Modeling and Characterization of Different Types of Fading Channel

Md. Golam Sadeque, Shadhon Chandra Mohonta, Md. Firoj Ali

***Abstract*- The performance of the wireless channel is affected by fading. This paper describes the principal characteristics and modeling for different types of fading channels. Different fading model are applicable for different types of environment. In this paper we present probability density function for Rayleigh, Nakagami, Log-normal and Weibull fading model. An effort has been made to illustrate the performance comparison of different types of fading channel in wireless transmission system.**

***Index Terms*- Fading, Multipath channels, Coherence time and Coherence Bandwidth, Raleigh Fading Model, Nakagami Fading Model, Weibull Fading Model.**

I. INTRODUCTION

Wireless communication is one of the most important areas in the communication field. An explosive development of the wireless technology has opened several new paths for its implementation however some unavoidable circumstances attenuate the signal energy and make barriers to achieving the optimum results from the system [1]. One of the most disturbing aspects in the wireless communication is fading [1]. Signal fading refers to the rapid change in received signal strength over a small travel distance or time interval [15]. Fading manifestations are shown in fig.1. Channel is the physical medium that is used to send the signal from the transmitter to the receiver. The radio link between the transmitter and receiver varies from simple line-of-sight to one that is severely obstructed by the buildings; mountains etc, and hence suffer from severe multipath fading [1]. However, the mobile channels are very different from the stationary as well as predictable wired channels, because of their randomness [1]. Wireless communication may be used to transfer information over short and long distances. Wireless operations permit some important services that are impossible or impractical to implement with the use of wires. In fixed wireless transmission, the transmitter and the receiver are static while mobile wireless transmission, the transmitter and the receiver are in motion but are moving at different speeds [3]. If a radio channel's propagating characteristics are not specified, one usually infer that the signal attenuation versus distance behaves as if propagation takes place over ideal free space. For most practical channels, where signal propagation takes place in the atmosphere and near the ground, the free space propagation model is inadequate to describe the channel and predict system performance [2]. In a wireless mobile communication system, a signal can travel from transmitter to receiver over multiple reflective paths; this phenomenon is referred to as multipath propagation. There are several kinds of communication impairments that are typical of the mobile wireless environment. Impairments may result mainly from multipath transmission, attenuation of signal power from large objects, relative transmitter receiver motion, interference, spreading of electromagnetic power and thermal or background noise [3]. The nature of these impediments changes over time in unpredictable ways due to user movements causing the received signal to fluctuate or vary. One of the most common methods for characterizing a fading channel is the use of a probability density function (pdf), which represents the probability density of the received signal strength. The envelope of the received signal can determine the ultimate Shannon channel capacity of a fading wireless link since received power is proportional to the square of received envelope [3]. Nowadays, the communication systems engineer has many distributions to predict the behavior of radio communication systems over fading channel. Many researchers have worked on some of the appropriate model for different environments in fixed wireless communication [3]. Radio-wave propagation through wireless channels is a complicated phenomenon characterized by various effects. A precise mathematical description of this phenomenon is either unknown or too complex for tractable communications systems analysis [8]. However, considerable efforts have been devoted to the statistical modeling and characterization of these different effects. The result is a range of relatively simple and accurate statistical models for fading channels which depend on the particular propagation environment and the underlying communication scenario [8].

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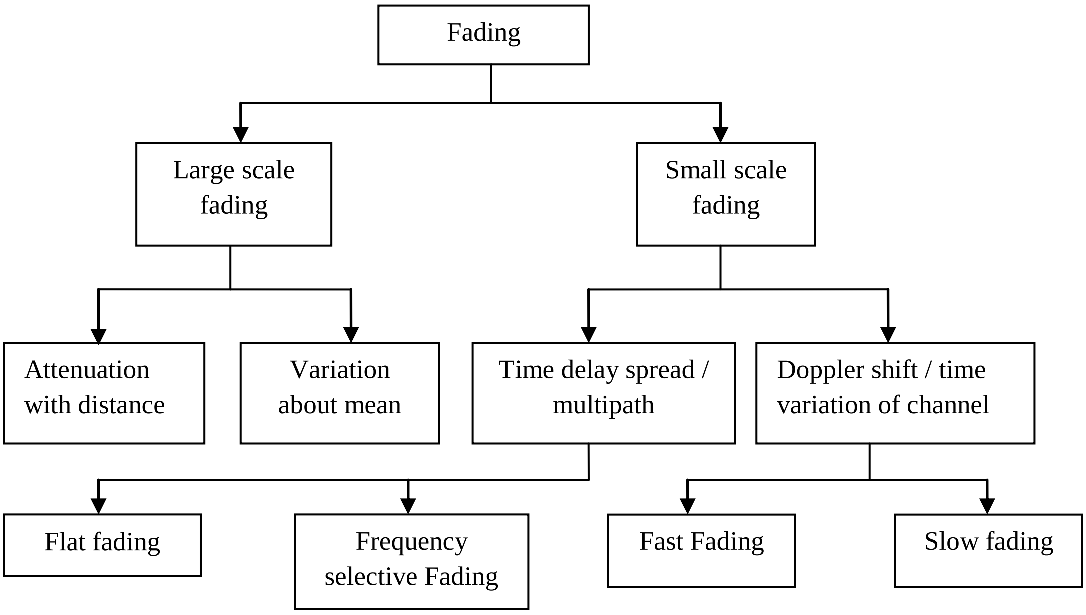

Fig. 1 Fading Manifestations

II. CHARACTERISTICS OF FADING CHANNELS

When a received signal experiences fading during transmission, both its envelope and phase fluctuate over time [8]. Ideal coherent modulations system corrects the phase effect due to fading at the receiver and for non Coherent modulations system phase is not needed. Hence performance analysis for both ideal coherent and non coherent modulation over fading channels requires only knowledge of the fading envelope statistics [8].

A. Large scale fading and small scale fading

Fig.1 represent an over view of fading channel. It mainly two types which characterizes the communication channel: Large scale fading and small scale fading. Large-scale fading, refers to path loss caused by the effects of the signal traveling over large areas. This phenomenon is affected by prominent terrain contours (hills, forests, billboards, clumps of buildings, etc.) between the transmitter and receiver [2]. The path loss is characterized by a mean loss and a variation around the mean loss. Small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes in the spatial separation between a receiver and transmitter [2]. Small scale fading also occur if the intermediate objects in the path of the signal changes. Many physical factors that cases small scale fading are Multipath propagation, relative motion between transmitter and receiver, speed of surrounding object and transmission bandwidth of signal. Multipath propagation occurs as a result of shadowing, diffraction, reflection and refraction. When a receiver moves over a large area then experience both types of fading; small scale fading and large scale fading shown in fig.3.

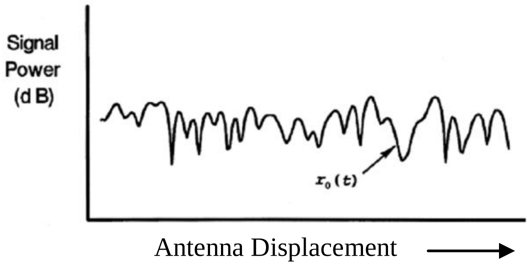

Fig. 2 Small scale fading

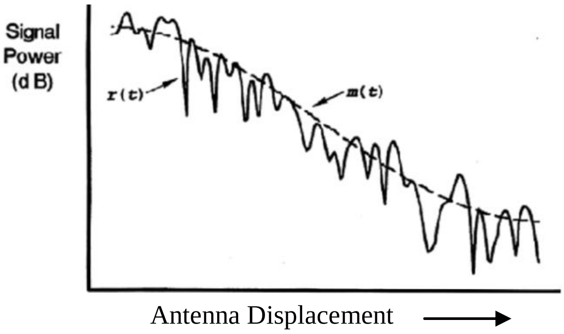

Fig. 3 Small and Large scale fading

B. Coherence bandwidth and coherence time

The coherence time is a measure of the minimum time required for the magnitude change of the channel to become uncorrelated from its previous value. Coherence time is actually a statistical of the time duration over which the channel impulse response is essentially invariant, and quantifies the similarity of the channel response at different times [16].The *coherence time* T_C of the channel, which measures the period of time over which the fading process is correlated [b]. The Doppler spread and coherence time are inversely proportional to one another. That is [16]

$$T_c \approx \frac{1}{f_m} \ldots\ldots\ldots\ldots\ldots.. (1)$$

If the coherence time is defined as the time over which the time correlation function is above 0.5, then the coherence time is approximately [16]

$$T_c \approx \frac{9}{16\pi f_m} \ldots\ldots\ldots\ldots\ldots (2)$$

Where, f_m is the maximum Doppler shift. A popular rule of thumb for modern digital communications is to define the coherence time as the geometric mean of Equations (1) and (2). That is [16],

$$T_c = \sqrt{\frac{9}{16\pi {f_m}^2}} = \frac{0.423}{f_m}$$

The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading. This is the bandwidth over which the channel transfer function remains virtually constant. The coherence bandwidth is related to the maximum delay spread $\tau_{\max}$ by [b]

$$f_C \cong \frac{1}{\tau_{max}}$$

C. Slow fading and fast fading.

The distinction between slow and fast fading is important for the mathematical modeling of fading channels and for the performance evaluation of communication systems operating over these channels [8]. The terms *slow* and *fast* fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes [17]. The fading is said to be slow if the symbol time duration T_s is smaller than the channel's coherence time T_c[8]. That is, $T_s < T_c$. If the symbol time duration T_s is greater than the channel's coherence time T_c then it is call fast fading. In a fast fading channel, the channel impulse response changes rapidly within the symbol duration of the signal. Therefore a signal undergoes fast fading if

$$T_s > T_c$$

D. Frequency flat and frequency selective fading

Frequency selectivity is also an important characteristic of fading channels[b]. If all frequency components of the signal will experience the same magnitude of fading then it called frequency flat fading. Frequency flat fading occurs the coherence bandwidth he coherence bandwidth of the channel is larger than the bandwidth of the signal. That is,

$$B_S < B_C$$

Where, B_S is the signal bandwidth and B_C is the coherence bandwidth. On the other hand, if all the frequency components of the transmitted signal are affected by different amplitude gains and phase shifts then the fading is said to be frequency selective. Frequency selective fading occurs when transmitted signal bandwidth is bigger than the channel's coherence bandwidth. That is,

$$B_S > B_C$$

III. MODELING OF FREQUENCY FLAT FADING CHANNEL

When fading affects narrowband systems, the received carrier amplitude is modulated by the fading amplitude α, where α is a RV with mean-square value $\Omega = \overline{\alpha^2}$ and probability density function (PDF) $p_\alpha(\alpha)$, which is dependent on the nature of the radio propagation environment [8]. Depending on the nature of the radio propagation environment, there are different models describing the statistical behavior of the multipath fading envelope [8].

A. Rayleigh Model

The Rayleigh distribution is frequently used to model multipath fading with no direct line-of-sight (LOS) path. The probability density function of received signal will be distributed according to [21]

$$p_\alpha(\alpha) = \frac{\alpha}{2\sigma^2}\, exp\left(-\frac{\alpha^2}{2\sigma^2}\right) \quad \alpha \geq 0$$

Where, α channel fades amplitude and σ^2 is the time average power of the received signal.

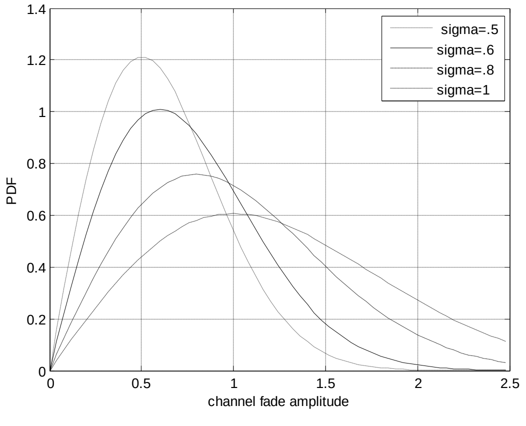

Fig. 4 Raleigh PDF for different value of σ.

B. Nakagami-q (Hoyt) Model

The Nakagami-q distribution, also referred to as the Hoyt distribution, is given in Nakagami by [8]

$$P_\alpha(\alpha) = \frac{(1+q^2)\alpha}{q\Omega}$$
$$exp\left[-\frac{(1+q^2)^2\alpha^2}{4q^2\Omega}\right] I_0\left(\frac{(1-q^4)\alpha^2}{4q^2\Omega}\right), \qquad \alpha \ge 0$$

Where, $I_0(.)$ is the zeroth-order modified Bessel function of the first kind, and q is the Nakagami-q fading parameter which ranges from 0 to 1

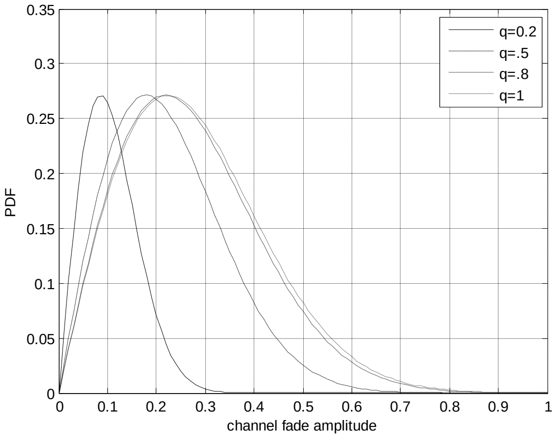

Fig. 5 Nakagami PDF for Ω=1 and different value of q.

C. Nakagami-n (Rice) Model

The Nakagami-n distribution is also known as the Rice distribution. It is often used to model propagation paths consisting of one strong direct LOS component and many random weaker components. Here the channel fading amplitude follows the distribution [8]

$$P_\alpha(\alpha) = \frac{2(1+n^2)e^{-n^2}\alpha}{\Omega}$$
$$\exp\left[-\frac{(1+n^2)\alpha^2}{\Omega}\right] I_0\left(2n\alpha\sqrt{\frac{1+n^2}{\Omega}}\right), \alpha \ge 0$$

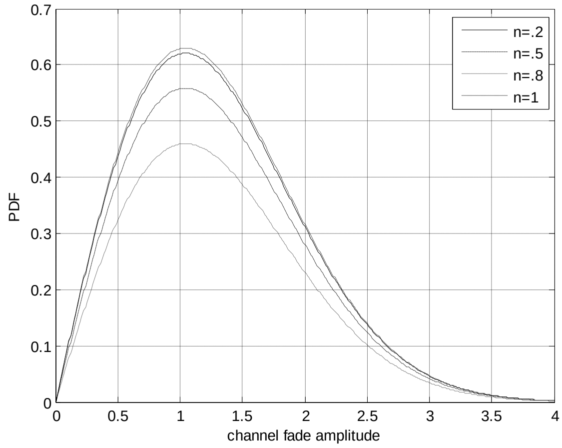

Fig. 6 Nakagami PDF for Ω=1 and different value of n.

Where, n is the Nakagami-n fading parameter which ranges from 0 to 1 and which is related to the Rician K factor by $K = n^2$. The Rice factor K is the relation between the power of the LOS component and the power of the Rayleigh component. When K = 0, no LOS component and Rayleigh PDF is equal to the Ricean PDF.

D. Nakagami-m Model

The Nakagami-m PDF is in essence a central chi-square distribution given by [8]

$$P_\alpha(\alpha) = \frac{2m^m\alpha^{2m-1}}{\Omega^m\Gamma(m)} \, exp\left(-\frac{m\alpha^2}{\Omega}\right), \qquad \alpha \ge 0$$

Where, m is the Nakagami-m fading parameter which ranges from $\frac{1}{2}$ to ∞.Figure 2.1 shows the Nakagami m PDF for Ω = 1 and various values of the m parameter.

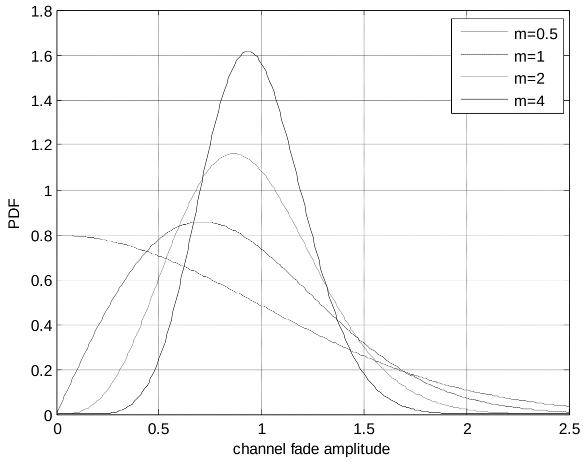

Fig. 7 Nakagami PDF for Ω=1 and different value of m.

E. Log-Normal Shadowing

Shadowing is the effect that the received signal power fluctuates due to objects obstructing the propagation path between transmitter and receiver. Log-normal distribution describes the random shadowing effects as a result of buildings and other objects on the propagation path which occurs over a large number of measurement locations which have the same transmitter and receiver separation [3]. Therefore, random fluctuations in the mean signal power occur over large distance. The probability density function (pdf) of a log-normal shadowing given by

$$P_\alpha(\alpha) = \frac{1}{\sigma\alpha\sqrt{2\pi}} \, exp\left(-\frac{(\ln\alpha - \mu)^2}{2\sigma^2}\right) \qquad \alpha \ge 0$$

Where, α channel fades amplitude

μ Is the mean value of $\ln\alpha$

σ is the standard deviation of $\ln\alpha$

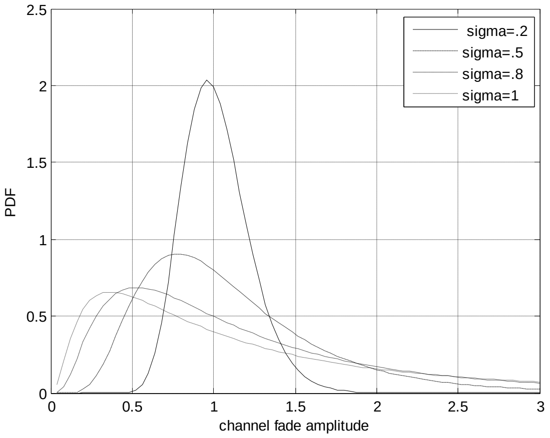

Fig. 7 Log normal PDF for zero mean and different value of σ.

F. Weibull fading model

Weibull distribution is a flexible statistical model for describing multipath fading channels for both indoor and outdoor propagation environments. Experimental data supporting the Weibull fading model was reported by Shepher and Hashemi considered its use as a model for indoor fading channels in [22]. The probability density function (PDF), of the Weibull distribution are given, by

$$P_\alpha(\alpha) = \frac{k}{\Omega}\alpha^{k-1}\exp\left[-\frac{\alpha^k}{\Omega}\right], \qquad \alpha \geq 0 \ldots (3)$$

Where, k > 0 is Weibull fading parameter can take values between 0 and ∞. As k increases the fading severity decreases, while for the special case of k=2, Eq. (3) reduces to the well-known Rayleigh PDF. Moreover, for the special case of k=1, Eq. (3) reduces to the well-known exponential PDF [25].

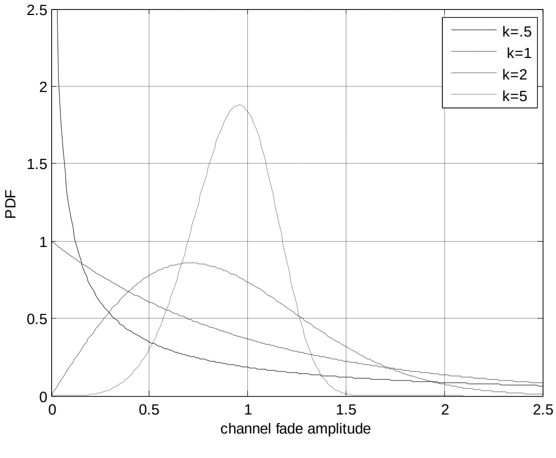

Fig. 4 Weibull fading PDF for Ω=1 and different value of k.

IV. MODELING OF FREQUENCY SELECTIVE FADING CHANNEL

When wideband signals propagate through a frequency-selective channel, their spectrum is affected by the channel transfer function, resulting in a time dispersion of the waveform. This type of fading can be modeled as a linear filter characterized by the following complex-valued low pass equivalent impulse response [8]:

$$h(t) = \sum_{l=1}^{L_p} \alpha_l e^{-j\theta_l}\,\delta(t-\tau_l)$$

Where $\delta(.)$ is the Dirac delta function, l the channel index, and, α, θ and τ the random channel amplitudes, phases, and delays, respectively. L_p is the number of resolvable paths (the first path being the reference path whose delay 0) and is related to the ratio of the maximum delay spread to the symbol time.

V. CONCLUSION

In this paper we have described different types fading models. In particular we have divided the models into two classes by flat fading and frequency selective fading. Moreover, several models for small scale fading have been considered such as Rayleigh, Nakagami and Weibull distributions. Probability density function is plotted for different types fading model. By using PDF the channel capacity will be calculated. Fading channel modeling depends on environment.

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