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Mitigation of Deep Fading by Wideband Transmission

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Author: John H. Cafarella
MICRILOR, Inc.
17 Lakeside Office Park, Wakefield, MA 01880
Phone: 781-246-0103
Fax: 781:246-0157
e-Mail: JohnCafarella@worldnet.att.net

Abstract

The use of high-bandwidth transmission enhances reliability of communication in multipath. High bandwidth resolves multipath, providing an increased number of independent trials, such that the probability that all paths take on low amplitude is smaller than for fewer. This note addresses the reduction in probability of deep fades accomplished by using wideband DSSS transmission. This effect can reduce the need for inclusion of a large “fade margin” in link budgets. A simple model for wideband transmission is combined with the infinitely diffuse Rayleigh channel model to demonstrate the statistical effect being offered for consideration.

Mitigation of Deep Fading by Wideband Transmission

Introduction

The use of higher bandwidth transmission enhances reliability of communication in multipath. High bandwidth resolves multipath, providing:

1) an increased number of independent trials, such that the probability that all paths take on low amplitude is smaller than for fewer paths;

2) reduced fluctuation of the path strengths in many environments.

This note addresses only the reduction in probability of deep fades accomplished by using wideband DSSS transmission. This effect can reduce the need for inclusion of a large “fade margin” in link budgets. A simple model is used to demonstrate the statistical effect being offered for consideration.

Independent Trials

We use the “infinitely diffuse Rayleigh channel” model[1] to demonstrate the effect of increasing the number of independent trials. The path model assumes that the channel impulse response comprises Rayleigh-distributed paths of discrete but arbitrarily small density

$$h_c(t) = \sum_{m=0}^{\infty} a_m \delta(t - mT_s)$$

where a_m is a complex amplitude whose components are Gaussian-distributed with the equivalent distributions:

$$p(\mathrm{Re}\{a_m\}) = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{\mathrm{Re}\{a_m\}^2}{2\sigma_m^2}}$$

components

$$p(\mathrm{Im}\{a_m\}) = \frac{1}{\sqrt{2\pi}\sigma_m} e^{-\frac{\mathrm{Im}\{a_m\}^2}{2\sigma_m^2}}$$

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$$p(a_m) = \frac{1}{2\pi\sigma_m^2} e^{-\frac{|a_m|^2}{2\sigma_m^2}}$$

complex amplitude

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[1] The term “infinitely diffuse” refers to the implicit assumption in this model that the individual path statistics remain Rayleigh-distributed no matter how high the signal bandwidth becomes. Such a model is not applicable to very wideband transmission, for which published channel-sounding measurements reveal substantial “specular” components in many environments. The infinitely diffuse model is used here because it represents an extreme of malicious multipath behavior.

$$p(|a_m|) = \frac{|a_m|}{\sigma_m^2} e^{-\frac{|a_m|^2}{2\sigma_m^2}}$$

$$p(Arg\{a_m\}) = \frac{1}{2\pi}$$

magnitude & phase

The path strengths are exponentially distributed in amplitude vs. delay

$$\sigma_m^2 = \frac{1-e^{-\frac{\delta}{T_s}}}{2} e^{-\frac{m\delta}{T_s}}$$

where T_s is the multipath delay spread and δ is the sampling interval. The normalization of the path strengths holds the total received signal power constant as other parameters are varied.

We seek to examine the receiver performance achieved as the signal bandwidth is increased. The data modulation will be fixed, although it is not necessary to specify it. The symbol rate will be held constant,[2] and the bandwidth will be increased by shortening the symbol pulse; this avoids such details as code side lobes.

For this simple calculation we model the effect of various bandwidths by assuming that there is an effective number of independent multipath components depending upon the bandwidth. This avoids complicated computations involving the analog waveform shape and multipath correlation coefficients. We specify the nominal resolution bandwidth by a parameter $N=T_s/\delta$, that is, the number of paths resolved within the delay spread. This parameter will be called the "sampling factor," and results in a path strength

$$\sigma_m^2 = \frac{1-e^{-\frac{1}{N}}}{2} e^{-\frac{m}{N}}$$

The joint distribution for the signal strengths may be easily written by virtue of the assumption of path independence.

$$\prod_{m=0}^{\infty} \frac{|a_m|}{\sigma_m^2} e^{-\frac{|a_m|^2}{2\sigma_m^2}}$$

We postulate a receiver which selects, during the acquisition phase, the strongest of the various resolved paths for demodulation. The probability that the signal strength S is smaller than some particular value S_{th} is the probability that all a_m are lower than this value.

$$\prod_{m=0}^{\infty} \int_0^{S_{th}} \frac{|a_m|}{\sigma_m^2} e^{-\frac{|a_m|^2}{2\sigma_m^2}} d|a_m| = \prod_{m=0}^{\infty} \left(1 - e^{-\frac{S_{th}^2}{2\sigma_m^2}} \right)$$

[2] The delay spread is assumed shorter than the inverse of the symbol rate for convenience. Long delay spreads will primarily exhibit large multipath interference, whereas the focus of the present discussion is mitigation of fading.

This expression is used to calculate the probability of fading vs. transmission bandwidth, as shown in Figure 1. We take the pure-Rayleigh limit to correspond to N=.25, where there is no significant resolution of paths. As N increases the probability of occurrence of a fade decreases; ultimately, for a particular fade depth, the probability

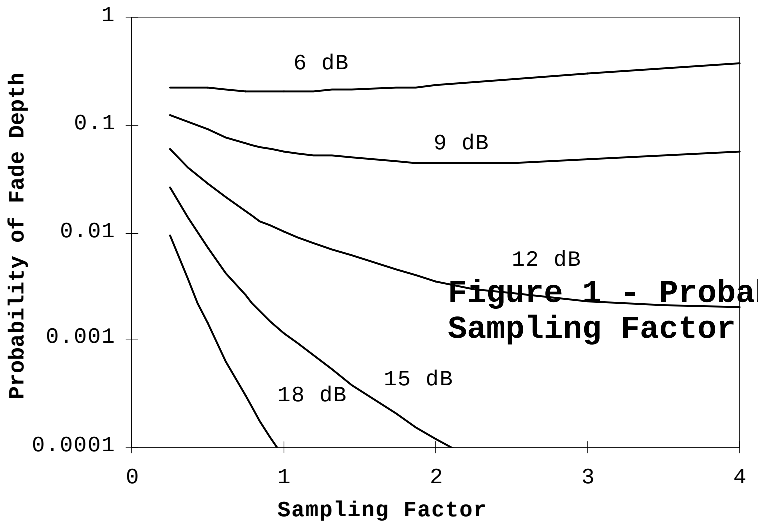

Figure 1 - Probability of Fade Depth vs. Sampling Factor

will again increase with N because of the continuing decrease in strength per path combined with the assumption that only a single path is processed. For each depth of fade there is an optimum sampling factor; for 6-dB, N=1; for 9-dB, N=2; etc. The use of oversampling of the delay spread is a "mini-max" strategy; while oversampling can increase slightly the probability of shallow fades, it can make exponentially small the probability of deep fades.

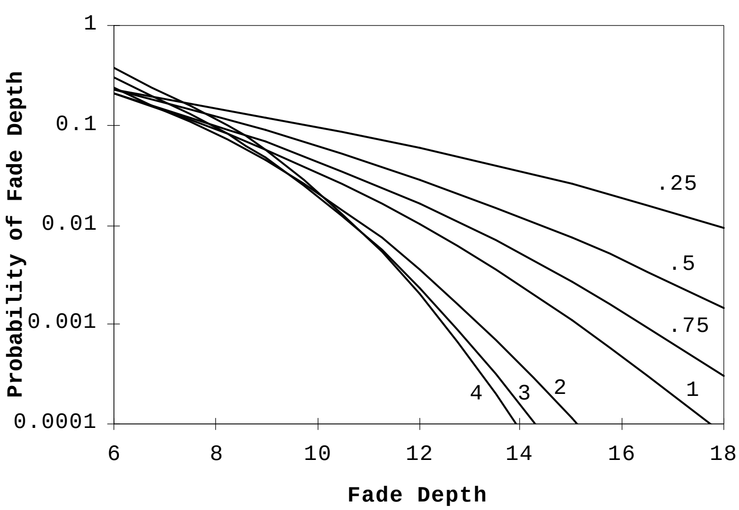

Figure 2 is another view, showing the probability of fade depth vs. fade depth. It is clear from this that even moderate spreading can greatly reduce the required fade margin.

This computation clearly shows the statistical effect achieved using wide bandwidth transmission to cause there to be more independent trials. It must be kept in mind, however, that the infinitely diffuse model does not take into account the very likely occurrence of specular multipath components. In the case of specular multipath, the reduction in probability of deep fade would be even more dramatic, and the slight increase in the probability of shallow fade would actually not occur since specular paths cannot be over-resolved.

Figure 2 - Probability of Fade Depth vs. Fade Depth.