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Performance of Nakagami – *m* Fading Channel with Equal Gain Combining and Maximal Ratio Combining Diversity Techniques

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ABSTRACT: Signal fading can drastically affect the performance of terrestrial communication systems. Fading caused by multipath propagation can degrade the bit-error-rate (BER) performance of a digital communication system resulting data loss or dropped calls in a cellular system.

The Nakagami-m distribution has gained widespread application in the modeling of physical fading radio channels. The primary justification of the use of Nakagami-m fading model is its good fit to empirical fading data. It is versatile and through its parameter m, we can model signal fading conditions that range from severe to moderate, to light fading or no fading.

This research paper discusses the generation of Nakagami – m data and once, the Nakagami-m distribution is generated, we applied BPSK modulation technique with Equal Gain Combining [EGC] Diversity technique and Maximal Ratio Combining [MRC] technique to study its SNR (Signal – to – Noise Ratio) and BER.

***Index Terms*— Nakagami – m fading, multipath propagation, Signal – to – Noise Ratio [SNR], Bit Error Rate [BER], Equal gain Combining [EGC] and Maximal Ratio Combining [MRC].**

I. INTRODUCTION

The biggest challenge for wireless system designers is to minimize the effect of multipath and time varying nature of the mobile radio channels. In addition to this, the designers have to meet certain

more complexities like increasing demand for higher data rates, better quality of service (QoS), fewer dropped calls, higher network capacity and user coverage call for novel techniques that improve spectral efficiency and link reliability.

One of the innovative techniques being developed to meet this growing demand for always-on access to data is use of multiple antennas to improve energy / spectral efficiency. Antenna diversity reception techniques are used extensively in fading radio channels to reduce the effect of flat fading in system performance. The basic principle of antenna diversity is that multiple antenna outputs experience different signals due to different channel conditions and thus it is highly likely for one antenna to receive a sufficiently strong signal while the other one is in a deep fade.

The performance of any diversity system depends on the combining technique used to merge signals received by the antenna elements. The output signals from the diversity antennas can be selected or combined in several ways to optimize the received signal power. Among the most popular combining schemes are selection combining (SC), maximal ratio combining (MRC) and equal gain combining (EGC).

In the recent years, radio-engineering requirements have become more stringent and necessitate not only more detailed information on median signal intensity, also much more exact knowledge on fading statistics in both ionospheric and tropospheric modes of propagation. Such circumstances demanded a large number of experiments and number of theoretical investigations to be performed. Field tests in a mobile environment are considerably more expensive and may require permission regulatory authorities. It is difficult to generate repeatable field test results due to random, uncontrollable nature of the mobile communication path. Atmospheric conditions and cost also play a key role in field test measurements. So, it is beneficial to simulate the results of performance of a particular wireless channel.

A typical mobile radio communication environment including PCS [Personal Communication Service] and digital cellular transmission link consists of an elevated base station antenna or multiple antennas and a relatively short distance line-of-sight (LOS) propagation path, followed by many non LOS propagation paths and a mobile antenna or antennas mounted on a moving vehicle or more generally on the transmitter/receiver (T/R) or transceiver of the mobile or portable unit. In such an environment, the transmitted waves often do not reach the receiving antenna directly. Among all the obstacles encountered in the mobile radio system design, the time varying nature of the propagation channel is the most difficult. Man-made or natural obstacles usually block the emitted electromagnetic waves. The received waves are a superimposition of waves coming from all the direction due to reflection, diffraction and scattering caused by obstacles. This effect is known as ***Multipath Propagation***.[15]

Due to this effect, the received signal consists of an infinite sum of delayed, phase-shifted and attenuated replicas of transmitted signal. The superposition can be constructive or destructive depending upon the phase of each replica.

There are three basic mechanisms that impact signal propagation in a mobile communication system. They are reflection, diffraction, and scattering. [15]

Reflection

Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave. In other words it can be said that if the plane wave is incident on a perfect dielectric, part of the energy is transmitted and part of the energy is reflected back into the first medium. If the second medium is a perfect conductor, all the energy is reflected back. Reflections occur from the surface of the earth and from buildings and walls. In practice, not only metallic materials cause reflections, but dielectrics also cause this phenomenon.

Diffraction

Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a Line of Sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction. Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a dense body with large dimensions compared to λ, causing secondary waves to be formed behind the obstructing body. It is often termed *shadowing* because the diffracted field can reach the receiver even when shadowed by an impenetrable obstruction.

Scattering

Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system.

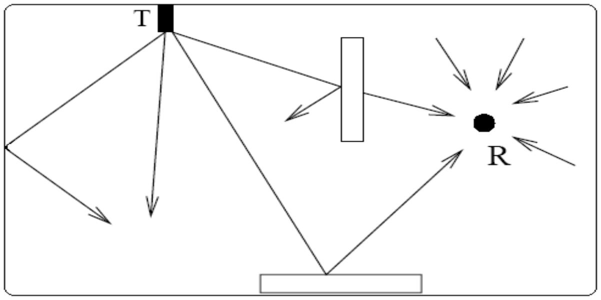

Figure 1.1 Multipath propagation in indoor environments. [The signal transmitted by the transmitter (T) is attenuated and reflected by the walls and floors. As consequence, the receiver (R) receives multiple distorted copies of the transmitted signal].

II. MODELS OF FADING

In this paper we have discussed Nakagami - m fading channel. This is a very versatile fading model, which by varying the values of the fading parameter ***"m"***, it can be modeled as either as Rayleigh model or Rician model. [7] [8] [16]

The Nakagami-m PDF is in essence a central chi-square distribution given by:

$$\boldsymbol{p_\alpha(\alpha) = \frac{2\, m^m\, \alpha^{2m-1}}{\Omega^m\, \Gamma(m)} \exp\left(-\frac{m\alpha^2}{\Omega}\right), \quad \alpha \geq 0} \qquad \textbf{(2.1)}$$

$\boldsymbol{m}$ is the Nakagami – m fading parameter which ranges from 0.5 to ∞.

$\boldsymbol{\alpha}$ is the channel fading amplitude.

Nakagami – m PDF for $\Omega = 1$ and various values of m is shown in figure 2.2

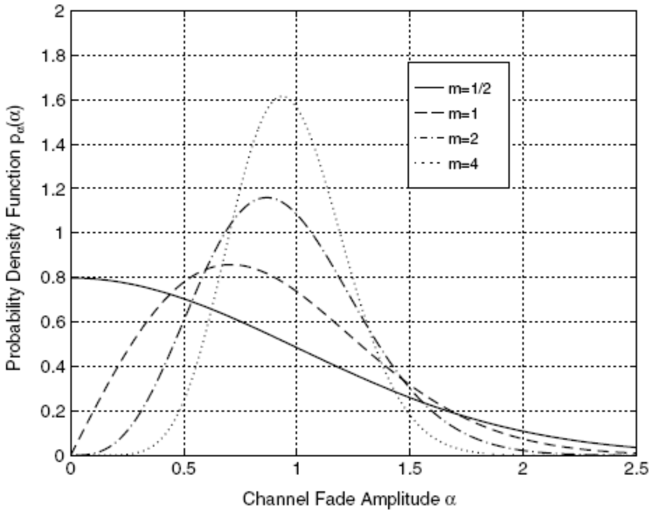

Figure. 2.1 Nakagami PDF for Ω = 1 and various values of the fading parameter *m*.

SNR per symbol, γ, is distributed according to a gamma distribution given by:

$$p_{\gamma}(\gamma) = \frac{m^m \ \gamma^{m-1}}{\bar{\gamma}^m \, \Gamma(m)} \exp\left(-\frac{m\gamma}{\bar{\gamma}}\right), \qquad \gamma \geq 0 \qquad (2.2)$$

When $m = 0.5$, the PDF of Nakagami – m distribution resembles one- sided Gaussian distribution as shown in Fig. 2. For m=1, the Nakagami – m distribution matches with that of Rayleigh distribution. As m approaches ∞, the fading channel converges to a non – fading AWGN channel.

When $m < 1$, m maps with q parameter and Nakagami – m distribution becomes closely related to Nakagami – q (Hoyt) distribution. The relation between m and q is quoted as:

$$m = \frac{(1+q^2)^2}{2\,(1+q^4)}, \qquad m \geq 1 \qquad (2.3)$$

When $m > 1$, m maps with n parameter or Rician K parameter and Nakagami - m distribution becomes closely approximated to Nakagami – n (Rice) distribution.

The mathematical relation between m and n is given as:

$$m = \frac{(1+n^2)^2}{1+2\,n^2}, \qquad n \geq 0 \qquad (2.4)$$

Thus, we can conclude that Nakagami - m distribution can be used to analyze fading with no direct line – of – sight between the transmitter and receiver antennas [as Rayleigh distribution] and the propagation path consisting of one strong direct LOS component and many other weaker components. Nakagami – m distribution best fits to the empirical data involving land – mobile propagation and indoor – mobile multipath propagation and ionospheric radio links.

III. DIVERSITY TECHNIQUES

Diversity has long been used as a low-cost method to help mitigate the multipath-induced fading that results from users' mobility. The basic idea of diversity is that if one radio path undergoes a deep fade, another independent path may have a strong signal. By having more than one path to select from, both the instantaneous and average SNRs at the receiver may be improved by a huge dB margin. [12]

In *Maximal Ratio Combining [MRC]* diversity technique, the signal in each branch is first co-phased and once the phase distortions are canceled out, the signal in each branch is weighted by a weighting factor proportional to the ratio of the carrier amplitude to the noise power for the i th branch. Therefore, the gain factor in MRC system is given as:

$$g_i = \frac{x_i \ e^{-j\alpha_i}}{n_i^2} \qquad \text{for } i = 1,\ldots\ldots.,M \qquad (3.1)$$

This gives an output SNR equal to the sum of the SNRs on the M branches for the maximal ratio system, i.e.,

$$\rho_{out} = \sum_{i=1}^{M} \frac{x_i^2/2}{n_i^2} \qquad (3.2)$$

In MRC, the receiver weights incoming signals on L antennas by the respective conjugates of the complex fading random variables.[11]

In practical implementations, the weighting factors for a MRC system are obtained by deriving a signal which has an amplitude proportional to the i th branch carrier amplitude and a phase that is the conjugate of the i^{th} branch carrier random phase. The original i^{th} branch signal is then multiplied with this derived signal.

In Equal Gain Combining [EGC] diversity technique, the received signal carriers are first co-phased as in the case of MRC and are then equally weighted by their amplitudes.[13] In other words, the branch weights are all set to unity. The possibility of producing an acceptable signal from a number of unacceptable inputs is still retained. The gain factor for an equal gain system can be written as:

$$g_i = e^{-j\,\alpha_i}, \qquad \text{for } i = 1, \ldots\ldots, M \ (3.3)$$

With equal noise levels in each branch, the output SNR of EGC system is expressed as,

$$\rho_{out} = \frac{\frac{1}{2}\left(\sum_{i=1}^{M} x_i^2\right)^2}{M\,n^2} \qquad (3.4)$$

The EGC receiver performance is superior to selection diversity performance and only marginally inferior as compared to MRC. EGC is often used in practice because of its reduced complexity relative to the optimum MRC scheme. This is because the latter requires the knowledge of the fading amplitude in each signal branch while the former requires no such knowledge.

IV. SIMULATION ANALYSIS & DISCUSSIONS

The modulation technique being applied here is BPSK [Binary Phase Shift Keying]. The phase of a constant amplitude carrier signal moves between zero and 180 degrees. On an *I* and *Q* diagram, the *I* state has two different values. There are two possible locations in the state diagram, so a binary one or zero can be sent. The symbol rate is one bit per symbol.

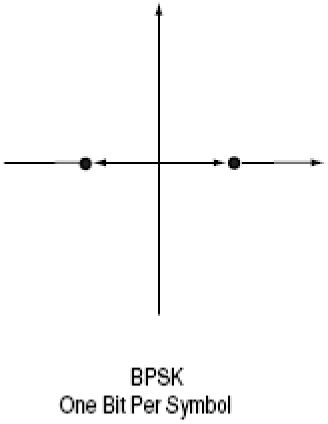

Figure 4.1 Constellation diagram for BPSK

We have assumed that the received signal is received over L independent slowly varying flat Nakagami – *m* fading channel.

Generation of Nakagami – m data set:

The Nakagami – *m* data set can be generated taking square root of gamma distributed samples. [20]

```
r = sqrt(gamrnd(m,omega./m, m, N))
```

Here, "*gamrnd*" is a MATLAB function which generates Gamma distributed samples.

"*sqrt*" is a MATLAB function which takes the square root of the defined values.

m – shape parameter whose values can be varied.

Omega / m – scale parameter.

N – No. of bits or symbols.

PDF of Nakagami – m data set:

The following MATLAB simulation shows that the theoretical and practical pdf of Nakagami – *m* moel closely approximates to each other. Moreover this is proved with the help of simulation that when the value of *m* is 0.5, the pdf resembles with one- sided Gaussian distribution and for *m*=1, the Nakagami – *m* distribution matches with that of Rayleigh distribution.

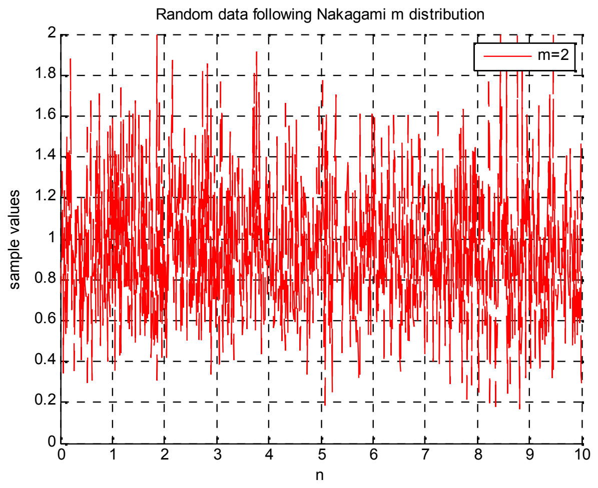

Figure 4.2. Random data following Nakagami – *m* distribution

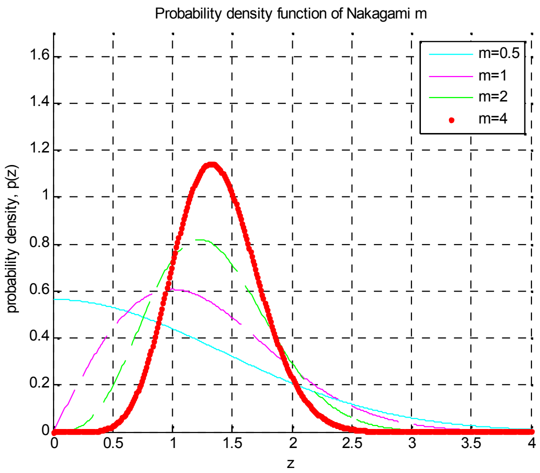

Figure 4.3. Theoretical PDF of Nakagami – *m* distribution

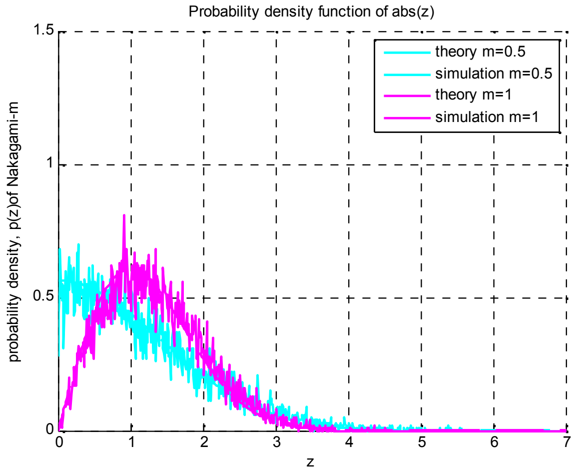

Figure 4.4 Simulated PDF of Nakagami – *m* distribution

SNR of Nakagami – m model with EGC: [14]

This has been assumed that AWGN is also present. This is being observed that as the number of antennas is being increased the SNR is getting improved. The performance of the model is also getting improved as the value of m is increasing from 0.5 to 1.5.

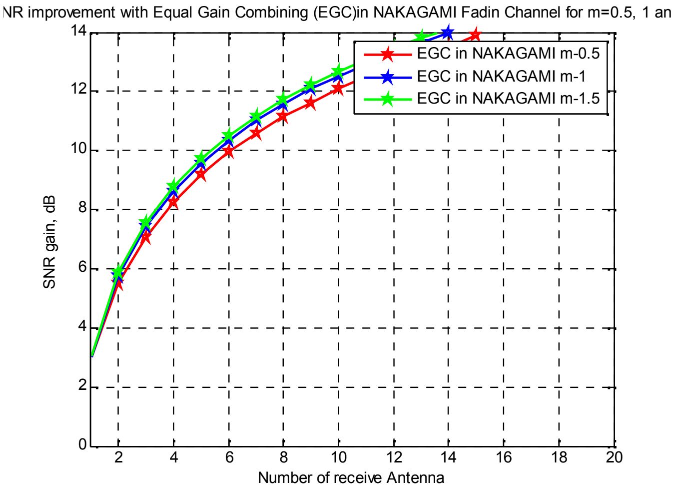

Figure 4.5 SNR of Nakagami – *m* channel with EGC.

SNR of Nakagami – m model with MRC:

We are again assuming that AWGN is present.

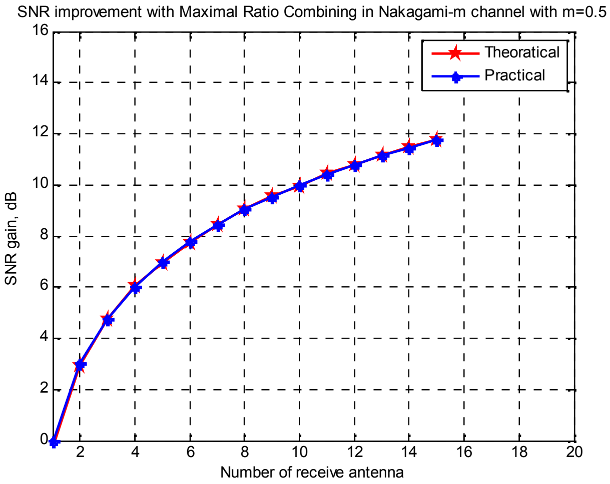

Figure 4.6 SNR of Nakagami – *m* channel with MRC

The analysis of the channel with MRC is a bit difficult to achieve as compared to EGC because the SNR has to be calculated at each value of m and this has been observed that theoretical values match very well with the simulated values of SNR. The above figure shows the SNR using MRC at m = 0.5.

BER comparison of Nakagami – m channel and AWGN: [17] [19s]

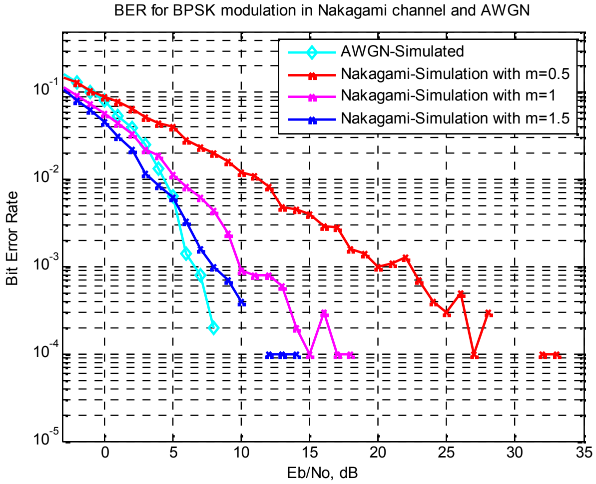

Figure 4.7 BER of Nakagami -*m* channel with EGC

This can be observed from the above simulation that BER of AWGN channel is the minimum. This can also be concluded that as the value of *m* is increasing from 0.5 to 1.5, the channel's performance is improving and it is coming near to approximation with AWGN channel. This goes with the theoretical fact that as the value of *m* approaches ∞, the Nakagami – m fading channel's response is the same as that of a no- fading AWGN channel.

BER analysis of Nakagami – m channel with BPSK and MRC:

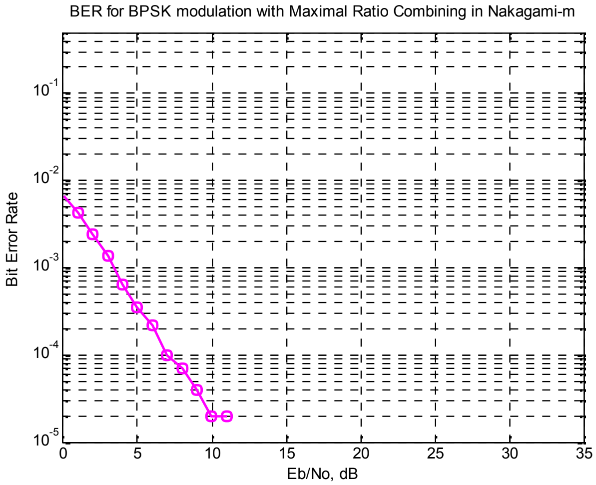

Figure 4.8 BER of Nakagami – *m* channel with MRC

This can be observed that BER of Nakagami – m model with MRC is much lower than that when simulated with EGC as diversity technique. This concludes that MRC's performance is better than that of EGC's.

The above simulation has been done with m = 0.5.

V. CONCLUSIONS & FUTURE SCOPE

This has been concluded that the Nakagami – *m* distribution can be modeled to other distributions by varying the values of *m*. Secondly, as the value of m increases, the BER as well as the SNR gets improved. The number of antennas also plays an important role in improving the performance of the Nakagami –*m* model.

This is also concluded that for same values of m. the performance of MRC is superior to that of EGC.

The future scope involves the use of better modulation schemes like GMSK, DPSK, OQPSK etc. In this paper we have discussed diversity techniques. The analysis of performance of Nakagami – *m* model can be done using equalizers and channel coding techniques.

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