Modeling and Performance Analysis of Wireless Channel

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Abstract –Men is a social animal and he needs to communicate to the people around him. There is a great demand of information sharing which uses wired and wireless mediums to transmit information from one point to another. Wireless transmission is getting more and more attention and is the most popular method of information sharing. When a signal travels through the wireless medium it is affected by various phenomenon taking place in the wireless medium hence it becomes necessary to evaluate the performance of the wireless mediums. The characteristics and the quality of performance of the wireless medium can be measured by calculating its Capacity, Spectral Efficiency, Bit Error Rate (BER), Level Crossing Rate (LCR) and Outage Probability etc. The performance of the basic wireless channel i.e. Additive White Gaussian Noise (AWGN) channel, is calculated and analyzed by evaluating its Capacity, Spectral Efficiency, Bit Error Rate (BER) and Outage Probability. This work will be helpful to evaluate the performance characteristics of other more complex channel models better and thus build on the available models and implement various enhancements and add-ons that could possibly help in developing channels with better properties and perhaps, with an element of better security and authentication features.

Keywords –AWGN; Bit Error Rate; Capacity; Doppler Shift; Fading; Rayleigh; Rician; Outage Probability.

I. INTRODUCTION

Wireless communication is getting popularity by attracting people from every walk of life every day. These days' data is being generated at a tremendous rate and it requires transmitting this data from one point on the earth to the other point(s). Therefore, we require reliable and efficient wireless channel models which can reflect the actual behavior of the wireless channels in different environmental and weather conditions and can support the required application requirements. When a message signal travels via a wireless medium, the energy of the signal decreases due to some inescapable phenomenon and this phenomenon put restrictions on optimum performance of the wireless systems. Many wireless channel models are available in the literature, which reflect the approximate effect of the environmental conditions on information transmission. Wireless channels are very different from the wired and stationary channels due to randomness in their characteristics. There are many causes which results in the instantaneous behavior of the wireless environment like ground attributes from sender to receiver, weather conditions and motion of the sender or receiver or both. The environmental conditions of the wireless channels for both the indoor and outdoor environment have been the topic of interest for the researchers for many years. The strength of the message signal at any particular instant of time could be estimated with the help of conventional large-scale and small-scale models.

Local variations of average signal strength can be represented by the small-scale channel models and the large-scale models can predict the average strength of received signal as a function of path length between sender and receiver. The lognormal model can emulate the large-scale fading effects for various wireless channel mediums, where the normal distribution shows the measured strength of the received signal about the average received signal strength. Keeping all the above mentioned conditions in mind, we discuss the AWGN, Rayleigh and Rician fading channels and evaluate AWGN channel performance by calculating its Capacity, Outage Probability, Bit Error Rate (BER) and Spectral Efficiency with respect to the signal to noise ratio (SNR) and analyze its performance and make conclusions based on our analysis.

Paper Organization: This work is arranged as follows: In section III, we discuss fading phenomenon and types of fading in different wireless channels. In section IV we analyzed the performance of the wireless channels in terms of capacity, spectral efficiency, and outage probability. Section V summarizes results and effect of SNR on the various performance parameters of the wireless channels like capacity and outage probability etc. Section V discusses the various conclusions drawn from the analysis of the wireless channels and the future scope of the work.

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I. II. RELATED WORK

When a message signal travels through a wireless medium its strength decreases due to various natural causes like reflection, refraction, scattering and fading. In order to evaluate the effect of wireless channels various models are given by different researchers. In [1], authors characterized the mobile-to-mobile Rician fading channels for mobile-to mobile communication when both the receiver and transmitter are in motion. Similarly in [2], co-channel interference from an annular field of Poisson cluster distributed interferers is modeled and authors develop a unified framework for analyzing interference models for various wireless network environments. Sensing technique also plays a vital role to reduce the complexity of the channel model as discussed in [3]. Security of the information traveling over a wireless medium is a great concern. Hence an encryption method called Perfectly Secure Message Transmission (PSMT) has been developed which provides a stronger security level than computational security and its performance has been evaluated for Multi-channel transmission on wireless sensor networks [4]. In [5], an opportunistic transmission method has been proposed and this method has been analyzed for Rayleigh fading channels. Results show that this method helps in mitigating fading effects and is less sensitive to co-channel interference. In order to use spectrum appropriately a spectrum sensing methodology for various wireless fading channels in a Cognitive radio network has been proposed in [6].The performance of Nakagami-m fading channels is much better than the other fading channels using this technique. A multiple-input multiple-output (MIMO) baseband fading channel simulator is developed with the help of a field-programmable gate array (FPGA) which can simulate many other spatio-temporal correlated fading channels along with independent and identically distributed channel model [7]. Nakagami-m fading channels models approximates wireless channel behavior more precisely than the other wireless channel models to analyze the performance of the wireless communication system as discussed in [8]. Various models have been derived to evaluate the impulse response of the wireless channels. In [9], wireless communication performance over $\alpha-\eta-\mu$ fading channels in terms of signal-to-interference ratio and outage probability has been studied. Effect of the metallic channel on the signal strength at 60 GHz has been analyzed in [10] and the results show that root mean square (RMS) delay spread of the concerned environment is reduced up to a significant level by covering the walls with an absorbing material. In [11], authors use spherically invariant random processes (SIRP) to model fading in wireless communication as SIRP are differential-entropy maximizes. Authors also derive the spherically invariant fading distributions for a given SNR and calculate the best and worst performance at the same SNR. Users' behavior and the wireless device orientation affect the network performance. The signal quality with the usage of device, angles of orientation, and the connected Networks is also analyzed for both voice and data communication in [12]. Another approach known as least square (LS) is used to estimate the channel state information (CSI) which helps to analyze the bit error rate performance of a cognitive radio scenario of the wireless channel as discussed in [13]. In [14], authors evaluated the performance of the (MIMO) Rayleigh fast-fading channels under correlated environment.

II. III. FADING IN WIRELESS CHANNELS

When a message signal travels through a wireless medium, the strength of the message signal deteriorates i.e. the amplitude, phase or both vary with time or space. Fading can be considered as the speedy variations in the phases, amplitudes, or multiple path time delays of a message signal over a small duration of time or travelled path length hence fading is one of the major issue in wireless communication. Therefore it becomes necessary to include the effect of fading caused by different travel distances for performance measurements and accurate designs of wireless communication schemes. It is well known that the accurate behavior of the wireless medium cannot be predicted but we can pursue our efforts to obtain as much precision as possible.

A. A. Factors Resulting Fading

There are various physical phenomena which results in fading of the radio signal propagating in a wireless medium.

Reflection:

When a wave propagating in a medium falls on the surface of an object having dimension larger than the wavelength of the propagating wave then the travelling wave is bounced back into the medium in which it was propagating, this is known as reflection [15]. Whether a propagating wave will get reflected completely or some amount of energy will be absorbed by the medium it depends on the type of objects' material. In this way, a wave traveling in a wireless medium loses energy and caused fading of the message signal. Reflection takes place from the walls, buildings and the surface of the earth etc.

Doppler Shift:

Talking while walking is a well-known fact, i.e. we see people around us talking over mobile phones while moving. When we talk during motion there is relative motion between the mobile transmitter and the mobile or stationary receiver due to which carrier signal frequency changes according to the speed of the mobile user or transmitter. This variation in the frequency of the carrier signal due to the motion of the transmitter or receiver or both is known as Doppler Shift. Doppler Shift is one of the main reason of the fading of the message signal.

Scattering:

When an electromagnetic wave travels in a medium having various obstacles with size smaller than the wavelength of the message signal then the message signal faces scattering [15]. The main reasons of the scattering of waves are the objects in the environment having dimensions smaller than the wavelength of the message signal, rough surfaces and irregularities in the channels etc. In practical scenario objects like electrical poles and street signs etc. causes scattering of the message signal in a wireless environment.

Diffraction:
When the path of a radio signal is obstructed by the objects having dimensions comparable to the wavelength of the radio signal then the radio waves bends around the corner of the object this phenomenon is known as diffraction of the radio waves. The amount of bending of the radio waves depends upon a number of factors like the amplitude, polarization and the phase of the incident wave and the size and the geometry of the obstacle at the point of diffraction. At higher frequencies diffraction is similar to the phenomenon of reflection.

B. B. Types of Fading

Fading is classified on the basis of channel variations like multipath time delay spread which results into two types of fading namely frequency selective fading and flat fading.

Flat Fading:
It is well known that the characteristics of the wireless medium changes with time due to which message signals travelling through the medium deteriorates. The Signal suffers from reflection, refraction, diffraction and scattering etc. due to which various components of the message signal reach the receiver at different instants of the time [15]. The received components of the signal have different phases and amplitudes. When the bandwidth of the message signal is less than the coherence bandwidth of the channel then every component of the message signal has same gain and linear phase gain over the coherence bandwidth of the channel. This phenomenon is known as flat fading. When a message signal undergoes flat fading its spectral characteristics remains unchanged while reaching at the receiver.

Frequency selective fading:
A message signal at the receiver end is said to experience frequency selective fading when the coherence bandwidth of the channel is less than the bandwidth of the message signal [15]. In this situation different components of the message signal gets different gains and phase variations are not linear for all the components. Moreover, the delay spread of the message signal is more than the symbol period within the channel which causes inter-symbol interference (ISI). Inter symbol interference results different gains to different frequency components.

Fading Caused by the Doppler Shift:
Whenever the transmitter or receiver is in motion the frequency of the propagating signal varies with speed of the mobile user or transmitter, this change in the frequency of the transmitted signal is termed as Doppler Shift. Two types of fading is caused by Doppler Spread which are mentioned below.

Fast Fading:
As mentioned above whenever the transmitter or the receiver are in motion, the strength of the propagating signal varies rapidly. When the wireless channel characteristics changes at a rate lesser than the symbol duration then the channel is said to have fast fading effect [15]. In other words the coherence time of the of the channel is less than the symbol period i.e. the channel variations are faster than the base band signal variations which causes signal distortion. Fast fading takes place for low data rates and increases with speed of the transmitter and receiver.

Slow Fading:
When the wireless channel characteristics changes at a rate greater than the symbol duration then the channel is said to slow fading effect [15].In other words the coherence time of the channel is greater than the symbol period i.e. the channel variations are slower than the base band signal. Moreover, it is known that the channel's Doppler Spread is lesser than the bandwidth of the baseband signal. The velocity of objects in the wireless channel and the velocity of transmitter and receiver and the baseband signaling defines whether a signal undergoes slow fading or fast fading. Time rate change of wireless channel characteristics and the baseband signal are dealt with the help slow and fast fading models.

IV. PERFORMANCE ANALYSIS OF WIRELESS CHANNELS

A wireless channel performance is evaluated by calculating its Channel Capacity, Bit Error Rate (BER), Spectral Efficiency, and Outage Probability etc.

1. AWGN Channel:
AWGN channel is the basic wireless channel which adds Gaussian noise to a baseband signal passing through the wireless medium. AWGN channel performance is analyzed by calculating its Capacity, Spectral Efficiency, Outage Probability and Bit Error Rate (BER) etc.

Capacity:
The Capacity of a wireless channel is defined as the highest data rate which can be supported by the channel while maintaining the minimum quality of the reliable communication. Shannon-Hartley was the first person who represented the capacity of an AWGN channel mathematically.
Shannon-Hartley equation for the Capacity of an AWGN channel:

$$C = \mathrm{B}\log_2(1 + SNR) \quad (1)$$

Where,

SNR=Signal to Noise Ratio (the ratio, and not in dB)
B=Bandwidth of AWGN channel (in Hz)
C=Capacity of AWGN channel (in bits/sec)

The capacity of AWGN channel can also be written as:

$$C_{awgn}(\mathrm{P}, \mathcal{W}) = \mathcal{W}\log\left(1 + \frac{\mathrm{P}}{N_0\mathcal{W}}\right) \text{ bits/s.}$$

(2)

The significance of the above equation is as follows:
Resources of the wireless channel define its performance.

- Received power per symbol (Watts). Represented by$\mathrm{P}$.
- Bandwidth of the channel (in Hz). Represented by$\mathcal{W}$.

- $\mathrm{P}/N_0\mathcal{W}$ = Received SNR

Effect of Power per symbol Pon the capacity of AWGN channel:

$$C_{awgn}(\mathrm{P},\mathcal{W}) = \mathcal{W}\log\left(1+\frac{\mathrm{P}}{N_0\mathcal{W}}\right) \quad (3)$$

It is called bandwidth limited region because it is linear in bandwidth and logarithmic in power.

When SNR << 0 dB

Capacity (in bits/sec) = $\frac{\mathrm{P}}{N_0}\log_2 e$ (4)

Since it is insensitive to bandwidth and linear in power hence it is called the power limited region. It has been observed that doubling power doubles the capacity.

Effect of Bandwidth on the capacity of AWGN channel:

The bandwidth of the AWGN channel affects its Capacity in two different ways:

1. The bandwidth of an AWGN increases degree of freedom usable for communication. It can be realized in the linear dependency on $\mathcal{W}$ for a fixed $SNR = \mathrm{P}/N_0\mathcal{W}$.

2. Suppose P is the received power of the signal, and we increase the bandwidth of the channel then the SNR per dimension decreases with bandwidth as the energy gets distributed more lightly among the degrees of freedom. It is analytically calculated and found that capacity of an AWGN channel is an increasing function of the bandwidth$\mathcal{W}$.When the signal to noise ratio is high and the bandwidth is small then small variations in the bandwidth do not affect the capacity of the AWGN channel. But when the bandwidth is increased, the capacity of the AWGN channel also increases because increase in the degree of freedom balances for the decrease in SNR. Thus, the system is in the bandwidth-limited region.

When the bandwidth is high and signal to noise ratio for each degree of freedom is small then,

$$\mathcal{W}\log(1+\mathrm{P}/N_0\mathcal{W}) \approx \mathcal{W}(\mathrm{P}/N_0\mathcal{W})\log_2 e = \mathrm{P}/N_0\log_2 e \quad (5)$$

Here,wireless channel capacity is proportional to the *total* received power all around the entireband. Now, the capacity of the channel is not affected by the variations in the bandwidth. Moreover the capacity of the channel increases with the increase in the received power linearly.

$$C_\infty = \frac{\mathrm{P}}{N_0}\log_2 e \text{ bits/sec} \quad (6)$$

The capacity of the AWGN channel is much affected by the received power and the bandwidth of the channel.

Spectral Efficiency:

Spectral efficiency is the measure of how efficiently the bandwidth of the channel is being utilized and it is defined as the number of bits per unit bandwidth and per unit time that can be communicated over the wireless channel reliably.

$$C_{awgn}\log_2(1+SNR)\text{bits/sec/Hz} \quad (7)$$

Spectral efficiency of an AWGN channel increases with the increase in SNR at a very slow rate.

Bit Error Rate:

Bit error rate is the main performance parameter of a wireless channel and is defined as the number of error bits found in a given bit sequence at the receiver end. Bit error rate depends on the value of SNR. It decreases with the increase in SNR.

Outage Probability:

In a wireless environment the properties and the behavior of the channel keeps changing at every instant of time. It is not possible to determine the exact behavior of the wireless channels because the received signals don not have constant power which depends on the channel, hence the power of the received signal cab be calculated probabilistically. Due to random nature of the channel SNR also becomes a random variable hence channel capacity is also a random variable. Outage Probability is defined as the probability that a required data rate will not be supported by the channel due to the variations in SNR at the receiver end and is given by:

$$\mathrm{P}_{out}(R) = \mathrm{P}\{\log(1+|h|^2 SNR) < R\} \quad (8)$$

III. IV. RESULTS IMPLEMENTATION & TESTING

Here, we discuss various simulation results obtained after implementing the various wireless.

A. A. Effect of Power per Symbol and Bandwidth on the Capacity of the channel.

In this part we mention the effect of the Power Per Symbol when SNR values are much higher and much lower as compared to 0 dB.

TABLE I. TABLE I.OUTAGE PROBABILITY STATISTICS AT VARIOUS SNR VALUES

No. of Bits	*SNR(dB)*	*Mean*	*Median*	*S.D*
2^15	10	3.7294	3.8789	1.4763
2^15	20	4.6253	4.8291	1.5933
2^15	30	5.1813	5.4222	1.6484
2^15	40	5.5904	5.8283	1.6759
2^15	50	5.8966	6.1395	1.6908

a. S.D. is the standard deviation

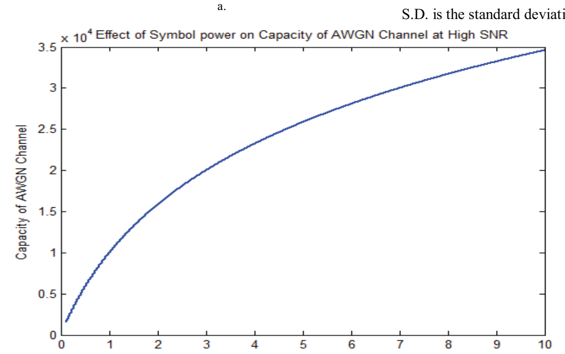

Fig.1. AWGN channel capacity as a function of high SNR

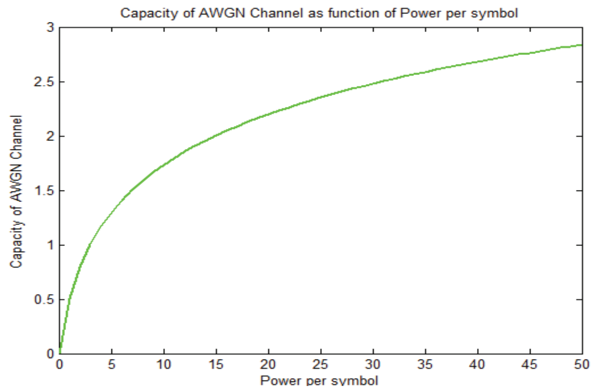

Fig..2. AWGN channel Capacity as a function of power per symbol with noise variance

1. Capacity of AWGN Channel as a function of Power per Symbol at high values of SNR (SNR >> 0 dB):

The capacity of an AWGN channel increases logarithmically in power, and linearly in bandwidth when the SNR is >> 0 dB, and hence this region is called band-limited region as shown in fig. 1. & fig. 2.

2. Spectral Efficiency as a function of SNR:

Spectral Efficiency of AWGN channel increases with the increase in SNR at a very slow rate as shown in fig. 3.

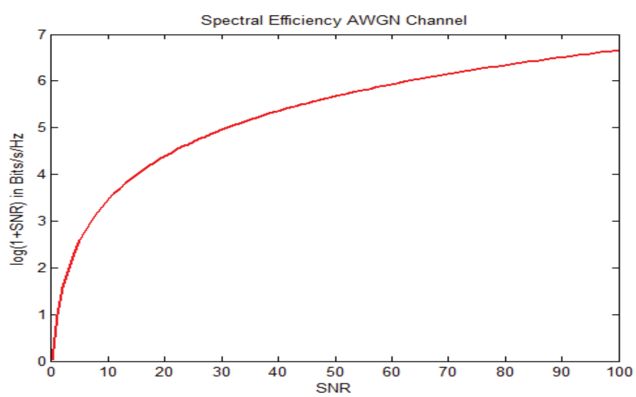

Fig 3.Spectral efficiency as a functionof SNR

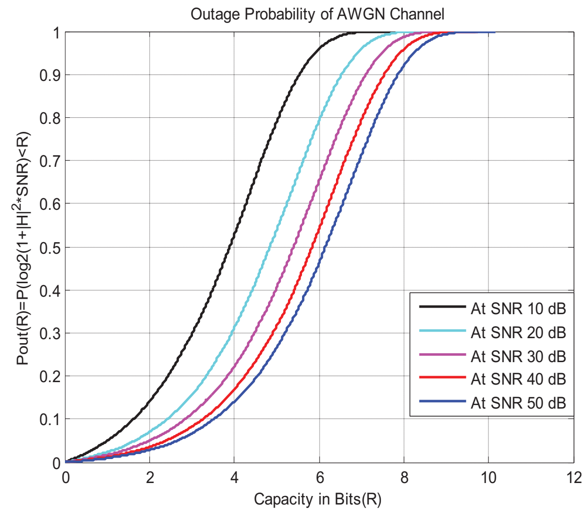

Fig 4. Outage probability at a specified SNR range

3. Outage Probability for AWGN channel at a specified range of SNR:

The Outage Probability of AWGN channel reduces when the signal to noise ratio is increased as shown in figure 4.

V. CONCLUSION AND FUTURE SCOPE

In this work, we have analyzed that the performance of the wireless channel (here, AWGN) depends on its parameters like bandwidth, power per symbol, etc. We have drawn the following inferences from our analysis:

AWGN channel capacity is a function of signal to noise ratio and increases with the increase in signal to noise ratio.

- When the signal to noise ratio is high, AWGN channel capacity increases logarithmically in power, and linearly in bandwidth.
- When the signal to noise ratio is low,AWGN channel capacity increases linearly in power, and insensitive to bandwidth.
- Efficiency of an AWGN channel increases with the increase in SNR at a very slow rate and moves towards the saturation point.
- BER of AWGN channel decreases with the increase in SNR. 0 BER is obtained at higher values of SNR as we increase the Frame length.
- The Outage probability of AWGN channel decreases with the increase in SNR. The curve becomes less steep with the increasing signal to noise ratio.

Outage probability is a function of the gain of the channel. Since the gain is random, hence the outage probability is also random and it varies according to the random gain of the channel depending on the environment.

- The BER for the Rayleigh fading channel with AWGN is very random and fluctuates from very high values to low values and do not attain a stable state with the increase in SNR.

- The BER for Rician fading channel with AWGN decreases with the increase in SNR and attains a stable state at high values of SNR with little fluctuations.

IV. VI. FUTUTRE SCOPE

When an electromagnetic wave is transmitted through a wireless medium it encounters various natural phenomena like reflection, scattering and diffraction which cause fading and distortion of the message signal. The power of the propagating signal reduces as the wave travels through the medium. Since a wireless channel shows random variations in their behavior hence it is not possible to model their behavior accurately. Therefore, many probabilistic models have been developed to analyze the random response of the channels. Since fading causes severe damage in the quality of the message signal it becomes necessary to analyze the effect of fading on the propagating signal in the wireless environment. AWGN channel is one of the fundamental wireless channels whose performance is analyzed in terms of capacity, spectral efficiency and outage probability with respect to the SNR. This work will help to model the other complex fading channel like Rayleigh and Rician fading channels. Some of the most used methods of mitigating fading effects is with the help of:

- MIMO
- Orthogonal Frequency Division Multiplexing (OFDM).
- Rake Receivers

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