Development of Propagation Model by Considering Different Climatic Conditions

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Abstract: It is important to consider many technical issues before going to design and establish an expensive Wireless system. It is necessary to see the mathematical predictions or calculations of different parameters before going to design such type of systems. One of those parameters is path loss. Here the mathematical study of path loss is carried out in different climatic conditions like summer, winter, etc. The study helped to design better wireless network for the urban areas which has the same atmospheric conditions like Narnaul, Haryana (INDIA). The comparative study between fields measured data and path loss models shows that the Okumura path loss model is giving better results than other path loss models. Still it needs some modification to give accurate results in the mentioned environment. The modification of Okumura model is given by considering climatic effects along with the area factor in the above mentioned area. The goal of this paper is to analyze attenuation impact on the performance of a mobile station respectively on the received signal quality to the end user. In the end of the paper, two approaches have been followed to verify and test the developed Okumura path loss model. In the first approach the developed path loss model attenuation has been compared with reference attenuation of Fog and Rain which were given by M. Sridhar and Altshuler. In second approach a comparative analysis has been done between field measured data and the developed Okumura model in Hisar (Haryana, India).

Keywords: Area Factor (AF), Climate Factor (CF), Fog Attenuation (FA), Propagation Path loss, Rain Attenuation (RA).

1. Introduction

THE quick growth in wireless communications made it possible for urban as well as rural people to access mobile phones as well as many wireless technical equipments. However, this growth came with many inherent problems. Some of which include poor signal reception in various climatic conditions. The cellular service providers are trying to evolve methods to handle these problems. Some of these problems are regular to any specific region whereas other problems are not regular. Therefore, for more accurate design coverage of present cellular networks, signal strength measurements should be taken into consideration to provide an efficient and reliable coverage area [1,2]. When an electromagnetic signal obtained from a transmitter station and travels to a receiver station in wireless communication passes through the earth's environment and this can commence certain losses [3]. This Transmission process at higher frequencies is usually changed by surrounding conditions and climatic conditions such as rain, vapor, dust, snow, cloud, and fog. Narnaul (Haryana, India) is a region where the weather is hot and dry. As with the other parts of Northern India there are two main seasons in the city. During this the increased earth moisture content during this period gives rise to greater ground conductivity. This condition is likely to affect GSM signal strength. Fog is a natural phenomenon which has been observed during winter.

Season in this region of India. It is described that fog forms from the condensation of atmospheric water vapour into water droplets that remain suspended in the air [4]. Fog is suspension of very small microscopic water droplets in the air. Fog forms during early morning hours or night when radiative cooling at the earth's surface cools the air near the ground to a temperature at or below its dew point in the presence of a

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shallow layer of relatively moist air near the surface [5].

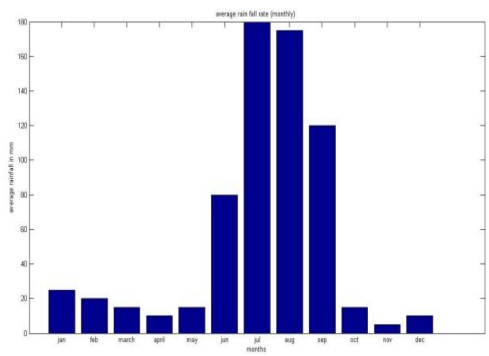

Figure 1 Average rain rates

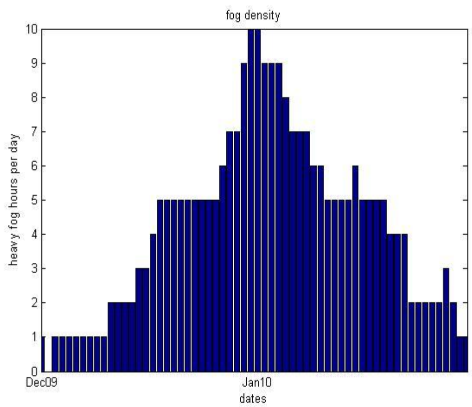

Figure 2 Average fog hours per day

Attenuation in the foggy days may cause significant anomalous attenuation for radio relay links in climatic regions [6]. For GSM operators to ensure all year round quality service delivery, the relationship or effects of greater ground conductivity and increased foliage on signal strength needs to be understood particularly in the specific region where such networks are deployed [7]. Fig 1 and fig 2 shows the average rain rate and average fog density in Narnaul city. The Received Signal strength of a radio signal at receiver were taken during drive tests by using a Global Positioning System (GPS) receiver, laptop, and TEMS phone. However, in this work, we have developed a simple mathematical model that is based on measurements taken in Narnaul region. The developed model was tested with the measurements in different climate conditions [8].

2. Literature Review

Abdullahi , mainly concentrated on the wireless network features and their effects on radio propagation quality [9]. In the year 2001, Isaac I. Kim, Bruce McArthur, and Eric Korevaar, worked on laser beam propagation at 785nm and 1550nm in fog and haze for optical wireless communication and found 785nm, 850nm and 1550 light suffer from atmospheric attenuation [10]. In the same vein, J. A. Weinman, R. Davies and R. Wu, concluded that Water or ice particles blown from the ground into the atmosphere take the form of liquid water as in rain, and fog as in clouds. electromagnetic waves travelling through air containing precipitation are scattered and absorbed by the particles of ice, snow or water. Water, with its larger dielectric constant scatters electromagnetic wave more strongly than ice [11,12]. In addition to above conclusion Akira ishimaru in 1978, gave a conclusion that dielectric loss and the attenuation due to thermal dissipation is greater for water particles than for ice particles. The conclusion given by Akira ishimaru is again discussed in 2004 by Jonathan H. Jiang and Dong L. Wu [13,14].

David M. Pozar , in his book mentioned that, attenuation is caused by the absorption of microwave energy by tropospheric gases when the frequency coincides with one of the molecular resonances of water or oxygen in the atmosphere [15]. Transmission of microwave signals above l0 GHz is vulnerable to precipitation, as has been shown by many researchers over several decades [16, 17]. The two main causes of attenuation are scattering and absorption. When the wavelength is fairy large relative to the size of raindrop, scattering is predominant. Conversely, when the wavelength is small compared to the raindrop size, attenuation due to absorption is dominant [18]. Lakshmi Sutha Kumar, Yee Hui Lee, and Jin Teong Ong concluded that lower rain rates, does not affect the communication links [19]. Due to

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the applied high carrier frequency (above 20 GHz) besides the existing interference and noise the main degrading factor in these systems is attenuation caused by precipitation, especially rain attenuation [20]. Dougherty H.T. et al, includes attenuation due to both rain and gases. Dutton has developed an updated computer program to predict the rain attenuation, cloud attenuation and attenuation due to atmospheric gases [21].

In 2009 Shkelzen Cakaj analyzed the rain attenuation impact on the performance of the respective ground station [22]. G. H. Bryant, I. Adimula, C. Riva and G. Brussaard described a new model for determining rain attenuation on satellite links and explained Rain attenuation statistics from rain cell diameters and heights [23]. Asoka Dissanayake et al, results indicate that the rain attenuation element of their model provides the best average accuracy internationally between frequencies 10GHz and 30 GHz [24]. Oyesola Olayinka Olusola explained the effect of various propagation losses on GSM signals [25, 26]. Bruce (2006) did research on the prediction of seasonal effects on cellular systems in the United States. Vaclav Kvicera and Martin Grabner explained that, The influence of climatic conditions effect the electromagnetic signals all the way through the medium of the lower troposphere. He gave many suggestions for efficient planning and utilization [27]. The aim of Shkelzen Cakaj is to analyse the rain attenuation impact on the performance of the respective earth station. Rain attenuation depends on geological location where the satellite ground station is implemented [22]. M. Sridhar et al mentioned various impairments which causes the signal fade in his technical paper and also explained that rain attenuation is dominant in those impairments. He used ITU-R model to predict the rainfall rate and attenuation due to rain [28]. Dong you choi presented the results of measurements of rain-induced attenuation in vertically polarized signals propagating at 12.25 GHz for the duration of definite rain events [wet season of 2001 and 2007 at Yong-in, Korea]. The rain attenuation over the link measured practically and compared with loss/attenuation got by the ITU-R model [10].

3. Comparative Analysis of Different Path Loss Models

The losses in signal strength that occur during transmission from the Transmitter antenna to the Receiver antenna are given by the path loss. When planning any radio or wireless system, it is necessary to have a broad understanding the elements that give rise to the path loss, and in this way design the system accordingly. Some of the major elements causing signal path loss for any radio wave system are free space loss, multipath and atmosphere [29,30,31]. Generally at low frequencies it affects radio signal paths, especially below 30-50MHz, the ionosphere has a major effect, reflecting them back to Earth. At frequencies above 50MHz and more the troposphere has a major effect on the radio path. For UHF broadcast this can extend coverage to approximately a third beyond the horizon. All the path loss models are designed by calculating field data in different environments [32]. All measurements are taken at 1.8 GHz frequency. The figure 3 shows the comparative analysis of different path loss models.

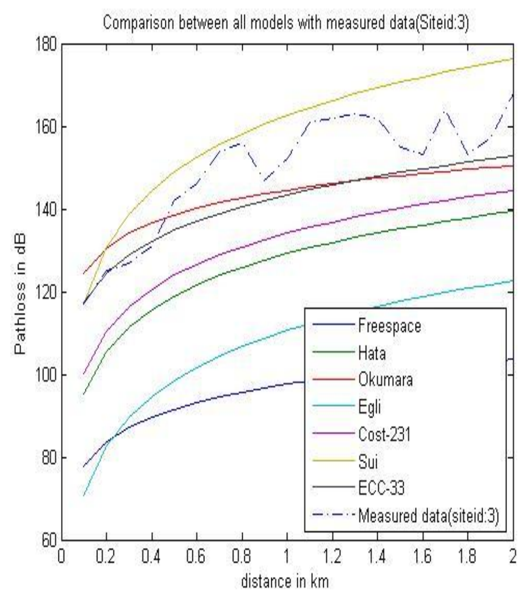

Figure 3 Comparative analysis of different path loss models with field measured data at Narnaul (INDIA)

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After the analysis of figure 3 it has been found that the okumura pathloss propagation model is best fit propagation model for this area. One of the most general models for signal prediction in large urban macro cells is Okumura's model [29]. This model is applicable frequency ranges of 150-1920 MHz and over distances of 1-100 Km. Okumura used extensive measurements of base station-to-mobile signal attenuation to develop a set of curves giving median attenuation relative to free space of signal propagation in irregular terrain. The base station heights for these measurements were 30-100 m, the upper end of which is higher than typical base stations today. The path loss formula of Okumura is given by

$$L50(dB) = Lf + Amu(f,d) - G(h_f) - G(h_r) - G_{AREA}$$

(1)

where d is the distance between transmitter and receiver, $L50$ is the median (50th percentile) value of propagation path loss, Lf is free space path loss, Amu is the median attenuation in addition to free space path loss across all environments, $G(ht)$ is the base station antenna height gain factor, $G(hr)$ is the mobile antenna height gain factor, and G_{AREA} is the gain due to the type of environment. The values of Amu and G_{AREA} are obtained from Okumura's empirical plots [29,33]. Okumura derived empirical formulas for $G(ht)$ and $G(hr)$ as

$$G(h_t) = 20\log_{10}\left(h_t/200\right), 30m < h_t < 1000m \qquad (2)$$

$$G(h_r) = 10\log_{10}\left(h_r/3\right), h_r \le 3m \qquad (3)$$

$$= 20\log_{10}\left(h_r/3\right), 3m < h_r < 10m \qquad (4)$$

To determine path loss using Okumura model, the free space path loss is first determined, and then the value of A_{mu}(from curve) is included to it having correction factors to account for the terrain type[29]. Okumura's model is totally based on measured data and doesn't provide any analytical explanation. The major disadvantage with the model is its slow response to rapid changes in the terrain; therefore the model is fairly good in urban and suburban areas, but not good in rural area.

The fig. 4 shows the variation of path loss predicted by Okumura model and practical field data collection in different climatic conditions (winter, winter with heavy fog conditions, Summer, Rainy season with heavy rain). By analysing fig 4, it has been concluded that there is a large difference between the predicted value and the field measured value. The average difference between the fields measured values and the predicted values by Okumura model is 4.26 in summer, 4.16 in winter, 5.26 due to heavy rain and 5.71 due to heavy fog.

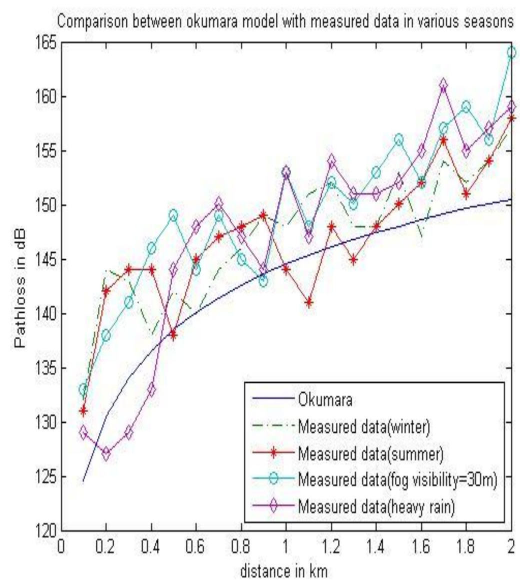

Figure 4 Comparison between Okumura path loss predicted values with field data collected in different climates of Narnaul (INDIA)

4. Development of Field Propagation Model

With the help of the above analysis it is clear that path loss model Okumura gives results more approximate to the practical data but not accurate. That means some more factors are

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influencing the signal strength in the mentioned environment where drive test is conducted. There are many reasons for this difference between the predicted loss and the measured loss in a particular area. Some of those effects are:

4.1 Rain Attenuation

In rainy season the increased earth moisture content gives rise to greater ground conductivity [34,35]. This condition is likely to affect received signal strength [36-39]. Determination of Rain Attenuation by ITU Radio communication Assembly, The specific attenuation Sa_R (dB/km) is obtained from the rain rate R (mm/h) using the power-law relationship:

$$Sa_R = K*(R^L) \quad (5)$$

Values for the coefficients K and L are determined as functions of frequency, f (GHz)

$$K = [K_H + K_V + (K_H - K_V)\cos^2\phi\cos 2\varphi]/2 \quad (6)$$

$$L = [K_H L_H + K_V L_V + (K_H L_H - K_V L_V)\cos^2\phi\cos 2\varphi]/2K \quad (7)$$

Where:

ϕ=20; path elevation angle

φ=45; polarization tilt angle

K_H=0.0000678;K_V=0.0000874;L_H=1.0564;

L_V=0.9102;

$$CorrectionRain = RA = Sa_R * d \quad \text{in dB} \quad (8)$$

4.2 Attenuation by Fog

Fog is suspension of very small microscopic water droplets in the air and it is generally difficult to directly measure fog density or to obtain its statistical data. The characterization of fog is based on water content, optical visibility, temperature and drop size distribution [6]. The types of fog, strong advection fog, light advection fog, strong radiation fog, and light radiation fog is mentioned [5,40]. Attenuation in the foggy days may cause significant anomalous attenuation for radio relay links in climatic regions such as semi-desert terrain.

The effect of the attenuation due to fog, fog attenuation (dB/km), can be related to atmosphere visibility, V (km), defined by the maximum distance that we can recognize a black object against the sky [6-7]. ε = 0.05. for V smaller than 3 km. Then the relation between fog attenuation and V can be expressed by the following equation.

Correction Fog (FA) = 10 $\log_{10}(\varepsilon)$/ in dB/km (9)

On the basis of the field data collection and the attenuation by rain and fog the Okumura path loss model can be developed as

Developed Okumura model= Okumura model+ AF+ CF; (10)

Where, AF is area factor = mean value (error between Path loss predicted by Okumura model and field measured data of path loss considering all seasons) and CF is climate factor

$$CF = \begin{cases} 0 & \text{(For ordinary climate conditions)} \\ 10\log_{10}(\varepsilon)/V * d & \text{(For dense fog less than 50m)} \\ Sa_R * d & \text{(Heavy rain greater than are equal to 100mm)} \end{cases}$$

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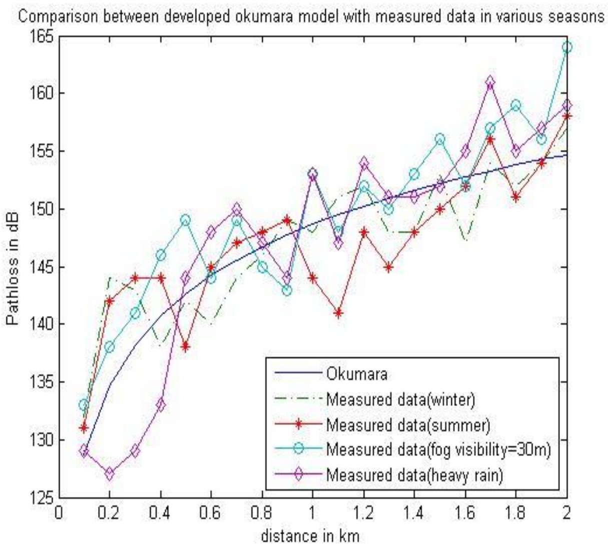

Figure 5 Comparison between developed Okumura model with measured data in various seasons at Narnaul (INDIA)

Fig 5 shows the Graph between the developed Okumura model and field data collection in different climatic conditions. Table 1 shows the difference between the predicted values by developed Okumura model and measured values in different climatic conditions like rain, summer, winter and foggy.

5 Validation of Developed Okumura Path Loss Model

The validation of developed Okumura propagation path loss model comprises two approaches:

- By taking reference model
- By applying the developed model in another city

5.1 By Taking Reference Model

In this approach two reference models has been considered, one is for fog attenuation and another is for rain attenuation to show the validation of developed Okumura propagation path loss model.

Table 1 Difference between Measured and Developed Okumura Model

Distance from base station (km)	Error (dB) Summer	Error (dB) Winter	Error (dB) Heavy rain	Error (dB) Heavy fog
0.1	1.9828	2.9828	-0.0179	3.7609
0.3	0.4403	4.4403	-2.5617	1.7748
0.5	-3.9966	-0.9966	1.0000	4.8941
0.7	1.0808	-1.9192	4.0761	1.5279
0.9	0.8979	0.8979	-4.1082	-3.0987
1.0	-2.0172	-1.0172	3.9760	1.7643
1.2	-0.6009	1.3991	3.3910	-1.2631
1.4	-3.9398	-3.9398	-0.9493	-2.0457
1.6	-1.0996	-2.0996	1.8895	-4.6492
1.8	-3.1227	-2.1227	0.8651	0.8840
2.0	2.9622	1.9622	3.9486	4.5252

5.1.1 Fog Attenuation Reference Model

In 1984 Altshuler gave a formula for fog attenuation which depends on wavelength and temperature. The equation for attenuation in [(dB/km)/(g/m^3)] is [41]:-

$$A=-1.347+0.0372\lambda+18/\lambda-0.022T_0 \quad (11)$$

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Where λ is wavelength in mm, T_0 temperature ^0C

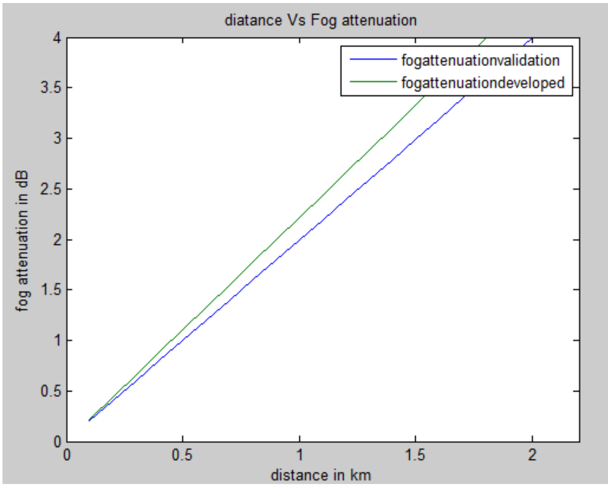

Figure 6 Comparison between developed fog attenuation and reference fog attenuation model

The figure 6 shows the comparsion between developed okumura model and reference model for fog attenuation model. The figure 6 and table 2 shows the error between fog attenuation of developed model and the reference model. The maximum error between these two models is 0.45 which is very less. Hence it has been conclude that the error between the reference model and the fog attenuation part of developed model is very less. Therefore the fog attenuation part of developed model predict correct values of signal strength.

5.1.2 Rain Attenuation Reference Model

M. Sridhar gave an equation to calculate rain attenuation. He explained that the rain drops absorb most of the electromagnetic energy and some of the energy gets scattered by Rayleigh and Mie scattering mechanisms [42]. The rain drop size distribution is exponential and the mathematical expression is:

$$N(D) = N_o e^{(\frac{-D}{D_m})} \quad m^{-3} \qquad (12)$$

$$D_m=0.122*(R.^{\wedge}0.21)dB/km \qquad (13)$$

Where, D_m is the median drop diameter and N(D)dD is the number of drops per cubic meter with rain drop diameters between D and D + dD mm [140]. The rainfall rate R in terms of N (D) and terminal velocity of V (D) is:

$$R = 0.6\times10^{-3}\pi\int D^3V(D)N(D)dD \qquad (14)$$

The expression for attenuation is

$$A = \int\left(\frac{D^3}{\lambda}\right)\left(N_o \times e^{\left(\frac{-D}{D_m}\right)}\right) \qquad (15)$$

The figure 7 shows the comparison between developed rain attenuation and reference rain attenuation. After careful observation, it has been observed that the developed attenuation is giving results same as that of reference attenuation taken for validation. The figure 7 and table 2 shows the difference between developed and reference rain attenuation. The maximum difference between these two attenuations is approximately zero (0.0048). Hence it has been observed that the prediction made by developed model and reference model are same.

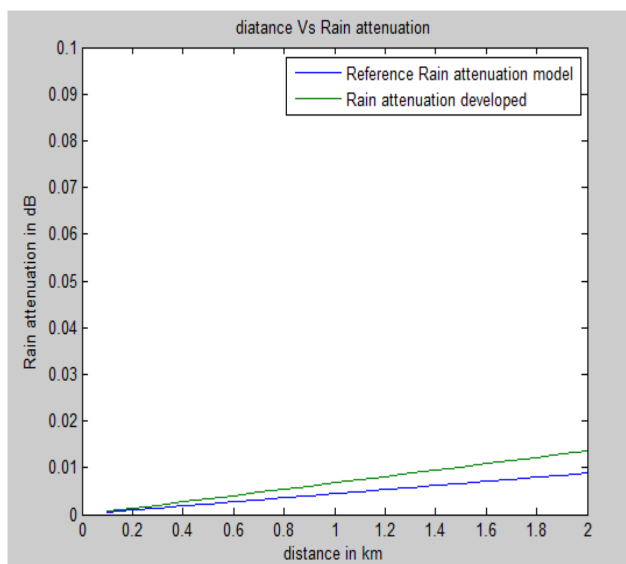

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Figure 7 Comparison between developed rain attenuation and reference rain attenuation model

5.2 By Applying the Developed Model in Another City

In this approach, the validation of developed propagation path loss model has been applied at different city of Haryana, India having the same climatic conditions. Here the city Hisar, Haryana has been taken whose long. 75.7 and lat. 29.1. The derive test has been performed in Hisar by considering a BTS id in highly populated area.

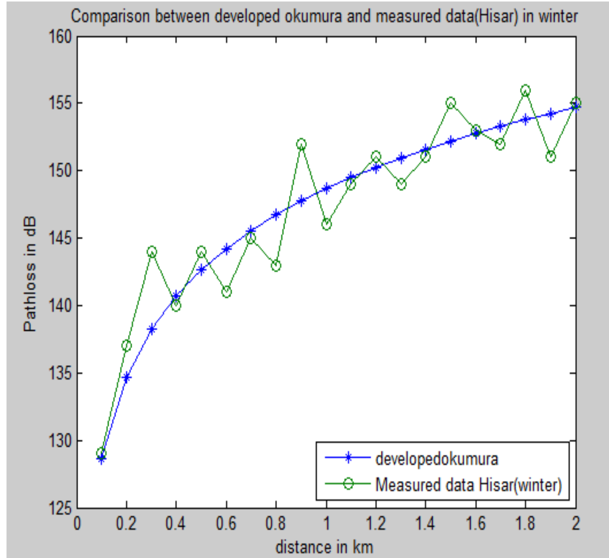

Figure 8 Comparison between developed Okumura model and field data taken (Hisar, INDIA) in winter season

Table 2 Error Between Fog Attenuation and Reference Model

Distance from base station (km)	Fog attenuation Considered in the modified model	Fog attenuation reference model	Difference between both fog attenuation equations	Rain attenuation Considered in the modified model	Rain attenuation reference model	Difference between both Rain attenuation equations
0.1	0.2219	0.1995	0.0223	0.0007	0.0004	0.0002
0.3	0.6656	0.5986	0.0670	0.0020	0.0013	0.0007
0.5	1.1093	0.9976	0.1116	0.0034	0.0022	0.0012
0.7	1.5530	1.3967	0.1562	0.0047	0.0031	0.0017
0.9	1.9967	1.7958	0.2009	0.0061	0.0040	0.0021
1.0	2.2185	1.9953	0.2232	0.0068	0.0044	0.0024
1.2	2.6622	2.3944	0.2678	0.0081	0.0053	0.0029
1.4	3.1059	2.7934	0.3125	0.0095	0.0062	0.0033

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1.6	3.5496	3.1925	0.3571	0.0109	0.0070	0.0038
1.8	3.9933	3.5915	0.4018	0.0122	0.0079	0.0043
2.0	4.4370	3.9906	0.4464	0.0136	0.0088	0.0048

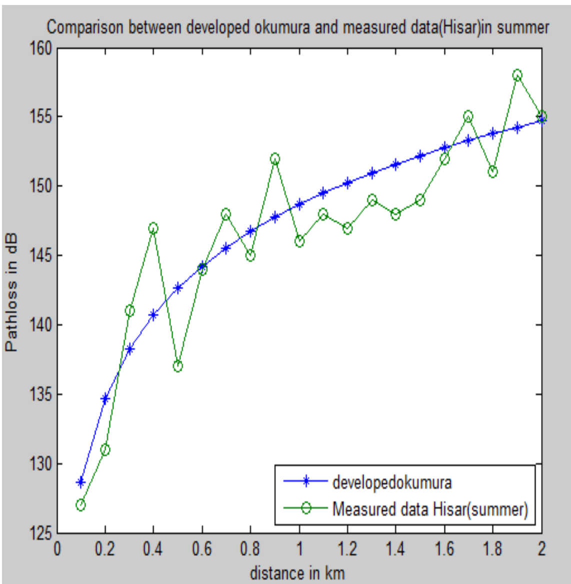

Figure 9 Comparison between developed Okumura model and field data taken (Hisar, INDIA) in summer season

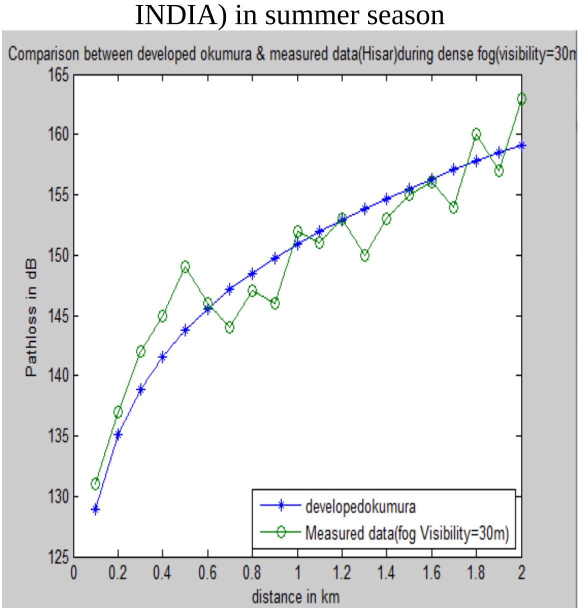

Figure 10 Comparison between developed okumura model and field data taken (Hisar, INDIA) in heavy fog condition

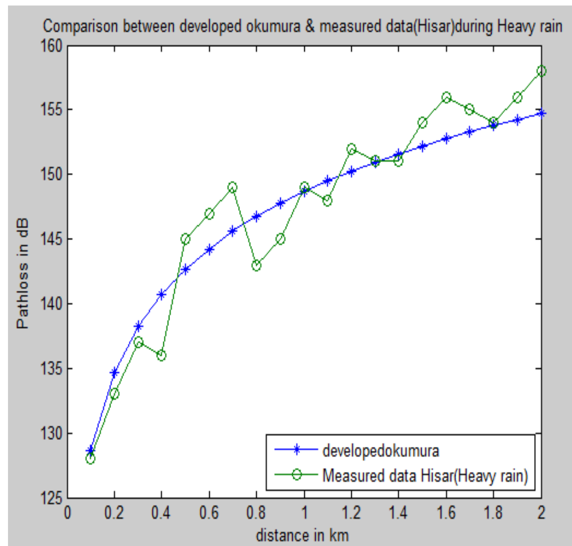

Figure 11 Comparison between developed okumura model and field data taken (Hisar, INDIA) in Heavy rain condition

The figures 8-11, show the comparsion between the field measured data in different climatic conditions of Hisar and developed okumura propagation path loss model. The field measured data has been taken in Hisar in diferent climatic conditions, winter, summer, rain and fog. In these four climatic conditions, a comparative analysis has been done. The table 3 shows the exact between the developed okumura model and the field measured data. After careful examination of table 3, it has been observed the error between the predicted values by developed model and the field measured data is less. Hence it has been conclude that the developed okumura propagation path loss model predict more accurately.

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6 CONCLUSION

In this paper the field measured data in different climatic conditions has been compared with the okumura path loss model. After the analysis, it has been observed that the error between measured value and predicted is a considerable value. On the basis of this analysis a pathloss prediction model has been proposed. The developed okumura pathloss model contains area factor and climate factor along with the original okumura model. It has been discussed that the pathloss models were designed on the basis of the area and environmental conditions. With the help of developed okumura model , the pathloss prediction is more precise as compared to the original okumura model. Validation of developed okumura model has been done using the reference attenuation models for rain and fog. The reference rain attenuation equation is taken from Mr. M. Sridhar research paper and the reference fog attenuation is taken from Mr. Altshuler research paper.

Table 3 Error between measured data (Hisar, Haryana, India) and developed Okumura model

Distance from base station (km)	Error (dB) winter	Error (dB) Summer	Error (dB) Heavy fog	Error (dB) Heavy rain
0.1	-0.33	1.66	-2.11	0.66
0.3	-5.790	-2.79	-3.12	1.21
0.5	-1.35	5.64	-5.24	-2.35
0.7	0.56	-2.43	3.12	-3.42
0.9	-4.24	-4.24	3.74	2.75
1.0	2.66	2.66	-1.11	-0.32
1.2	-0.74	3.25	-0.08	-1.74
1.4	0.58	3.58	1.69	0.59
1.6	-0.25	0.74	0.29	-3.23
1.8	-2.22	2.77	-2.23	-0.21
2.0	-0.31	-0.31	-3.87	-3.29

In this investigation the difference in both attenuation equations is very small. Further the developed Okumura model has been verified and tested in another city Hisar (Haryana, India) having similar climatic conditions. This investigation shows that the developed model is valid through out the Haryana and the area which has the similar climatic conditions.

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