Proceedings of ISAP’04, Sendai, JAPAN

1A2-1

Modeling of Arrival Wave Distribution for Mobile Adaptive Array Antenna in Suburban Area

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1.Introduction

In the fourth generation mobile communication systems, a frequency band higher than 3 GHz is required to achieve high-rate transmission and high user capacity. Since the use of a higher frequency band incurs significant propagation loss, the system gain must be improved to secure a larger service area. Introducing the adaptive array antenna (AAA) is an efficient way to address the above issues, and by implementing AAA at not only the base station (BS) but also the mobile station (MS), an increase in the system gain can be easily achieved.

The mean effective gain (MEG), which is the antenna gain in an actual environment, should be taken into consideration when the mobile antenna is designed. Incident wave models were reported in which the mean power distribution (MPD) of the angle of elevation is approximated as a Gaussian or exponential distribution[1,2]. On the other hand, the MPD with respect to the azimuth was assumed to have a uniform distribution because a MS moves randomly in a service area although some strong incident waves are observed in various directions in the MS environment [3]. These models are suitable for evaluating the MEG of the omni-directional antenna. However, since the AAA tracks the desired waves such as the strongest wave, its performance greatly depends on the conditions of the MPD that change minutely with the movement of the MS. Therefore, conventional models do not have the required accuracy to evaluate the MEG and the tracking performance of the AAA in the MS, and an arrival wave model, which represents the relation between the power distribution of each incident wave and the actual mobile environment conditions, is required.

We propose a novel MPD model for evaluating the AAA at the MS. In Section 2, the statistical model of the MPD at the MS is described. The results of the 3-Dimensional (3D) measurements carried out to confirm the model parameters of the MPD are presented in Section 3, and the proposed MPD model for a suburban area is described in Section 4.

2. Statistical Model of MPD at MS

Many incident waves are observed around a MS. Some waves have high power and their arrival angles have regularity, while other waves have low power and it is difficult to determine their characteristics in detail, such as scattered waves around a MS [3,4]. The former are called specific waves (SWs), and the latter are called unspecific waves (UWs) in this paper. The MS MPD consists of SWs and UWs. Therefore, the general statistical MPD model can be represented as follows. Spherical coordinates in a mobile radio environment are given in Fig. 1.

$$P(\theta,\phi)=\sum_{n=1}^{M} Ps^{(n)}(\theta,\phi)+Pu(\theta,\phi) \tag{1}$$

$$Ps^{(n)}(\theta,\phi)=As^{(n)}\exp\left\{-\frac{\left(\theta-\theta s_m^{(n)}\right)^2}{2\sigma s_\theta^{(n)2}}\right\}\bullet\exp\left\{-\frac{\left(\phi-\phi s_m^{(n)}\right)^2}{2\sigma s_\phi^{(n)2}}\right\} \tag{2}$$

$$Pu(\theta)=Au\exp\left\{-\frac{\left(\theta-\theta u_m\right)^2}{2\sigma {u_\theta}^2}\right\}+Bu \tag{3}$$

Here, Eq. (2) shows the MPD of the SW. The azimuth and elevation angles of the *n-th* SW are considered to have Gaussian distributions because the arrival angle fluctuates minutely according to the movement of the MS. The number of SWs is M. Terms $\theta s_m^{(n)}$ and $\sigma s_\theta^{(n)}$ represent the mean angle and standard deviation in elevation, and $\phi s_m^{(n)}$ and $\sigma s_\phi^{(n)}$ represent those in azimuth of the *n-th* SW, respectively. Equation (3) shows the MPD of the UW, and θu_m and σu_θ represent the mean angle and standard deviation in elevation. The azimuth MPD of the UW is assumed to have a uniform distribution. Furthermore, since many waves that have very weak power are distributed around the MS uniformly, stationary

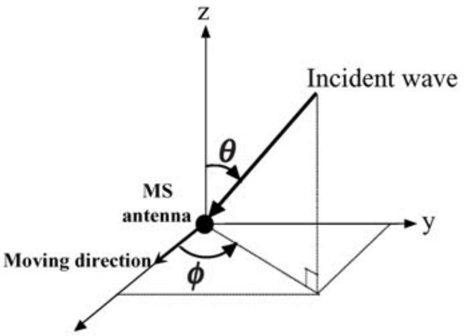


Fig. 1 Spherical coordinates in mobile radio environment.

ISBN: 4-88552-206-4 C3055©IEICE

element Bu is given in the second term of Eq. (3). Terms $As^{(n)}$ and Au represent the amplitude of the SW and the UW, respectively. Equations (1) to (3) are adopted for both the vertical polarization (V-Pol) and the horizontal polarization (H-Pol).

3. 3D-MPD Measurement in Suburban Area

A 3D-measurement of the power distribution was carried out in a suburban area where the residences are regularly spaced in a line as depicted in Fig. 2. Since this area is located on a hill, there are no buildings that cause reflections. We selected three receiving courses where the street angle, Φ, is different. The power distribution is measured every meter along each of the three courses (A-C). The length of the receiving courses is 60 m. The measurement conditions are given in Table 1. A microstrip antenna with a beamwidth of 10 [deg] is adopted for the reception antenna, and is installed on a rotating table. The range of the 3D-measurement is the circumference per degree in azimuth and per 10 [deg] from $\theta = 20$ to 130 [deg] in elevation. The power delay profiles are also acquired in an area 5 m around the center as a reference. The chip rate is 50 M [bit/sec]. The standard of the azimuth $\phi = 0$ deg is set to the direction shown in Fig. 2. The measurement is stopped temporarily to obtain measurement data in a semi-static environment while cars or people enter the receiving course.

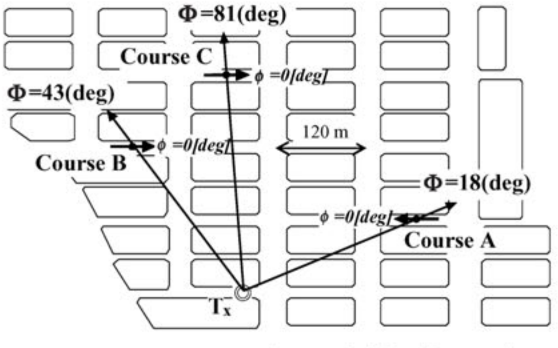
Figure 3 shows the MPD of the V- and H-Pol along Course B. Several waves with high power are distributed at specific angles. Table 2 gives the arrival conditions of the SWs with V-Pol within 10 dB based on the maximum wave and those with H-Pol, which have the same number of waves as that of the V-Pol. The arrival waves with higher power, which are in bold in Table 2, arrive from four directions in azimuth and depend on the street angle, Φ, as shown in Fig. 4. Assuming that the SWs arriving from Directions D (Dir. D) and C (Dir. C) are reflected once and twice at the walls of houses along the street, respectively, θ of these SWs can be determined by the equations below.

$$\theta_C = \pi/2 - \tan^{-1}\left[\{(H_h - H_m) \bullet \sin\Phi\} / 3W_r \right] \qquad (4)$$

$$\theta_D = \pi/2 - \tan^{-1}\left[2\{(H_h - H_m) \bullet \sin\Phi\} / 3W_r \right] \qquad (5)$$

Here, H_h and H_m represent the average height of the houses and the MS, respectively, and W_r represents the street width. When H_h =8 m, H_m =1.5 m and W_r =10 m, which correspond to the measurement conditions, the results of θ_C = 81.6 [deg] and θ_D = 73.5 [deg], the angles of which are in good agreement with the results of the measurements as shown in Table 2, can be obtained. The arrival angles of the H-Pol SWs do not exhibit regularity. To evaluate the MEG strictly, the MPD of the V- and H-Pol should be considered; however, since the AAA has a directional beam that contributes slightly to cross polarization and the power of the H-Pol is very weak compared to that of the V-Pol, the parameters of the V-Pol are clarified in this paper.

Figure 5 shows the average power delay profiles along the measurement course B. The wave that arrives in the shortest time has an excess delay time of $\tau = 0$ [sec] and

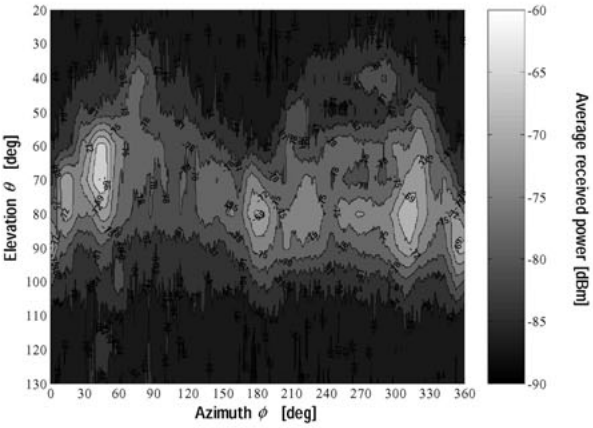


Average height of houses:8m

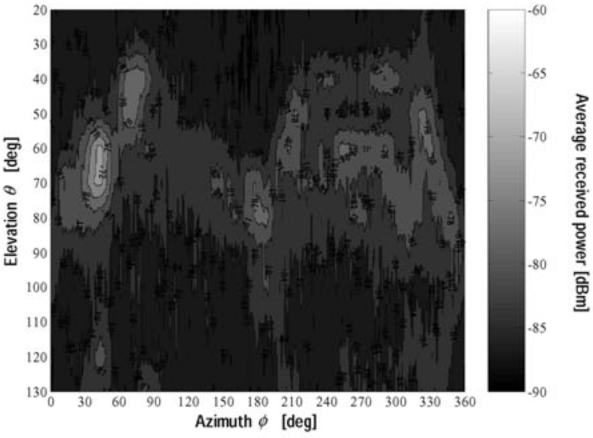
Fig. 2 Measurement area.

Table 1. Measurement conditions.

Frequency	3.35 GHz	
Transmission power	+28 dBm	
Modulation	CW	
Transmission antenna	λ/2-sleeve dipole antenna	
Height of Tx	15 m	
Transmission polarization	V-Polarization	
Reception antenna	Microstrip antenna (Beamwidth:10 deg, Gain:22.8 dBi, XPD:more than 40 dB)	
Height of Rx	1.5 m	
Reception polarization	V- and H-Polarization	
Distance between Tx and Rx	Course A (Street angle Φ = 18 [deg])	219 m
	Course B (Street angle Φ = 43 [deg])	205 m
	Course C (Street angle Φ = 81 [deg])	210 m



(a) V-Pol



(b) H-Pol

Fig. 3 3D MPD observed along Course B (Φ = 43 deg).

is used as the standard. Many waves that have an excess delay within 0.1μ [sec] are distributed around the mobile station and the waves arriving from the direction of the road have a long delay as reported in Ref. 4. This excess delay of less than 0.1μ [sec] corresponds to the difference in propagation length. Several groups of waves are distributed in Direction A (Dir. A) and B (Dir. B). These waves are considered to be reflected waves and/or diffracted waves from the corner of the intersections and houses since the interval between the groups of delayed waves is approximately 0.3 to 0.4 μ [sec], which corresponds to the distance between the intersections or houses. SWs except those from Dir. A to Dir. D are scattered waves with high power. Direction E (Dir. E) described in Fig. 4 is the reflected wave from a sidewall.

Similar results were observed for Courses A and C.

4. Proposed MPD Model in Suburban Area

Table 3 gives the model parameters determined by approximating the measured MPD employing the least-square method. The calculated standard deviations of the SWs $\sigma s_{\theta}^{(n)}$, $\sigma s_{\phi}^{(n)}$, are very small from 5 to 10 [deg]. These values are obtained using the following equation, $\sigma s_{\theta,\phi}^{(n)} = \sqrt{\sigma m_{\theta,\phi}^{(n)2} - \sigma ant_{\theta,\phi}^{(n)2}}$, which can suppress the influence of the antenna pattern from the measured results. Terms $\sigma m_{\theta,\phi}^{(n)}$ and $\sigma ant_{\theta,\phi}^{(n)}$ are the standard deviations approximated from the measured results and from the antenna patterns with Gaussian distribution, respectively. These results show that the gain of the AAA at the MS improves as the beamwidth becomes narrower. The relationship between the received power of the SWs and the street angle, Φ, is shown in Fig. 6. The received power of the SWs from Dir. A to Dir. D can be approximated by a linear function for Φ and the difference among their power levels is approximately 3 dB. Next, the model parameters of the UWs are obtained using the linear function for Φ after approximating the measured MPD employing the least-squares method. It is assumed that the UWs are distributed over a range except for $\sigma s_{\theta}^{(n)}$ and $\sigma s_{\phi}^{(n)}$ around the SW. Figure 7 shows the parameters for the UWs versus Φ. Each parameter of the UWs is also approximated linearly for Φ. For reference, the average cross-polarization discrimination (XPD) according to the angle of the existing SWs is approximately 10 dB. This means that the contribution of cross polarization is too small to evaluate the MEG of the AAA. Similar results are obtained for Courses

Table 2. Conditions of SWs
of V-Pol. Along Course B.

(a) V-Pol

Path No.	ϕ [deg]	θ [deg]	Average Received Power [dBm]	Type of Wave
1	**44**	**70**	**-63.3**	**D**
2	**311**	**80**	**-66.5**	**C**
3	**356**	**90**	**-67.4**	**A1**
4	**182**	**80**	**-68.5**	**A1**
5	**15**	**70**	**-69.6**	**A2**
6	268	80	-71.6	
7	221	80	-72.6	E
8	255	80	-72.6	

(b) H-Pol

Path No.	ϕ [deg]	θ [deg]	Average Received Power [dBm]	Type of Wave
1	**41**	**70**	**-71.4**	**D**
2	73	40	-75.6	
3	**184**	**80**	**-77.0**	**B1**
4	254	60	-77.0	
5	328	60	-77.1	
6	261	60	-77.5	
7	290	60	-77.8	
8	207	60	-77.9	

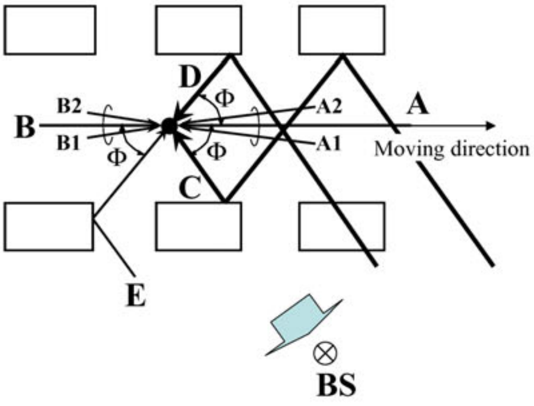
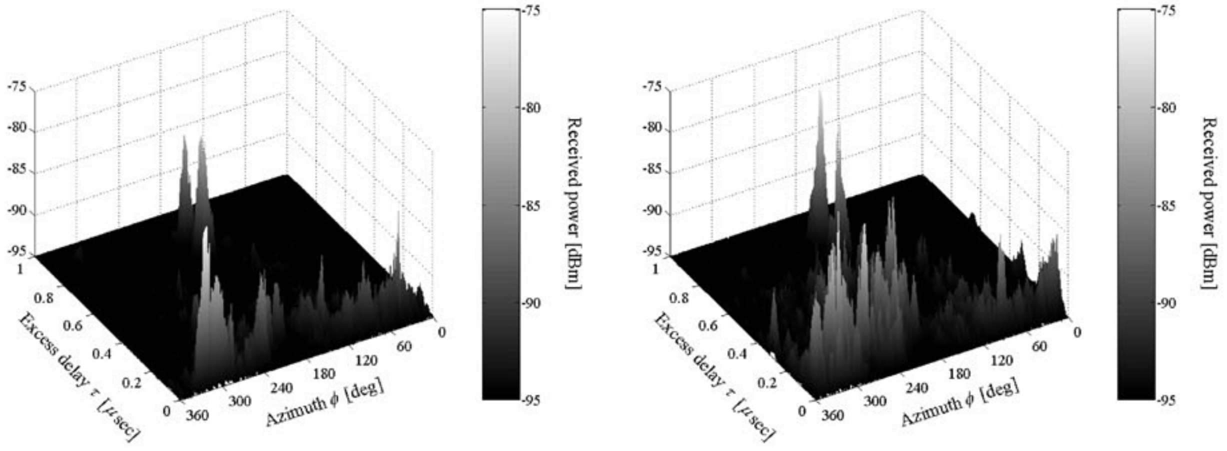


Fig.4 Main azimuth angles of SWs



(a) θ =70deg

(b) θ =80deg

Fig.5 Examples of average power delay profiles (Φ = 43 deg).

A and C.

Dominant waves for the AAA are those that arrive from only Dir. A to Dir. D. Therefore, the proposed MPD model for the AAA considers only a part of the SWs in Eq. (1), i.e., Eq. (2). The following equations are proposed for the MPD in a suburban area.

$$P(\theta,\phi)=\sum_{n=1}^{4} As \exp\left\{-\frac{\left(\theta-\theta s_m^{(n)}\right)^2}{2\times(\pi/36)^2}\right\}\bullet\exp\left\{-\frac{\left(\phi-\phi s_m^{(n)}\right)^2}{2\times(\pi/36)^2}\right\} \qquad (6)$$

$$As=-0.08\bullet\Phi+63.1 \qquad (7)$$

$$\left[\phi s_m^{(1)},\phi s_m^{(2)},\phi s_m^{(3)},\phi s_m^{(4)}\right]=[0,\Phi,\pi,2\pi-\Phi] \qquad (8)$$

$$\left[\theta s_m^{(1)},\theta s_m^{(2)},\theta s_m^{(3)},\theta s_m^{(4)}\right] =\left[\pi/2,\pi/2-\tan^{-1}\left[\{(H_h-H_m)\bullet\sin\Phi\}/3W_r\right],\pi/2,\pi/2-\tan^{-1}\left[2\{(H_h-H_m)\bullet\sin\Phi\}/3W_r\right]\right] \qquad (9)$$

Here, the amplitude As of the SWs from Dir. A to Dir. D are given as the approximating function shown in Fig. 6. Terms $\sigma s_\theta^{(n)}$ and $\sigma s_\phi^{(n)}$ adopt the average value of 5 [deg] from the measured results. For Dir. A and Dir. B, $\phi s_m^{(n)}$ are easily set to 0 and π. Since the power of the UW is approximately 10 dB lower than that of the SW, for example, we set $Pu(\theta)$ to -20 dB to take into consideration a continuous distribution over a 3D surface.

Note that the proposed model can be applied to the evaluation of an AAA with more than a 10 [deg] beamwidth because the directional antenna with a 10 [deg] beamwidth is used in the measurement. When the AAA comprising omni-directional antennas, such as dipole antennas, is adopted, Eq. (6) can be simplified to

$$P(\phi)=\sum_{n=1}^{4} As\bullet\delta\left(\phi s_m^{(n)}\right) \qquad (10)$$

5. Conclusions

The relationship between the arrival angle, the power of the incident waves, and the street angle were clarified from the 3D-MPD obtained in a suburban area. Furthermore, the model parameters of the statistical MPD model, which comprises elements of the SWs and the UWs, were determined. The MPD of four SWs should be considered to evaluate the performance of the AAA at the MS in a suburban area.

Acknowledgment

The author thanks Dr. Tokio Taga and Dr. Shinichi Ichitsubo for their guidance. The author also wishes to thank Mr. Katsuyuki Sakaino for his efforts regarding the measurement.

References

[1] T. Taga, "Analysis for Mean Effective Gain of Mobile Antennas in Land Mobile Radio Environments", IEEE Trans. on VT, Vol. 39, No. 2, MAY 1990.

[2] K. Kalliora, K. Sulonen, H. Laitinen, O. Kivekas, J. Krogerusand and P. Vainikainen, "Angular Power Distribution and Mean Effective Gain of Mobile Antenna in Different Propagation Environments", IEEE Trans. on VT, Vol. 51, No. 5, September 2002.

[3] F. Ikegami and S. Yoshida, "Analysis of Multipath Propagation Structure in Urban Mobile Radio Environments", IEEE Trans.on AP, vol. AP-34, no. 4, pp. 531-537, 1977.

[4] A. Kuchar, J.P. Rossi, and E. Bonek, "Directional Macro-Cell Channel Characterization from Urban Measurements", IEEE Trans. on AP, Vol. 48, No. 2, February 2000.

Table 3. Parameters of SWs in V-Pol.

Path No.	Azimuth ϕ [deg]		Elevation θ [deg]		$As^{(n)}$[dB]
	$\phi s_m^{(n)}$	$\sigma s_\phi^{(n)}$	$\theta s_m^{(n)}$	$\sigma s_\theta^{(n)}$	
1	43.3	4.0	66.9	5.6	-62.6
2	310.6	7.1	80.8	6.9	-66.4
3	356.4	3.2	88.7	3.4	-67.0
4	181.6	5.7	80.7	4.3	-68.2
5	15.1	4.5	73.9	4.4	-68.2
6	268.6	9.9	90.4	4.4	-71.5
7	221.8	14.6	78.2	8.7	-72.2
8	254.5	5.2	79.7	5.7	-72.2

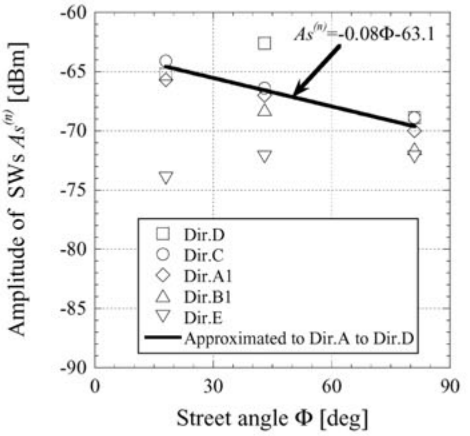
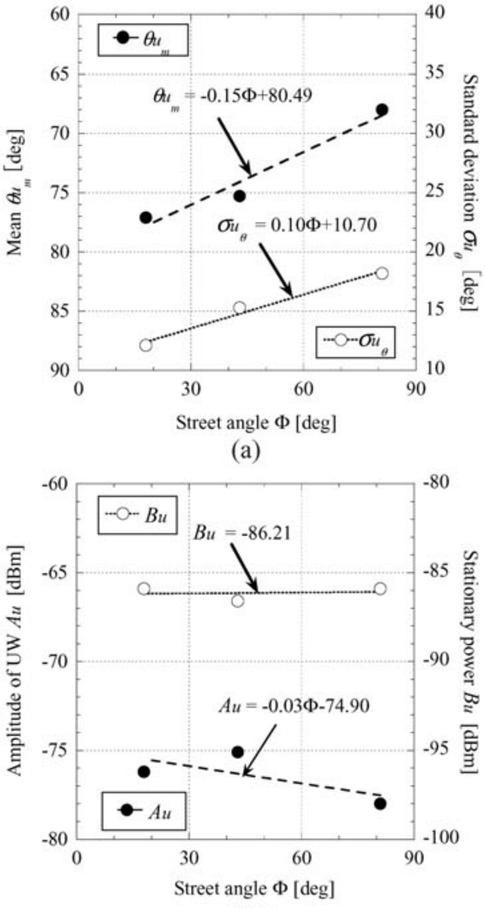


Fig. 6 Power of SWs vs street angle.



(a)

(b)

Fig.7 Parameters of UW vs street angle.