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Land Mobile Satellite Propagation Measurements in Japan Using ETS-V Satellite

Noriaki Obara, Kenji Tanaka
Shin-ichi Yamamoto and Hiromitsu Wakana

Kashima Space Research Center,
Communications Research Laboratory,
Ministry of Posts and Telecommunications
893-1 Hirai, Kashima
Ibaraki 314, Japan
Phone: +81-299-84-4144
Fax: +81-299-84-4149

ABSTRACT

Propagation characteristics of land mobile satellite communications channels have been investigated actively in recent years [1], [2], [3]. Information of propagation characteristics associated with multipath fading and shadowing is required to design commercial land mobile satellite communications systems, including protocol and error correction method. CRL (Communications Research Laboratory) has carried out propagation measurements using the Engineering Test Satellite-V (ETS-V) at L band (1.5 GHz) through main roads in Japan by a medium gain antenna with an autotracking capability. This paper presents the propagation statistics obtained in this campaign.

INTRODUCTION

Expressways, by which almost all main cities are connected, play a very important role for land transportation in Japan. Since vegetative shadowing and blockage due to buildings are rare along expressways, satellite communication services such as voice, video and message transmission are suitable over wide areas in Japan. CRL carried out propagation measurements through main expressways and several ordinary roads, which totaled more than 4,000 km. This paper presents the propagation characteristics in this campaign, especially, sta-

tistical characteristics of receiving signal power and non-fade/fade durations.

EXPERIMENTAL CONFIGURATION

A continuous wave (1.5 GHz band) transmitted from the geostationary ETS-V satellite was received by an electronically steerable 19-element phased array antenna with about 12 dBi antenna gain. This antenna is controlled by two vehicle's directional sensors: an optical fiber gyroscope and a geomagnetic sensor [4]. Since receiving signal power is sampled every 6.28 cm by pulses that are generated at the wheel axle of a test van, propagation characteristics are measured independently of the van's speed. Satellite elevation angles along these roads are about 40 to 50 degrees. Figure 1 shows experimental routes in this campaign and Table 1 shows typical examples of environmental conditions. Figure 2 shows the measurement van running on an expressway.

MEASUREMENT RESULTS

Based on a given threshold of a signal level, it can be determined whether a propagation channel is on a fade state (below the threshold) or a non-fade state (above the threshold). When the threshold is less than -5 dB, fade states are mainly caused by obstacles such as overpasses and guideposts along roads. Figure 3 shows examples of distributions of obstacles in expressways.

Receiving Signal Power

Figure 4 shows cumulative distributions of receiving signal power with respect to the line-of-sight level. Since every curves are straight in the range of about -2 to 2 dB, probability density distributions are Gaussian distributions in this range. This distribution corresponds to Rician distribution with high SN ratio (large Rice factor). Between about -4 dB and system noise level (about -25 dB), every curves have moderate inclinations and are fixed, especially in expressways data. In this range, the fades are mainly caused by shadowing and blockage. The propagation channel in expressways has a stronger tendency to be classified into two states (available or unavailable for communication) than in ordinary roads. Two states correspond to a line-of-sight condition and a blockage condition due to man-made structures such as overpasses and tunnels. Since most satellite links are power-limited, a large fade margin above 5 dB to combat shadowing and blockage is ineffective for providing acceptable services. When the fade margin is 5 dB, satellite communication services are available at least about 90 % of the total distance in expressways, even though including tunnels.

Non-fade/Fade Duration Distribution

Non-fade Duration Distribution

In Figure 5, cumulative distributions of non-fade durations for different threshold levels and measuring conditions are presented, respectively. The ordinate is Gaussian scale and shows the probability of non-fade duration exceeding the abscissa value. Characteristics of these measured curves are almost independent of the threshold level except the threshold of -3 dB, which include level fluctuation due to thermal noise and antenna tracking error under a line-of-sight condition, as shown in Figure 5 (a), and the probability density function (PDF) of non-fade durations in both ordinary roads and expressways can be represented

by a combination of two log-normal distributions with different mean values and deviations [3], [5], as follows.

$$\begin{aligned} & \text{P.D.F.}(\ln(x)) \\ &= w_0 \cdot \frac{1}{n_f} \cdot \frac{1}{\sqrt{2\pi}\sigma_0} \exp\left\{-\frac{(\ln(x)-\ln(m_0))^2}{2\sigma_0^2}\right\} \\ &+ w_1 \cdot \frac{1}{\sqrt{2\pi}\sigma_1} \exp\left\{-\frac{(\ln(x)-\ln(m_1))^2}{2\sigma_1^2}\right\} \\ &\quad \text{for } x \geq 6.28(\text{cm}) \quad (1) \end{aligned}$$

where w_0 and w_1 are weight factors ($w_0+w_1=1$), m_0 and m_1 are mean values, and σ_0 and σ_1 are standard deviations of each log-normal distribution term. The factor n_f is normalizing factor for truncated log-normal distribution.

In ordinary roads, the probability of non-fade duration longer than 100 m is less than 10 % within all non-fade states, but in expressways, it exhibits 10~50 % probability, as shown in Figure 5 (b). Moreover, expressways data show that durations longer than 1 km exhibit 5 % probability on an average.

Fade Duration Distribution

Figure 6 shows cumulative distributions of fade durations for different threshold levels and measuring conditions. Characteristics of these curves are almost independent of the threshold level except -3 dB threshold level as shown in the non-fade duration case.

Since expressways have obstacles of two specific lengths in overpasses and tunnels, these curves have large inclination at durations of both about 10 m and 1 km, as shown in Figure 6 (a), (c). Therefore, the curves do not fit such simple model as that in non-fade durations. In ordinary roads, however, the PDF of fade durations can be approximated very well with the model of equation (1). Especially in rural and suburban areas that are mainly shaded

owed by trees, the PDF are almost straight lines in log-log scale, as shown in Figure 6 (b). Therefore, the PDF can be also represented by an exponential function,

$$\text{P.D.F.}(x) = a \cdot x^{-D} \quad (2)$$

where a and D are constant values. To study complex structures in nature, the terminology "fractal" is recently used in many aspects of physical phenomena. This characteristics of fade duration correspond to fractal dimension of D .

Non-fade/Fade State Transition Frequency

For designing of communications protocol or error correction method, it is useful to know how frequently communications channels are interrupted. Table 2 shows frequency of transition from non-fade state to fade state per kilometer and a ratio of total durations of fade states to the total measuring distance. The transition frequencies on expressways are less than that on ordinary roads by about five times. Even if vehicle's speed on expressways is twice larger than that on ordinary roads, transition frequency per minute is less than that on ordinary roads by twice on an average.

CONCLUSIONS

Measured data show that propagation channels in expressways can be classified into two states. Two states correspond to a line-of-sight condition and a blockage condition due to overpasses and tunnels. When the fade margin is 5 dB, satellite communication services are available at least about 90 % of the total distance. Distributions of non-fade durations can be approximated by the combination of two log-normal distributions, and distributions of fade durations can be approximated by a simple exponential function, especially in rural areas. Expressways data also show that non-fade states exhibit durations of longer than 1 km at 5 % probability on an aver-

age. This value is larger than that on ordinary roads by about ten times. Moreover, non-fade/fade states transition frequency is about five times less than that on ordinary roads. Therefore, expressways in Japan are more suitable for land mobile satellite communications services.

ACKNOWLEDGMENT

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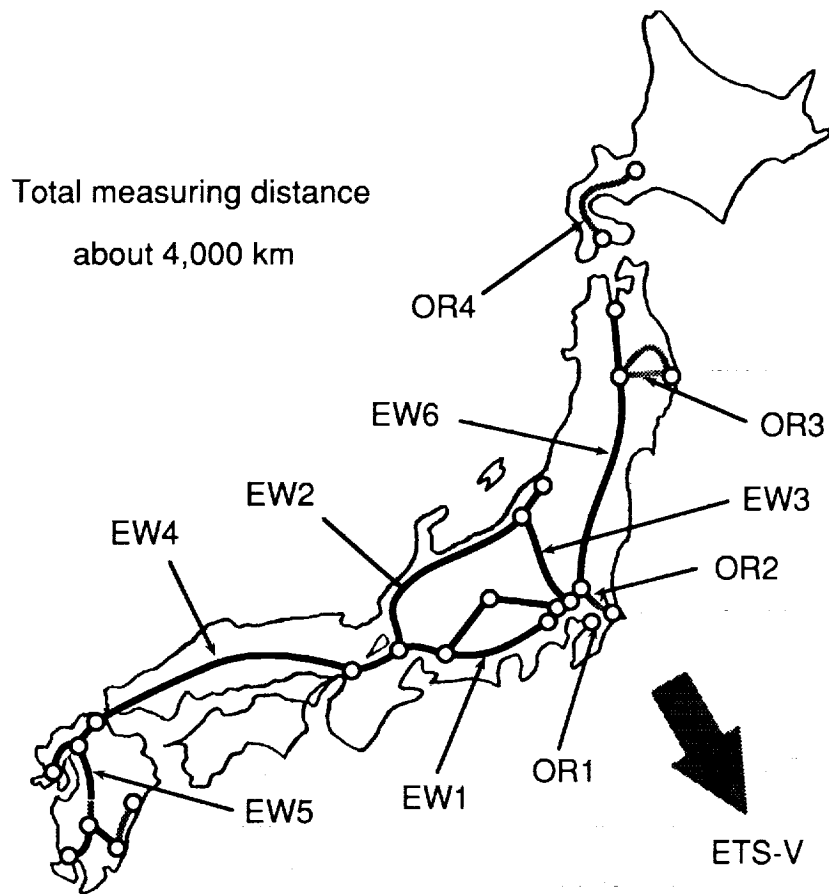


Figure 1. Experimental routes in this campaign.

Table 1. Typical examples of environmental conditions.

Data Name*	Route Name	Total Distance (km)	General Environmental Conditions
EW1	Toumei	400.7	Hilly terrain, infrequent shadowing by overpasses and guideposts.
EW2	Hokuriku	495.2	Mountainous terrain, infrequent shadowing by overpasses and tunnels.
EW3	Kan-etsu	254.3	Hilly terrain, infrequent shadowing by overpasses and tunnels.
EW4	Chugoku	566.1	Mountainous terrain, shadowing by overpasses, tunnels and trees.
EW5	Kyushu	331.2	Mountainous terrain, shadowing by overpasses, tunnels and trees.
EW6	Tohoku	681.0	Hilly terrain, infrequent shadowing by overpasses and guideposts.
OR1	Chiba City	25.7	Urban roads, frequent shadowing by buildings and overpasses.
OR2	Route 356 & 16	101.5	Suburban roads, infrequent shadowing by utility poles, guideposts and trees.
OR3	Route 106	108.7	Rural roads through hilly terrain, shadowing by trees and tunnels.
OR4	Route 5, 37 & 230	243.5	Rural roads including hilly terrain, shadowing by trees and tunnels.

Note: * "EW" is an expressway and "OR" is an ordinary road.



Figure 2. Measurement van running on an expressway.

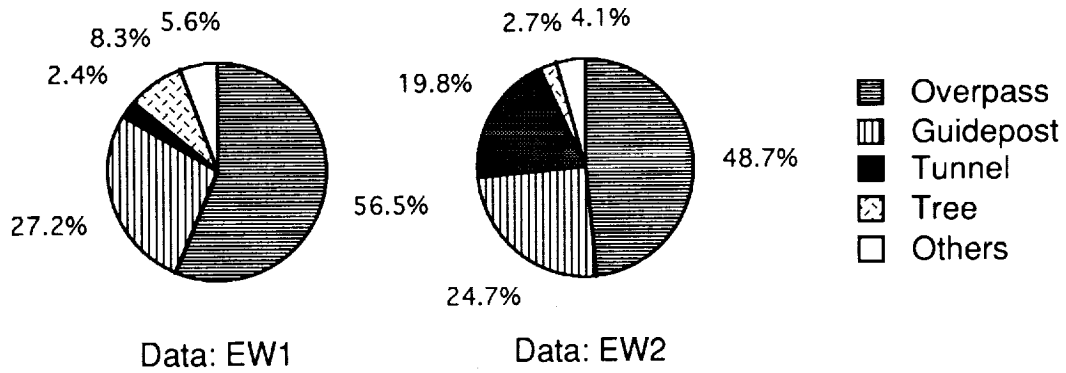


Figure 3. Distributions of obstacles in expressway.

Table 2. Ratio of total duration of fade states to the total measuring distance and transition frequency from non-fade state to fade state with -5 dB threshold level.

Data Name	Fade States Ratio (%)	Non-fade/Fade States Transition Frequency (counts/km)
EW1	3.35	3.33
EW2	13.60	0.97
EW3	8.82	1.86
EW4	8.76	18.10
EW5	10.02	10.74
EW6	2.88	2.37
OR1	21.46	62.01
OR2	1.70	23.34
OR3	11.48	57.32
OR4	5.14	25.54

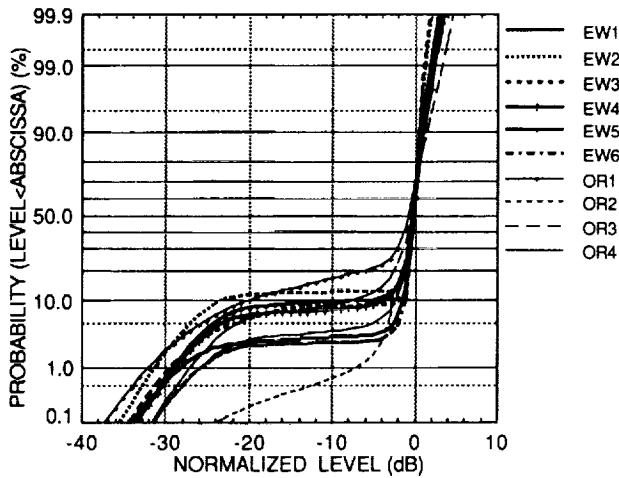


Figure 4. Cumulative distribution of receiving signal power.

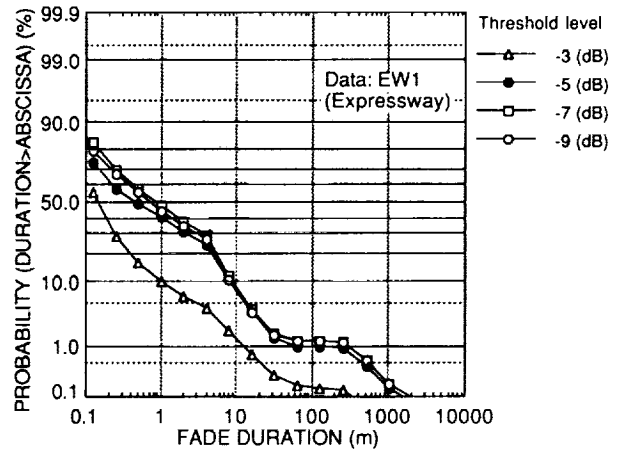


Figure 6 (a). Fade duration distribution of EW1 (expressway).

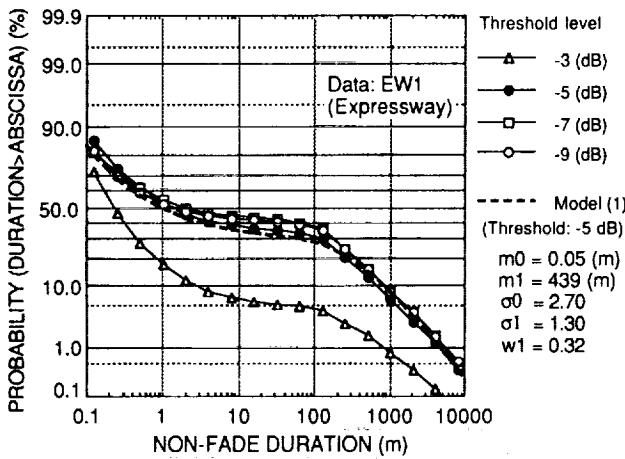


Figure 5 (a). Non-fade duration distribution of EW1 (expressway).

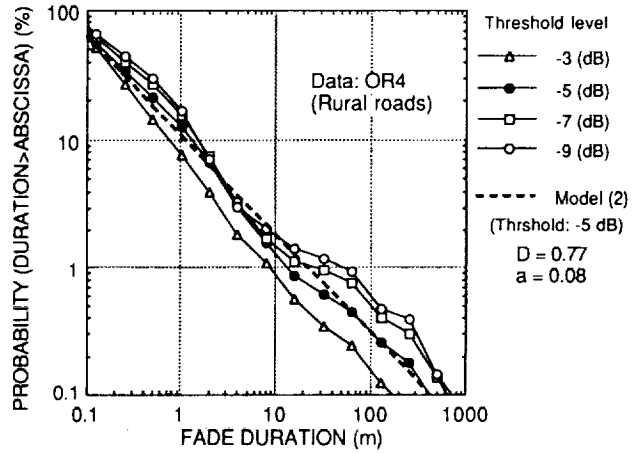


Figure 6 (b). Fade duration distribution of OR4 (rural roads).

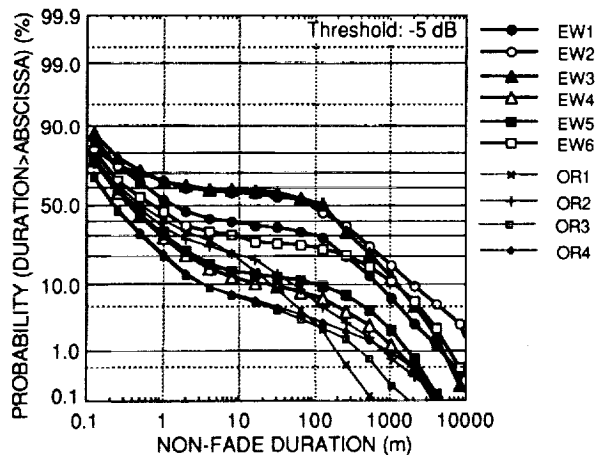


Figure 5 (b). Non-fade duration distribution for different measuring conditions.

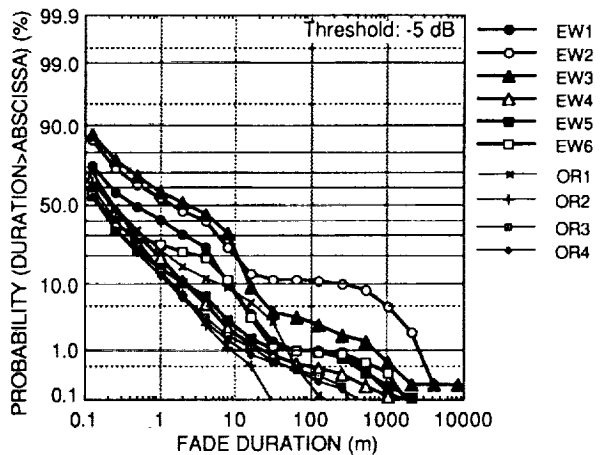


Figure 6 (c). Fade duration distribution for different measuring conditions.