Justification of Rayleigh Faded Channel for Data Transmission in Wireless Environment

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Abstract-- An accurate assessment of the performance of a newly developed radio system can be done through repeated tests of the system over an actual channel. When comparison is to be made between two or more systems over a real channel, they must all be tested simultaneously. The channel characteristics and transmission conditions vary uncontrollably. Hence tests can't be repeated at other times. Moreover it is not possible to test a system repeatedly for the same channel conditions. The computer simulation of channel model using C++ on Linux shows good degree for accuracy between input and output. The signal to noise ratio for different channel conditions can be calculated easily for rating the channel.

The most challenging technical problem being faced by communication system engineers is fading in a mobile environment. The term fading refers to the time variation of received signal power caused by changes in the transmission medium or path(s). In a fixed environment, fading is affected by changes in atmospheric conditions, such as rainfall. But in a mobile environment, where one of the two antennae is moving relative to the other, the relative location of various obstacles changes over time, creating complex transmission effects.

Keywords—Fading, Rayleigh, Rician, Multipath transmission, Doppler Effect

1. TYPES OF FADING

Fading effects in a mobile environment can be classified as either fast or slow. Referring to Fig 1, as the mobile unit moves down street, rapid variations in signal strength occur over distances of about one-half a wavelength. The rapidly changing waveform is an example of the spatial variation of received signal amplitude. The changes of amplitude can be as much as 20 or 30 dB over a short distance. This type of rapidly changing fading phenomenon, known as *fast fading*, affects not only mobile devices in automobiles, but even a mobile phone user walking down.

As the mobile user covers distances well in excess of a wavelength, the environment changes. Over these longer distances, there is a change in the average received power level about which the rapid fluctuations occur. This is referred to as *slow fading.*

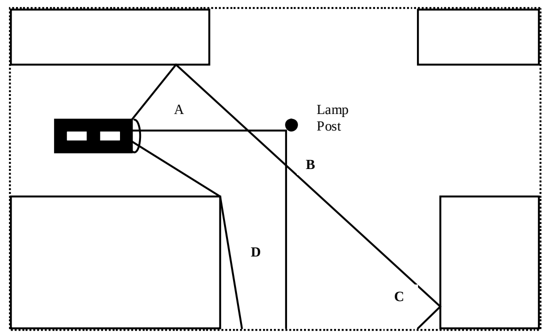

Fig. 1 Mobile unit signal reflections

Rayleigh fading occurs when there are multiple indirect paths between transmitter and receiver and no distinct dominant path, such as a Line of Sight path. This represents a worst-case scenario. Fortunately, Rayleigh fading can be dealt with analytically, providing insights into performance characteristics that can be used in difficult environments, such as downtown urban settings.

Rician fading best characterizes a situation where there is a direct LoS path in addition to a number of indirect multipath signals. *The Rician model is often applicable in an indoor environment whereas the Rayleigh model characterizes outdoor settings.* The Rician model also becomes more applicable in smaller cells or in more open outdoor environments. The channels can be characterized by a parameter **K**, defined as follows.

$$K = \frac{\text{Power in the dominant path}}{\text{Power in the scattered paths}}$$

When K=0 the channel is Rayleigh (i.e., numerator is zero) and when K=∞, the channel is AWGN (i.e., denominator is zero). With a reasonably strong signal, relative to noise, an AWGN exhibit provides fairly good performance, as do

Rician channels with larger values of K. The performance would be adequate for a digitized voice application, but for digital data applications noise has to be compensated. Some environments produce fading effects worse than the so-called worst case of Rayleigh. In these cases, no level of E_b/N_0 will help achieve the desired performance, and compensation mechanisms are mandatory.

2. JUSTIFICATION OF RAYLEIGH FADING CHANNEL MODEL

Let the complex valued transmitted signal S(t) be represented by:

$$S(t) = u(t) \exp(j2\prod f_c\ t + \theta)$$

Where f_c = the carrier frequency and

θ = the phase introduced by the transmitter oscillator.

In the expression of S(t)

$$u(t) = \sqrt{(2P)} \sum_{m=-\infty}^{\infty} b_m \psi_r(t - m T_s)$$

where **b_m** is the transmitted symbol transmitted at a rate of $1/T_s$ per second,

P is the transmitted signal power and

ψ_r(t) is the symbol waveform.

When S(t) is transmitted through frequency-selective Rician fading channel with complex low pass equivalent, the time variant channel impulse response $h(\tau ; t)$ is given by

$$h(\tau ;t) = \gamma\ \delta(t) + C(\tau ;t)$$

where γ is the direct component and is deterministic;

$C(\tau ;t)$ is the remaining dispersive, Rayleigh faded component.

When $\gamma = 0$, the channel becomes *Frequency-Selective Rayleigh fading channel.*

If the received signal has a steady component, the impulse response $C(\tau ; T)$ is no longer zero mean and the envelope has a Rician probability distribution. Due to it's correspondence with the observed characteristics of RF and troposcatter channels, the *Rayleigh fading model is widely observed*.

3. MULTIPATH RECEPTION

The auto-correlation function of $C(\tau ; T)$ may be defined as

$$\phi_c(\tau 1 ; \tau 2 ; \Delta t) = 1/2\ E[\, c(\tau 1 ; t)\ c(\tau 2 ; t + \Delta t)]$$

where E[.] is the statistical average. Since the channel is uncorrelated also,

$$1/2\ E[\, c(\tau 1 ; t)\ c(\tau 2 ; t + \Delta t)] = \phi_c(\tau 1 ; \Delta t)\ \delta(\tau 1 - \tau 2)$$

Where $\phi_c(\tau 1 ; \Delta t)$ is the average power output as a function of the time delay (path delay) and the difference Δt in observation time. As a special case when $\Delta t = 0$ we get $\phi_c(\tau ; 0) \equiv \phi_c(\tau)$. This is the average power output of the channel as a function of the time delay τ . $\phi_c(\tau)$ is called the *Multipath intensity profile or the Delay power spectrum* of the channel. The range of values of τ over which $\phi_c(\tau)$ is essentially non zero is called the *Multipath* spread T_m of the channel.

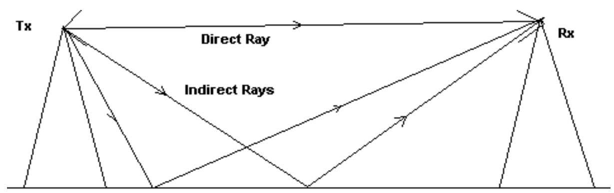

Fig 2 Multipath Reception

For a large number of paths, the Central Limit Theorem can be applied. It states "The probability density of a sum of N independent random variables tends to approach a Gaussian density are respectively the sum of the means and the sum of the variances of the N independent random variables. The theorem applies even when the individual random variables are not Gaussian and not independent."

4. RAYLEIGH FADED CHANNEL MODEL

Let the impulse response of base-band channel be denoted by $\{h_n\} = h_{(nT)}$. The response of the channel to an input sequence $\{ x_n \}$, in the absence of noise is

$$y_n = \sum_k h_k x_{n-k}$$

$$= h_o x_n + \sum_{k<0} h_k x_{n-k} + \sum_{k>0} h_k x_{n-k}$$

Where 1st term = Desired data symbol

2nd term = Precursors of the channel impulse response that occur before the made sample h_o associated with the desired data symbol

3rd term = Post cursors of the channel impulse response that occur after the made sample.

A single Rayleigh fading path is modeled as shown in Fig 3, $q_1(t)$ and $q_2(t)$ are two random process. In simulating a Rayleigh fading sky wave these random processes should be Gaussian with zero mean and the same variance. They should be statistically independent and the shape of the power spectrum must be Gaussian, having same rms frequency f_{rms}. Thus the power spectrum of $q_1(t)$ and $q_2(t)$ are given by

$$| Q_1(f) |^2 = | Q_2(f) |^2 = \exp(-f^2 / (2 f^2_{rms}))$$

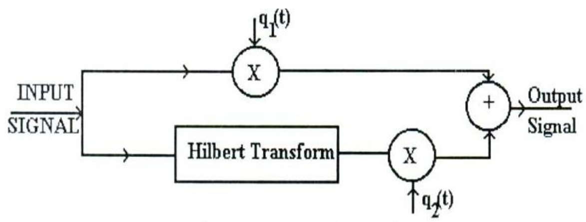

Fig 3 Single Rayleigh Fading Path

The fading rate can be controlled by the band width of the power spectrum of the Gaussian variables $q_1(t)$ and $q_2(t)$.

Table – 1 Channel Parameters for Different Channels

S.No	Condition	Freq. Spread (Hz)	Delay (ms)
1	Flat Fading	0.2	0.0
2	Flat Fading (Extreme)	1.0	0.0
3	Good	0.1	0.5
4	Moderate	0.5	1.0
5	Poor	1.0	2.0

The Doppler frequency spread f_{sp}, introduced by $q_1(t)$ and $q_2(t)$ into an unmodulated carrier defined as the width of the power spectrum and is given by $f_{sp} = 2f_{rms}$. The rms frequency is related the fading rate f_e which is defined as the average number of down ward crossings per unit time of the envelope through the median value. According to the equation

$$f_{rms} = f_e / 1.475$$
$$f_{sp} = 1.356\ f_e$$

Doppler spread is under 0.01 Hz (very slow fading). For a more notorious RF channel, Doppler spread can be upto 1-2 Hz. Table -1 lists the channel parameters for different channels.

5. CONCLUSION:

In a mobile environment, the relative location of various obstacles changes over time, creating complex transmission effects. Fading is also going to effect the received signal strength drastically. Out of many types of fading effects, it is observed that Rayleigh fading is proved to be severe, particularly in mobile environment. It occurs when there are multiple indirect paths between transmitter and receiver and no distinct dominant path, such as a Line of Sight path. Channel model that is based on the Rayleigh fading is best suitable for simulating the wireless channel for data transmission. In the present work even the multipath transmission, reception and Doppler effect is also considered.

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