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PROPAGATION DATA AT 20/40 GHZ AND THE PROPAGATION NEEDS OF MILSTAR

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1. Introduction

Milstar system planners are in the process of creating accurate service definitions, evaluating resource requirements, and assessing performance. An important factor in the determination of the resource allocations to provide acceptable network performance is accurate link analysis. The Milstar system utilizes EHF communication links, 44 GHz on the uplink and 20 GHz on the downlink. There are various environmental factors which can affect the link performance at these frequencies , and the propagation factors for which there are inadequate characterizations are of most concern. These inadequacies result from either an inadequate data base which precludes the derivation of a proper propagation model, or, if the data do exist, they have not been assimilated in a form which is readily utilized.

The Milstar system incorporates terminals of varying sizes, and the performance of the small field terminals, which have relatively small link margins, are most affected by atmospheric phenomena. With small link margins, clouds, foliage, light rain, and molecular absorption can affect link closure. At low elevation angles, the effects are more pronounced, and in addition, multipath, refraction, and turbulence effects may become significant. Especially important for Milstar system planning is an adequate characterization of cloud and rain effects on link performance. The interaction of the electromagnetic field with cloud particles is well understood, but a usable statistical description of the integrated liquid water content along an arbitrary earth-to-space path at locations of interest is lacking. Measured data, taken for a limited time, are available for a few locations, but for system planning, cloud effects cannot be adequately modeled for most sites. As with clouds, the effects of rain on radio propagation are also well understood. Unlike clouds, there are sufficient rain data to provide viable global rain models which can be used to give annually averaged statistical estimates of link outages in many regions of the world. In many cases the data will support more detailed rain models which would be more helpful to system planners. For example, the user is not usually interested in the statistics of annual averages over large climate regions, but rather in the statistics in the deployment area, while he is there. Therefore, monthly and worst month statistics for many and smaller regions are much more useful. The assimilation of all available data of this type to derive a monthly global rain model would greatly benefit system planning. Long term weather patterns may change, and when predictable, should be incorporated in the rain model. Also, the planner would like to have an indication of how long the link outage is likely to last, and how often the outages occur. This information can serve as a guide on whether to drop the data rate, design for a backup, etc. Rain data are available to provide information for some of these concerns, and in this paper one of the rain induced statistics of interest, outage duration, will be examined.

2. Estimates of Outage Duration Statistics

Available experimental data, with some theoretical justification [1], indicate that rain rate, and thereby rain attenuation, is approximately lognormally distributed. Also, for the same reasons, the time durations for given rain rates are lognormally distributed. When it rains at a particular rain rate or greater, the probability density for the time duration, t, is modeled as

$$p(t) = \frac{1}{\ln(s)\ \sqrt{2\pi}} \frac{1}{t} \exp\left[-\left(\frac{\ln(t)-\ln(m)}{\sqrt{2}\ \ln(s)}\right)^2\right] \quad (1)$$

where ln(m) and ln(s) are the mean and standard deviation of the logarithm of the variable, t. The value m is the median time duration. Given that it is raining at a given rain rate or greater, the probability that the duration T is greater than t is given by

$$P(T \geq t] = \frac{1}{2} erfc\left[\frac{\ln(t)-\ln(m)}{\sqrt{2}\ \ln(s)}\right] \quad (2)$$

where erfc is the complementary error function.

Tattelman and Knight [2] described a method for extracting one minute rain rates from original raingage recordings. Using this method, Tattelman and Larson [3] obtained 1 minute average rain rate data over a 10 year period at 41 locations in the contiguous U. S. In particular, they have plots of the average number of occurrences of rain at particular rain rates for 6 duration times at these locations. A sample plot is shown for International Falls, Mn. The event occurrences are counted in the following way. As an example, a contiguous period of 23 minutes during which the rain rate exceeds the critical rate is counted as twenty three 1-minute events, four 5-minute events, two 10-minute events, one 15-minute event, and one 20-minute event.

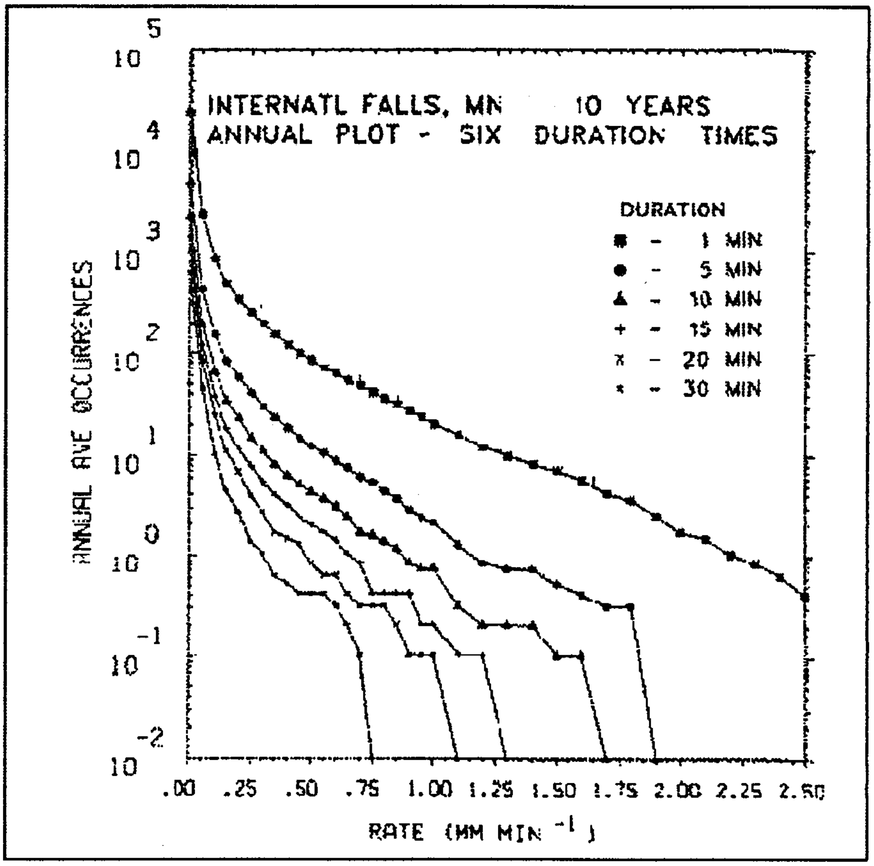

Fig. 1. Annual average number of occurrences of 1-minute rain rates for 6 duration times. Rain rates are those equalled or exceeded during each minute of the specified duration.

If the duration times are truly lognormally distributed, the data above can be used to estimate the median, **m**, and **s** for a particular rain rate. The predicted occurrences of 1-minute duration events are given by

$$N_1 = K[n_1+2n_2+3n_3+ \cdots] \quad (3)$$

where n_i is the normalized number of events between i and i+1 minutes, as given by (1), and K is a constant which converts the normalized values to the actual observed 1-minute occurrences in a year. In general, the number of occurrences for the time duration t is given by

$$N_t = K[\sum_{i=t}^{2t-1} n_i+2\sum_{i=2t}^{3t-1} n_i+ \cdots] \quad (4)$$

The procedure for estimating the median and standard deviation in the lognormal distribution is as follows. For a given rain rate, the average number of occurrences of the 1, 5, 10, 15, 20, and 30-minute durations are obtained from Fig. 1. Then a value of m and a value of s are assumed and the predicted number of the 1, 5, 10, 15, 20, and 30-minute occurrences are obtained from (4). The process is repeated with a range of values for **m** and **s** and the best least squares fit for **m** and **s** will give the minimum value of L, where

$$L = \sum_t [N_{mt}-N_t]^2 \quad t=5,10,15,20,30 \quad (5)$$

where N_{mt} is the measured occurrence for duration t and N_t is the predicted occurrence.

As an example, suppose a rain rate of 9 mm/hr will cause an outage on the uplink for an EHF terminal located at International Falls. From Fig. 1, for this rain rate (9 mm/hr or 0.15 mm/min), there will be an average of approximately 500 1-minute events, 88 5-minute events, 37 10-minute events, 19 15-minute events, 11 20-minute events and 5.5 30-minute events in a year. For this example, the best least squares fits for the median, **m**, and **s** are 11 and 2.4 minutes, respectively. Plots of the average number of occurrences as a function of outage duration and the probabilities that the outage will be greater than a given duration are shown in Fig. 2. Also shown on the plot are the measured occurences of the 1, 5, 10, 15, 20, and 30-minute durations.

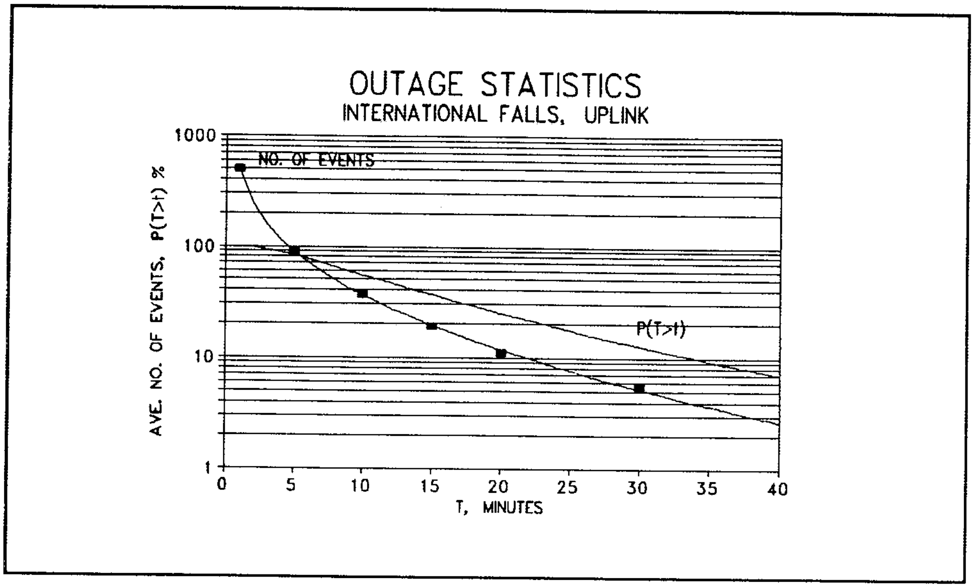

Fig. 2. Annual average number of outage events of duration t and the probability that the duration will be greater than t. The rain rate is 9 mm/hr. The solid rectangles are the values obtained from Fig. 1, and the solid curve is that for the best fit values of **m** and **s**.

3. Summary

There are a number of propagation issues that need further investigation for efficient system planning for EHF communication systems. Especially needed are better cloud and rain characterizations. A method for estimating one of the rain induced effects of interest, outage duration, is presented.

4. References

1. S. H. Lin, "Statistical Behavior of Rain Attenuation", Bell Syst. Tech. Journ. 52, 557, 1973.

2. P. Tattelman and R. W. Knight, "Analyses of 1-min Rain Rates Extracted from Weighing Raingage Recordings", Journ. of Appl. Meteorolgy 27, 928, 1988.

3. P. Tattelman and K. P. Larson, "Effects on Rain Attenuation on Satellite Communications in the United States", AFGL Report AFGL-TR-89-0012, Jan. 8, 1989.