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A Modified Formulation of Path Loss Models for Broadcasting Applications

Pardeep Pathania, Parveen Kumar, Shashi B. Rana

Abstract: In this paper, we have used exclusively the FM band as this band is slowly gaining its popularity due to the liberalization policy of Govt. of India for its implementation. So, it is absolutely essential to find best fit propagation model. In the present work, we have used the field strength measurements of two FM broadcasting stations, each operating on different transmitted power and at different transmitting antenna heights. These field strength measurements (readings) on conversion into path loss and thereafter further be compared with the various available path loss models. An appropriate modification has been suggested and applied after calculating the mean square error (MSE) between the measured path loss and calculated path loss with the help of available models. For practical implementation, all the measurements have been taken in Punjab state of India (border district of Gurdaspur). It is further emphasized that all the measurements have been taken in an open area, so suggested model in this paper would be the best fit for open area conditions in the north bordering area of Punjab. All the measurements (readings) have been taken using the Anritsu site master by carrying it using car and with the available Anritsu dipole antenna. Using the corrected (modified) formula we have been able to reduce the Mean Square Error (MSE) value to one fourth value. For 100 W FM broadcasting station the value of MSE is coming exactly within the 6 dB limit, which is the necessary and appropriate condition for the good propagation model and for 10 KW FM stations is nearly coming closer to the 6 dB, which is the limit of a good propagation model.

Keywords: FM band, Okumara model, Cost-231, Extension of Hata model, Mean square error and standard deviation.

I. INTRODUCTION

In developed countries, FM band has shown extraordinary significance and is being used for so many purposes such as community radio and entertainment etc. In developing countries like India FM band is slowly being liberalized day by day. From last decade, many private channels came into existence and many more are in queue for permission from Govt. of India. Recently Government of India has allocated 400 to 500 licenses and many more to come. So, it is quite mandatory to study the various existing available path loss models and to verify them as per Indian subcontinent conditions.

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So it is compulsory to suggest any modification so that they all must fit best with the environmental and terrain conditions particularly for Punjab state in India. In our study, we have taken a survey of various empirical models and in comparison with our field strength measurements; modified (generalized) formulas have been devised on calculating the mean square error (MSE). Because our primary objective is to minimize the mean square error within 6 dB limit as suggested on analysis of the various propagation models. In this paper, we considered only FM band for our analysis purpose and for the empirical modelling. Although, we have considered the frequency value more than 150 MHz frequency, but as per the Preze Vega model the standard FCC standard curves the exponent of distance remains fairly constant at different frequencies in similar propagation environments [1]. So, the statistical behaviour of the propagation channel in the VHF and UHF band can reliably be verified by using this model. It is quite evident the exponent of distance and path loss does not show the dependence on bandwidth, wave propagation and type of modulation [2]. Brief organization of this research paper is as follows: In section 2, we have elaborated the brief survey of different propagation models namely free space model, Okumara model, Okumara Hatta model, Extension of Hata Model, The Hata-Davidson Model and Extended COST-231 Hata model. In section 3, data measurements method using Anirtsu meter has been discussed in bordering area of Punjab (State: India) and bordering area of Jammu (State: India) at different power of broadcasting station with different antenna height. Then suitable correction factor (modification) has been applied to already explain models. It has been found that modified formula results in reducing the standard deviation and mean square error (MSE) by 6 dB, condition most suited for good propagation model.

II. RELATED WORK DONE

Different researchers have contributed great work related to path loss model. In this regard, Preze Vega, et al. [2008] has developed a path loss model of UHF band 4 & 5. In their investigations they found that for VHF and UHF band path loss does not depends on frequency, type of modulation and bandwidth. They also concluded that statistical behaviour of the propagation channel in the VHF and UHF band can be characterized using the model with measurement taken at other frequency not necessarily be the frequency of interest. While Purnima K. Sharma, et al. [2008] has investigated comparative analysis of propagation path loss models with field measured data. She finally concluded that the cost – 231 and SUI models shows the best results in all

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the three categories and particularly in urban and suburban environments. In that reference again Purnima K. Sharma, et al. [2011] has carried out a modified approach to calculate the path loss in urban areas. In her investigation, she presented a modified path loss model and comparative analysis of the same has been done with the field measured data. Further work has been extended by Obot, et el. [2011] who presented a comparative analysis of path loss prediction model for the macro cellular environment. In their investigation, they found Hata model to be more accurate and reliable path loss prediction model for the macro cellular environment. Because in this model value of MSE calculated to be 2.37 dB which is much smaller than the minimum acceptable MSE value of 6 dB for good signal propagation.

III. SURVEY OF VARIOUS PROPAGATION MODELS

There are two approaches are there for calculating path loss (a) deterministic and (b) statistical approach. In deterministic approach one has to take all the elements within the particular area and a lot of computational efforts are required for its implementation. On the other hand, for statistical approach which normally rely on measured data and average loss for the particular radio link and hence further used for planning of radio and cellular broadcast stations. The deterministic models are complex in nature and yield an unnecessary amount of details as the network designer is hardly interested in the particular locations to be covered and only interested in the overall extent of the coverage area. One of appropriate method to remove these complexities is to adopt an empirical model. These empirical models use different parameters such as received signal strength, frequency, antenna heights and terrain profiles, derived from a particular environment through the use of extensive measurement and statistical analysis. This modelling can further be used to design the systems in similar environments to the original measurements with respect to original measurements [3].

3.1Free Space Propagation Model

Free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear and unobstructed line-of-sight path between them (Friis 1946) [4]. Since in most of radio wave propagation models, the free space model states that the received power decays as a function of the separation between Transmitter-Receiver raised to some power (i.e. a power law function) (Saunders 2005). Although the free space path loss model does not hold good for most of terrestrial situations and due to other effects from the ground, objects in the path. But it is also useful as one of the basis for understanding many real life radio propagation situations. In this case free space, power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance d is given by the Friis free space equation (Friis 1946),

$$PL(dB) = -10\log_{10}(G_t) - 10\log_{10}(G_r)$$

$$-20\log_{10}\left[\frac{(c\times10^3)}{4\pi\times f\times10^6}\right] - 20\log_{10}(1/d)$$

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \text{.. .... (1)}$$

Where P_t is the transmitted power, P_r (d) is the received power, G_t is the transmitter antenna gain, Gris the receiver antenna gain, dis the transmitter-receiver separation distance in meters and λ is the wavelength in meters.

$$PL(dB) = -G_t(dB) - G_r(dB) + 32.44 + 20\log_{10}(d/km) + 20\log_{10}(f/MHz) \text{..... (2)}$$

3.2 Okumura Model

The Okumura's model is an empirical model based on extensive drive test measurements made in Japan at several frequencies within the range of 150 to 1920 MHz and further be extrapolated up to 3000 MHz Okumura's models is developed from macro cells with cell diameters in the range from 1 to 100 km. In this case the height of the base station antenna is kept between 30-100 m. The Okumura model has taken into account several propagation parameters such as the type of environment and the terrain irregularity.Okumura developed a set of curves which gives the median attenuation relative to free space (Amu), in an urban area over a quasi-smooth terrain with a base station effective antenna height (h_b) of 200m and a mobile antenna height (h_m) of 3 meters [5]. Figure 1. Illustrate the correction factor applied for G_{AREA} for different type of geographical condition.

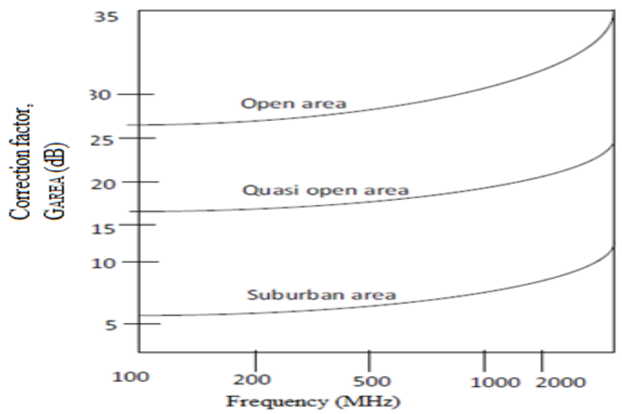

Figure 1 Correction Factor GAREA for Different Types of Terrain

These curves were developed from extensive measurements using vertical Omni-directional antenna at both the base and mobile. In this case curves are plotted as a function of frequency in the range of 100 MHz to 1920 MHz, and as a function of distance from the base station in the range from 1 km to 100 km. The path loss prediction formula according to Okumura's model is expressed as:

$$L_{50}\,(dB) = L_F + Amu_{(f_d)} - G_{(h_b)} - G_{(h_m)} - G_{AREA} \text{.................... (3)}$$

Where L_{50} (dB) is the median value (i.e. 50^{th} percentile) of the path (propagation) loss, L_F is the free space loss. The value of Amu is the median attenuation relative to free space, G $_{(h_b)}$ is the base station antenna height gain factor, G$_{(h_m)}$ is the mobile antenna height gain factor, and G_{AREA} is the gain or correction factor owing to the type of environment. Amu (f_d) and

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G_{AREA} are determined by observing the Okumura curves.

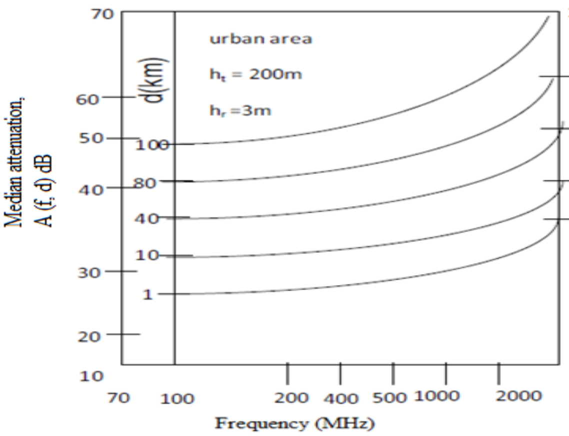

Figure 2 Median Attenuation Relative to Free Space Over Quasi-Smooth Terrain

The term $G_{(hb)}$ and $G_{(hm)}$ can be calculated by using these simple formulas :

$G_{(hb)} = 20 \log_{10}$ 1000m >hb> 30m .. .. .. (4)

.

$G_{(hm)} = 10 \log_{10} (hm/3)$ hm ≤3m.............(5)

$G_{(hm)} = 20 \log_{10} (hm/3)$ 10m ≤ hm≤3m.....(6)

Okumura's model is considered to be the simplest and most excellent in terms of accuracy in path loss prediction for mature cellular and land mobile systems in a cluttered environment. The main disadvantage of the Okumura model is its sluggish response to rapid changes in terrain condition. Consequently the model is fairly good in urban and suburban areas but, not as good (suited) for rural areas. The negative side of the Okumura-Hata model is that it is valid only for frequency between 150 MHz and 1500 MHz, with base antenna height between 30 m to 200 m and receiving antenna between 1 m and 10 m. However, this model does not pose any problem since measurements are taken within the ranges mentioned above. Figure 2 showed the value of median attenuation in free space for urban area. Another problem encountered by this model is that in some countries measurements have been in disagreement with the predictions. The reason cited for this difference is due to characteristics of Tokyo city. Kozono and Watanabe (1977) have tried to modify the model by including a measure of building density, but such approach has not found common acceptance till date.

3.3 Okumura-Hata Path Loss Model

The Okumura-Hata model (1980) is an empirical formulation of the graphical path loss data provided by Yoshihisa Okumura, and is valid from 150 MHz to 1500 MHz. The Hata model basically is a set of equations based on measurements and extrapolations from the curves derived by Okumura. Hata presented the urban area propagation loss as a standard formula, along with additional correction factors for application in other situations such as suburban and rural area. Only four parameters are required in the Hata model as a result the computation time is very short on this model. This is one of the main advantages of this model. However, the model neglects the terrain profile (condition) between the transmitter and receiver i.e. hills or other obstacle that exists between the transmitter and receiver.

Type of area	$A(h_2)$	K
Open	$(1.1log_{10}f_{MHz} - 0.7)h_2 - (1.56log_{10}f_{MHz} - 0.8)$	$4.78(log_{10}f_{MHz})^2 - 18.33log_{10}f_{MHz} + 40.94$
Sub urban		$2[log_{10}(f_{MHz}/28)]^2 + 5.4$
Medium –small city		0
Large city ($f_{MHz} >$ 300)	$3.2(log_{10}11.75h_2) - 4.97$	0
Large city ($f_{MHz} <$ 300)	$8.29(log_{10}1.54h_2) - 1.10$	0

This is because both Hata and Okumura models have made the assumption that the transmitters would normally be located on hills [6].

The basic formula for the median propagation loss given by Hata is:

$L(dB)=69.55+26.16\log_{10}f_{MHz}-13.82\log_{10}h_1-a(h_2)+(44.9-6.55log_{10}h_1)log_{10}d_{km}-K$ ....(7)

where fc is the carrier frequency (in MHz) from 150 MHz to 1500 MHz, h_b is the base station antenna height (in meters) ranging from 30m to 200m, h_m is the mobile antenna height (in meters) ranging from 1 m to 10 m, d is the base station to mobile separation distance (in km), and $a(h_m)$ is the correction factor for effective mobile antenna height which is a function of the size of the coverage area.

Hata Model Parameters

3.4 Extension of Hata Model to Longer Distances

An empirical formula for extending the Hata Model range up to distances 20 to 100 km was developed by ITU-R and is given by equation given below:

$$L_{ITU}(dB)=69.55+26.16\log_{10}f_{MHz}-13.82\log_{10}h_1-a(h_2)+(44.9-6.55\log_{10}h_1)(\log_{10}d_{km})^b-K......(8)$$

Where

$$b=\begin{cases}1\ , & d_{km}<20\\ 1+\left(\begin{matrix}0.14+\\0.000187f_{MHz}\\+0.00107h_1'\end{matrix}\right)(\log_{10}(d_{km}/20))^{0.8}, & d_{km}\geq 20\end{cases}$$

$$h_1'=\frac{h_1}{1+7\times10^{-6}h_1^2}$$

3.5The Hata-Davidson Model

The Telecommunications Industry Association (TIA) recommended in their publication TSB-88A the following modification to the Hata model to cover a broader range of input parameters. The modification consists of the addition of correction terms in the Hata model [7]:

$L_{HD} = L_{Hata} + A(h_1, d_{km}) - S_1(d_{km}) - S_2(h_1, d_{km}) - S_3(f_{MHz}) - S_4(f_{MHz}, d_{km})$ ....(9)

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in which A and S_1 are the distance correction factors extended in the range up to 300 km, S_2 is a base station antenna height correction factor extended in the range of h_1 values up to 2500 Km, while S_3 and S_4 are frequency correction factors extended in the frequency [7] range up to 1500 MHz

distance	$A(h_1, d\ km)$	$S_1(d_{km})$
$d_{km} < 20$	0	0
$20 \leq d_{km} < 64.38$	$0.62137(d_{km} - 20)[0.5 + 0.15\log_{10}(h_1/121.92)]$	0
$20 \leq d_{km} < 64.38$	$0.62137(d_{km} - 20)[0.5 + 0.15\log_{10}(h_1/121.92)]$	$0.174(d_{km} - 64.38)$

$S_2(h_1, d_{km}) = 0.00784|\log_{10}(9.98/d_{km})|(h_1 - 300)$ for $h_1 > 300$

$S_3(f_{MHz}) = f_{MHz}/250\ \log_{10}(1500/f_{MHz})$

$S4(f_{MHz}, d_{km}) = [0.112\ \log_{10}(1500/f_{MHz})](d_{km} - 64.38)$ for $d_{km} > 64.38$

3.6 Extended COST-231 HataModel

This model (COST 231 Final Report 1999 cited in Tapan et al. 2003 and Zreikat and Al- Begain) is derived from the Hata model and depends upon four parameters for the prediction of propagation loss: frequency, height of a receiving antenna, height of a base station and distance between the base station and the receiver antenna. A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model. The COST-231 Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz. It also contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors will help us to predict the path loss model at the particular value of the frequency band.

From equation (3), the urban model is given by the equation.

$$L(urban)(dB)=46.33+33.9\log f_c-13.82\log h_{tx} -a(h_{rx})+(44.9-6.55\log h_{tx})\log d \ldots\ldots(10)$$

The path loss in a suburban area is given by:

$$L(dB)=L(urban)-2[\log(f_c/28]^2-5.4$$

Where $a(h_{rx})$ is obtained from Hata model.

Where, fis the frequency in MHz, *d* is the distance between AP and CPE antennas in km, and h_b is the AP antenna height above ground level in meters. The parameter *cm* is defined as 0 dB for suburban or open environments and 3 dB for urban environments.

The parameter ah_m is defined for urban environments as:

$ah_m = 3.20(\log(11.75hr)) - 4.97$, for f > 400 MHz for suburban or rural (flat) environments,

$ah_m = (1.1 \log f - 0.7)h - (1.56 \log f - 0.8)$

Where, h_r is the CPE antenna height above ground level.

IV. DATA MEASUREMENTS METHOD

In this research paper all the curves and tables have been highlighted using following notations for different stations in India as given below

- Gsp - Gurdaspur
- Tal - Talwara
- Pkt - Pathankot
- kth - Kathua
- rec - Receiving

Field measurement data have been taken with the help of Anritsu site master and Anritsu dipole antenna by carrying it in car with fixed receiving antenna height of 4 meters. The Anritsu receiving antenna has an isotropic gain of 2.15 dB. The measurements have been taken at two FM radio station one is installed at Gurdaspur (Punjab), 100W FM radio transmitter working on frequency of 100.1 MHz, transmitting radio waves with a transmitting antenna height of 45 m and transmitting antenna gain is 4.15 dBi which is referred to isotropic antenna. For this station measurement has been taken at two radii distances as:

- Gurdaspur to Pathankot (State: Punjab, India)
- Gurdaspur to Talwara (State: Punjab, India)

For second field strength measurement, we have taken Kathua (State: Jammu, India) FM broadcasting station situated in bordering district of Punjab state. This is a 10 KW transmitter operating at a frequency of 102.2 MHz at the transmitting antenna height of 100 meters and transmitting antenna gain of 7.15 dBi which is referred to isotropic antenna. The field measurement for Kathua FM station has been taken for only one radial route (toward Punjab district) which is given below:

- Kathua (State: Jammu, India) to Dinanagar (via Taragarh) (State: Punjab, India)

Now from the measured values of field strength at various distances, the other parameter values have been calculated using the available formulas.

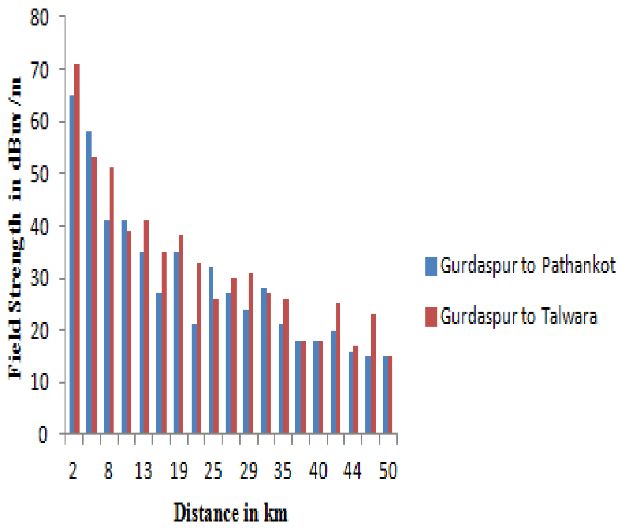

Figure 3 Field Strength v/s Distance for Gurdaspur FM using 100 W Transmitters

Fig. 3 & 4 shows the measured field strength values for Gurdaspur FM 100 W transmitter and 10 KW Kathua broadcasting station respectively. This field strength value has been converted into path loss in dB using below given formula [8]:

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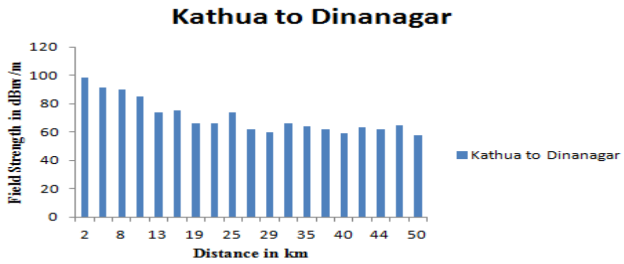
P_{iso}= 1/480 $(E*\lambda/\pi)^2$ Watts.................. (11)

Where P_{iso} is received power in Watts

Figure 4 Field Strength v/s Distance for Kathua FM 10 KW Transmitter

This received power in watts has been converted into dBm values and then path loss has been given as [9]:

Path loss = Transmitted power + Transmitting antenna gain + Receiving antenna gain – Received power



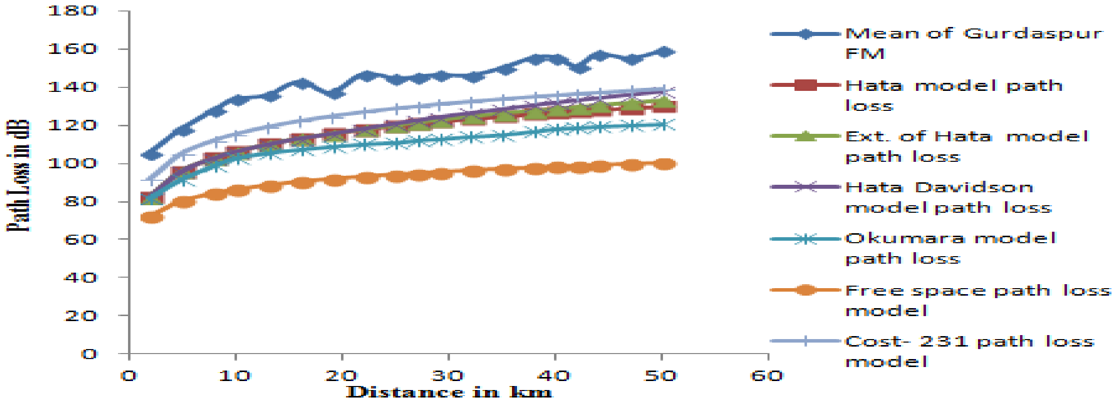


Figure 5 Path Loss in dB v/s Distance for Gurdaspur FM 100W, Transmitting Antenna Height of 45 Meters

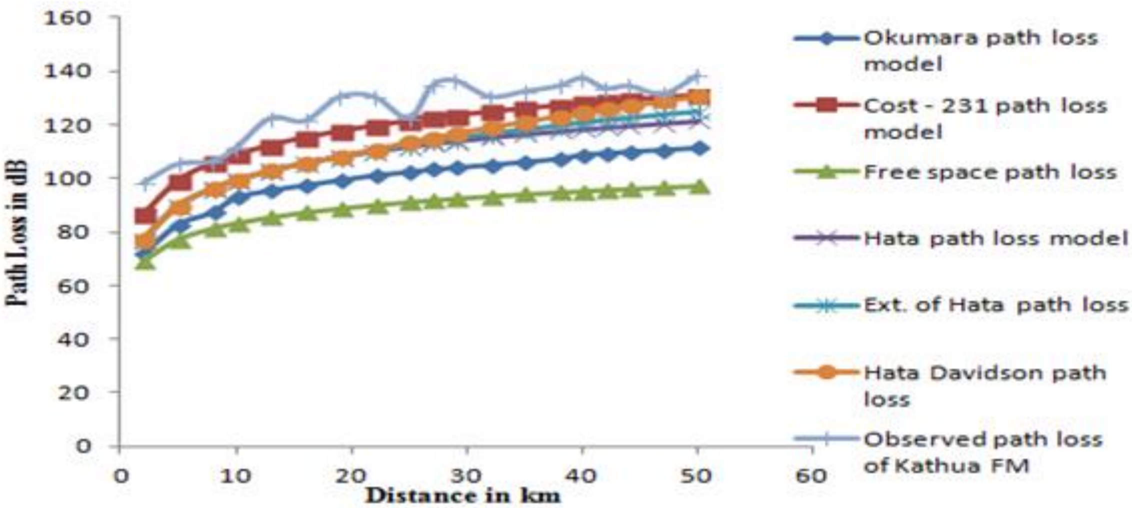


Figure 6 Path Loss in dB v/s Distance in Kms for Kathua FM 10 KW, Transmitter Antenna Height of 100 Meters

V. RESULTS AND DISCUSSION

The observed path loss values of two FM broadcasting stations have been shown in tables 1 and 2 respectively. Figure 5 shows the value of Path loss in dB with respect to distance for Gurdaspur (State: Punjab, India) FM 100W transmitter which is at transmitting antenna height of 45 meters. In graph comparison of different model with respect to the mean value of two radii (1) Gurdaspur to Talwara (2) Gurdaspur to Pathankot station have been plotted. In the graph of Figure 5 values of model Cost -231 is coming somewhat near to mean value with respect to other models.

While Figure 6 shows the plot of path loss (dB) with respect to distance (Kms) for high power FM transmitter situated in Kathua (State: Jammu, India) which is at the transmitter antenna height of 100 meters. From the graph of figure 6 it is evident that the observed value of path loss (dB) for high power transmitter (10 KW) situated in Kathua (State: Jammu, India) is coming somewhat near in Cost-231 path loss model in comparison to other model. So need to apply the correction (modification) so that we can predict the accurate and precise model, because for good propagation model the value of MSE must come closer to 6 dB value.

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Table 1 Path loss in dB measured and calculated from discussed models at different distances for Gurdaspur (State: Punjab, India) FM radio station

Sr. No.	Distance in Km	Observed path loss GSP to TAL (1)	Observed path loss GSP to PKT (2)	Average (mean) of (1) & (2)	Hata model path loss	Ext. of Hata model path loss	Hata Davidson model path loss	Okumara model path loss	Free space path loss	Cost-231 model path loss
1	2	102.7	108.5	105.61	82.2	82.2	82.2	81.65	72.19	91.63
2	5	120.5	115.5	118	95.76	95.76	95.76	91.57	80.11	105.2
3	8	122.7	132.9	127.77	102.7	102.7	102.7	98.66	84.20	112.1
4	10	134.5	132.9	133.67	106.0	106.0	106.0	102.6	86.14	115.4
5	13	132.7	138.6	135.66	109.9	109.9	109.9	105.4	88.41	119.3
6	16	138.6	146.7	142.65	113.0	113.0	113.0	107.2	90.22	122.4
7	19	135.5	138.6	137.05	115.5	115.5	115.5	108.8	91.71	124.9
8	22	140.7	152.7	146.72	117.7	117.9	118.2	110.1	92.98	127.1
9	25	147.5	141.5	144.52	119.6	120.0	120.9	110.9	94.09	129.0
10	27	143.7	146.7	145.22	120.7	121.4	122.6	112.0	94.76	130.1
11	29	142.7	150.0	146.34	121.8	122.7	124.2	112.7	95.38	131.2
12	32	146.7	145.5	146.1	123.2	124.5	126.4	114.0	96.24	132.6
13	35	147.5	152.7	150	124.5	126.2	128.5	115.0	97.02	133.9
14	38	155.6	155.5	155.5	125.8	127.6	130.6	116.8	97.73	135.2
15	40	155.6	155.5	155.54	126.5	128.6	131.9	118.1	98.18	135.9
16	42	148.4	153.5	150.9	127.2	129.5	133.1	118.7	98.60	136.7
17	44	156.6	158.0	157.28	127.9	130.5	134.3	119.3	99.00	137.4
18	47	150.6	159.6	155.09	128.9	131.7	136.1	120.0	99.58	138.3

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19	50	158.6	159.6	159	129.8	133.0	137.8	120.6	100.1	139.3

Table 2 Path loss in dB measured and calculated from discussed models at different distances for Kathua (State: Punjab, India) FM radio station

Sr. No.	Distance in Km	Observed path loss Kathua to Dinanagar	Hata model path loss	Ext. of Hata model path loss	Hata Davidson model path loss	Okumara model path loss	Free space path loss	Cost-231 model path loss
1	2	98.55	76.93	76.93	76.93	71.83	69.33	86.43
2	5	105.57	89.58	89.58	89.58	82.78	77.28	99.08
3	8	106.55	96.07	96.07	96.07	87.37	81.37	105.57
4	10	111.51	99.16	99.16	99.16	92.81	83.31	108.66
5	13	122.56	102.78	102.78	102.78	95.58	85.58	112.28
6	16	121.57	105.65	105.65	105.65	97.49	87.39	115.15
7	19	130.53	108	108	108	99.38	88.88	117.52
8	22	130.53	110.04	110.3	110.64	101.15	90.15	119.55
9	25	122.56	111.8	112.41	113.32	102.46	91.26	121.31
10	27	134.55	112.87	113.7	115	103.38	91.93	122.37
11	29	136.55	113.86	114.93	116.6	104.05	92.55	123.36
12	32	130.53	115.22	116.6	118.87	105.11	93.41	124.72
13	35	132.47	116.46	118.19	121.02	106.19	94.19	125.96
14	38	134.55	117.6	119.7	123.08	107.4	94.9	127.09
15	40	137.48	118.3	120.76	124.39	108.85	95.35	127.8
16	42	133.57	118.98	121.67	125.68	109.47	95.77	128.48
17	44	134.55	119.62	122.55	126.9	109.97	96.17	129.12
18	47	131.55	120.53	123.83	128.75	110.75	96.75	130.03
19	50	138.5	121.38	124.93	130.51	111.38	97.28	130.88

The comparison between the observed and predicted path loss models has been calculated by using MSE (Mean Square Error) and Standard Deviation (SD) as given [10] in the equation below:

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$$MSE = \sqrt{\sum_{i=i}^{n} \frac{(Pm-\mathbf{Pr})2}{n-1}}$$

$$SD = \sqrt{\sum_{i=i}^{n} \frac{(Pm-Pr)2}{n}}$$

Where P_m= Measured path loss in dB
P_r= Predicted path loss in dB
N = No. of measured data points

The results are as shown below:

Table 3 Observed Statistical evaluation of MSE and SD of discussed models (Gurdaspur FM radio station, 100.1 MHz, 100 W and mast height of 45 meters)

Evaluation	Hata model	Ext. of Hata model	Hata Davidson model	Okumara model	Cost-231 model
MSE	26.83	25.74	24.14	34.24	17.23
SD	26.12	25.06	23.5	33.33	16.77

Table 4 Observed Statistical evaluation of MSE and SD of discussed models (Kathua FM radio station, 102.2 MHz, 10 KW and mast height of 100 meters)

Evaluation	Hata model	Ext. of Hata model	Hata Davidson model	Okumara model	Cost-231 model
MSE	17.72	16.63	15.2	26.63	8.49
SD	17.25	16.18	14.79	25.92	8.27

For the calculation of MSE we have taken an average of two radii path loss of the Gurdaspur FM station. Here we have seen that cost – 231 model mean square error is 8.49 and 17.23 for Kathua and Gurdaspur FM respectively. This is the lowest in comparison to other model. A common fixed numerical value has been calculated separately for each model after taking average MSE of the respective model. The fixed numerical value that we were getting for each model has been added to the respective model formula and a new formulated formula has been modified (created) now and modified as under:

Okumura model:

$L_{50}(dB) = L_F + Amu_{(fd)} - G_{(hb)} - G_{(hm)} - G_{AREA} + 30.43$

Okumura-Hata path loss model:

$L(dB)=91.82+26.16\log_{10}f_{MHz}-13.82\log_{10}h_1-a(h_2)+(44.9-6.55\log_{10}h_1)\log_{10}d_{km}-K$

Extension of Hata Model to Longer Distances:

$L_{ITU}(dB)=90.73+26.16\log_{10}f_{MHz}-13.82\log_{10}h_1-a(h_2)+(44.9-6.55\log_{10}h_1)(\log_{10}d_{km})^b-K$

The Hata-Davidson Model:

$L_{HD} = L_{Hata}+ A(h_1, d_{km}) - S_1(d_{km}) - S_2(h_1, d_{km}) - S_3(f_{MHz}) - S_4(f_{MHz}, d_{km}) + 19.67$

Extended COST-231 Hata model:

$L(urban)(dB)=46.33+33.9\log f_c-13.82\log h_{tx}-a(h_{rx})+(44.9-6.55\log h_{tx}) \log d$

The path loss in a suburban area is given by:

$L(dB)=L(urban)-2[\log(f_c/28]^2+ 7.46$

The value of path loss and MSE of each model has been calculated again for both stations and shown in tables given below:

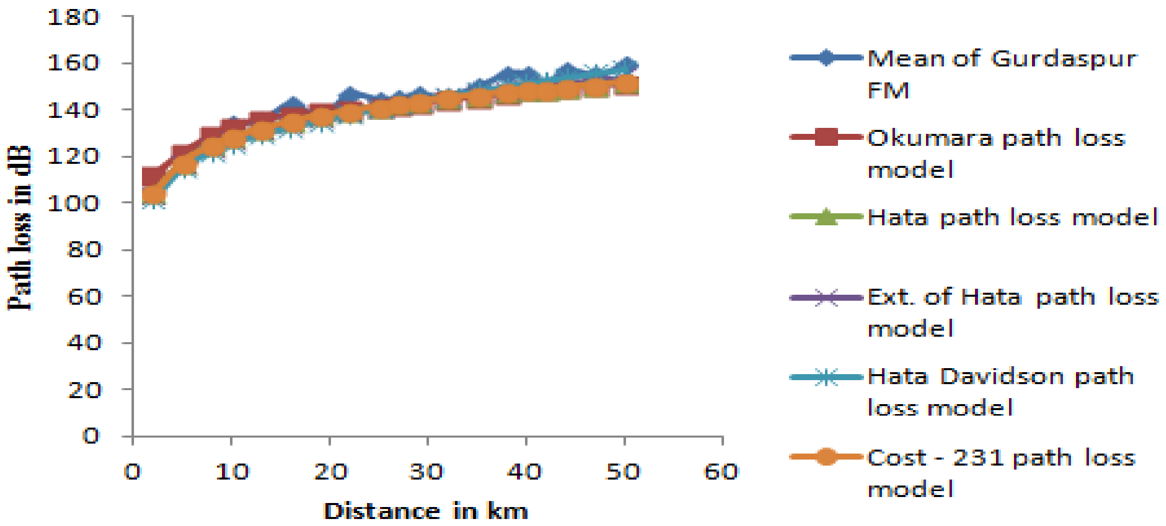

Figure 7 Formulated Path loss in dB v/s distance for Gurdaspur FM 100W, transmitting antenna height of 45 meters

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Table 5 Formulated Path loss in dB measured and calculated from discussed models at different distances for Gurdaspur FM radio station

Sr. No.	Distance (Km)	Observed path loss GSP to TAL (1)	Observed path loss GSP to PKT (2)	Avg.(mean) of (1) & (2)	Hata model path loss	Ext. of Hata model path loss	Hata Davidson model path loss	Okumara model path loss	Cost-231 model path loss
1	2	102.7	108.5	105.61	104.47	103.38	101.87	112.08	104.49
2	5	120.5	115.5	118	118.03	116.94	115.43	122.0	118.05
3	8	122.7	132.9	127.77	124.99	123.9	122.39	129.09	125
4	10	134.5	132.9	133.67	128.29	127.2	125.69	133.03	128.31
5	13	132.7	138.6	135.66	132.17	131.08	129.57	135.8	132.19
6	16	138.6	146.7	142.65	135.24	134.15	132.64	137.61	135.26
7	19	135.5	138.6	137.05	137.78	136.69	135.18	139.2	137.8
8	22	140.7	152.7	146.72	139.95	139.08	137.89	140.57	139.97
9	25	147.5	141.5	144.52	141.84	141.185	140.57	141.32	141.86
10	27	143.7	146.7	145.22	142.98	142.59	142.25	142.45	143.0
11	29	142.7	150.0	146.34	144.04	143.9	143.84	143.12	144.06
12	32	146.7	145.5	146.1	145.44	145.68	146.1	144.43	145.46
13	35	147.5	152.7	150	146.82	147.35	148.22	145.41	146.84
14	38	155.6	155.5	155.5	148.04	148.82	150.25	147.22	148.06
15	40	155.6	155.5	155.54	148.80	149.79	151.54	148.57	148.82
16	42	148.4	153.5	150.9	149.52	150.69	152.8	149.09	149.54
17	44	156.6	158.0	157.28	150.21	151.68	154.02	149.74	150.23
18	47	150.6	159.6	155.09	151.18	152.88	155.78	150.42	151.2
19	50	158.6	159.6	159	152.1	154.18	157.51	151.0	152.12

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Table 6 Formulated Statistical evaluation of MSE and SD of all the discussed models (Gurdaspur FM radio station, 100.1 MHz, 100 W and mast height of 45 m.)

Evaluation	Hata model	Ext. of Hata model	Hata Davidson model	Okumara model	Cost – 231 model
MSE	4.66	4.58	4.86	4.96	4.66
SD	4.54	4.46	4.73	4.82	4.54

Table 7 Formulated Path loss in dB measured and calculated from discussed models at different distances for Kathua FM radio station

Sr. No.	Distance in Km	Observed path loss Kathua to Dinanagar	Hata model path loss	Ext. of Hata model path loss	Hata Davidson model path loss	Okumara model path loss	Cost-231 model path loss
1	2	98.55	99.2	98.11	96.6	102.26	99.29
2	5	105.57	111.85	110.76	109.25	113.21	111.94
3	8	106.55	118.34	117.25	115.74	117.8	118.43
4	10	111.51	121.43	120.34	118.83	123.24	121.52
5	13	122.56	125.05	123.9	122.45	126.01	125.14
6	16	121.57	127.92	126.83	125.32	127.92	128.01
7	19	130.53	130.27	129.18	127.67	129.81	130.38
8	22	130.53	132.31	131.48	130.31	131.58	132.41
9	25	122.56	134.07	133.59	132.99	132.89	134.17
10	27	134.55	135.14	134.88	134.67	133.81	135.23
11	29	136.55	136.13	136.11	136.27	134.48	136.22
12	32	130.53	137.49	137.78	138.54	135.54	137.58
13	35	132.47	138.73	139.37	140.69	136.62	138.82
14	38	134.55	139.87	140.88	142.75	137.83	139.95
15	40	137.48	140.57	141.94	144.06	139.28	140.66
16	42	133.57	141.25	142.85	145.35	139.9	141.34
17	44	134.55	141.89	143.73	146.57	140.4	141.98
18	47	131.55	142.8	145.0	148.42	141.18	142.89
19	50	138.5	143.65	146.11	150.18	141.81	143.74

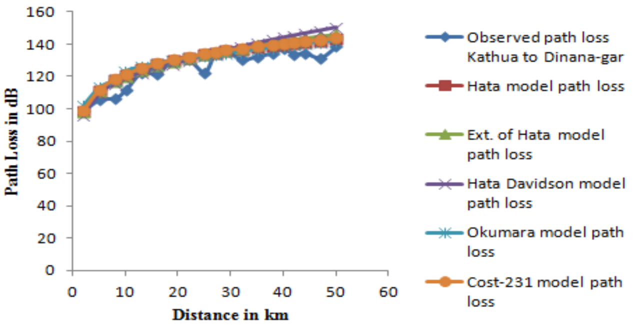

Figure 8 Formulated value of Path Loss in dB v/s Distance in Km for Kathua FM 10 KW, transmitter antenna height of 100 meters

Table 8 Formulated Statistical evaluation of MSE and SD of discussed models (Kathua FM radio station, 102.2 MHz, 10 KW and mast height of 100 meters)

Evaluation	Hata model	Ext. of Hata model	Hata Davidson model	Okumara model	Cost-231 model
MSE	6.87	7.23	8.27	6.39	6.95
SD	6.69	7.04	8.05	6.22	6.76

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We have seen in the table 3 and 4 that there is a large MSE for Okumara model and it does not fit at for open area and prevailing environmental and geographical conditions of Punjab (India). For other models also there found to be large MSE but lower than in comparison with Okumara model. Table 5 and 7 has shown the formulated (corrected) path loss of different models after modification of the respective models for Gurdaspur FM station and Kathua FM station respectively. It is observed from the tables that path has shown very near resemblance with respect to the observed measured data of the respective station at known distances. The modified (corrected) value of path loss models has been shown in graphical form in fig 7 and 8. By observing both the figures we can conclude that the observed and calculated path loss of different models is showing very close resemblance. Now from the available formulated path loss models we can calculate the MSE and SD and the same has been shown in table 6 and 8. After observing the table, we observed that the mean square error has been reduced by almost one fourth value from the previous available models.Now to further reduce the value of MSE and SD within limit of 6 dB, which is a necessary condition for the good propagation model, we have modified the formula of each model separately for 100 W and 10 KW FM station. In the modified MSE we have seen that it has been almost reduced by one fourth than earlier formula.

VI. CONCLUSIONS

In this research paper, we presented modified path loss models for broadcasting applications. The path loss values have been confirmed and verified for 100 W and 10 KW FM stations and simultaneously for different transmitting antenna heights. For the practical observations, we considered the open area of the north district of Punjab (India). Authors have tried their level best to modify the path loss formula and hence this formula will definitely be used in India where FM is slowly gaining its importance. This modified model presented in this paper could be very much helpful to access the path loss of the newly installed station more accurately and precisely. In the modified formulas the MSE has almost reduced to one fourth value. For 100 W stations it has exactly come within the 6 dB limit which represents a good propagation model. For 10 KW station, though it is still coming under the permissible limit i.e. closer to 6 dB limit due to different terrain condition. So, we can conclude that modified models presented in this paper is best fitted for 100 W to 10 KW FM stations and be further be checked for their accuracy for other power levels also.

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