PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

AUTOCORRELATION FOR RECEIVED SIGNAL-LEVEL IN A WIDE-BAND MOBILE RADIO CHANNEL

Hiroaki NAKABAYASHI, Ken TAKAHASHI and Shigeru KOZONO
Department of Electronic Engineering, Chiba Institute of Technology
2-17-1, Tsudanuma, Narashino-shi, Chiba-ken 275, Japan

1. Introduction

In accordance with the expansion of mobile communications, various types of new services involving the transmission of facsimiles, data, and images will be demanded. To realize these services, mobile communication will have to change from narrow-band analog transmission to high-grade wide-band digital transmission. According to studies on mobile propagation, though, received signal-level variation in wide-band transmission is entirely different from that of narrow-band transmission[1].

Therefore, we have examined the autocorrelation dependence on the received bandwidth and the angle spread of arriving waves, theoretically and by computer simulation.

2. Model and Derivation of the Autocorrelation Equation

a) Propagation model

Figure 1 shows the propagation model in wide-band transmission. It assumes that multipath waves arrive at a receiving point under the following conditions.

i) The arriving waves have amplitude A_i and path length L_i. These are distributed uniformly within a fixed range, and are independent of each other.
ii) The number of arriving waves is N. The arriving angle θ_i of the waves is distributed uniformly in a horizontal plane over an angle of 2π.
iii) The amplitude of each wave is constant over the received bandwidth.

For the transmitted and received power,

iv) Transmitted power spectrums are constant over the frequency band $f_c \pm \Delta F$.
v) The received bandwidth is $2\Delta f$ and is centered at f_c, where $\Delta f \le \Delta F$.

b) Derivation of the autocorrelation equation

For the propagation model shown in Fig.1, the received power P and the autocorrelation of the received signal-level $\rho(z)$ are given by (1) and (2), respectively[1].

$$P = 2\Delta f \sum_{i=1}^{N} A_i^2 + \frac{2}{K} \sum{}' \sum{}' \frac{A_i A_j}{\Delta L_{ij}} \left[\cos(K f_c \Delta L_{ij}) \sin(K \Delta f \Delta L_{ij}) \right], \tag{1}$$

$$\rho(z) = \frac{\left\langle \sum{}' \sum{}' \dfrac{\left(\cos\delta_2 - \cos(2\phi_2 - \delta_2)\right)\cos\delta_1}{\Delta L_{ij} \Delta L'_{ij}} \right\rangle}{\sqrt{\left\langle \sum{}' \sum{}' \dfrac{1 - \cos(2\phi_2)}{\Delta L_{ij}^2} \right\rangle \left\langle \sum{}' \sum{}' \dfrac{1 - \cos(2\phi_2 - 2\delta_2)}{\Delta L'^2_{ij}} \right\rangle}}, \tag{2}$$

where $\phi_1 = K f_c \Delta L_{ij}, \phi_2 = K \Delta f \Delta L_{ij}, \delta_1 = K f_c \Delta l_{ij}, \delta_2 = K \Delta f \Delta l_{ij}$,

$\Delta L_{ij} = L_i - L_j, \Delta L'_{ij} = \Delta L_{ij} - \Delta l_{ij}, \Delta l_{ij} = (\cos\theta_i - \cos\theta_j) z, K = 2\pi / c,\ \sum{}' \sum{}' = \sum_{i=1}^{N} \sum_{j=1}^{N} (i \ne j)$,

c is the velocity of light, z is the distance that a receiving point moves, and < > denotes an ensemble average.

Assuming that $\Delta L_{ij} \gg \Delta l_{ij}$ and $f_c \gg 2\Delta f$, Eq.(2) can be expressed as

$$\rho(z) = \left\langle \sum{}' \sum{}' \cos\delta_1 \right\rangle. \tag{3}$$

These assumptions mean that the distance moved is much smaller than the difference in path length, and the received bandwidth is much smaller than the radio frequency. We then substituted δ_1 into Eq.(3) and modified it to get

$$\rho(z) = \left\langle \sum{}' \cos(kz\cos\theta_i) \right\rangle \left\langle \sum{}' \cos(kz\cos\theta_j) \right\rangle = \left\{ \frac{1}{2\pi} \int_0^{2\pi} \cos(kz\cos\theta) d\theta \right\}^2 . \quad (4)$$

Using a mathematic formula, Eq.(4) becomes[2]

$$\rho(z) = J_0^{\,2}(kz) = J_0^{\,2}(2\pi z / \lambda_c), \quad (5)$$

where $J_0(x)$ is the Bessel function of the first kind and $k = Kf_c$. Equation (5) shows the autocorrelation of the received signal-level for wide-band transmission. Therefore, the autocorrelation coefficient equation in wide-band transmission is the same as that in narrow-band transmission[3].

3. Simulation and Results

a) Simulation method

To clarify the autocorrelation characteristics, a computer simulation based on Eq.(2) was carried out. The autocorrelation was examined for i) dependence on the receiving bandwidth and the difference in path length, and ii) dependence on the spread of the arriving angles. Table 1 shows the simulation parameters. The main conditions are the center frequency f_c is 1500MHz, the number of arriving waves $N = 10$, $|\Delta L_{ij}| < 30, 500$m, and the receiving bandwidth $2\Delta f = 0.015$, 3MHz.To evaluate the dependence on the receiving bandwidth or difference in path length, the spread of the arriving angles were distributed uniformly over an angle of 2π. On the other hand, to evaluate the dependence on the spread of arriving angles, as shown in Fig.2, the arriving waves were set within a spread angle $\pm S$, centered on a moving direction θ_0. First, a simulation was carried out, when $\theta_0 = 0°$ and $S = 180°$. Then simulations with $S = 60°, 30°$, and $15°$ at $\theta_0 = 0°$ were carried out by using data from the first set of simulations with the spread angles S multiplied by 1/3, 1/6, and 1/12, respectively. The other data such as A_i and L_i were unchanged.

b) Autocorrelation dependence on received bandwidth and difference in path length

Figure 3(a) shows the simulation results for $\rho(z)$ on the basis of Eq.(2) when the received bandwidths $2\Delta f$ were 0.015 and 3MHz. The results for both the narrow-band and wide-band show the independence of the received bandwidth. The ■ symbols in Fig.3(a) are values of $J_0^{\,2}(2\pi z / \lambda_c)$, and the simulation results agree well with these values. Figure 3(b) shows simulation results $\rho(z)$ when the difference in path length $|\Delta L_{ij}|$ is less than 30 and 500m, and both simulations produce similar results. Therefore, $\rho(z)$ is also independent of the difference in path length.

c) Autocorrelation dependence on the spread of arriving angles

Figure 4 shows an example of the received signal-level variation as a parameter of S when direction of arriving waves is $\theta_0 = 0°$ and $90°$. As shown in Fig.4, fading pitch becomes large when S is small. Furthermore, the fading pitch for $\theta_0 = 90°$ is smaller than that for $\theta_0 = 0°$ when S is small. Therefore, it seems that the autocorrelation depends on both θ_0 and S.

Figure 5 shows simulation results $\rho(z)$, corresponding to those in Fig.4. In this case, $\rho(z)$ decreases as S increases, especially when θ_0 is large.

4. Conclusion

Autocorrelation characteristics in wide-band transmission were examined theoretically and by computer simulation. The results show that i) the autocorrelation coefficient $\rho(z)$ is independent of the received bandwidth and the difference in path length, and is expressed by $J_0^{\,2}(2\pi z / \lambda_c)$, ii) $\rho(z)$ depends on the spread angle S and direction θ_0 of the arriving waves, and decreases as S increases, especially when θ_0 is around 90°.

REFERENCES

[1]S.Kozono, "Received Signal-Level Characteristics in a Wide-Band Mobile Radio Channel", IEEE Trans. Vhe. Technol., Vol.43, No.3, pp.480-486(1994-08).

[2]H.Nakabayashi, K.Takahashi, S.Motooka, S.Kozono, "Study of Autocorrelation for Received Signal-Level in a Wide-Band Mobile Radio Channel", Trans. IEICE, Vol.J78-B-II, pp.658-660, (1995-10).

[3]W.C.Jakes, "Microwave Mobile Communications", John Wiley & Sons, Inc, 1974.

Table 1 Simulation Parameters

	Dependence on $2\Delta f$ and $\lvert\Delta L_{ij}\rvert$	Dependence on S
Center Frequency f_c(MHz)	1500	1500
Number of Arriving Waves N	10	10
Difference in path length $\lvert\Delta L_{ij}\rvert$(m)	< 30, 500	< 500
Received Bandwidth $2\Delta f$ (MHz)	0.015, 3	0.00125
Direction of Arriving Waves θ_0(degree)	——	0, 45, 90, 135, 180
Spread of Arriving Angles S (degree)	——	180, 60, 30, 15

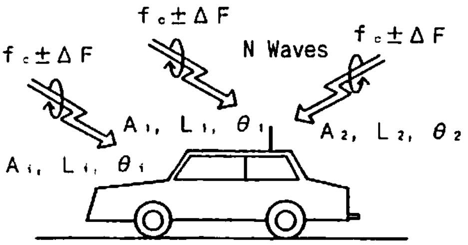


Fig.1 Propagation Model

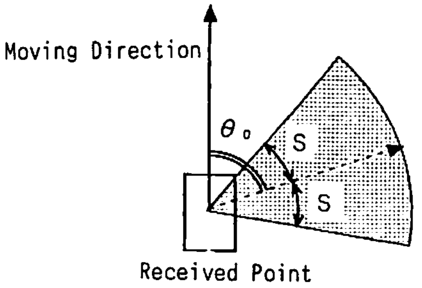
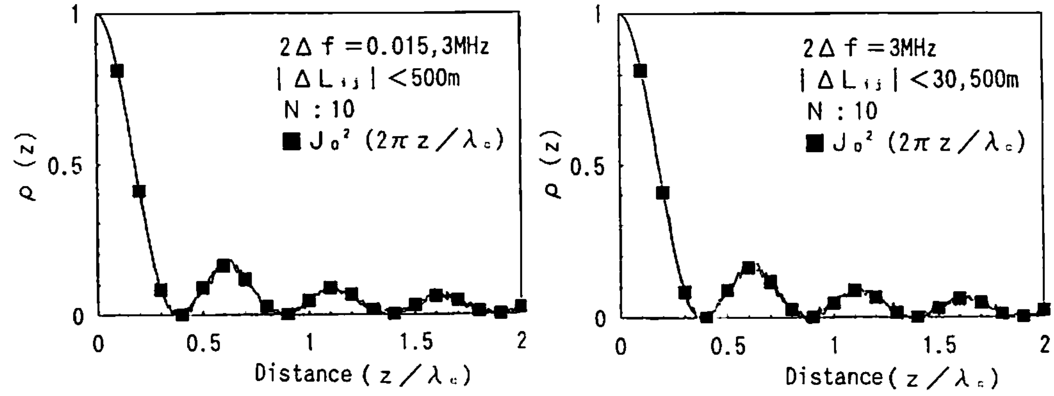
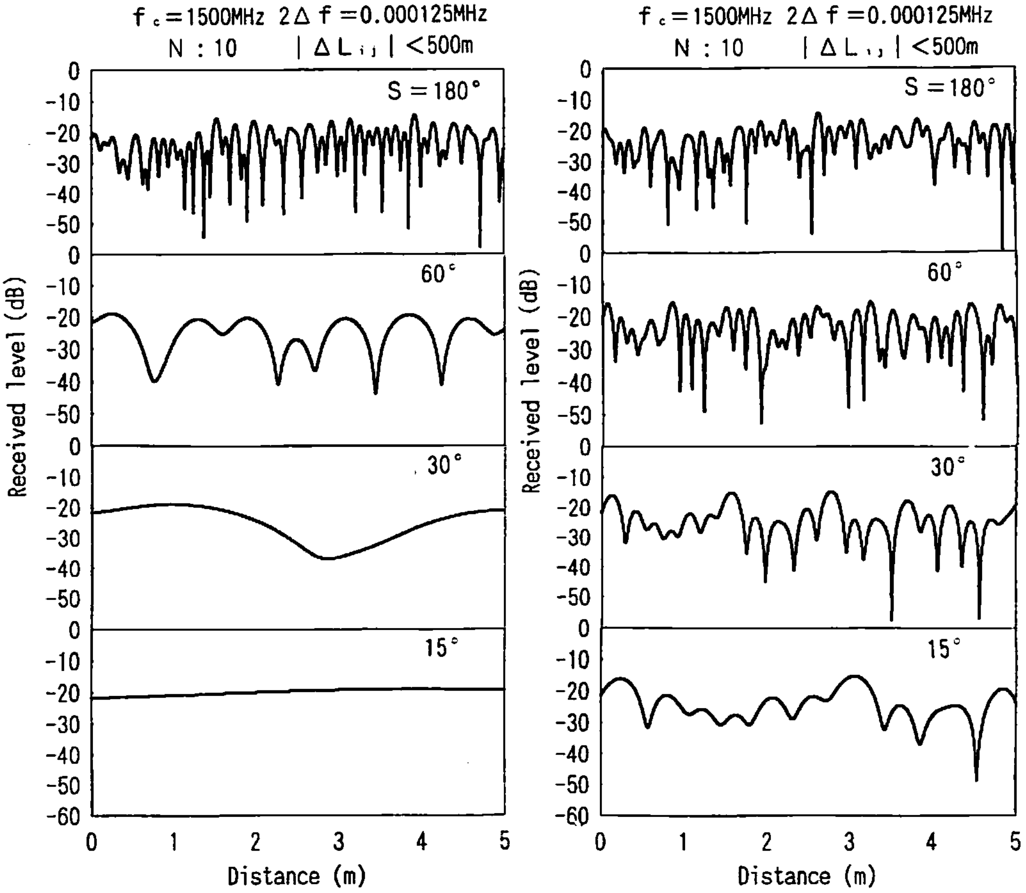


Fig.2 Direction of Arriving Waves θ_0 and Spread of Arriving Angles S



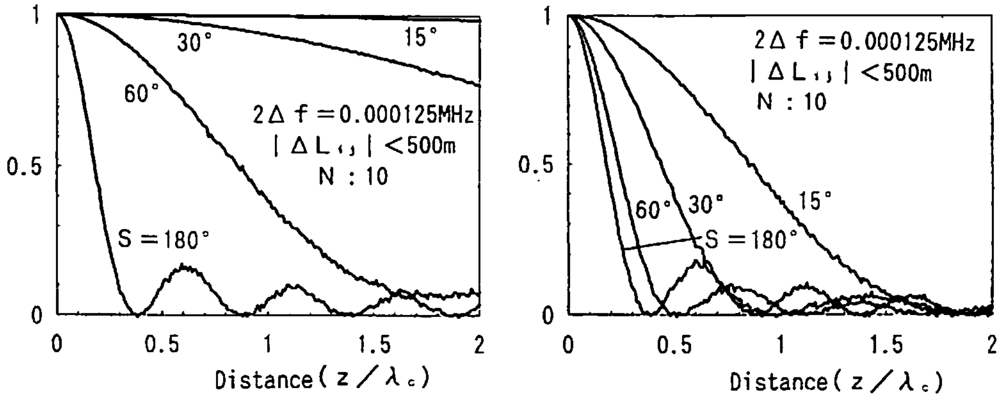
(a) Dependence on Received Bandwidth (b) Dependence on Difference in Path Length

Fig.3 Autocorrelation Characteristics



(a) $\theta_0=0°$ (b) $\theta_0=90°$

Fig.4 Example of Received Signal-Level



(a) $\theta_0=0°$ (b) $\theta_0=90°$

Fig.5 Dependence on Spread of Arriving Angles