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PROPAGATION MODELING FOR LAND MOBILE SATELLITE SYSTEMS

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ABSTRACT

A simplified empirical model for predicting primary fade statistics for a vegetatively shadowed mobile satellite signal is presented, and predictions based on the model are presented using propagation parameter values from experimental data. Results from the empirical model are used to drive a propagation simulator to produce the secondary fade statistics of average fade duration.

INTRODUCTION

The reliability of Mobile Satellite Systems (MSS) is of major concern due to the unique problems that arise from propagtion induced fading. Satellite-mobile links, operating with low signal margins, will encounter path outages due to obstruction by highway overpasses and vegetative shadowing. Whereas terrestial land mobile systems are often able to exploit relatively strong multipath signals, MSS will be power limited and dependent on the line of sight signal component. This paper details efforts to model MSS signals and to predict fade distributions and fade durations using a combination of analytical modeling and simulation.

PROPAGATION THEORY

The MSS signal is divided into two propagation categories: unshadowed and vegetatively shadowed due mainly to trees. Each is treated separately and then the results are combined to form a complete model.

The unshadowed signal consists of an unobstructed line of sight (LOS) component and a multipath path component due to scattering from the surrounding terrain. The LOS component is assumed to have a constant amplitude and phase; thus, phase variations due to changes in path length are ignored. The multipath component has been shown to have a Rayleigh amplitude distribution [1]. The sum of a constant signal and a Rayleigh distributed signal is Rice distributed. The Rician signal is specified by the parameter K, defined as the ratio of the average multipath power to the average LOS power, usually expressed in dB.

The shadowed signal consists of a vegetatively shadowed LOS component and a terrain induced multipath component. As in the unshadowed case, the multipath component is modeled as a Rayleigh distributed signal described by the parameter $\overline{K}$, defined as the ratio of the average multipath power to average direct path power. The shadowed LOS component fade is modeled as a lognormally distributed signal and is specified by its mean, μ, and standard deviation, σ. We model the shadowed direct component as being the sum of an unshadowed LOS component and a lognormally distributed scattered signal, the sum of which is still lognormally distributed. This slight deviation from the traditional representation permits more insight into the physics of the fading process.

A model for a mixed shadowed/unshadowed mobile path is obtained by combining the distributions described above weighted by the fraction of shadowing encountered along the route, P. The total distribution for a mixed shadowed/unshadowed mobile path is expressed as [2]

$$G(F) = G_u(F)*(1-P) + G_s(F)*P \qquad (1)$$

where $G_u(F)$ is the fade distribution for an unshadowed signal, $G_s(F)$ is the fade distribution for a shadowed signal, and P is the fraction of vegetative shadowing along the mobile path.

A SIMPLE EMPIRICAL MODEL FOR FADE DISTRIBUTIONS

The statistical model for fade durations described in the previous section can be evaluated analytically if the parameter values K, $\overline{K}$, μ, σ, and P are known. But this requires the numerical evaluation of several integrals. A computer model to evaluate these fade distributions has been developed [2]; while valuable for validation, it is cumbersome for general use. So, a simple empirical model has been developed [3], which is described next.

For an unshadowed signal, the probability that a fade will be less than F dB is

$$G_u(F) = 1 - e^{-(F-U1)/U2} \qquad (2)$$

where

$U1 = 0.01*K^2 - 0.378*K + 53.98$
$U2 = 331.35*K^{-2.29}$
K = avg. multipath power/avg. LOS power [dB]

For a vegetatively shadowed signal, the probability that a fade will be less than F dB is

$$G_s(F) = 1 - [(F + 50)/V1]^{V2} \qquad (3)$$

where

$V1 = 0.275*b_0 + 0.723*\mu + 0.336*\sigma + 56.987$
$V2 = 0.006*b_0 - 0.008*\mu + 0.013*\sigma + 0.121$

$b_0 = \overline{K} - 3$ [dB]
= avg. multipath power/ avg. direct power [dB]
μ = mean of lognormal signal [dB]
σ = standard deviation of lognormal signal [dB]

This simple model was developed from experimentally derived fade durations and the analytical computer model mentioned above.

We have compiled a data base of experiments including fade statistics reported in the open literature and raw data supplied by Vogel [4]. This MSS data base is used for model and simulator development, testing, and verification at Virginia Tech. Since it is difficult to measure the propagation model parameter values accurately, they were determined by a best fit of the analytical model to experimental data. The empirical model of (2) and (3) was developed from the analytical model. It provides good agreement to experimental data as illustrated in Fig. 1. The empirical model was developed for the typical propagation parameter value ranges given in Table 1.

THE PROPAGATION SIMULATOR AND SIMULATOR RESULTS

A software simulator has been developed by Schmier [4] to simulate MSS signals and predict primary and secondary fade statistics. This simulator is unique because instead of generating the simulated signal from statistical functions, it is generated using databases, derived from experimental data supplied by Vogel, with known statistical properties. By processing Vogel's experimental data, databases for each signal component having the proper statistical properties can be created. These databases are scaled to have the proper statistical distribution and recombined to form a composite signal. The output of the simulator simulates a time sequence signal that can be used to produce secondary statistics of average fade duration and of level crossing rate. The simulator output is normalized to produce samples every 0.1 wavelength traveled in order to remove the effect of vehicle speed from the simulation.

The databases are generated by first separating the experimental data into shadowed and unshadowed data points using a 2 dB below LOS criterion. Then the running mean of the data is calculated using a 20 wavelength sliding window. For the shadowed data, this running mean has been found to be lognormally distributed. Subtracting the running mean from the shadowed data on a point by point basis, generates a database which has been found to be Rayleigh distributed.

In Schmier's original simulator, there were separate scattered multipath databases for shadowed and unshadowed signal; the difference being in the phase of the Rayleigh signals. The unshadowed Rayleigh database had a uniform phase distribution while the shadowed Rayleigh database had a phase distribution centered around 0 and 180 degrees. This difference in phases caused a disagreement between the simulator and the analytical model. According to theory, the phase of a Rayleigh signal is uniformly distributed between 0 and 360 degrees. Our modification to Schmier's original simulator consisted of regenerating the shadowed Rayleigh database with a uniform phase. The modified simulator now generates fade distributions that agree with the analytical model. Figure 2 shows a comparison of fade distributions predicted by the analytical model and the modified simulator showing good agreement.

A measure of the fade duration secondary statistic is the average fade duration (AFD) defined for a fade level F as

$$AFD(F) = \frac{D(S<F)}{N(F)} \tag{4}$$

where

$D(S<F)$ = total duration of data with signal levels less than F (wavelengths)

$N(F)$ = total number of fade events below F

AFD is expressed in wavelengths since the simulator output is sampled in wavelengths. Figure 3 shows a comparison between the AFD predicted by the modified simulator and that measured from a one minute record of experimental data measured by Vogel.

A possible method of reducing fade effects is the use of two receive antennas on a mobile in a diversity configuration. The propagation simulator (with a 0.1 wavelength resolution) has been used in a preliminary study of diversity improvement. Our study indicates it is possible to obtain useful diversity gain with as small as 1 wavelength separation. At the 99 percentile, our simulation shows a diversity gain of 2 dB for 1 wavelength separation and a diversity gain of 3.5 dB for 5 wavelengths separation. There seems to be little improvement beyond 5 wavelengths.

FIGURE 1.
COMPARISON OF MEASURED VS EMPIRICAL MODEL

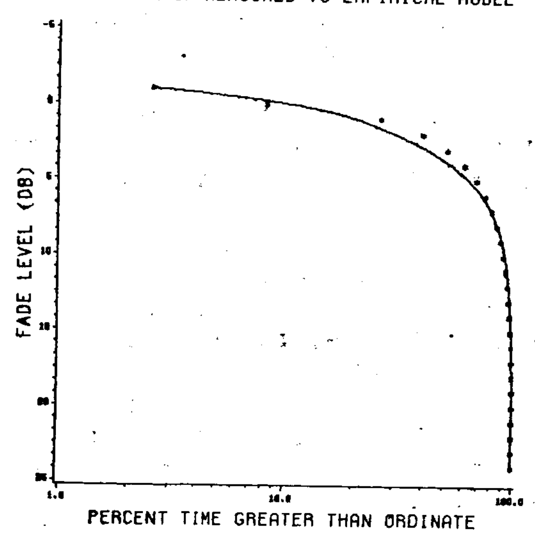


Table 1. Typical values for propagation parameters

$$-13 \text{ dB} < K < -22 \text{ dB}$$
$$-12 \text{ dB} < \overline{K} < -18 \text{ dB}$$
$$-1 \text{ dB} < \mu < -10 \text{ dB}$$
$$0.5 \text{ dB} < \sigma < 3.5 \text{ dB}$$

FIGURE 2.
COMPARISON OF SIMULATOR VS ANALYTICAL MODEL

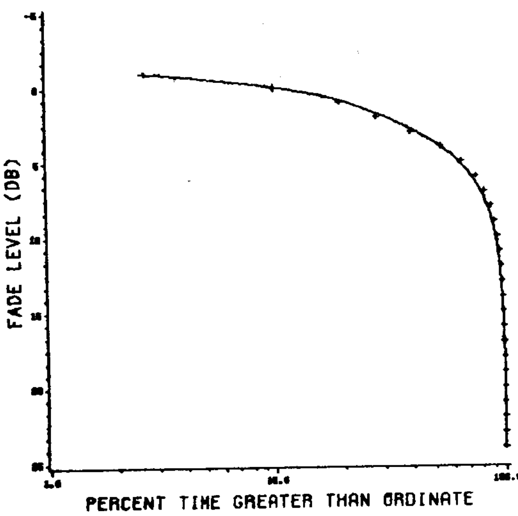
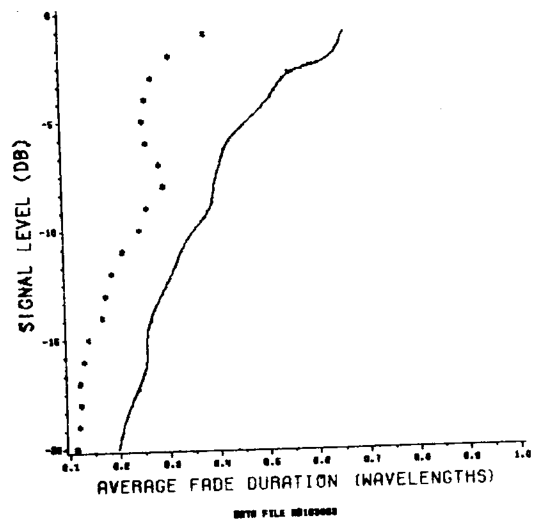


FIGURE 3.
SIMULATED VS MEASURED AVERAGE FADE DURATION



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