

Fading Measurements from a Maritime Mobile Troposcatter Link

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Abstract—Tropospheric scatter, also known as troposcatter, communications has been around since the 1950s but has recently received interest as a means for long distance beyond line-of-sight (BLOS) communications. According to the literature, Rayleigh fading is expected for troposcatter links. In this paper, measurement results are presented for a long-distance maritime link in the coastal area of Southern California; however, the measurements indicate that the observed fading was not Rayleigh. To the authors' knowledge, this is the first reported finding of non-Rayleigh fading for a troposcatter link and demonstrates the need for further investigation of troposcatter channels.

Keywords—troposcatter; Weibull; small-scale fading;

I. INTRODUCTION

Troposcatter communications has been around since the 1950s for long distance communications, but over time, it lost popularity to satellite communications (SATCOM) [1]. Recently, there has been renewed interest in troposcatter communications for military and spectrum sharing applications [1]-[2]. In the literature, Rayleigh fading is expected for troposcatter links, due to the forward scattering of the signal in the common volume [3]-[4]. However, this paper will present measurements from a maritime troposcatter link that indicates other statistical distributions provide a better fit than the Rayleigh distribution for the observed data.

This paper is organized as follows. Section II provides information on the communications link. Section III presents experimental results. Section IV provides a discussion. Section V contains concluding remarks.

II. COMMUNICATIONS LINK DESCRIPTION

The TrellisWare Low Power Troposcatter Radio (LPTR) is specifically designed for troposcatter communications. Two LPTRs were used to form a full duplex link over a distance of 163 km along the coast of Southern California. One radio was stationary at a fixed shore site while the other was mobile on a commercial ship. Both nodes used 1.2 m parabolic dish antennas with 35 dB gain and operated in the C band. Both nodes also utilized an antenna tracking algorithm to keep the antennas pointed correctly while the ship node moved [5].

III. EXPERIMENTAL RESULTS

As part of the waveform, the radio performs channel estimation at the receiver to mitigate channel effects and improve the link performance. These channel estimates were logged and analyzed in post-processing to determine the small-scale fading characteristics of the troposcatter channel. RF

bandwidths of 1.25 MHz and 5 MHz were tested. In both cases, only a single multipath arrival was observed. The results for a 33-minute test with 5 MHz bandwidth and a 144-minute test with 1.25 MHz bandwidth are shown in Figures 1 and 2, respectively. Also shown are curves for the Rayleigh, Weibull, Generalized Extreme Value (GEV), and Nakagami probability density functions (PDFs) whose parameters were obtained using maximum likelihood estimation (MLE). As seen in the figures, all three of the distributions other than Rayleigh visually fit the data better than Rayleigh, with the Weibull and GEV distributions having the closest fits.

The Akaike Information Criterion (AIC) has been used previously to determine which distribution provides the best fit for channel measurements [6]. The AIC values were computed and are shown in Table I. As seen in the table, the Weibull distribution had the lowest AIC value for both tests and thus provides the best fit out of the 4 distributions. The Nakagami and GEV distributions had the next lowest AIC values. The Rayleigh distribution had the largest AIC value for both tests, which indicates that it provides the worst fit. This agrees with what is visually seen in Figures 1 and 2.

According to [4], small-scale fading has been found to be approximately Rayleigh distributed for intervals up to 5 minutes long. Consequently, the results for the 33-minute test were partitioned into 5-minute intervals and shown in Figure 3. For ease of visibility, only the Rayleigh and Weibull curves are shown using MLE. The Weibull distribution again fits the data better than Rayleigh for all six of the intervals. Only the data during the fifth interval comes close to resembling a Rayleigh distribution.

IV. DISCUSSION

When the Weibull distribution fits the small-scale fading better than the Rayleigh distribution and its shape parameter is less than 2, as was the case for the data presented in Section III, the fading is more severe than Rayleigh [7]. This means that the fading margin in link budget calculations needs to be larger than what it would be if Rayleigh fading occurred. For troposcatter links where the signal-to-noise ratio (SNR) can be low at far distances, inaccurate fading margin calculations could lead to poorer than expected link performance.

In order to confirm that the results indeed occurred as a result of troposcatter and not atmospheric ducting, the path loss was also analyzed. The path loss was measured to be 225 dB. ITU-R P.617 estimated that the path loss should be approximately 200–235 dB for the link due to troposcatter. The Advanced Refractive

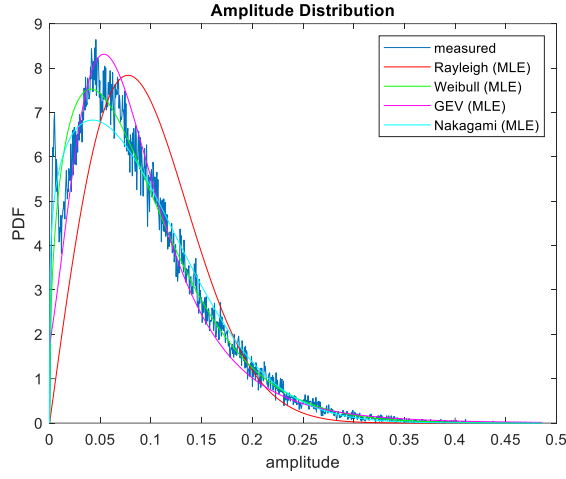


Figure 1. Amplitude distribution of channel (5 MHz bandwidth).

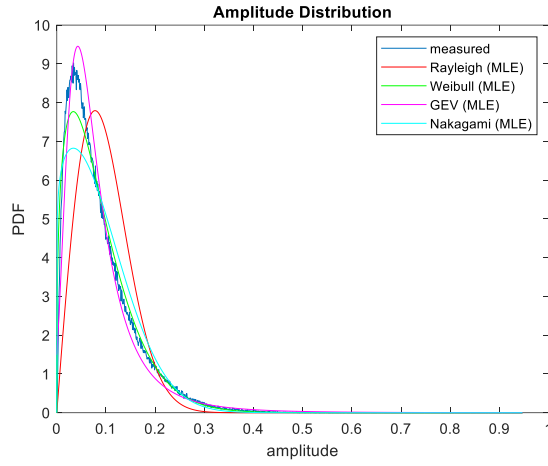


Figure 2. Amplitude distribution of channel (1.25 MHz bandwidth).

Effects Prediction System (AREPS) is the most popular propagation model for atmospheric ducting [8]. It predicted that the path loss should be 229 dB, assuming a standard atmosphere. The Terrain Integrated Rough Earth Model (TIREM) propagation model is also applicable for troposcatter links in land/sea environments in the C band [9]. TIREM predicted that the path loss should be 225 dB, assuming a standard atmosphere. Since the measured path loss agrees well with the loss predicted by the aforementioned models, it can be concluded that the link most likely experienced troposcatter and not an atmospheric duct.

V. CONCLUSIONS

Experimental results of the small-scale fading for a maritime troposcatter link were presented. Other distributions were shown to fit the data better than the Rayleigh distribution, which differs from the literature. The results demonstrate the unique nature of the maritime environment and the need to properly characterize the channel. The authors will be supporting a follow-on effort in the near future to perform measurements over a much longer duration to collect detailed channel measurements, i.e., delay spread, fading, path loss, and Doppler spread. The goal of the extended measurement experiment is to collect data that will

TABLE I. AIC VALUES.

Distribution	AIC Value (5 MHz Bandwidth)	AIC Value (1.25 MHz Bandwidth)
Rayleigh	-2.752e5	-1.155e6
Weibull	-2.992e5	-1.308e6
GEV	-2.931e5	-1.292e6
Nakagami	-2.986e5	-1.286e6

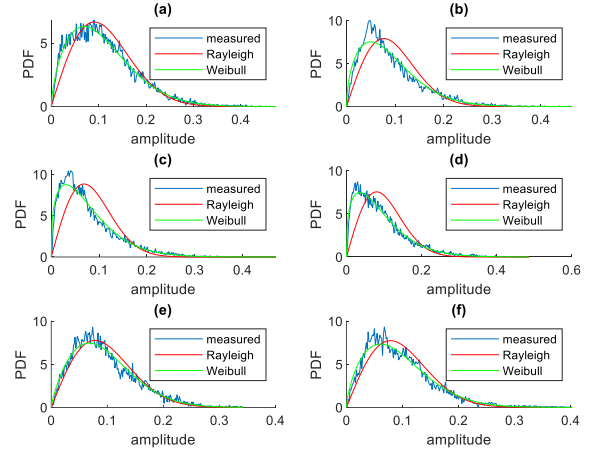


Figure 3. Amplitude distributions of 5 MHz channel over 5-minute intervals: (a) first interval, (b) second interval, (c) third interval, (d) fourth interval, (e) fifth interval, and (f) sixth interval.

help assess and refine the accuracy of current and future troposcatter propagation models.

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