

A Performance Evaluation of Multi-User Time-Variant Multipath Channel Model Operating at 2400MHz and 5300MHz for Various Power Spectrum

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Abstract -- There has been a significant advancement in the field of wireless communication networks. The main aim of the development is to provide a higher data rates even under complex channel environments. This has necessitated in modeling the propagation channel under complex environmental conditions. The paper focuses on developing a channel model and scrutinizes the effect of various channel impairments under adverse environments in which mobile networks operate. The physical environmental phenomena considered are types of terrains, Doppler shift, multipath fading and propagation. A tapped delay line based channel line model has been implemented and analyzed and the performance of the channel was studied for time variant input. In the results of the simulation it was observed that there is no significant influence of carrier frequency and the number of taps needed in TDL comes to be around 8. Considering the environments with respect to the mobility it is observed that Jakes Doppler Spectrum is best suitable for intense mobility urban environmental conditions. Whereas the Gaussian Doppler spectrum is observed to be best suitable for low mobility urban environments and for hilly terrain under low and high mobility.

Keywords — Complex channel environments, Channel model, Doppler shift, Tapped Delay Line (TDL) , Jakes Doppler Spectrum, Gaussian Doppler spectrum.

I. INTRODUCTION

BACKGROUND AND MOTIVATION

One of the prime significant factors that affect the radio wave propagation through wireless channels is multipath fading and the shadowing. The nature of the wireless signal are due to numerous phenomena such as line of sight path linking the transceiver antennas, reflection, refraction and diffraction, the relative motion between the transceivers, the attenuation of the signal as it travels through the medium and finally the noise induced in the propagating signal. In order to obtain the reliable commutation over a wireless communication system, propagation channel plays a very vital role in accurately recovering the transmitted signal at the receiver end as most of the above mentioned factors are main contributors that affect the propagation channel. Thus this has paved in flawless characterization and modeling of propagation channel under complex time-varying environments. The multipath fading is due to the arrival of signals with different amplitudes and phase at the receiver side. The broad categorization of such a fading signal is Large Scale Fading and Small Scale Fading [1][3][16][18]. The representation of the path loss due to motion over a large surface area is coined as Large Scale Fading. The result of small changes due to the spatial separation between transceivers will creates a rapid fluctuations in signal phase and amplitude is termed as Small Scale Fading. The small scale fading results in two manifestations mechanism namely time-spreading of signal and time-variation with respect to propagating channel. The multipath fading channel characterization depicted in Figure 1. The paper focuses on study of the channel characterization based on the physical phenomenon such as multipath propagation, type of terrains, and Doppler shift due to motion of the mobile[17]. The paper further aims in developing a radio channel model and examining the impact of various parameters on the behavior of the channel under the varying environmental state of affairs over which the wireless communication network operate.

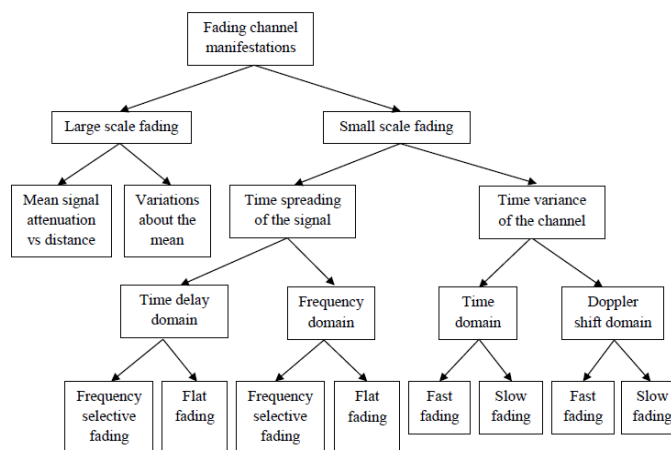


Figure 1. Fading Channel Manifestation.

A. Small-Scale Multipath Propagation

Small scale fading is mainly due to multipath in the radio channels. The three most important effects are:

- Propagation signal will undergo rapid changes over a period of time or as a distance varies;
- Observation of random frequency modulation due to Doppler shifts on diverse multipath signals; and
- Multipath propagation delays causing time dispersion.

One of the major reasons for multipath fading effect in Urban environmental conditions is the heights of building and height of the antenna, so there might not be the a single LOS path between transceiver system. Even if LOS exists there would be other reflected signal from other surrounding surfaces which aids for the multiple received signals at the receiver. The only advantage of the multipath effect is that it helps in successfully establishing the correlation between the transceiver even if the LOS is not established. Thus it successfully over comes the all the obstacles and establishes the communication. The three major impairments that are caused due to this is delay spread, interference between the multiple paths connecting the transceivers which can be termed as Rayleigh Faded signal, random frequency modulation due to Doppler shift on the different paths [4].

The three main propagation mechanisms that govern the radio wave propagation are *a*. Reflection, *b*. Refraction and *c*. Scattering. The effect of these three propagation mechanism will help to categorize the received signal into Multipath fading, Large-Scale Path loss and Large-Scale Shadowing. Radio links in the metropolitan environment are densely effected by above mentioned propagation mechanism, causing the signal to severely degrade.

B. Delay Spread

The channel impulse response in the wireless channel appears like a series of pulses. The maximum time difference between the arrival of the initial and final multipath signal that move towards the receiver and which is a function of the transmission environment is termed as delay spread. Here the direct path signal will approach the receiver first and then the multipath reflected signal will later turn up [2]. Because of this consequence the receiver will intercept the signals from different paths at different time instances of time which is showcased in Figure 2.

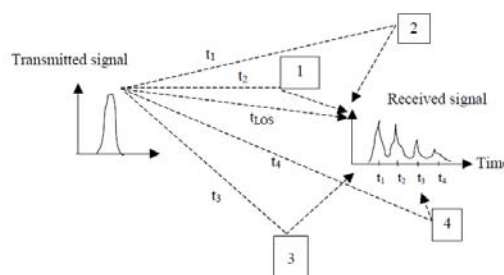


Figure 2. Multipath Delay Spread.

Various multipath channels are compared using the parameters that quantify a multipath channel [6][7]. The profile of power delay is used to determine the mean excess delay and root mean square delay spread. The mean excess delay is the first moment of the power delay profile and is defined to be

$$\bar{\tau} = \frac{\sum_K a_K^2 \tau_K}{\sum_K a_K^2} = \frac{\sum_K P(\tau_K) \tau_K}{\sum_K P(\tau_K)} \quad (1)$$

where a_k is the amplitude of the k^{th} signal, τ_k is the time of the k^{th} signal, and $P(\tau_K)$ is the absolute power level of the k^{th} signal. The rms delay spread is the square root of the power delay profile and is defined [6] to be

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \quad (2)$$

Where

$$\overline{\tau^2} = \frac{\sum_K a_K^2 \tau_K^2}{\sum_K a_K^2} = \frac{\sum_K P(\tau_K) \tau_K^2}{\sum_K P(\tau_K)} \quad (3)$$

The path, reflectivity and distance between the echoing object viz structures, mountain peaks, and many other surrounding objects. In open-air mobile radio channels conditions the rms delay spreads turns out to be few microseconds whereas in the closed conditions it is comes to nanoseconds [6]. The received signal to noise ratio and the presence of the significant multipath components will aid to the high delay spread.

C. Rayleigh and Ricean Fading

The multipath propagating signal will interfere constructively or destructively thus the received signal will experience a phase and magnitude variations. The Rayleigh distribution is a case when there is no single significant domination at the receiver end. If the contribution is there by a single dominant signal then there would be LOS path is created and the conclusion would be that it follows Ricean distribution. The work mainly highlights on Rayleigh fading [5].

a) Rayleigh Distribution

Rayleigh fading is also known as small scale fading [2] there are no LOS signal components but it yields the multiple reflective components. The signal appears at the receiver with the signal affected by the reflection, diffraction or scattering from the surrounding environmental obstacles. The signal encounters the NLOS path between transceiver stations. The following equation gives the descriptions about the envelope of the received Rayleigh probability density function (pdf)

$$f_R(r) = \begin{cases} r/\sigma^2 \exp[-r^2/2\sigma^2] & \text{for } r \geq 0 \\ 0 & \text{for } r < 0 \end{cases} \quad (4)$$

where the envelope amplitude of the received signal is symbolized by r and σ is the rms value of the received voltage signal before envelope detection.

b) Ricean Distribution

The Ricean fading is the consequence of the signal occurring at receiver due to LOS and also due to the multipath phenomena

The deterministic component is added by LOS to the multipath signal whose pdf given by

$$f_R(r) = \begin{cases} r/\sigma^2 \exp - (r^2 + A^2)/2\sigma^2 I_0(Ar/\sigma^2) & \text{for } A \geq 0, r \geq 0 \\ 0 & \text{for } r > 0 \end{cases} \quad (5)$$

where A is the peak amplitude of the dominant signal and I_0 is the zero-ordered modified Bessel function.

The result of the random disperse is termed as the ‘‘Diffuse’’ component and ‘‘Direct’’ component is mainly due to LOS component [8]. Therefore, in Ricean fading there is the existence of both diffuse and direct component. The Ricean distribution is often gauged by the ratio of the power of the direct component to the power of the diffuse component. Ricean factor, K , given by

$$K(dB) = 10 \log \left[\frac{A^2}{2\sigma^2} \right] \quad (6)$$

K approaches to infinity while the peak amplitude A approaches zero, then there does not exists any direct path and the Ricean distribution transforms into Rayleigh. The Ricean distribution LOS component provides a steady signal and intends to reduce the effects of fading.

D. Doppler Effect

The radio channel experiences the time-varying channel because of the motion between the transceiver resulting in path variations. The relative movement between the transceiver would lead to the Doppler effect [6]. The frequency variation f_d gives the relative movement between the mobile and the source station. The Doppler shift is given by

$$f_d = \frac{1}{2\pi} \frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda} \cos \theta \quad (7)$$

Where $\Delta\theta$ is the phase changes during time Δt , v is the mobile velocity, λ is the wavelength of the incident wave and angle of incidence is denoted by θ .

Equation (7) relates the Doppler shift to the mobile velocity and the spatial angle between the directions of motion. The Doppler shifts approaches to be positive if the mobile receiver heads in the same path as that of direction of the wave arrival; received frequency increases apparent. However, the Doppler shift is negative if the mobile is moves away from the direction of arrival of the wave; received frequency is decreased. The contribution to the Doppler Spreading of the signal received is because of the advent of the multipath components that approaches the receiver from multiple routes, thus increasing the signal bandwidth.

E. Impact of Atmosphere on wireless channel

The significant impact on the wireless propagating channel is the atmospheric effect that it undergoes due to the surrounding environmental conditions, other than the scattering and reflections; absorption is one of the prime causes. The molecular absorption by oxygen will significantly attenuate the signal ranging between 60000 and 118000 MHz and due to water vapor in the 22000, 183000 and 325000 MHz bands [2].The most noteworthy result is due to the showers where the energy absorption and scattering are the major effects that a signal undergoes.

The frequency selective absorption characteristics of the atmosphere can be estimated by a transfer function is depicted in equation 8 [9]:

$$H(f) = H_0 \exp\{j0.02096f[10^6 + N(f)]l\} \quad (8)$$

where H_0 is a constant and is the complex refractivity of the atmosphere in parts per million $N(f)$

F. Additive White Gaussian Noise

Other than the impairments mentioned earlier a wireless propagating channel has to undergo effects imposed by AWGN. It is one of the limiting factors in the performance of the communication system. Independently every transmitted symbols is affected. The term “additive” means that the noise is superimposed to the signal and it becomes intrinsic component of the transmitted information.

AWGN channel is one of the simplest practical models of wireless transceiver system [10].This system is showcased in the Figure 6. Notation ‘A’ indicates the path loss, and received signal $y(t)$ also encompasses the noise which is given by

$$y(t) = Au(t) + n(t) \quad (9)$$

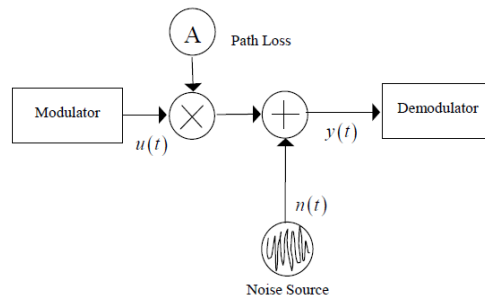


Figure 6. The AWGN Channel Communication System.

In the wireless terrestrial communication channels are usually modeled as multipath channels as the propagating signal adopts multiple paths.

II. WIRELESS CHANNEL MODEL UNDER TIME-VARYING TERRESTRIAL ENVIRONMENT

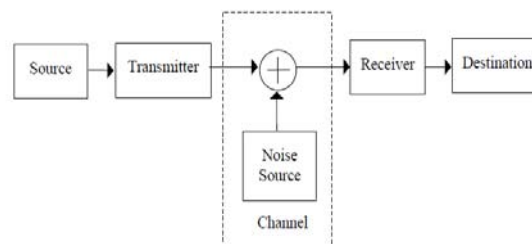


Figure 7.Illustration of Effective Base Band Wireless Channel PHY Layer

The common structural design of a communications system[8] [11] is showcased in Figure 7. When there is a transmission from the source to the destination, suitable conversion of the data is carried out at each stage before being transmitted over a time-varying channel. The signal transformed by the time-varying transmission channel making it difficult to recover receiver. It is therefore required to design a receiver which is capable of overcoming such unpredictable modification and be able to deliver the information to its destination with controlled errors.

A. *Multipath Fading Channel Model*

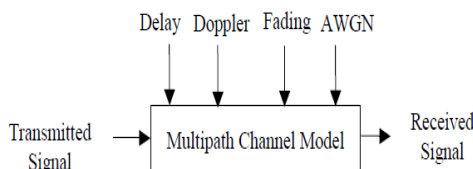


Fig 8 Multipath Channel Model and associated parameters

Various wireless channel models have been put forth for characterizing time-variant multipath channels. Most of them have utilized the random process technique for characterizing the fading channel [15][18]. By this it is easy to describe the mobile wireless radio channel as random, time-variant linear channel as changes in environmental conditions would affect the wireless channel characteristics to vary randomly and also bring around the changes in the signal received. Figure 8 illustrates the major associated parameters to be considered for modeling a multipath channel model.

The diffuse and discrete multipath channels are the two broad categories of the channel models. The multipath signals are amass of a comparatively small and recognizable number of components reflected by small valleys, towers, and surrounding structures encountered in open areas and suburban environments [10]. While modeling a wireless time-variant channel restricted number of multipath components is accounted. Such a channel modeling is appropriate to rapidly time-varying environmental conditions and is coined as a discrete multipath channel.

In some mobile radio channels, the received signal also composed of an interrelationship of components arriving from various paths [10]. The diffuse multipath channel is mainly due to the dispersion and reflection from very large terrains.

For modeling the channel a linear time-varying system with a complex low pass impulse response $\tilde{c}(\tau, t)$ for both the cases mentioned above [10]. For N discrete multipath components, the resultant of the channel consists of the summation of N delayed and attenuated versions of the transmitted signal as given by

$$\tilde{y}(t) = \sum_{k=1}^{N(t)} \tilde{h}_k(t) \tilde{s}(t - \tau_k(t)) \quad (12)$$

where $\tilde{h}_k(t)$ are the complex attenuation coefficients, $\tilde{s}(t)$ is the transmitted signal, $\tau_k(t)$ is the delay of kth multipath at time t, and N(t) is the number of multipath components. The impulse response of this representation can be represented by

$$\tilde{c}(\tau, t) = \sum_{k=1}^N \tilde{h}_k(t) \delta(\tau - \tau_k(t)) \quad (10)$$

The mobile radio channel uses both diffuse and discrete multipath. A range of models have been devised under variant operating conditions [10]. Both the models are identical and they made-up of tapped delay lines whose gains tend to be complex Gaussian random processes. The major distinguishing factor between the two models are the average power, number of taps, the spacing between tap, and the power spectral density (PSD) related with each tap gain. Here the main focus is on the discrete multipath delay components.

B. Tapped Delay Line (TDL) channel model

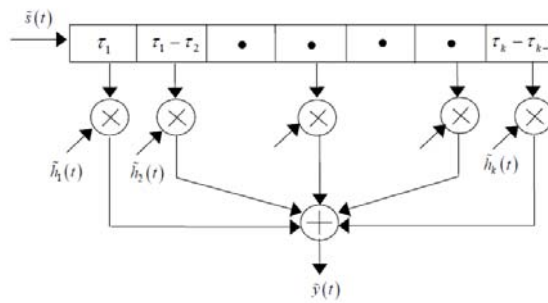


Figure 9. Variable-delay TDL model.

Figure 9 illustrates the structure of variable-delay Tapped Delay Line Model with time varying coefficients [10]. The prime cause for the distortions is due to the scattering components with dissimilar propagation delays. The signal that is being received is poised of weighted replicas of the transmitted signal and an infinite number of delayed. The notation of the above Figure 8 are $\hat{s}(t)$ is the transmitted signal, t are the complex attenuation coefficients, $h_k(t)$ is the delay of the k multipath at time t and $y(t)$ is the output signal.

The problem possessed by the variable-delay TDL model is that the delays are not integer multiples of T_s [10]. This problem will lead to extreme sampling rates, resulting in unacceptable computational results.

The solution to above mentioned problem is band limiting the time-variant frequency selective channel. A uniformly spaced TDL as illustrated in Figure 10. The band limiting filter is an ideal rectangular filter. The bandwidth of the filter is equal to that of the signal. Equally spaced TDL given by equation 11 which helps in obtaining tap gains

$$h_k^{\sim}(t) = \int_{-\infty}^{\infty} c(\tau, t) \text{sinc}(B(\tau - nT)) d\tau \quad (11)$$

where B is the signal bandwidth.

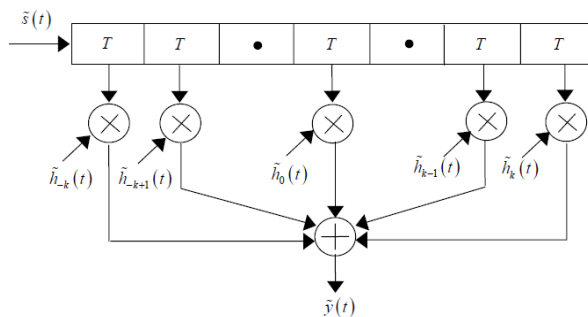


Figure 10. Uniformly spaced TDL model.

Substituting Equation (10) into Equation (11), which yields the equation for the representation of tap gains:

$$h_k^{\sim}(t) = \int_{-\infty}^{\infty} \sum_{n=1}^N \hat{a}_n^{\sim}(t) \delta(\tau - \tau_k) \text{sinc}(B(\tau - nT)) d\tau \quad (12)$$

and integrating Equation (15) would result in:

$$h_k^{\sim}(t) = \sum_{n=1}^N \hat{a}_n^{\sim}(t) \text{sinc}(\tau_k - nT) = \sum_{n=1}^N \hat{a}_n^{\sim}(t) \alpha(k, n) \quad (13)$$

Where

$$\alpha(k, n) = \text{sinc}((\tau_k/T) - n) \quad (14)$$

and T is the sampling period.

C. Generation of Tap Gain Process

The tap gain processes are termed as stationary random processes with a known PDF (probability density function) and PSD (power spectral density) [10]. The discrete multipath model implementation involves basically two main steps. The initial step is the generation of white Gaussian processes. The tap gain processes assumes them to be uncorrelated and complex zero-mean Gaussian processes. Using Doppler filter the Gaussian processes are filtered the tap gain processes are being generated which is depicted in Figure 11. The shaping of the PSD of these processes to that of the Doppler spectrum at each tap location is carried out in subsequent step.

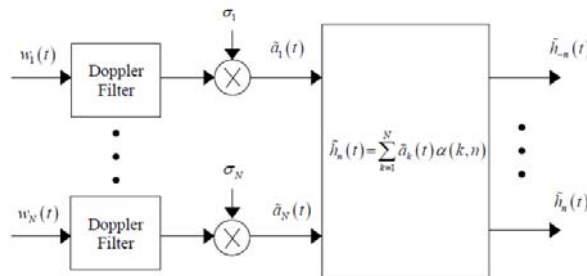


Figure 11. Generation of the tap gain processes.

D. Doppler Power Spectrum

Since there are large quantities of drops in a pulse volume, they will each provide their own backscattered power and Doppler shift. The Doppler spectral requires only real-valued filter to accomplish the shaping [10]. The following equation gives the transfer function of the shaping filter's amplitude:

$$|H(f)| = \sqrt{S(f)} \tag{15}$$

where $S(f)$ is the DPS of the filter. Depending upon the environment conditions, three Doppler spectra can be stated: Flat, Gaussian and Jakes.

a) Flat Spectrum

The flat spectrum will have a rectangular shape and it is showcased in Figure 12. Proper scaling and band limiting is required in order to attain the preferred bandwidth [10]. The flat spectrum is given by

$$S_f(f) = \begin{cases} \frac{\sigma^2}{f_d} & -f_d < f < f_d \\ 0 & \text{otherwise} \end{cases} \tag{16}$$

where σ^2 is the total signal power and f_d is the maximum Doppler frequency. After substitution into Equation (15), the filter response is given by

$$H_f(f) = \begin{cases} \sigma/\sqrt{f_d} & -f_d < f < f_d \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

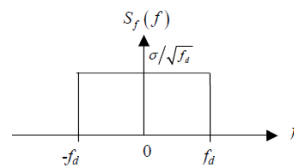


Figure 12.Flat Spectrum

b) Gaussian Spectrum

Figure 13 illustrates the Gaussian and its mathematical description is gives as fallows [10]

$$S_g(f) = (2\sigma^2/\sqrt{\pi}(f_d)^2) \exp\{-f/f_d\} \tag{18}$$

where σ^2 is the total signal power and f_d is the maximum Doppler frequency. The corresponding shaping filter response function is given by

$$H_g(f) = (\sqrt{2}\sigma/f_d \pi^{1/4}) \exp(-f/f_d) \tag{19}$$

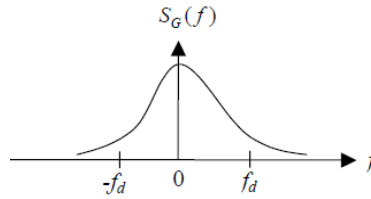


Figure 13. Gaussian Spectrum

c) Jakes spectrum

Many mobile radio channel models are derived using Jakes Doppler spectrum for efficiently modeling Doppler effects [13]. The radio channel model characterized by Jakes spectrum is showcased as in equation 20

$$S_j(f) = \begin{cases} \frac{1}{4} f_d \sqrt{1 - (f/f_d)^2} & |f| \leq f_d \\ 0 & \text{otherwise} \end{cases} \quad (20)$$

The shaping function is highlighted as below

$$H_j(f) = [S_j(f)]^2 = \begin{cases} \frac{1}{16} f_d^2 [1 - (f/f_d)^2]^2 & |f| \leq f_d \\ 0 & \text{otherwise} \end{cases} \quad (21)$$

Figure 14 depicts the Jakes power spectrum, where the majority of the energy is concentration can be observed around the maximum Doppler shift, f_d .

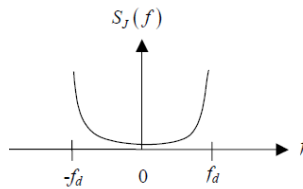


Figure 14. Jakes Power Spectrum

III. SIMULATION RESULTS

For the purpose of simulation two frequency ranges have been selected one is the higher range and other is the shorter range 2400MHz and 5300MHz. These band of frequencies are mainly considered because of their application is IEEE 802.11 series [12]. The successful channel characterization and modeling mainly depends on choice of parameters are their association to the performance of the system under consideration. When the consideration is based on the TDL model, the following parameters and functions must be specified: the number of taps, the Doppler spectrum of each tap, the Ricean factor K for indoor environment, and the power distribution of each tap [14].

The characteristics of the communications channel between the transceivers are time-varying since the parameters of the channel, such as the attenuation and delay, are changing owing to the relative motion among the transmitter and the receiver. The channel model simulated here has a finite tap gain 6 to 32. The number of taps should be minimum in order to attain the maximum computational efficiency. The multipath intensity profile decisively depends upon the type of the terrain there in this approach mainly the Sub-Urban, Urban and Hilly (Village) terrain s are chosen and the model is analyzed using Jakes, Flat or Gaussian Power Spectrum. QPSK modulation is chosen for the purpose of simulation. The simulation has been carried out for various combinational scenarios for the purpose of analysis. Simulations were conducted in five different set of parameters which has been illustrated in Table 1.

Table 1. Parameters time-varying channel outdoor model.

S.No	Taps Number	Velocity in MPH	Operating Frequencies In MHz	Terrain	Power Spectrum
1	6	30 and 80	2400 5300	Sub-Urban/Urban/ Hilly	Jakes/ Flat/ Gaussian
2	12	30 and 80	2400 5300	Sub-Urban/Urban/ Hilly	Jakes/ Flat/ Gaussian
3	16	30 and 80	2400 5300	Sub-Urban/Urban/ Hilly	Jakes/ Flat/ Gaussian
4	24	30 and 80	2400 5300	Sub-Urban/Urban/ Hilly	Jakes/ Flat/ Gaussian
5	32	30 and 80	2400 5300	Sub-Urban/Urban/ Hilly	Jakes/ Flat/ Gaussian

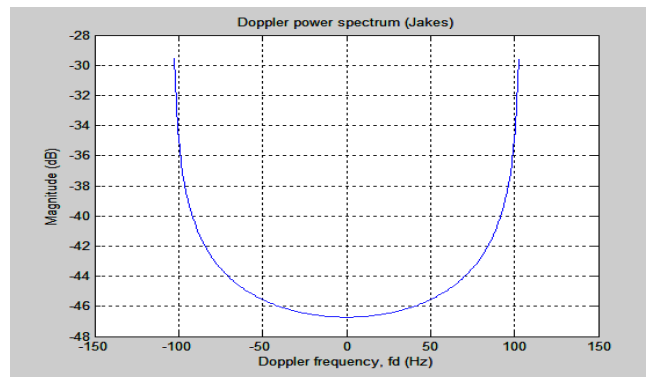


Figure 15. Jakes Doppler power spectrum at a velocity of 30 mph, 6 Taps and a carrier frequency of 2400MHz.

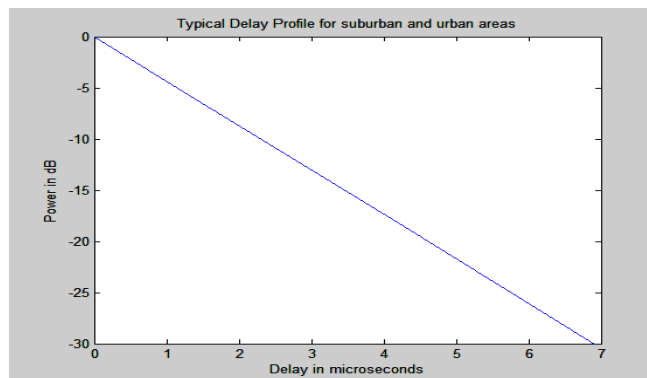


Figure 16. Delay Profile for Urban Areas

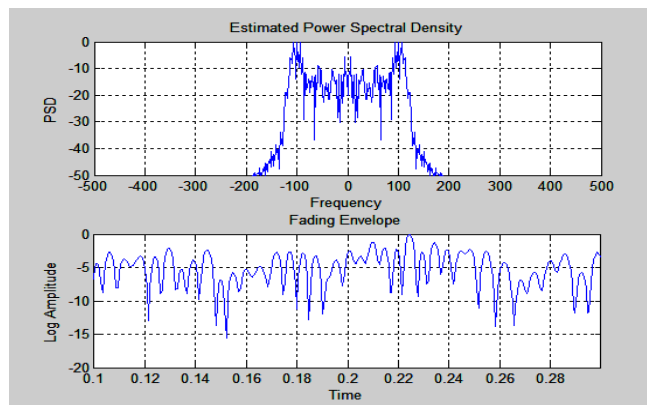


Figure 17. Estimated PSD and Fading Envelope for channel model with the following parameter settings: 2400MHz, 30 mph, urban area, and Jakes spectrum.

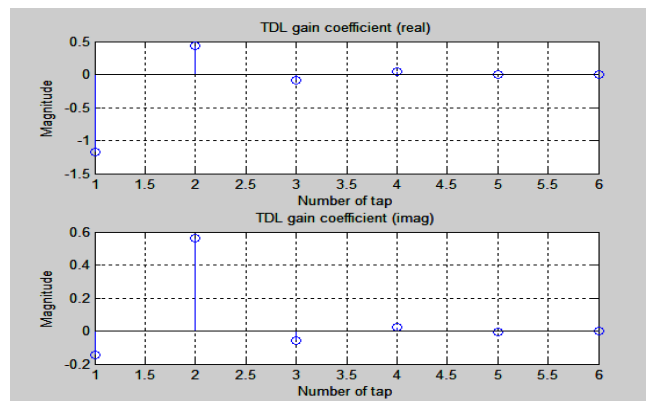


Figure 18. TDL gain coefficient for a 6-tap filter using Jakes spectrum

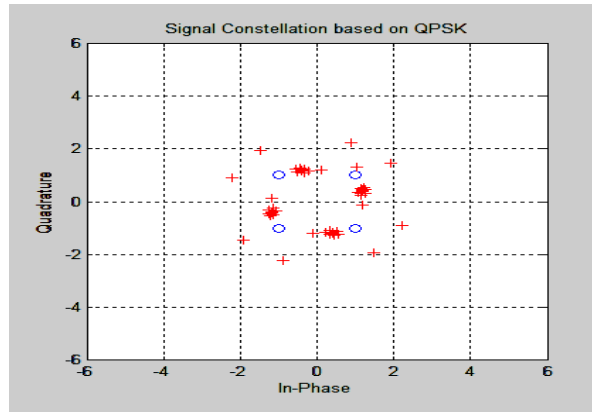


Figure 19.QPSK signal constellation for a channel model with the following parameter settings: 2400MHz, 30 mph, urban area, and Jakes spectrum.

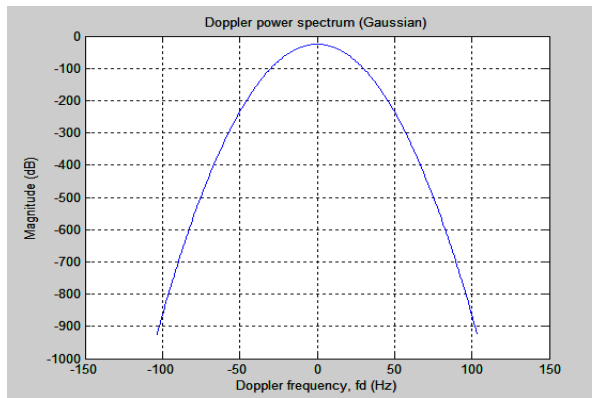


Figure 20 .Gaussian Power Spectrum

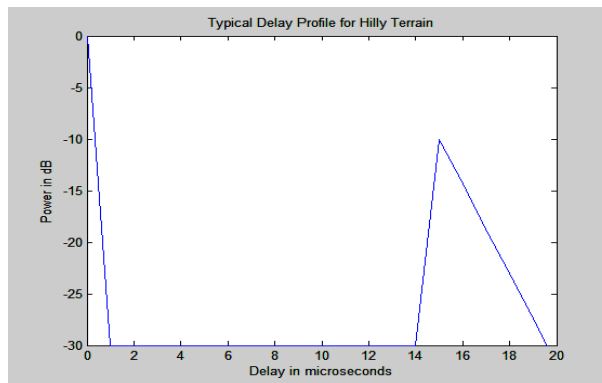


Figure 21.Hilly delay Profile

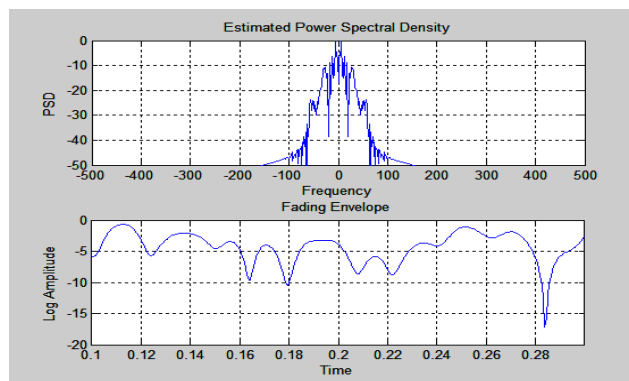


Figure 22.PSD and Fading envelope for channel model with the following parameter settings: 2400MHz, 30mph urban area, and Gaussian spectrum.

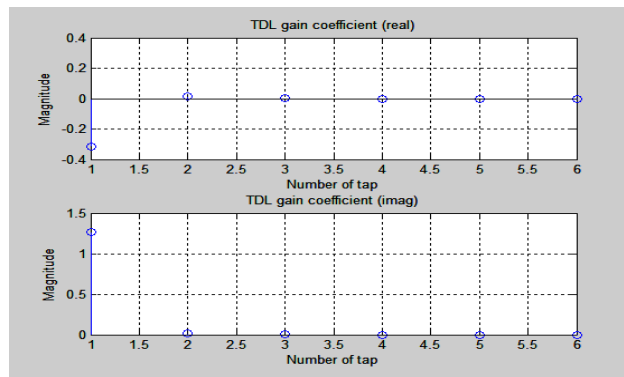


Figure 23. TDL gain coefficients for a 6-tap filter using Gaussian spectrum.

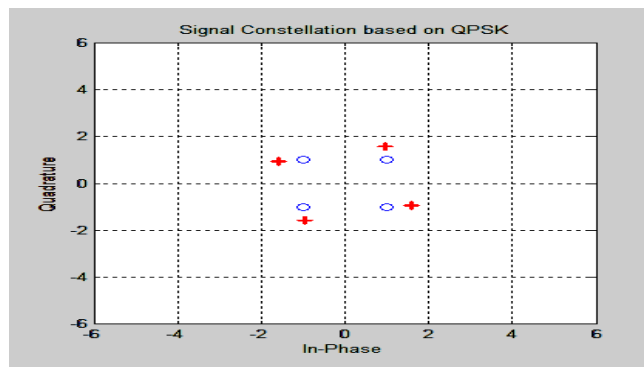


Figure 24. QPSK signal constellation for a channel model with the following parameter settings: 2400MHz, 30mph Urban area and Gaussian spectrum

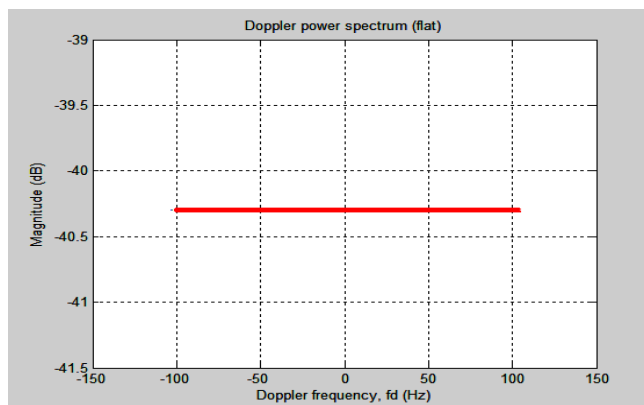


Figure 25. Flat Doppler Power Spectrum

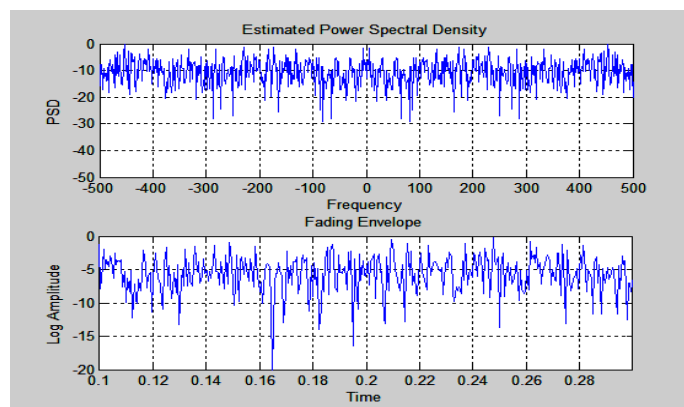


Figure 26. PSD and Fading envelope for channel model with the following parameter settings: 2400MHz, 30 mph, urban area, and Gaussian spectrum.

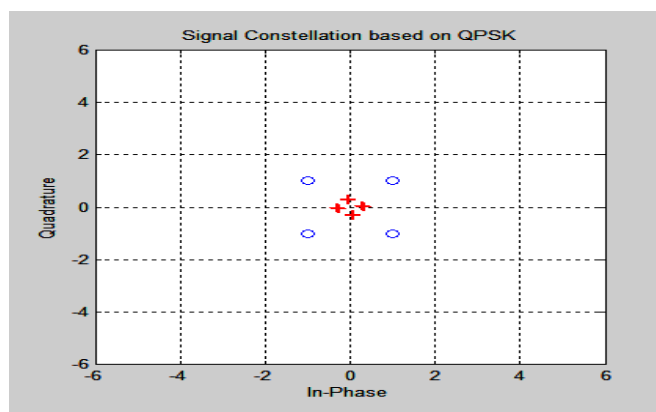


Figure 27.QPSK signal constellation for a channel model with the following parameter settings: 5300MHz, 80 mph, hilly terrain, and Gaussian spectrum,

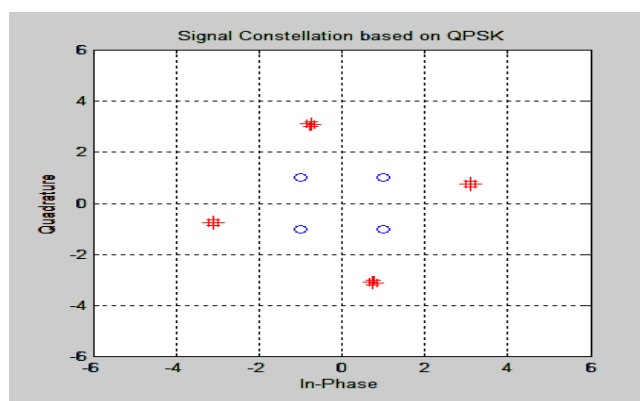


Figure 28 .QPSK Signal Constellation for a channel model with the following parameter settings 5300MHz, 80 mph, hilly terrain and Jakes Spectrum

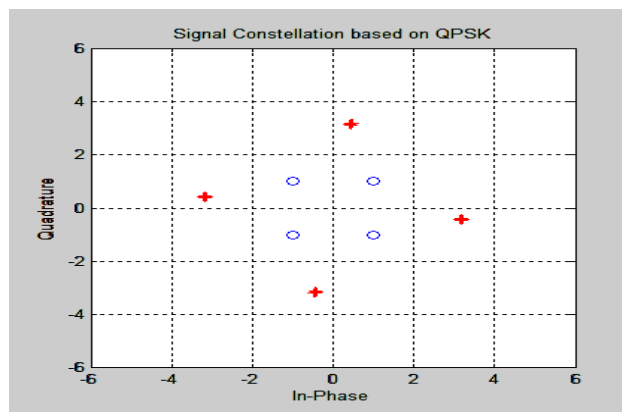


Figure 29.QPSK signal constellation for a channel model with the following parameter settings: 5300MHz, 80 mph, hilly terrain, and Flat spectrum.

IV. CONCLUSION

The paper mainly contributed with the perception of an outdoor mobile radio communications environment for various terrain conditions. The time-varying wireless channels are affected by several hazardous surrounding environmental conditions. The survey of the wireless channel characterization. The paper focuses on the time-varying multipath propagation, fading effect, types of terrain and Doppler effect. The time-varying wireless communication channel is modeled as a TDL structure. Three Doppler power spectral densities, namely, Flat Jakes and Gaussian, were studied and also implemented to quantify the mobility in the channel. The transmission signal is modulated using QPSK. The TDL channel model was simulated. The simulation results incorporated plot of the Doppler power spectrum, delay profile, PSD of the filter output, TDL gain coefficients and the signal constellation. The signal constellation for each combination gives a qualitative measure of the system performance. The outcome of the simulation point out that the smaller number of tap gains of the TDL channel model to be incorporated for designing. The observation was that the results obtained

for two different carrier frequencies of 2400MHz and 5300MHz did not influence the performance significantly. We tried to use 30mph and 80mph mobile speeds in the simulation, representing a low and a high mobility scenario, respectively. The simulation results indicate that the Gaussian and Jakes are more suitable Doppler spectra for mobile radio channels than the flat spectrum. Two types of environments urban and hilly terrain were considered for simulation where the results suggested that Jakes Doppler spectrum performance well in urban environments with high mobility; the Gaussian Doppler spectrum is the choice for low mobility urban environments and for the hilly terrain under both low and high mobility.

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