildings statistically and can predict the Cumulative Distribution Function (CDF) of signal diffraction losses in urban areas as a function of system parameters such as frequency and elevation angle, environmental (urban structure) parameters such as number of building stories and width, and average road width.

LMSS PROPAGATION MODEL APPLICABLE TO URBAN AREAS

Basic Concept of Proposed Model

In general, the following propagation phenomena should be taken into account for propagation model in LMSS.

(1) Visibility of a direct wave from a satellite.
(2) Diffraction losses of a direct wave near and in shadow regions.
(3) Effects of multipath fading due to reflection from buildings and ground.

However, it seemed too complicated to consider the correlation between direct wave power affected by shadowing and average power of reflected waves, so the model proposed in this paper only takes the above items (1) and (2) into account as the first step in the development of the propagation model.

Generally, signal degradation caused by a single building can be calculated with fairly good accuracy by a knife-edge diffraction model [5]. In our proposed model, we apply this single knife-edge diffraction model to a number of buildings randomly distributed along a road.

The condition of buildings in an urban area is treated statistically as environmental parameters in our model. The parameters consist of the distribution of the number of building stories, building width as a function of building stories, and average number of buildings per km along a road. These parameters incorporated into the

model are easily obtained from a public data base.

The important character of our model is to be able to relate signal diffraction losses in dB caused by buildings with the environmental parameters. By using this model, we can calculate the CDF of signal diffraction losses in urban areas.

Proposed Model and Calculation of CDF

Table 1 shows environmental parameters used in this propagation model. These parameters can be obtained easily from a public data base.

To develop the LMSS propagation model for urban areas, it becomes important to decide how to deal with the conditions of buildings. In our model, we assume that a building of height z [story] has a width W(z)[m], and that the depth is the same as the width.

The PDF of building stories B(z) and the building width W(z) of height z [story] are given in the following equations [3],[4], respectively,:

$$B(z) = \begin{cases} \dfrac{1}{F-G} \exp\left(-\dfrac{z-G}{F-G} \right) & (z \geq G) \\ 0 & (z < G) \end{cases} \quad (1)$$

$$W(z) = 55\{1.0 - 1.1\exp(-0.1z)\} \quad [m] \quad (2)$$

where F and G represent an average building height in stories and a minimum building height in stories, respectively.

Figure 1 shows the model of a building used in our propagation model. We assume that an antenna is located at a distance x [m] from the building and that the antenna height is h_a [m]. The antenna receives a satellite signal diffracted by the building edge. Further, we assume that the shadow length L(z) exists at the antenna position x along a road.

At first, we will estimate the diffraction loss at the antenna position x and the shadow length L(z) as in Fig.1.

A diffraction loss caused by a building can be evaluated from a knife-edge model with fairly good accuracy, and a diffraction loss J(v) in dB is calculated by the following equations [5],:

$$J(v) = 6.9 + 20\log\left\{ \sqrt{(v-0.1)^2 + 1} + v - 0.1 \right\}$$
$$(v > -0.7 \text{ for } J(V) > 0) \quad [dB] \quad (3)$$

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)} \cong h\sqrt{\frac{2}{\lambda d_2}} \quad (4)$$

$$d_2 = \sqrt{\left(h_s \cdot z - h_a\right)^2 + \left(x \cdot \csc(\phi)\right)^2} \quad [m] \quad (5)$$

where:
h = height of the building edge above the straight line joining the antenna position to the satellite [m]
d_1 = distance from the satellite to the building edge [m]
d_2 = distance from the antenna position to the building edge [m]
λ = signal wavelength [m]
h_s = building height per story [m/story]
ϕ = azimuth angle [degree].

The relation between the edge height h and the number of building stories z can be expressed by the following equations,:

$$h = \left\{ \left(h_s \cdot z - h_a\right) - x \cdot \csc(\phi) \cdot \tan(\theta) \right\} \cos(\theta)$$
$$[m] \quad (6)$$

where:
θ = elevation angle [degree].

As is evident from Eq.(3) and (4), a diffraction loss J is defined as a function of the edge height h. By using Eq.(3)-(6), we can solve the edge height h at which a diffraction loss gives J [dB]. Once we calculate h as a function of J , we can obtain the edge length Le [m] as in Fig.1. At any position on the Le, a diffraction loss is equal to J(h).

To be exact, the edge length Le is not equal to the shadow length L(z) as in Fig.1, but we assume that both lengths are equal in order to simplify the calculation of the CDF of signal diffraction losses. This assumption may result in overestimation of the edge length when the azimuth angle ϕ is near 0° or 180°.

Then the shadow length L(z), in which the diffraction loss due to a building of z [story] is equal to J(h), is given by the following equations,:

$$L(z) = \begin{cases} W(z)\left(1 + \cot(\phi)\right) & [m] \quad (x \leq H_s) \\ W(z) + \cot(\phi)\left\{(h_s \cdot z - h_a)\cot(\theta)\sin(\phi) - x\right\} \\ \qquad\qquad [m] \quad (H_s \leq x \leq H_e) \\ W(z) & [m] \quad (H_e \leq x) \end{cases}$$
$$(7)$$

where H_s [m] and H_e [m] are the distances between a building and shadow boundaries in a shadow cast by a building as shown in Fig.1.

In Eq.(7), if $H_e \leq x$, the antenna position x is located out of the shadow cast by a building. However, the diffraction losses are caused by the edge at the top of a building, so we assume that $L(z)$ is equal to $W(z)$ in $H_e \leq x$.

From the above discussion, it is evident that to calculate the CDF of signal diffraction losses is equivalent to summing up the shadow length $L(z)$ along a road on which diffraction losses are larger than a given threshold value J_{thr}[dB].

Therefore, the total shadow length T per km on which diffraction losses are larger than J_{thr} can be estimated by integrating $L(z)$ from z_{thr} to infinity as in Eq.(8),:

$$T = \int_{z_{thr}}^{\infty} D \cdot B(z) \cdot L(z) \ dz \qquad [m] \qquad (8)$$

where:
z_{thr} = number of stories of buildings which cause a diffraction loss J_{thr} at an antenna position x [story]

D = average number of buildings per km shown in Table1 [/km]. This is easily obtained from a public data base.

Finally, the CDF of signal diffraction losses J[dB] which are larger than a given threshold value J_{thr}[dB] can be obtained by Eq.(9),:

$$P(J \geq J_{thr}) = 100 \cdot \frac{T}{1000} \qquad [\%]. \qquad (9)$$

Here we summarize the procedure for estimating the CDF of signal diffraction losses.

Step1: Give the diffraction loss (threshold value) J_{thr} in dB.

Step2: Calculate the building height z_{thr} [story] at which the diffraction loss is J_{thr} [dB] (Eq.(3)-(6)).

Step3: Estimate shadow length L [m] as a function of height z [story] (Eq.(7)).

Step4: Estimate the total shadow length T [m] per km over which the diffraction

losses are larger than J_{thr} [dB] (Eq.(1), (2), (8)).

Step5: Calculate CDF; $P(J \geq J_{thr})$ [%] (Eq.(9)).

Figure 2 shows one example of the cumulative distribution of signal fading calculated by the model presented here. A person with a handheld L-band terminal for LMSS is assumed to be on a sidewalk in an urban area. The environmental parameters are set at values for a typical urban area in Tokyo, Japan, and h_s is assumed to be 4 [m/story] [4]. Since buildings registered in original public data bases are higher than 4 stories or more (i.e. height ≥16m), a minimum number of stories G in Eq.(1) is set at 4 in the calculation. The definition of azimuth angles Az is shown in Fig.3. For example, L90 means 90° to the left of the direction of travel and R90 means 90° to the right of the direction of travel.

COMPARISON BETWEEN CALCULATED VALUES AND MEASURED DATA

An Outline of a Field Experiment

In order to examine the validity of this model, we carried out a field experiment in an urban area. In the experiment, satellite visibility (Line-Of-Sight(LOS) condition) was measured by measuring sky noise temperature T_n [K] with a radiometer as a function of azimuth and elevation angles.

If T_n is higher than a given threshold value T_{thr} [K], we understand that the LOS condition is lost. Since the boundary of the LOS condition gives a signal diffraction loss of 6dB, we compared satellite visibility measured by the radiometer with the percentage of locations where diffraction losses were smaller than 6dB estimated by this model.

The center frequency of the radiometer was 12GHz (bandwidth: 100MHz, time constant: 0.1sec) and a horn antenna (half-power beamwidth: about10°) was used. All experimental equipment was installed aboard a van.

Calibration of the measurement system for the determination of T_{thr} toward the direction of the shadow boundary was carried out at a site where there was only one building. As a result of the

357

measurement, a noise temperature of 176.6K was assigned to T_{thr} .

The experiment was carried out in one of the most built-up areas (Shinjyuku area in Tokyo) in Japan. The values of the environmental parameters are the same as the ones shown in Fig.2 except for x=10m, h_a=3m and R=29.1m.

The van was driven round a course, the length of one circuit being about 6.5 km. The antenna direction relative to the travel direction of the vehicle was maintained constant for the period of each experiment. The definition of azimuth angles Az in this experiment is shown in Fig.3.

Results

Figure 4 shows examples of measured noise temperatures for elevation angles El = 20°, 40° and 60° at Az=R90. Each dashed line means a noise temperature of T_{thr}. From this figure, we can clearly recognize that the visibility depends on elevation angles.

Figure 5 shows a comparison between calculated values expressed as lines and measured data expressed by symbols. For example, the line R90 means calculated values for Az=R90 in Fig.3, and the symbol MR90 means measured data for the same Az. The calculated values represent the percentage of locations where signal diffraction losses are smaller than 6dB estimated by the model presented here. The measured visibility is defined as the percentage ratio of the distance for which $T_n \leq T_{thr}$ to the length of one circuit (6.5 km).

As seen from this figure, the agreement between calculated values and measured data is excellent in predictions for cases having visibilities more than 50%. However, we can recognize some discrepancies between the calculated values and the measured data for cases having a measured visibility smaller than 50%. This discrepancy may be caused because buildings with a height of lower than 4 stories (i.e. height < 16m) are completely omitted in the calculation.

CONCLUSIONS

We proposed a new type of prediction model of signal degradation in LMSS for urban areas. Good agreement was confirmed between satellite visibility estimated by this model and that measured by experiments. Since we use environmental parameters easily obtained from a public data base, this model can be expected to be useful for estimating the feasibility of providing LMSS in urban areas in many countries.

In future, the effects of both direct wave degradation and multipath fading should be related to environmental parameters.

REFERENCES

[1] CCIR, "Factors affecting the choice of antennas for mobile stations of the land mobile-satellite service," *Rep.925-1*, vol.VIII, ITU,1990.
[2] E. Lutz et al.,"The Land Mobile Satellite Communication Channel-Recording, Statistics and Channel Model," *IEEE Trans.Vehicle.Tech.*, vol.40, no.2, pp.375-386, May 1991.
[3] E. Ogawa and A. Satoh, "Path visibility and reflected wave propagation characteristics in built-up areas," *IEICE Trans.* , vol.J69-B, no.9, pp.958-966, September 1986.
[4] Y. Ito, "Propagation characteristics for mobile reception of satellite broadcasting in urban areas," *IEICE Trans.* , vol.J73-B-II, no.7, pp.328-335, July 1990.
[5] CCIR, "Propagation data for land mobile-satellite systems for frequencies above 100MHz," *Rep.1009-1*, vol.V, ITU, 1990 including the contribution document to CCIR WP5B (Dec., 1991) from Japan (Doc. 5B/3-E).

Table 1. Environmental parameters used in the propagation model

parameters	notation	unit
building stories	z	[story]
building height per story	h_S	[m/story]
average number of buildings per km	D	[/km]
PDF of building stories	B(z)	
building width (as a function of z)	W(z)	[m]
average road width	R	[m]

ϕ: Azimuth angle [degree]
θ: Elevation angle [degree]
x: Position of antenna [m]
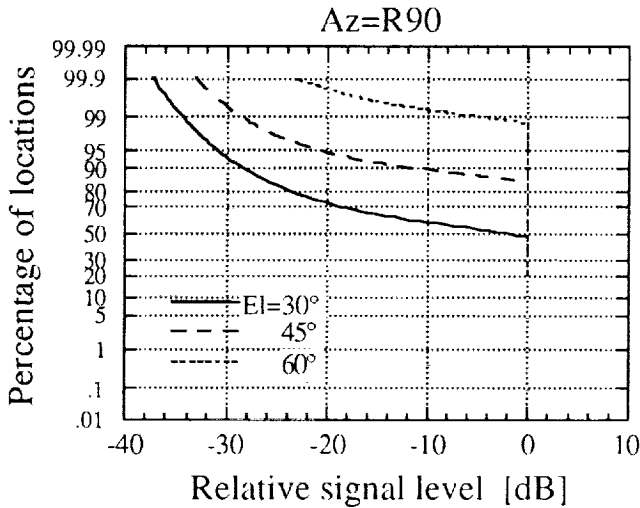h_a: Height of antenna [m]
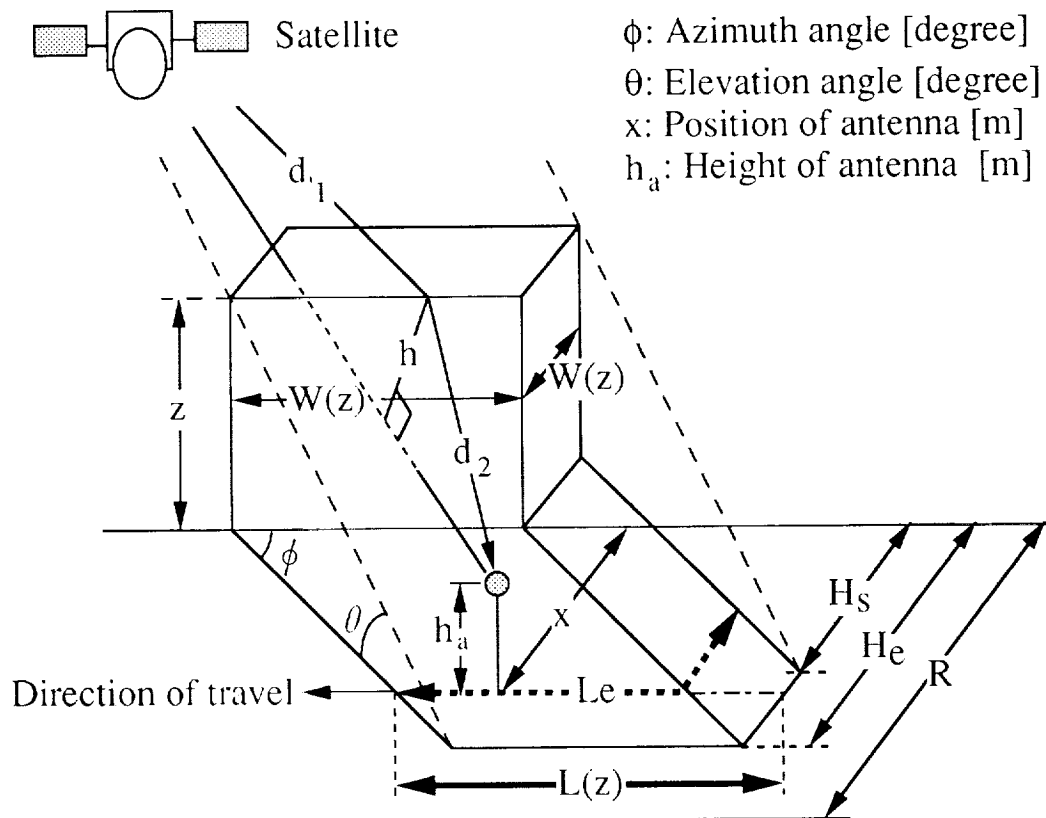
Figure 1. Model of a building for estimating signal diffraction losses.

Az=R90

Minimum Stories [story]   : G   = 4.000
Mean Stories [story]   : F   = 5.800
Average Number of
  Buildings per km [/km]   : D   = 26.460
Azimuth Angle [degree]   : ϕ = 90
Position of Antenna [m]   : x   = 2.000
Height of Antenna [m]   : h_a = 1.500
Road Width [m]   : R   = 30.000
Frequency [GHz]   = 1.540
Wave Length [m]   : λ = 0.195

Figure 2. One example of cumulative
distribution of signal fading calculated
by the proposed model.

(a) Elevation angle of 60°

(b) Elevation angle of 40°

(c) Elevation angle of 20°

Figure 4. Examples of measured noise
temperatures for three elevation angles
(Az=R90). Each dashed line means
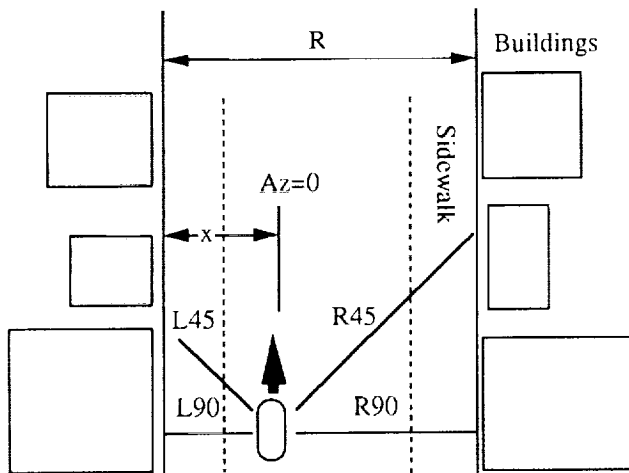T_{thr} (176.6K).

Figure 3. Definition of azimuth angles. For
example, L90 means 90° to the left of
the direction of travel and R90 means
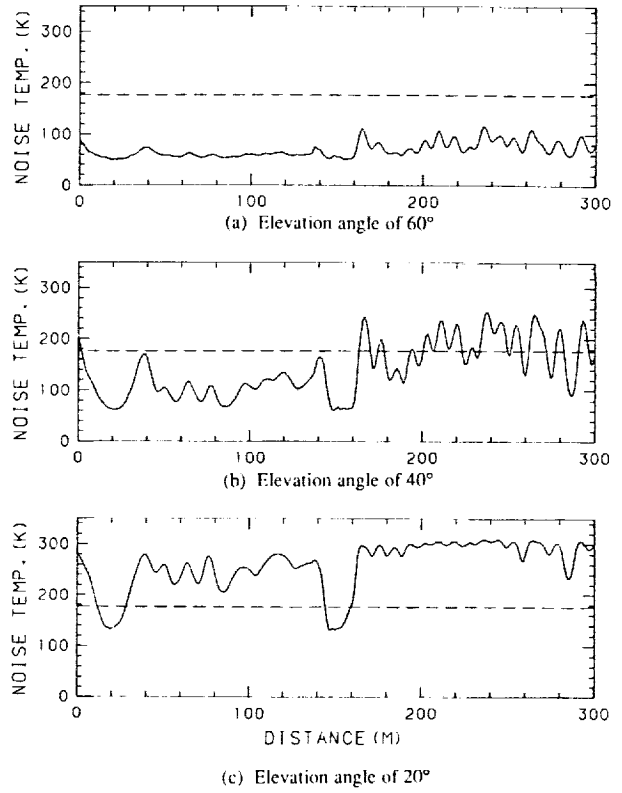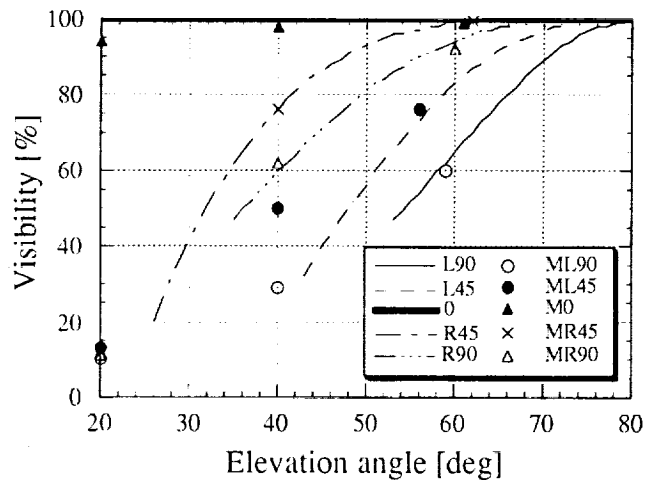to the right of the direction of travel.

Figure 5. Comparison of visibility between
measured values and calculated ones
(the percentage of locations where
signal diffraction losses are smaller
than 6dB).