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Analysis of Fast Fading in Wireless Communication Channels

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ABSTRACT

The performance of a wireless signal propagation can be estimated with the properties or characteristics of the channel. This paper begins with the classification of the important characteristic of a channel i.e, fading. After that fast fading modeling for multipath with no direct path and multipath with direct path is analyzed in the fourth part of this paper. In the last section of this paper, by considering motion of the fast fading channel, plot is developed for Doppler fading channel with multiple paths.

1. INTRODUCTION

Free-space transmission occurs when the received signal is exclusively the result of direct path propagation. In this case there is no interference at the receiver caused by multipath signals. The received signal strength calculations are straightforward and deterministic. However, the free-space model is unrealistic because it fails to account for the numerous terrestrial effects of multipath. It is normally assumed that the propagation channel includes at least two propagation paths. A channel is defined as the communication path between transmit and receive antennas. The channel accounts for all possible propagation paths as well as the effects of absorption, spherical spreading, attenuation, reflection losses, Faraday rotation, scintillation, polarization dependence, delay spread, angular spread, Doppler spread, dispersion, interference, motion and fading. It may not be necessary that any one channel has all of the above affects but often channels have multiple influences on communication waveforms. Obviously, the complexity of the channel increases as the number of available propagation paths increases. It also becomes more complex if one or more variables vary with time such as the receiver or transmitter position[1,2].

2. FADING

Fading is term used to describe the fluctuations in a received signal as a result of multipath components. Several replicas of the signal arrive at the receiver, having traversed different propagation paths, adding constructively and destructively. The fading can be defined as fast fading or slow fading. Additionally, fading can be defined as flat or frequency selective fading.

Fast fading is propagation which is characterized by rapid fluctuations over very short distances. This fading is due to scattering from nearby objects and thus is termed small-scale fading. Generally fast fading can be observed up to half-wavelength distances. When there is no direct path(line-of-sight), a Rayleigh distribution tends to best fit this fading scenario, thus fast fading is sometimes referred to as Raleigh fading. When there is a direct path or a dominant path, fast fading can be modeled with a Rician distribution.

Slow fading is propagation which is characterized by slow variations in the mean value of the signal. This fading is due to scattering from more distant larger objects and thus is termed large-scale fading. The slow fading mean value is generally found by averaging the signal over 10 to 30 wavelengths[3]. A log-normal distribution tends to best fit this fading scenario, thus slow fading is sometimes referred to as log-normal fading. A superimposed plot of fast and slow fading is developed and is shown below.

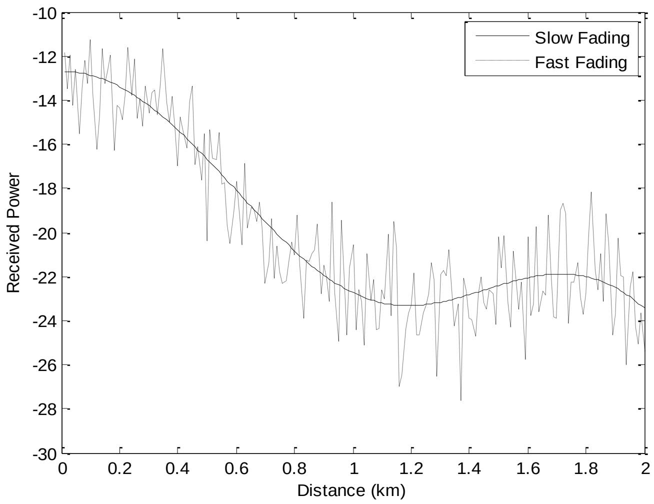

Figure.1 Slow and Fast fading

2.1 FAST FADING MODELING

MULTIPATH WITH NO DIRECT PATH: Based upon the scenario by assuming that no direct path exists but the entire received electric field is based upon multipath propagation. The received voltage can be expressed as the sum of all the possible multipath component voltages within the receiver

$$v_{rs} = \sum_{n=1}^{N} a_n e^{-j(kr_n - \alpha_n)} = \sum_{n=1}^{N} a_n e^{j\emptyset_n} \quad 2.1.1$$

Where

a_n = random amplitude of the n^{th} path

α_n= random phase associated with n[th] path
r_n = length of n[th] path
$\emptyset_n = -kr_n + \alpha_n$

By assuming a large number of scattering structures N, which are randomly distributed, we can assume that the phases $\emptyset_n$ are uniformly distributed. The time-domain version of the received voltage can be expressed as

$$v_r = \sum_{n=1}^{N} a_n \cos(w_0 t + \emptyset_n)$$

$$\sum_{n=1}^{N} a_n \cos(\emptyset_n)\cos(w_0 t) - \sum_{n=1}^{N} a_n \sin(\emptyset_n)\sin(w_0 t) \quad 2.1.2$$

Equation 2.1.2 can be further simplified by using simple trigonometric identity as

$$v_r = X\cos(w_0 t) - Y\sin(w_0 t)$$
$$= r\cos(w_0 t + \emptyset) \qquad 2.1.3$$

where $X = \sum_{n=1}^{N} a_n \cos(\emptyset_n)$
$Y = \sum_{n=1}^{N} a_n \sin(\emptyset_n)$
$r = \sqrt{X^2 + Y^2} = envelope$
$\emptyset = tan^{-1}(\frac{Y}{X})$

In the limit, as N → ∞, the central limit theorem dictates that the random variables X and Y will follow a Gaussian distribution with zero mean and standard deviation σ. The phase $\emptyset$ can also be modeled as a uniform distribution such that $p(\emptyset) = \frac{1}{2\pi}$ for $0 \le \emptyset \le 2\pi$.The envelope r is the result of a transformation of the random variables X and Y and can be shown to follow a Rayleigh distribution[4,5]. The Rayleigh probability density function is defined as

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \quad r \ge 0 \qquad 2.1.4$$

where σ^2 is the variance of the Gaussian random variables X or Y.

For the Rayleigh-fading channel, by substituting the values in equation(2.1.4) as $\sigma = 0.003$, we can find the probability of the received voltage envelope $p(r)$ as exceeding a threshold of 5 mV is

$$p(r \geq 0.005) = \int_{0.005}^{\infty} \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} dr$$
$$= 0.249.$$

This is shown as the shaded area under the curve in below figure.

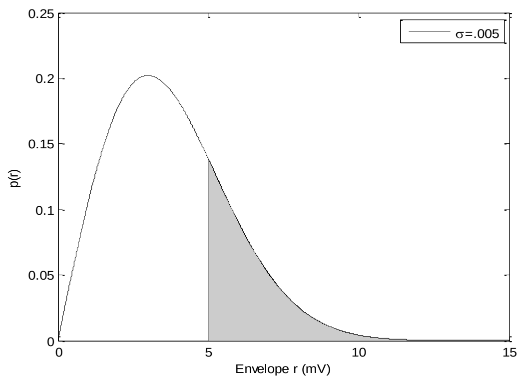

Figure.2 Rayleigh probability density with specified threshold

MULTIPATH WITH DIRECT PATH: If a direct path is allowed in the received voltage, we must modify the equations (2.1.2 & 2.1.3) by adding the direct path term with the direct path amplitude A volts as

$$v_r = A\cos(w_0 t) + \sum_{n=1}^{N} a_n \cos(w_0 t + \emptyset_n)$$

$$= [A + \sum_{n=1}^{N} a_n \cos(\emptyset_n)]\cos(w_0 t) - \sum_{n=1}^{N} a_n \sin(\emptyset_n)\sin(w_0 t) \quad (2.1.5)$$

Again, the envelope $r = \sqrt{X^2 + Y^2}$.Now
We must accordingly revise the random variables X and Y.

$$X = A + \sum_{n=1}^{N} a_n \cos(\emptyset_n)$$

$Y = \sum_{n=1}^{N} a_n \sin(\emptyset_n)$ The random variable X is Gaussian with mean of A and standard deviation of σ. Random variable Y is Gaussian with zero mean and standard deviation of σ. The probability density function for the envelope is now a Rician distribution and is given by

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\frac{rA}{\sigma^2}\right) \quad (2.1.6)$$

$$r \geq 0 \quad A \geq 0 \qquad (2.1.7)$$

For the Rician-fading channel, by substituting the values in equation (2.1.7) as $\sigma = 3\ mV$, the direct path amplitude A=5 mV, we can find the probability of the received voltage envelope $p(r)$ as exceeding a threshold of 5 mV is

$$p(r \geq 0.005) = \int_{0.005}^{\infty} \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\frac{rA}{\sigma^2}\right) dr = 0.627.$$

This is shown as the shaded area under the curve in below figure.

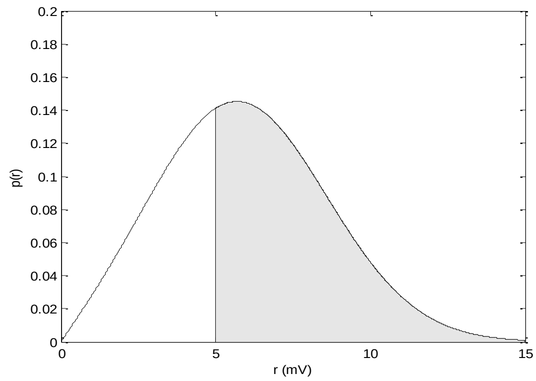

Figure.3 Rician probability density with specified threshold

As compared the multipath with no direct path and multipath with direct path of figures 2 and 3 indicates that the likelihood of having a detectable signal dramatically increases when the direct path is present. MOTION IN A FAST FADING CHANNEL: In the above concepts of line-of-sight(LOS)and non-line-of-sight(NLOS) propagation, it is assumed that there is no motion in the channel. Motion will change the channel behavior by changing the location of the transmitter or receiver. In addition, motion introduces many discrete Doppler shifts in the received signal. As the vehicle moves at a constant velocity, many factors change with time. The angles $(\theta_n)$of each multipath signal are time dependent. Each multipath experiences a different Doppler shift because the angle of scattering with respect to the moving vehicle is different for each scattering object. Also, the overall phase shift (α_n) changes with time because the propagation delays are changing.
The maximum possible Doppler shift is given by

$$f_d = f_0 \frac{v}{c} \qquad (2.1.8)$$

where f_d = Doppler frequency
f_0 = Carrier frequency
v = vehicle velocity

$c =$ speed of light

Since the direction of vehicle travel is at an angle θ_n with the n^th multipath, the Doppler shift is modified accordingly. The Doppler shift for n^th path is given by

$$f_n = f_d \cos\theta_n = f_0 \frac{v}{c} \cos\theta_n \qquad (2.1.9)$$

By rewriting the equation 2.1.2 accounting for the Doppler frequency shifts f_n.

$$v_r = \sum_{n=1}^{N} a_n \cos(2\pi f_n t + \emptyset_n - \sum_{n=1}^{N} a_n \sin(2\pi f_n t + \emptyset_n) \sin(w_0 t)$$

$$= \sum_{n=1}^{N} a_n \cos(2\pi f_d \cos(\theta_n) t + \emptyset_n) \cos(w_o t) - \sum_{n=1}^{N} a_n \sin((2\pi f_d \cos(\theta_n) t + \emptyset_n) \sin(w_0 t)$$

(2.1.10)

We now have three random variables a_n, $\emptyset_n$ and θ_n.The amplitude coefficients are Gaussian distributed whereas the phase coefficients are presumed to have a uniform distribution such that $0 \leq \emptyset_n$ and $\theta_n \leq 2\pi$. The envelope of v_r again has a Rayleigh distribution. The envelope r is given by

$$r = \sqrt{X^2 + Y^2} \qquad (2.1.11)$$

where

X= $\sum_{n=1}^{N} a_n \cos(2\pi f_d \cos(\theta_n) t + \emptyset_n)$ and

Y= $\sum_{n=1}^{N} \sin(2\pi f_d \cos(\theta_n) t + \emptyset_n)$.

This model is called the Clarke flat fading model[6,7].

By considering the values as the carrier frequency 2 GHz, vehicle velocity 50 mph, the phase angles $\emptyset_n$ and θ_n are uniformly distributed, the coefficient a_n has a Gaussian distribution with zero mean and standard deviation of $\sigma = 0.001$ and the number of scatterers N=10, we can plot the envelope in equation 2.1.11.

By converting the given velocity into meters/second. Therefore, 50 mps = 22.35 m/s. Thus the maximum Doppler shift is

$$f_d = 2 * 10^9 \left(\frac{22.35}{3*10^8}\right) = 149 \text{ Hz.}$$

The result is plotted as shown in figure below.

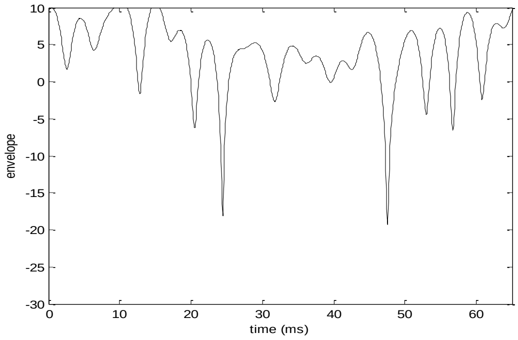

Figure.4 Doppler fading channel with N=10 3. CONCLUSION

As compared the multipath with no direct path and multipath with direct path of figures 2 and 3 indicates that the likelihood of having a detectable signal dramatically increases when the direct path is present. The plot which is shown in figure 4. is representative of Doppler fading but makes assumptions that are not realistic. In this approach, the scattering from objects is angularly dependent. Thus, the coefficients a_n will be a function of time. Additionally, the phase angles $\emptyset_n$ and θ_n change with time. The Clarke model can be modified to reflect the time dependence of $\emptyset_n$, θ_n and a_n .

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