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Performance Analysis of Wireless link in Rician Fading Channel

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Abstract: In wireless communication fading is a phenomenon which degrades the performance of the link it includes Rayleigh, Nakagami-q, Nakagami-m, Rician fading. In this paper the performance of wireless link over Rician fading channel have been analysed. A closed form expressions of outage probabilities, bit error rate (BER), end to end average received signal to noise ratio (SNR) and channel capacity are derived for Rician fading channel. Outcome of this paper will be helpful for establishing wireless link in Rician fading channel.

Keywords: Bit error rate, channel capacity, outage probability, Rician fading channel, signal to noise ratio.

I. INTRODUCTION

In wireless communication the performance of the channel degrades due to fading nature of the signal [1]. Different parameters like bit error rate, outage probability, average signal to noise ratio and channel capacity to be improved.Fig.1 shows the Rician fading model where direct line of sight (LOS) paths are available with non LOS paths the performance of the channel improves by combining these LOS and non LOS signals [2].

The BER improves when diversity order of receiver increases; it also depends on the rice factor (K) which is the ratio of the specular power s^2 to scattered power σ^2. When the value of K increases the performance of channel improves [9].

The BER analyses of the Rician fading channel have been studied in [3]. Outage probability of the Rician fading channel has been analysed in [4].

The average received SNR of the Ricianfading chanel have been studied in [6]. The average capacities of Rician fading channel have been studied in [7],[8]. The Rician fading model have been discussed in [10],[11].Contribution of this paper is as follows.

1. Previous Performance Analysis of Wireless Link[1]in Weibull fading channels and [2] in α-μ Fading Channel has been carried out which is now generalized for Rician fading channels.

2. Previous the performance analysis of wireless link has been carried out for Rayleigh fading channel [7] and [8] Nakagami–m fading channel which is generalized for Rician fading channel.

The rest of paper is organized as follows. In Section II, the Rician fading model and its probability density function is briefly discussed. In Section III, performance analysis of Rician fading channel is discussed. In Section IV numerical and simulation results is investigated. The paper is concluded in Section V.

II. THE RICIAN FADING MODEL

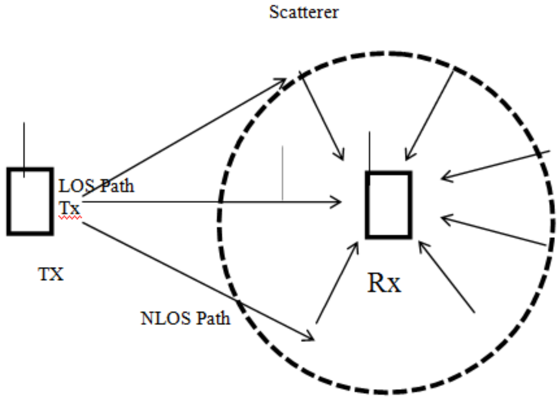

Fig 1.Rician fading model

A. Rician Fading

Some types of scattering environment have specular or LOS components. If $g_I(t)$ and $g_Q(t)$ are Gaussian random process with non-zero mean $m_I(t)$ and $m_Q(t)$. If we again assume that these process are uncorrelated and random variable $g_I(t)$ and $g_Q(t)$ have the same variance σ^2. Then magnitude of the received complex envelop at time t has a Rician distribution is defined from [12, Eq.(2.45)]

$$P_\alpha(x) = \frac{x}{\sigma^2} e^{-\frac{(x^2+s^2)}{2\sigma^2}} I_0\left(\frac{xs}{\sigma^2}\right) \quad x>=0, \qquad (1)$$

Where

$I_0(.)$iszero order modified Bessel function of the first kind

$$s^2 = m^2{}_I(t) + m^2{}_Q(t) \qquad (2)$$

is called the non-centrality parameter. This type of fading is called Ricean fading and is very often observed in

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microcellular and mobile satellite applications. A very simple Ricean fading model assumes that the means $m_I(t)$ and $m_Q(t)$ are constants, i.e. $m_I(t) = m_I$, and $m_Q(t) = m_Q$. The means $m_I(t)$ and $m_Q(t)$ corresponding tothe in phase and quadrature components of the LoS signal are given

$$m_I(t) = s.\cos(2\pi f_m \cos\theta_0 t + \phi_0) \quad (3)$$
$$m_Q(t) = s.\sin(2\pi f_m \sin\theta_0 t + \phi_0) \quad (4)$$

Where $f_m\cos\theta_0$ and ϕ_0 are the Doppler shift and random phase off set associatedwith the LoS or specular component, respectively.

The **Rice factor,** K, is defined as the ratio of the specular powers s^2 toscattered power $2\sigma^2$ i.e. $K= s^2/2\sigma^2$, When K= 0 the channel exhibitsRayleigh fading, and when $K=\infty$ the channel does not exhibit any fading atall [12].

α = received complex envelop which is Rician distributed
$\alpha = \sqrt{N(m_I, \sigma^2) + j*N(m_Q, \sigma^2)}$
N (. , .) = Normally or Gaussian distributed random variable
x= running variable
j = complex operator

III. PERFORMANCE ANALYSIS

Performance parameters: the following parameters have been used in this paper to analyse the performance of a wireless channel.

1. Average Received Signal to Noise Ratio (SNR):

Average received SNR at the destination is a standard performance measure of diversity systems operating over fading channels and is defined as the statistical average of the received SNR over the probability distribution of the fading. It measures the overall fidelity of the system which can be written as

$$\bar{\gamma}^{Rx} = \int_0^\infty \gamma f_\gamma(\gamma) d\gamma \quad (5)$$

Here γ denotes the instantaneous SNR, where $f_\gamma(\gamma)$ denotes the probability density function (PDF) of γand $\bar{\gamma}$ is an average SNR [10, Eq. (1.1)]

$\gamma = |\alpha|^2$

Therefore $f_\gamma(\gamma) = \frac{1}{2\sqrt{\gamma}} f_\alpha(\sqrt{\gamma})$

$$f_\gamma(\gamma) = \frac{1}{2\sqrt{\gamma}} \frac{\sqrt{\gamma}}{\sigma^2} e^{\frac{-((\sqrt{\gamma})^2+s^2)}{2\sigma^2}} I_0\left(\frac{\sqrt{\gamma}\, s}{\sigma^2}\right)$$

$$f_\gamma(\gamma) = \frac{1}{2\sigma^2} e^{\frac{-(\gamma+s^2)}{2\sigma^2}} I_0\left(\frac{2\sqrt{\gamma}\, s}{2\sigma^2}\right)$$

After putting the value of average receive SNR $2\sigma^2 = \bar{\gamma}$ we get

$$f_\gamma(\gamma) = \frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} I_0\left(\frac{2\sqrt{\gamma}\, s}{\bar{\gamma}}\right) \quad (6)$$

Where $I_0\left(\frac{2\sqrt{\gamma}\, s}{\bar{\gamma}}\right) = \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2k}$ is evaluated from [5, Eq. (8.445)]

By substituting the value of $I_0(.)$ in equation (6) we get PDF of SNR as

$$f_\gamma(\gamma) = \frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2k} \quad (7)$$

Average SNR at Receiver

$$\bar{\gamma}^{Rx} = \int_0^\infty \gamma f_\gamma(\gamma) d\gamma$$
$$\bar{\gamma}^{Rx} = \int_0^\infty \gamma \left[\frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2k}\right] d\gamma$$
$$\bar{\gamma}^{Rx} = \int_0^\infty \frac{\gamma}{\bar{\gamma}} \left[e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2k}\right] d\gamma$$
$$\bar{\gamma}^{Rx} = \int_0^\infty \frac{\gamma}{\bar{\gamma}} \left[e^{-\frac{\gamma}{\bar{\gamma}}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{\gamma^k s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!}\right] d\gamma$$
$$\bar{\gamma}^{Rx} = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!} \int_0^\infty \gamma^{k+1} e^{-\frac{\gamma}{\bar{\gamma}}} d\gamma$$

The above equation can be evaluated from [5, Eq. (3.381.4)]

$$\bar{\gamma}^{Rx} = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!} \left[\frac{1}{\frac{1}{\bar{\gamma}^{k+2}}} \Gamma(k+2)\right]$$
$$\bar{\gamma}^{Rx} = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{s^{2k}}{\bar{\gamma}^{2k} k!^2} \left[\bar{\gamma}^{k+2}\Gamma(k+2)\right] \quad (8)$$

Where

$\Gamma(.)$ is gamma function [5, Eq. (3.381.4)]
k = running variable

2. Bit Error Rate (BER)

Bit Error Rate is a metric which can be employed to characterise the performance of a communication system.

$$\text{Average Bit Error Rate} = \frac{\text{number of bits in error}}{\text{total number of bits transmitted}}$$

BER for Rician Distribution.

$$BER = \int_0^\infty f_\gamma(\gamma)\, Q(\sqrt{b\gamma})\, d\gamma$$
$$BER = \int_0^\infty \frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2k} Q(\sqrt{b\gamma}) d\gamma$$
$$BER = \int_0^\infty \frac{1}{\bar{\gamma}} e^{-\frac{\gamma}{\bar{\gamma}}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{\gamma^k s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!} Q(\sqrt{b\gamma}) d\gamma$$
$$BER = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!} \int_0^\infty \gamma^k e^{-\frac{\gamma}{\bar{\gamma}}} Q(\sqrt{b\gamma}) d\gamma$$
$$BER = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{s^{2k}}{\bar{\gamma}^k \bar{\gamma}^k \Gamma(k+1)k!} \int_0^\infty \gamma^k e^{-\frac{\gamma}{\bar{\gamma}}} Q(\sqrt{b\gamma}) d\gamma$$
$$BER = e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{(s^k)^2}{\bar{\gamma}^k k!} \frac{1}{\bar{\gamma}^{k+1}\Gamma(k+1)} \int_0^\infty \gamma^k e^{-\frac{\gamma}{\bar{\gamma}}} Q(\sqrt{b\gamma}) d\gamma$$

After putting the value of $b = 2\sin^2\left(\frac{\pi}{M}\right)$, $c = \frac{b}{2a}$ and a = 1, where value of M is equals to 2 for BPSK and 4 for QPSK modulationis evaluated from[10, Eq. (5A.3)].We get

$$BER = e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\bar{\gamma}^{k+1}k!} \frac{(s^k)^2}{\bar{\gamma}^k k!} \left[\frac{\sqrt{c/\pi}}{2(j+c)^{k+\frac{3}{2}}} \frac{\Gamma(k+\frac{3}{2})}{\Gamma(k+2)} {}_2F_1\left(1, k+\frac{3}{2}; k+2; \frac{1}{1+c}\right)\right] \quad (9)$$

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where ${}_2F_1$ **(., .; .;.)**is Gausshyper geometric function [5, Eq. (9.14.2)]

Q(x) is Gaussian Q function [10, Eq. (4.1)]

$Q(x) = \int_x^{\infty} \frac{1}{2\pi} \exp(-\frac{y^2}{2})\, dy$

3. Outage Probability (P_{out})

$\mathbf{P_{out}}$is defined as the probability that the instantaneous error probability exceeds a specified value or equivalently the probability that the output SNR γ falls below a certain specified threshold. Outage threshold (u) is evaluated by [10, Eq. (1.4)]

Outage Probability

$$P_{out} = \int_0^u f_\gamma(\gamma) d\gamma \quad (10)$$

$$P_{out} = \int_0^u \frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{\Gamma(k+1)k!} (\frac{\sqrt{\gamma}\, s}{\bar{\gamma}})^{2k} d\gamma$$

$$P_{out} = \int_0^u \frac{1}{\bar{\gamma}} e^{-\frac{\gamma}{\bar{\gamma}}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{\frac{s^2}{\bar{\gamma}} s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!} d\gamma$$

$$P_{out} = \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{[\int_0^u e^{-\frac{\gamma}{\bar{\gamma}}} \gamma^k\, d\gamma] s^{2k}}{\bar{\gamma}^{2k}\Gamma(k+1)k!}$$

$$P_{out} = \frac{e^{-\frac{s^2}{\bar{\gamma}}}}{\bar{\gamma}} \int_0^u e^{-\frac{\gamma}{\bar{\gamma}}} \sum_{k=0}^{\infty} \frac{1}{k!k!} \frac{s^{2k}}{\bar{\gamma}^{2k}} \gamma^k\, d\gamma$$

$$P_{out} = \frac{e^{-\frac{s^2}{\bar{\gamma}}}}{\bar{\gamma}} \sum_{k=0}^{\infty} \frac{1}{k!k!} \frac{s^{2k}}{\bar{\gamma}^{2k}} [\int_0^u e^{-\frac{\gamma}{\bar{\gamma}}} \gamma^k\, d\gamma]$$

The above equation can be evaluated from [5, Eq. (3.381.8)]

$$P_{out} = \frac{e^{-\frac{s^2}{\bar{\gamma}}}}{\bar{\gamma}} \sum_{k=0}^{\infty} \frac{1}{k!^2} \frac{s^{2k}}{\bar{\gamma}^{2k}} [\frac{\Gamma(\boldsymbol{k+1}, \frac{\boldsymbol{u}}{\bar{\gamma}})}{(\frac{1}{\bar{\gamma}})^{\boldsymbol{k+1}}}]$$

$$P_{out} = \frac{e^{-\frac{s^2}{\bar{\gamma}}}}{\bar{\gamma}} [\sum_{k=0}^{\infty} (\frac{s^k}{k!\bar{\gamma}^k})^2 \frac{\Gamma(\boldsymbol{k+1}, \frac{\boldsymbol{u}}{\bar{\gamma}})}{(\frac{1}{\bar{\gamma}})^{\boldsymbol{k+1}}}] \quad (11)$$

4. Average capacity(C):

Average (Shannon or ergodic) capacity provides the maximum limit of data transfer over wireless channel. In fading channel, it (in terms of bit per second per Hertz) can be defined as

$$C = \int_0^{\infty} log_2(1+\gamma)\, f_\gamma(\gamma)\, d\gamma \quad (12)$$

$$C = \int_0^{\infty} log_2(1+\gamma) \left[\frac{1}{\bar{\gamma}} e^{-\frac{(\gamma+s^2)}{\bar{\gamma}}} \sum_{i=0}^{\infty} \frac{1}{\Gamma(i+1)i!} \left(\frac{\sqrt{\gamma}\, s}{\bar{\gamma}}\right)^{2i}\right] d\gamma$$

$$C = \int_0^{\infty} \log_e(1+\gamma) \log_2 e \left[\frac{1}{\bar{\gamma}} e^{-\frac{\gamma}{\bar{\gamma}}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{i=0}^{\infty} \frac{1}{\Gamma(i+1)i!} \frac{\gamma^i s^{2i}}{\bar{\gamma}^{2i}\Gamma(i+1)i!}\right] d\gamma$$

$$C = \log_2 e \frac{1}{\bar{\gamma}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{i=0}^{\infty} \frac{1}{(i!)^2} (\frac{s}{\bar{\gamma}})^{2i} \int_0^{\infty} \log_e(1+\gamma)\, e^{-\frac{\gamma}{\bar{\gamma}}}\ \gamma^i\, d\gamma$$

The above equation can be evaluated by [5, Eq. (4.337.5)]

$$C = \log_2 e^{-\frac{1}{\bar{\gamma}}} e^{-\frac{s^2}{\bar{\gamma}}} \sum_{i=0}^{\infty} \frac{1}{(i!)^2} (\frac{s}{\bar{\gamma}})^{2i} \sum_{i=0}^{\infty} \frac{i!}{i-\mu!} [\frac{-i-\mu-1}{i-\mu}\ e\ Ei(-1) + \sum_{k=1}^{i-\mu} (k-1)!\,(-1)^{i-\mu-k}\ ] \quad (13)$$

Ei(.) is Elliptical intriguer

$$Ei\ (x) = -\int_{-x}^{\infty} \frac{e^{-t}}{t} dt = \int_{-\infty}^{x} \frac{e^t}{t} dt = li\ (e^x)\ [x < 0] [5,\ Eq.\ (8.211.1)]$$

Where γ is the instantaneous SNR at the destination and $f_\gamma(\gamma)$is the PDF ofγ.

i,µarerunning variable

IV. NUMERICAL RESULTS

The Rician fading model is presented in fig.1when the rice factor is 0 the channel works as Rayleigh distribution and average SNR is equal to the received SNR. When the value of rice factor is 1 the average SNR increases. Bit error rate analysis of binary phase shift keying modulated signal is shown in fig.4 which shows that the bit error is $10^{-1.9}$ when then value of SNR is 10 and K=0, at the same SNR when K=1 the bit error improves to $10^{-2.3}$. The outage probability is shown in fig.5at 10 dB SNR when the value of K=0 the outage probability is 10^{-1} and it improves to $10^{-1.8}$ when the value of K=1. The threshold of Rician fading channel is shown in fig.6 which is 5 for K=0 and improves to 8 when it K=1. The average channel capacity have been shown in fig.7 at SNR 5 it is 2 for K=0 and improves to 3for K=1.

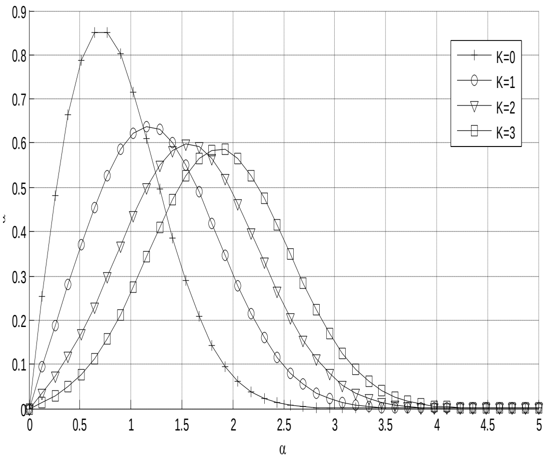

Fig 2.Fading Envelop PDF of Rician channel

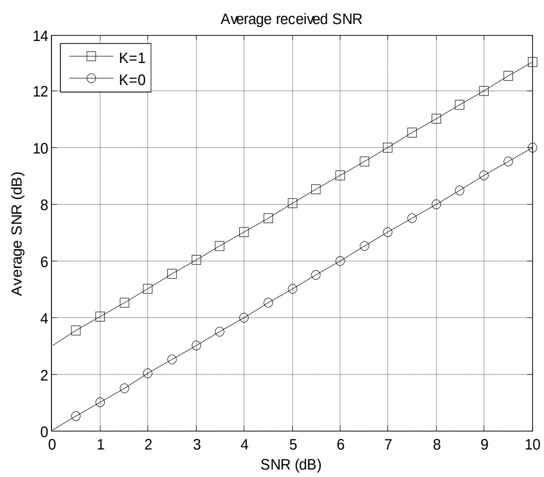

Fig 3. Average Received SNR ($\bar{\gamma}^{Rx}$)

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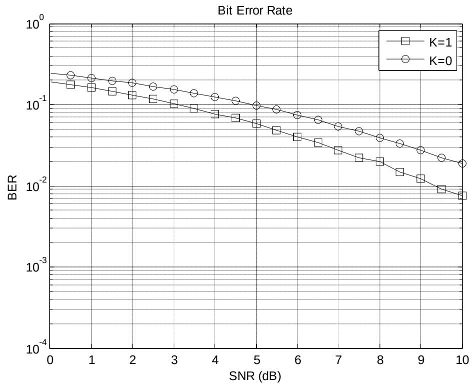

Fig4. Bit Error Rate for BPSK Modulated signal With respect to SNR

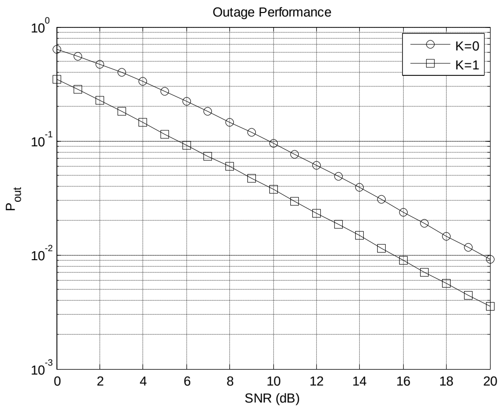

Fig 5. Outage Performance with respect to SNR

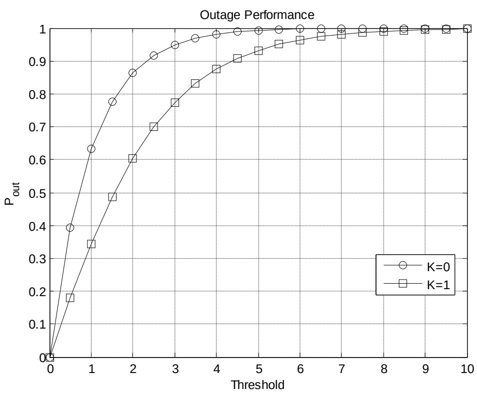

Fig6.Outage Performance with respect to Threshold (u)

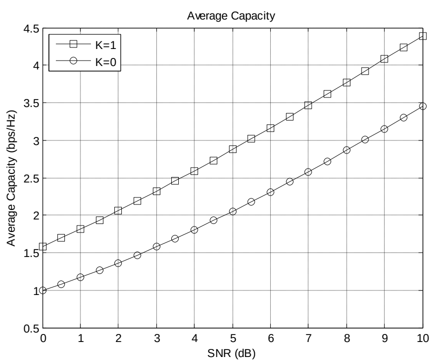

Fig 7. Average Channel Capacity

V. CONCLUSION

In this paper performance parameters of Rician fading channel is discussed. PDF of fading envelop of Rician fading is analysed which shows that when the value of rice factor increases probability of lower values of fading envelop decreases and higher values of fading envelop increases. Hence the outage performance, error performance, average received SNR and channel capacity improved for higher values of rice factor ‘K’.

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BIOGRAPHY

SuryakantPathak received his MCA, M.Tech in Computer Science & Engineering and pursuing Ph.D. in Wireless Communication from BBD University Lucknow, India. He had worked in Indian Air Force, 1983-2003. Faculty at DOEECC Centre, Madan Mohan Malviya University of Technology campus Gorakhpur(U.P.), India, 2004-2006. Lecturer at Amity University Lucknow (U.P.), India, 2007-2008. Assistant Professor at Sagar Institute of Technology & Management Barabanki (U.P.), India, 2009-2013.At present he is Associate Professor &Head of Department Computer Science & Engineering Dr. KN Modi University Newai, Rajasthan, India. His research

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interests include almost all aspects of wireless communications with a special emphasis on MIMO systems, MIMO-OFDM, spread spectrum system, cooperative diversity schemes.

Himanshu Katiyar received his B.E. degree in Electronics and Communication Engineering from M.I.T. Moradabad (M.J.P. Rohilkhand University, Bareilly) in 2001, M.Tech degree from Madan Mohan Malviya Engineering College, Gorakhpur (U.P. Technical University, Lucknow) in 2004and Ph.D. degree in the area of wireless communication at the Indian Institute of Technology, Guwahati, Assam India in 2011. From2004–2005 he was lecturer of Electronics and Communication Engineering Dept. at SRMSCET, Bareilly, Uttar Pradesh, India and from2005–2006 he was lecturer of Electronics and Communication Engineering Dept. at NIEC, Lucknow, and Uttar Pradesh, India. At present he is Associate Professor of the Electronics and Communication Engineering Dept. at BBDNIIT, Lucknow, and Uttar Pradesh, India. He was awarded from IETE research fellowship and he was project investigator (from September, 2009 to December, 2010) of an IETE sponsored research project. He has published over thirteen research papers in SCI journals, twelve research papers in non SCI journals and ten national/ international conference papers. His research interests include almost all aspects of wireless communications with a special emphasis on MIMO systems, MIMO-OFDM, spread spectrum system, channel modelling, infrastructure-based multi-hop and relay networks, cognitive radio communication, cooperative diversity schemes, adaptive array processing for Smart Antenna and Arduino based embedded system.