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PERFORMANCE ANALYSIS OF DIVERSITY RECEPTION FOR MOBILE APPLICATIONS IN RICEAN FADING ENVIRONMENT

[1] M.Ramana, [2]S.Krishna, [3]K.V.SrinivasaRao
[1,2,3]Department of Electronics and Communication Engineering, Aurora's engineering college,Bhongir, Hydrabad,India,508116.

Abstract-Multi-path interference in the mobile communication environment is a major issue. Signal fading due to the multi-path propagation can be reduced using antenna diversity techniques, most commonly introduced by two antenna functions at the mobile terminal. The purpose of this paper is to introduce diversity techniques as a promising way of improving the performance at the mobile terminals. The goal is more profound, dealing with analysis of the correlation between received signals and the propagation environments that diversity improvement depends on. Correlation and diversity performance for small diversity patch antenna are simulated using MATLAB. Gaussian and Laplacian distributions are popular for estimation of fading effects in long distance free space communication and mobile communications. But, Ricean distribution is an intermediate estimation from Gausssian to Rayleigh. The results confirmed comparison between two fading mobile environments viz., Rayleigh and Rice distributions by calculating correlation and diversity gain. We illustrated the effects of correlation and propagation models on diversity improvement. It is concluded that Ricean distribution gives getter model for prediction of diversity gain

Keywords- Fading, diversity reception, probability density functions, Rayleigh, Rice, antenna gain, correlation, polarization

I.Introduction

Nowadays, it is of great concern to increase the performance of the mobile antennas to be able to answer to the demand of faster and more reliable communication services. There is a need for higher performance of the mobile terminals, accomplished by increasing capacity or reducing multi-path interference. Power loss between transmitter and receiver is a result of three different phenomena: distance-dependent decrease of the power density called path loss or free space attenuation, absorption due to the molecules in the atmosphere of the earth and signal fading caused by terrain and weather conditions in the propagation path. Effect of signal

Fading can be resolved by using various diversity methods. Diversity performance is a large, interesting and promising area within the antenna theory that can be transferred into practical applications not only in base station antenna systems, but also in the area of small mobile terminals. This has been shown in this study by applying diversity performance techniques on a patch antenna in various propagation environments. After many simulations, measurements and calculations on the prototype, the final diversity results have shown an evident improvement in the received signal, being about 7-9 dB for the two antenna systems with high antenna efficiencies and low correlations. Even for antenna systems with lower efficiencies and higher correlations the improvement is quite obvious.

II. Signal Fading

Fading is an attenuation that varies between a maximum and minimum value in an irregular way. Terminals move through areas with obstacles of various sizes, such as mountains, buildings and tunnels. Occasionally, these obstacles will shadow or completely cut off the signal. Although the consequences of such shadowing effects will depend on the size of an obstacle and on the distance to it, the received signal strength will inevitably vary. This type of fading is referred to as shadow fading. The effect of shadow fading can be decreased with proper network planning. By placing base stations as high as possible or close to each other it is possible to avoid some obstacles in transmission. Rayleigh fading, multi-path fading or short term fading is a kind of fading involving irregular signal strength variations and it is problematic to overcome.

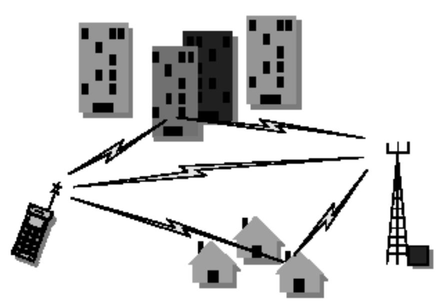

Figure 1. Multi-path propagation

[1]Corresponding Author

Rayleigh fading is a result of a reception of several signals at the receiver incoming reflected from many different objects and directions in the area. Due to their different traveling distances the signals are usually not in phase, reinforcing or extinguishing each other (fig. 1). It is possible that the received signal strength is zero when the reflected signals arriving at the mobile unit are out of phase. Rayleigh fading is mostly observed in urban localities. Dips will occur more frequently at higher frequencies and more rapid mobile movement. To avoid dips it is necessary to attain a sufficient fading margin. The average value of the signal must be at least as many decibels above the receiver sensitivity level as the strongest expected dip. (fig. 2)

III. Diversity Reception

Multi-path fading variations of the signal received at one antenna have a tendency of being independent of fading variations at the other antenna, assuming a sufficient spacing between the two antennas. This observation leads to an experiment where a switch was used to derive the output signal from the stronger of the two antennas at the observed time and resulted in a reduction of the depth of the fading effects compared to signals from either antenna alone. If the two signals are uncorrelated.

Most popular techniques employed in diversity schemes are given below.

Space diversity

The most common and probably the simplest mechanism for achieving diversity branches is space or spatial diversity. Using two antennas with a distance between them the phase delay makes multi-path signals arriving at the antennas differ in fading.

Frequency diversity

Frequency diversity utilizes transmission of the same signal at two different frequency carriers achieving two independently fading versions of a signal.

Angle diversity

Signals arriving at the antennas are coming from different directions. Being independent in their fading variations these signals can be used for angle or angular diversity.

Diversity Gain

The effectiveness of diversity is usually presented in terms of Diversity Gain (DG). Diversity gain can be defined as the improvement in signal-to-noise ratio (SNR) from combined signals from a diversity antenna system, relative to the SNR from one single antenna in the system, preferably the best one. This definition is conditioned by the probability that the SNR is above a reference level. The probability value is optional but usually set to 50% or 99% reliability. The general mathematical expression for diversity gain is, [1]

$$DG = \left[\frac{\gamma_c}{\Gamma_c} - \frac{\gamma_1}{\Gamma_1}\right]_{P(\gamma_c < \gamma_s/\Gamma)} \quad \text{(dB)}$$

Where γ_c is the instantaneous SNR of the diversity combined signal, Γ_c is the mean SNR of the combined signal, γ_1 is the highest SNR of the diversity branch signals, Γ_1 is the mean value of γ_1 and γ_s/Γ is a threshold or reference level. The probability P is dependent on the number of branches M in the diversity system.

IV. Mobile Environment Models

The incident waves are reflected over buildings, and scattered by different objects in the terrain. Since there is no way of predicting the size, height, shape and materials of the objects that the incident waves come across propagating in the different environment structures, the incident waves´ direction varies. Antenna performance is heavily affected by the environment that the antenna is positioned in. The propagation possibilities in different terrain and surroundings can have both positive and negative effects on the performance. Propagation models covering the most common environments for mobile terminals are defined here to be included in a diversity performance.

Moving an antenna randomly in this environment, it is said that the incident waves arrive over a random route or statistically they are uniform in the azimuth. In this paper, two propagation models are taken, with the assumption that the power spectra of both vertical and horizontal polarization are uniform in the azimuth direction. The power spectra in the elevation direction however are not uniformly distributed. There are different distributions describing the incoming polarized waves in elevation and the most common are Rayleigh and Gaussian distributions. In addition to them Rice distribution is also taken for analysis.

1. Gaussian distribution

$$P_\theta(\theta) = A_\theta \exp\left[-\frac{\left|\theta - \left(\frac{\pi}{2} - m_v\right)\right|^2}{2\sigma_v^2}\right] \qquad 0 \le \theta \le \pi$$

$$P_\varphi(\theta) = A_\varphi \exp\left[-\frac{\left|\theta - \left(\frac{\pi}{2} - m_H\right)\right|^2}{2\sigma_H^2}\right] \qquad 0 \le \theta \le \pi$$

Where m_v and m_H are mean elevation angles of the vertical and horizontal polarized wave distributions respectively, and σ_v and σ_H are the standard deviations of the vertical and horizontal wave distributions (fig. 2), respectively. $A_\theta$andA_φ are constants determined by the following conditions:[2]

$$\int_0^{2\pi}\int_0^{\pi} P_\theta(\theta,\varphi)\sin(\theta)\,d\theta\,d\varphi = \int_0^{2\pi}\int_0^{\pi} P_\varphi(\theta,\varphi)\sin(\theta)\,d\theta\,d\varphi = 1$$

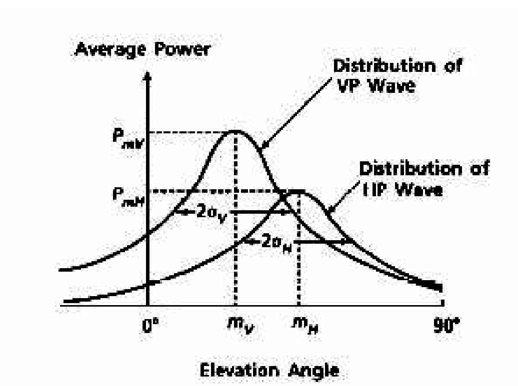

Figure 2. Gaussian distribution model of incident waves in elevation

2. Laplaciandistribution (fig. 3)

$$P_\theta(\theta) = A_\theta \exp\left[-\frac{\sqrt{2}\left|\theta-\left(\frac{\pi}{2}-m_V\right)\right|^2}{\sigma_V}\right] \quad 0 \le \theta \le \pi$$

$$P_\varphi(\theta) = A_\varphi \exp\left[-\frac{\sqrt{2}\left|\theta-\left(\frac{\pi}{2}-m_H\right)\right|^2}{\sigma_H}\right] \quad 0 \le \theta \le \pi$$

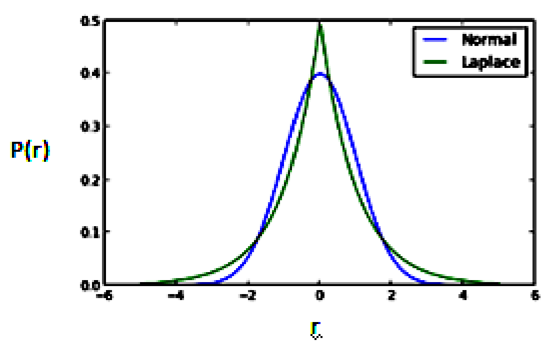

Figure 3.Laplacian distribution

3.Ricean Distribution

When there is a dominant stationary (non fading) signal component present, such as a line-of-sight propagation path, the small scale fading envelop distribution is Ricean. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. The effect of a dominant signal arriving with many weaker multipath signals gives rise to the Ricean distribution. As the dominant signal becomes weaker, the composite signal resembles a noise signal which has an envelope that is Rayleigh. Thus, the Ricean distribution degenerates to a Rayleigh distribution when the dominant component fades away. (fig.4)

General distribution is given by

$$P(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_{0\left(\frac{Ar}{\sigma^2}\right)} for(A \ge 0, r \ge 0) \\ 0 \qquad for(r < 0) \end{cases}$$

for the elevation angle θ

$$P_\theta(\theta) = \frac{\theta^2}{\sigma_V^2}\exp\left[-\frac{\theta^2 + A_\theta^2}{2\sigma_V^2}\right] I_0\left[\frac{A_\theta\theta}{\sigma_V^2}\right] 0 \le \theta \le \pi$$

$$P_\varphi(\theta) = \frac{\theta^2}{\sigma_H^2}\exp\left[-\frac{\theta^2 + A_\varphi^2}{2\sigma_H^2}\right] I_0\left[\frac{A_\varphi\theta}{\sigma_H^2}\right] 0 \le \theta \le \pi$$

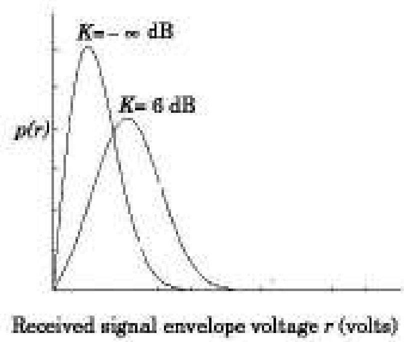

Figure 4.Ricean Distributions: K= -∞ dB (Rayleigh) and K= 6dB.

The parameter K is known as the Ricean factor and completely specifies the Ricean distribution. As A→0, K→ -∞ dB, and as the dominant path decreases in amplitude, the Ricean distribution degenerates to a Rayleigh distribution.

4. Rayleigh distribution

In Mobile radio channels, the Rayleigh distribution function is commonly used to describe the statistical time varying nature of the received envelop of a flat fading signal, or the envelop of an individual multipath component. . The Rayleigh distribution has a probability density function given by

General pdf is given by (fig. 5)

$$p(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{(r^2)}{2\sigma^2}} for(0 \le r \le \infty) \\ 0 \qquad for(r < 0) \end{cases}$$

For elevation angle θ,

$$P_{\theta}(\theta) = \frac{\theta}{\sigma_{v}^{2}} \exp\left[-\frac{\theta^{2}}{2\sigma_{v}^{2}}\right] \qquad 0 \le \theta \le \pi$$

$$P_{\varphi}(\theta) = \frac{\theta}{\sigma_{H}^{2}} \exp\left[-\frac{\theta^{2}}{2\sigma_{H}^{2}}\right] \qquad 0 \le \theta \le \pi$$

Where σ is the rms value of the received voltage signal before envelop detection. And σ^2 is the time average power of the received signal before envelop detection.

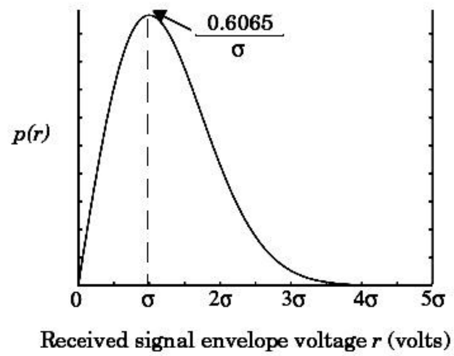

Figure 5. Rayleigh probability density function

In multi-path environments the mean effective gain (MEG) defines the power received by the antenna. It is a characteristic that includes antenna radiation power pattern$(G_{\theta}(\Omega), G_{\varphi}(\Omega))$, antenna efficiency and propagation effects$(P_{\theta}(\Omega), P_{\varphi}(\Omega))$. It is defined by [3]

$$MEG = \int_{0}^{2\pi}\int_{0}^{\pi}\Big(\frac{XPR}{XPR+1} G_{\theta}(\Omega)P_{\theta}(\Omega) + \frac{1}{XPR+1} G_{\varphi}(\Omega)P_{\varphi}(\Omega)\Big)\, d\Omega$$

MEG is normalized by a normalization of the gains

V. Correlation Process

The independency of multipath reflected signals is seen in terms of a very low correlation, ideally having a correlation coefficient equal to zero. In practice the faded signals are not completely independent, which affects the probability that the combined signal will be above the given threshold. The independency can be measured using the general expression of the envelope cross correlation coefficient □, in angulardomain [4]

$$\rho_e = \frac{\left(\oint (XPR E_{\theta\chi}(\Omega)E^{*}_{\theta Y}(\Omega)P_{\theta}(\Omega) + E_{\varphi\chi}(\Omega)E^{*}_{\varphi Y}(\Omega)P_{\varphi}(\Omega))\, d\Omega\right)^{2}}{\oint (XPR G_{\theta\chi}(\Omega)P_{\theta}(\Omega) + G_{\varphi\chi}(\Omega)P_{\varphi}(\Omega))\, d\Omega . \oint (XPR G_{\theta Y}(\Omega)P_{\theta}(\Omega) + G_{\varphi Y}(\Omega)P_{\varphi}(\Omega))\, d\Omega}$$

Where Ω= (θ, φ),$G_{\theta} = E_{\theta}(\Omega)E^{*}_{\theta}(\Omega)$,$E_{\theta\chi}(\Omega)$ and $E_{\theta Y}(\Omega)$ are the θ polarized complex radiation patterns of antenna X and antenna Y in the diversity system and $d\Omega = \sin\theta\, d\varphi\, d\theta$. $P_{\theta}(\Omega)$and$P_{\varphi}(\Omega)$ represent incident power spectrum for both polarizations and XPR (cross polar discrimination) is the ratio of time average vertical (θ) power to time average horizontal (φ) power.

$$XPR = \frac{P_v}{P_H}$$

Correlation can also be expressed using the complex cross correlation coefficient

$\rho_e$related to envelope correlation coefficient by:

$$\rho_e = |\rho_s|^2$$

Computation of correlation coefficient above requires radiation pattern of antennas and involves integral calculation. ρ_eCan also be found using [5]

$$\rho_e = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^{2}}{\left(1-(|S_{11}|^{2}+|S_{21}|^{2})\right)\left(1-(|S_{22}|^{2}+|S_{12}|^{2})\right)}$$

VI. Simulation Results

The studies and the evaluation of the diversity performance have been realized by creating a set of Matlab programs for calculation of signal correlation coefficient and diversity gain of the diversity antenna system, including the different propagation environments and using data from simulations. The study has been performed for mainly patch antenna.

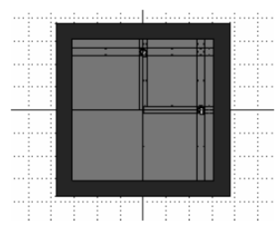

Figure 6.Simulationprototype

The patch antenna used in this study is a two orthogonally fed antenna using the spacing and orthogonal placements of feeding points as a diversity technique. The size of the antenna is 33x33 mm^2 with a parasitic metal plate (size 39x39 mm) placed about 11 mm above the ground plane for an increased bandwidth. The antenna system resonance frequency is at 2.7 GHz and it is a very well matched with a very low mutual coupling. (fig. 6, fig. 7). Distribution simulation results are shown in fig. 8 and fig. 9

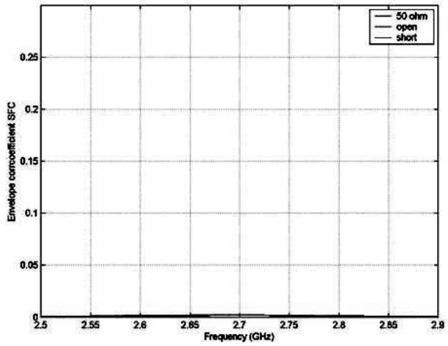

Figure 7. Envelope correlation coefficient for the **two-feed patch antenna system**

Propagation Models		ρ_e	DiversityGain (dB)
Gaussian	Outdoor	0.011	9.6, 2.4
	Indoor	0.014	9.4, 1.9
	Isotropic	0.015	9.3, 1.8
Laplacian	Outdoor	0.01	9.6, 2.4
	Indoor	0.02	9.5, 2.0
	Isotropic	0.015	9.3, 1.8
Rayleigh	Outdoor	0.01	9.5, 2.4
	Indoor	0.025	9.5, 2.0
	Isotropic	0.010	9.8, 1.8
Ricean	Outdoor	0.01	9.6, 2.4
	Indoor	0.02	9.2, 2.2
	Isotropic	0.018	9.3, 1.6

Table: Diversity performance results

Results

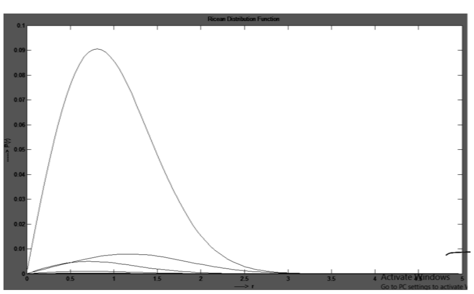

Figure 8.RiceanMatlab program and results

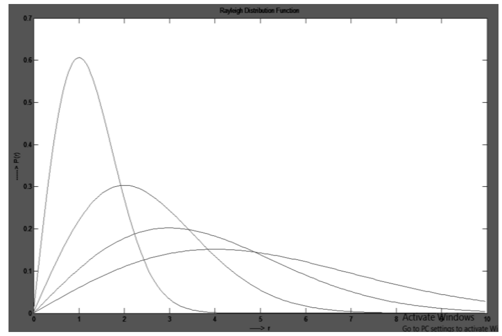

Figure 9.Rayleigh Matlab program and results

VII. Conclusion

The studies confirmed that calculation of the correlation coefficients using far-field pattern or S-parameters is equivalent for matched antennas in an antenna diversity system and assuming uniformly incoming waves. Matlab based program is made for calculation of diversity gain and diversity system gain considering different propagation models. However, the S-parameter method is only valid for the isotropic propagation model. The diversity performance of the antenna system is dependent on the environment but since the results have shown that most of the models affect the diversity performance similarly, no model has attracted any special attention. But emphasis is made on Ricean distribution and Rayleigh distribution.

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