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OPTICALLY DERIVED ELEVATION ANGLE DEPENDENCE OF FADING FOR SATELLITE PCS

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Abstract - Images of urban Japan taken vertically through a 180° fisheye lens were analyzed to derive, as a function of elevation the fraction of sky that is clear, shadowed by trees, or blocked by buildings. At 32° elevation, results match those derived from satellite measurements fit to a 3-state fade model. Using the same model, for the first time the elevation angle dependence of mobile satellite fading is predicted.

INTRODUCTION

Fading for mobile satellite communications can be modeled by assuming that distinct signal level statistics pertain to three major propagation states, i.e., when the line-of-sight is clear (C), shadowed by trees (S), or blocked by buildings (B). In [1], Karasawa et al. derived percentages of (C, S, B) by fitting L-Band satellite fade data obtained in urban Japan at 32° elevation to a cumulative probability distribution consisting of a weighted linear combination of Rice (C), Loo (S) [2], and Rayleigh (B) fading, as in

$$f_v(v) = C * f_{Rice}(v) + S * f_{Loo}(v) + B * f_{Rayleigh}(v), \tag{1}$$

where $f(v)$ denotes the density function for the signal envelope [3] and the individual fade distributions are the Ricean density function,

$$f_{Rice}(v) = \frac{v}{\sigma^2} \exp\left[\frac{-(v^2 + a^2)}{2\sigma^2}\right] I_0\left(a\frac{v}{\sigma^2}\right), \tag{2}$$

Loo's density function,

$$f_{Loo}(v) = \frac{8.686\, v}{P_S\, s\sqrt{2\pi}} \int_0^\infty \frac{1}{z} \exp\left[-\frac{(20\log(z) - m)^2}{2s^2} - \frac{(v^2 + z^2)}{2P_S}\right] I_0\left(\frac{vz}{P_S}\right) dz, \tag{3}$$

and the Rayleigh density

$$f_{Rayleigh}(v) = \frac{v}{\sigma^2} \exp\left[\frac{-v^2}{2\sigma^2}\right]. \tag{4}$$

The parameters assumed for the three fade distributions, with *a*, the direct signal's voltage set to $\sqrt{2}$ for a direct power of P_d=1, are given in Table 1.

Table 1 Parameters for fade densities

state	distribution	parameter	Karasawa	optical fit
C	**Rice** scattered power P_S relative to direct power P_a	$\sigma = 10^{P_S(dB)/20}$	-8 dB	-7.5 dB
S	**Loo**			
	diffuse power P_S relative to direct power	$P_S = 10^{P_S(dB)/10}$	-13 dB	-13 dB
	mean power of lognormal process	$m\ (dB)$	-10 dB	-10 dB
	standard deviation of lognormal process	$s = 10^{s(dB)/10}$	3 dB	3 dB
B	**Rayleigh** diffuse power relative to direct power	$\sigma = 10^{P_S(dB)/20}$	-20 dB	-17 dB

We employed an optical method [4], applied to 236 fisheye lens images taken in urban Japan during the fall of 1993, to evaluate where the Earth-satellite path is clear, shadowed, or blocked as a function of the elevation angle. The photogrammetrically derived fade state probabilities are compared to [1] at 32° and then used to predict, for the first time, fade probabilities for elevation angles from 5° to 85°.

PHOTOGRAMMETRIC RESULTS

The fisheye images were taken at random urban locations in Tokyo, Kyoto, Nara, Hiroshima, and Kamakura, Japan. As the fisheye lens gives a full hemispheric view, the 35mm camera was always pointed vertically. The lens was held 1¾m above ground near the street-side edge of any sidewalk and its direction was aligned with a compass. The fraction of potential satellite paths with clear, shadowed, or blocked line-of-sight was calculated in 5° elevation angle increments from 0° to 89° and is plotted in Fig. 1. For example, in the low-elevation interval from 10° to 14°, 17% of the sky is clear, 8% is shadowed, and 75% is blocked, compared against the higher elevation interval of 60° to 64°, where (C, S, B) equals (80%, 3%, 17%). The environment states from 0° to 89° in 5° increments for urban Japan are also listed in Table 2.

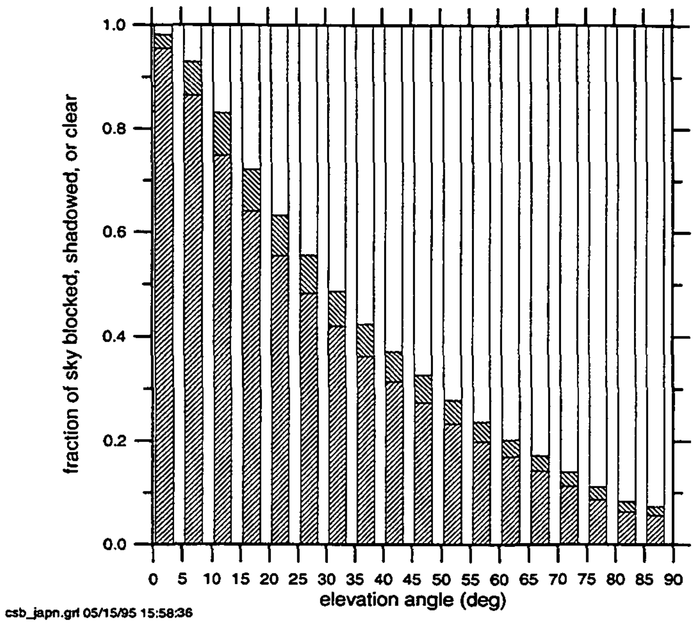

Fig. 1 The fraction of urban Japanese sky that is clear (white), shadowed by trees (diagonal hatch, down), or blocked by buildings (diagonal hatch, up) as a function of elevation angle.

Table 2 Environment states in urban Japan

Elevation	Clear	Shadowed	Blocked
0-4	2%	3%	95%
5-9	7%	6%	86%
10-14	17%	8%	75%
15-19	28%	8%	64%
20-24	37%	8%	56%
25-29	44%	7%	48%
30-34	51%	7%	42%
35-39	58%	6%	36%
40-44	63%	6%	31%
45-49	67%	5%	27%
50-54	72%	5%	23%
55-59	76%	4%	20%
60-64	80%	3%	17%
65-69	83%	3%	14%
70-74	86%	3%	11%
75-79	89%	2%	9%
80-84	92%	2%	6%
85-89	93%	2%	6%

COMPARISON TO SATELLITE MEASUREMENT

In Fig. 2, three cumulative fade distributions are drawn for comparison. The circles represent the satellite beacon measurement at 32° elevation and the dashed line the fit to the data in [1], with (C, S, B) estimated at (55%, 10%, 35%). The solid line is the result of applying the photogrammetrically derived states (C, S, B) of (51%, 7%, 42%) at 32° with the distribution parameters adjusted (see Table 1) to minimize the squared deviation from the measurement on the logarithmic scale. As a small fraction of fading was due to tree shadowing, only the parameters for the C and B states were allowed to vary. Although no attempt was made to link the propagation measurement locations to the image locations other than through their generic "urban Japan" description, the agreement between distributions is quite close and validates the optical method. The divergence between the fade measurement and the fitted and optically predicted distributions at fades greater than 25 dB is most likely due to the limited fade margin of the satellite system. The oscillating prediction error might call for further refinement of the 3-state model.

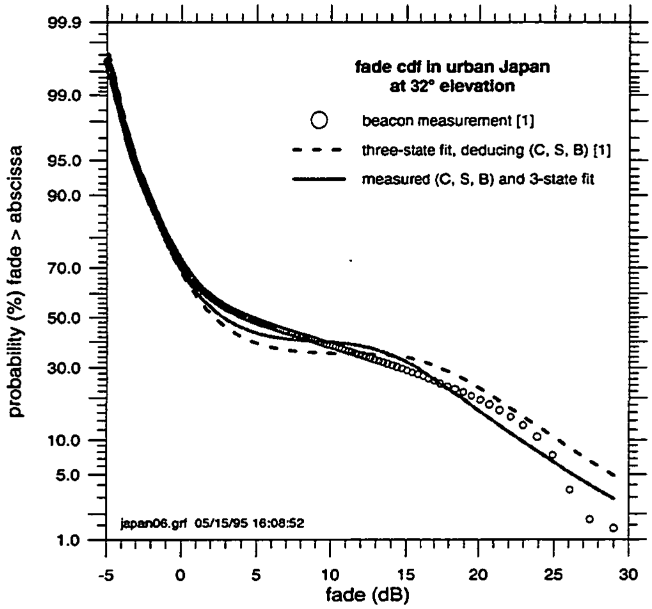

Fig. 2 Cumulative fade distributions resulting from satellite measurement and fit [1] vs. the photogrammetric environment sensing method.

ELEVATION ANGLE DEPENDENCE OF FADING

By inserting the environmental state probabilities of Table 2 with the optically derived distribution parameters of Table 1 into (1), we obtain a family of cumulative fade distributions, as shown in Figure 3. It shows, for instance, that in the urban area a system with a 25 dB fade margin can give 90% coverage at an elevation angle of 17°, respectively. This procedure assumes that the three-state model can be extended over the entire elevation angle range with the parameters give in Table 2. At elevations below about 20°, specular ground reflections can become significant [5] and might influence the overall distribution. That effect, however, is mainly significant in open, rural environments. Similarly, high elevation angle distributions might be affected by reflections from vertical building surfaces prevailing in urban areas. Such effects can be included in the model once data are available for verification.

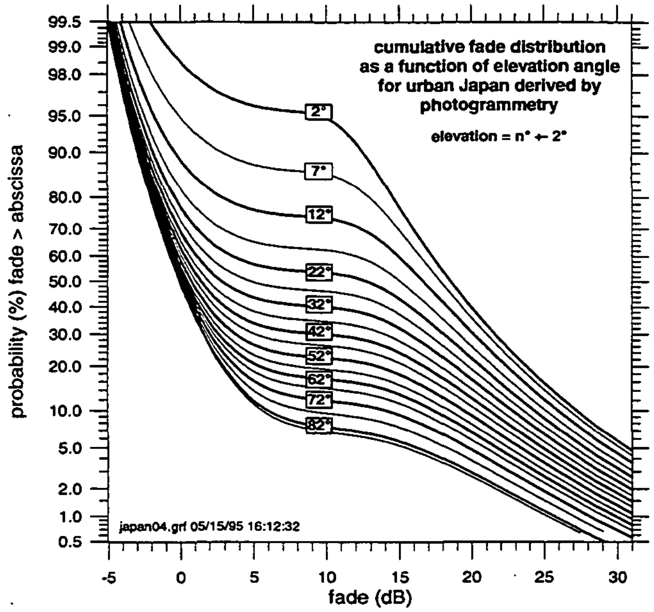

Fig. 3 Cumulative fade distributions for urban Japan as a function of elevation angle derived using photogrammetry combined with 3-state modeling.

DISCUSSION

The dominance of building blockage fading in urban areas is expressed in the terracing of the cumulative distribution. As a consequence, increasing the coverage significantly beyond what is available with a 5 dB fade margin requires a quantum-increase to beyond 15 dB. Once in the Rayleigh domain, the minimum elevation with 90% coverage decreases by about 5° per dB of additional fade margin.

Acknowledgments

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