New Angular Profile Model for Urban Mobile Propagation Channels

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1. Introduction

Due to the demands of cellular system users, it is essential to provide multimedia services such as video and computing applications, over the mobile network. To provide such multimedia services, the microwave frequency band will be required because its wider bandwidth enables high speed data transmission. This frequency band, however, suffers from low receiving levels as the shorter wavelengths cause high path loss. One effective way of overcoming the increase in path loss is the introduction of directive antennas at base stations[1]. The receiving level is improved as the antenna beam width is narrowed.

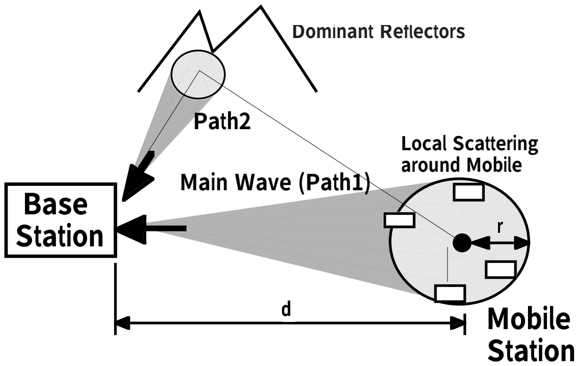


Fig.1 : Typical local scattering and multipath scenario

In actual multipath propagation environments, shown in Fig. 1, incoming waves, which are scattered from sites surrounding the mobile station (main wave) and reflected from distant sites (Path 2), are received by the base station. In this environment, maximum power is achieved if the antenna picks up only the main (desirable) wave. That is, the effective beamwidth of the directive antenna depends on the main wave angular spread in the multipath propagation environment. Clarification of this angular spread is necessary to specify the most suitable beamwidth of the directive antennas at base stations.

A well-known approach to evaluating the angular spread is to assume that the received signal at the base station originates from scatterers within a circle with radius r centered on the mobile station which separated by d from the base station[2], [3]. In this estimation, the beamwidth of the main wave decreases with distance between mobile station and base station assuming that radius r is constant. Consequently, the angular spread also decreases as the mobile-base station distance is increased and thus base station - mobile station separation is one of the most important factors determining angular spread. Each incoming wave is accompanied by a number of multipath components whose path levels fluctuate independently due to shadowing and so on. In particular, main wave fluctuations influence the angular profile. In the line-of -sight (LOS) condition, the main wave includes a high level direct path component, so the angular profile is sharpened by the high level direct wave and angular spread is small even if the mobile-base station distance is short. The angular spread depends not only on the distance between the base station and mobile station, but also the existence of an LOS path.

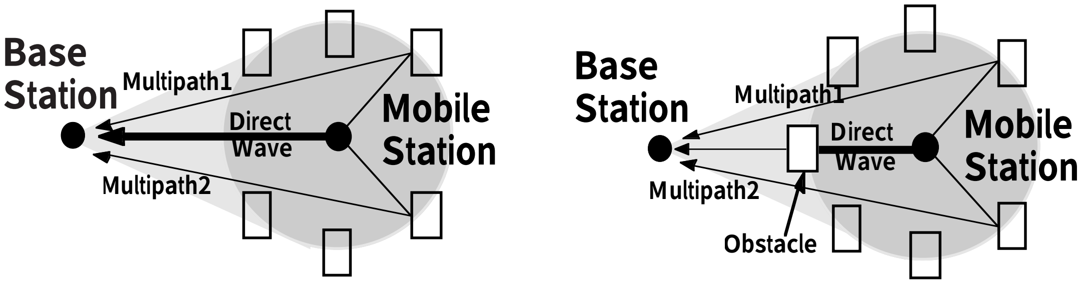
This paper proposes new angular profile model for multipath propagation. This model includes the effect of LOS existence and assumes that r is constant. The model's accuracy is confirmed by experiments.

2. Proposed angular profile model

The main wave single sided beamwidth θ_W is estimated by mobile-base station distance d and local scatterers' radius r and given by

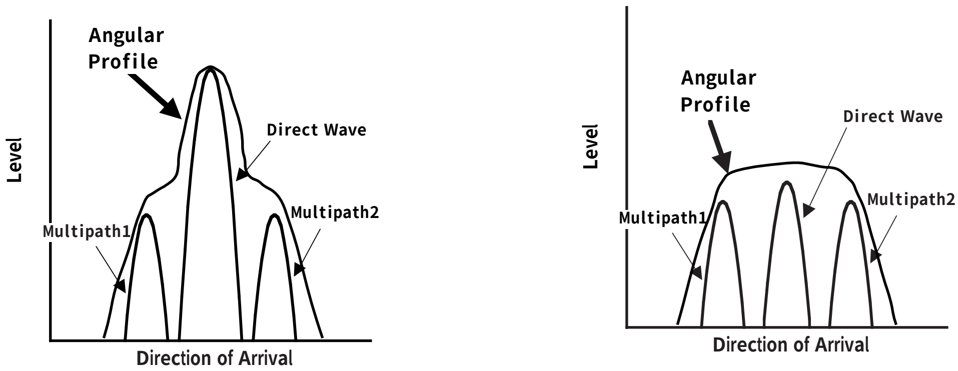
$$\theta_W = \arcsin(r / d). \tag{1}$$

The beamwidth θ_W thus decreases as d increases assuming that r is constant.



(a) LOS condition (b) OBS condition

Fig. 2 : LOS and OBS condition



(a) LOS condition (b) OBS condition

Fig. 3 : Angular profiles in LOS and OBS condition

In the LOS condition shown in Fig. 2(a), no obstructions lie between mobile and base station, and a direct wave is received whose loss is basically determined by free space propagation loss. In the obstructed line-of-sight (OBS) condition shown in Fig. 2(b), where obstructions lie between mobile and base station, the direct wave loss is decreased by shadowing due to the obstructions. Accordingly, LOS quantity is defined by the difference between direct wave loss and free space propagation loss, and LOS quantity decreases as more obstructions are found on the LOS path.

In this estimation, the main wave consists of the direct wave and multipath components. If an LOS path exists, the LOS quantity is high and the angular profile has a sharp peak shown in Fig. 3(a) due to the high level direct wave; angular spread is small. In the OBS condition, the direct wave loss is decreased but multipath components arriving from other directions are not influenced by the obstruction, so the angular profile is blunt as shown in Fig. 3(b); the angular spread is large.

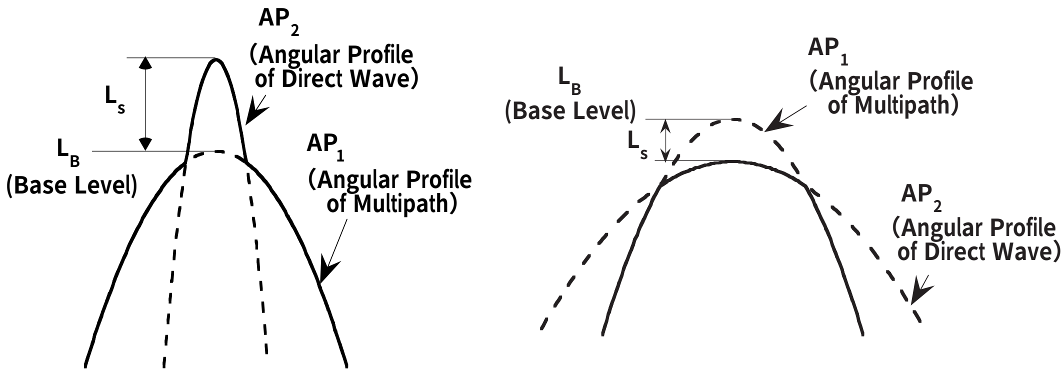
Accordingly, the proposed model includes LOS quantity as well as the beamwidth of the main wave as shown in Fig. 4. In Fig. 4, base level L_B is regarded as the product of LOS quantity and constant, α, and free space propagation loss, L_f (d): $L_B = \alpha L_f(d)$. L_B is defined for the peak of angular multipath profile. It is assumed that direct wave peak level is L_s higher than peak multipath level. L_s, defined as the LOS quantity, is given as follows:

$$L_s = L(d)/L_B = L(d)/\alpha L_f(d). \tag{2}$$

It is assumed that propagation loss L(d) decreases in proportion to d^{-n}, for example n=3.5 if L(d) follows Okumura-Hata formula[4]. In this case, L_s decreases in proportion to $d^{-1.5}$, so that LOS quantity decreases as mobile-base station distance is increased. Thus, angular profile of multipath $AP_1(\theta)$ and angular profile of the direct wave $AP_2(\theta)$ are given as follows:

$$AP_1(\theta) = L_B \exp\left(-\frac{\theta^2}{2\theta_w^2}\right) = \alpha L_f(d) \exp\left(-\frac{\theta^2}{2\theta_w^2}\right) \tag{3}$$

$$AP_2(\theta) = L_B L_s \exp\left(-\frac{\theta^2}{2\theta_d^2}\right) = L(d) \exp\left(-\frac{\theta^2}{2\theta_d^2}\right) \tag{4}$$



(a) High LOS quantity (b) Low LOS quantity

Fig. 4 : Proposed angular profile model

where θ is the angle of arrival. Define $\int AP_1(\theta)d\theta = \int AP_2(\theta)d\theta$, θ_d and θ_W are related as follows:

$$\frac{1}{\sqrt{2\pi}\theta_d} = \frac{1}{\sqrt{2\pi}\theta_W} L_s. \tag{5}$$

Accordingly, when both a direct wave and multipath are received, angular profile AP(θ) is given as follows:

$$AP(\theta) = \begin{cases} L_s L_B \exp\left(-\dfrac{\theta^2}{2\left(\dfrac{\theta_W}{L_s}\right)^2}\right) = L(d)\exp\left(-\dfrac{\theta^2}{2\left(\dfrac{\theta_W}{L_s}\right)^2}\right) & -\theta_a < \theta < \theta_a \\ L_B \exp\left(-\dfrac{\theta^2}{2\theta_W{}^2}\right) = \alpha L_f(d)\exp\left(-\dfrac{\theta^2}{2\theta_W{}^2}\right) & \theta < -\theta_a, \theta > \theta_a \end{cases} \tag{6}$$

where -θ_a and θ_a are the intersection angles of multipath angular profile AP_1 (θ) and direct wave angular profile AP_2 (θ).

3. Measurements

Measurements were made in the 8 GHz microwave frequency band. The mobile station was located at 58 positions in an urban area (Tokyo). A narrow-beam parabola antenna (3-dB width: 3 degree) was used as the base station antenna and an omni-directional antenna was used as the mobile station antenna. The base station antenna height was set to 100 m to evaluate the environments typical of macrocells. The mobile station was set at each position and the angular profile measured by rotating the base station antenna.

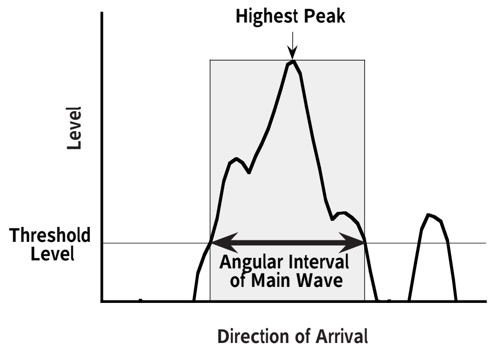


Fig. 5 : Angular interval of main wave

The angular spread of the main wave was calculated from the measured angular profile. First, the threshold level was estimated. The angular interval of the main wave was defined as the region around the maximum peak within which the level exceeded some threshold as shown in Fig. 5. Main wave angular spread was given as the angular spread as indicated by the calculated main wave angular interval. Here, the threshold was set at -20 dB from the highest peak. The angular spread also depends on measurement antenna resolution. In order to correct the calculated angular spread, we used the following formula[5]: $AS = \sqrt{AS_{measurement}{}^2 - AS_{antenna}{}^2}$, where $AS_{measurement}$ is angular spread calculated by measured angular profile including the effect of antenna pattern and $AS_{antenna}$ is standard deviation of antenna pattern.

4. Discussion

Figure 6 shows the distance dependence of the LOS quantity, which is defined as the difference between propagation loss L_p and free space propagation loss L_f (d). propagation loss L_p is adapted of the highest peak level of measured angular profile. The solid curve shows recursion by d^{-n} , and in this estimation n=3 to freespace propagation loss.

Figure 7 shows the LOS quantity dependence of angular spread, for 4 groups of distances. Solid curves are angular spread calculated by the proposed model (L_B = -20 dB, r = 150 m). In Fig. 7, the angular spread calculated by proposed model increases in inverse proportion to LOS quantity for each distance group and increases in inverse proportion to the distance between mobile and base station distance. It is found that measured angular spread lies around the solid curves derived by the proposed model.

Figure 8 shows the distance dependence of angular spread. Dotted line is beamwidth of main wave, and the solid line is the angular spread yielded by the proposed model (L_B = -20 dB, radius r = 150 m, L(d): recursive curve in Fig. 6). In Fig. 8, although main wave beamwidth decreases steeply in inverse proportion to the distance, the trend of angular spread calculated by proposed model is moderate. This result reflects the LOS quantity dependences of shown in Fig. 6 and Fig. 7. Measured angular spread is less than 4 degree, and agrees with the results of the proposed model rather than with the main wave beamwidth.

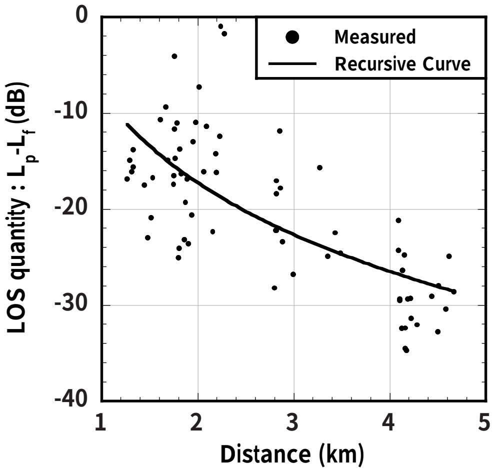


Fig. 6 : Distance dependence of LOS quantity

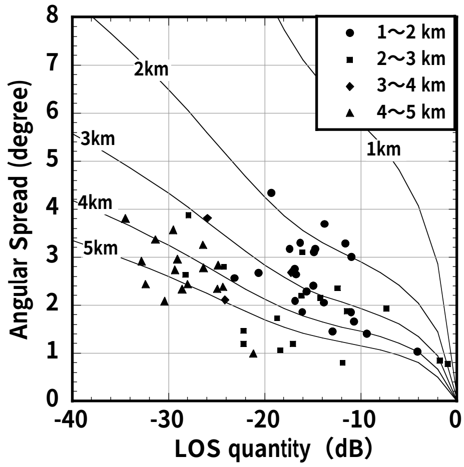


Fig. 7 : LOS quantity dependence of Angular spread

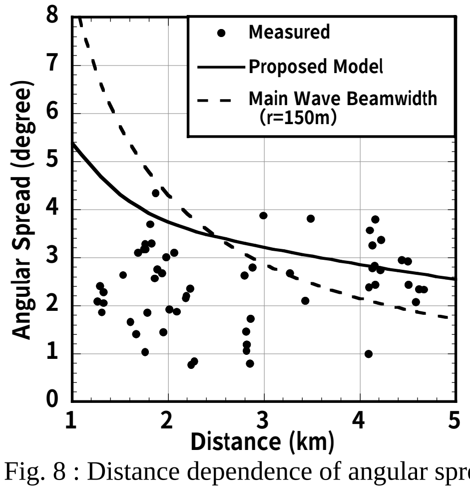


Fig. 8 : Distance dependence of angular spread

5. Conclusions

A new angular profile model based on the beamwidth of the main wave and LOS quantity was proposed. Its effectiveness was confirmed by measurements which showed that the angular spread agreed with the results of the proposed model rather than with the main wave beamwidth. The angular spread calculated by the proposed model shows less distance dependency than the main wave beamwidth. The number of measurement points was rather limited and we plan to conduct further trials to confirm the model's accuracy.

References

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