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Performance Evaluation of different Path Loss Models for Broadcasting applications

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***Abstract*: -** In this paper we highlighted the performance evaluation of different path loss model and envisage the most suitable model for plane area in northern region of India i.e. border district of Punjab and Jammu. In this paper we compared the different path loss propagation models with measured field data and investigated the appropriateness of the model which gave us results closer to measured (field) data. In the present work we used many path loss models for comparative analysis. This research paper presents a comparative analysis of six empirical path loss models with respect to measured data for plane area in state of Punjab and Jammu (India). The preferred six models under investigation are COST- 231, Hata, Okumara, Free space model, Extention of Hata model and Hata Davidson model. For investigations and analysis purpose, firstly the measured field data has been taken in the Gurdaspur (State: Punjab) by using the 100w FM radio transmitter and transmitting antenna height of 45m, and in second case we used 10 kw FM transmitter at Kathua (State: Jammu) i.e. situated in bordering area of Punjab and Jammu at transmitting antenna height of 100m with fixed receiving antenna height of 4 meters. On analyzing the different results we found that Cost–231 model is best suited for plane area in norhen region of the border district of Punjab (India). Although in our investigations Hata Davidson model shows better results than the extension of Hata model for longer distances, but the mean square error of cost – 231 was found to be minimum as compared to other models.

***Keywords*: -** *Path loss, free space model, Cost-231model, Hata mode, Okumara model, Extension of Hata model, Hata Davidson model.*

I. INTRODUCTION

Revolutionary exponential growth of communication devices leads to increased interest amongst the various scientists, researchers and engineers in the field of radio communication. In present days, more and more number of scientists are devoting a lot efforts to refine radio propagation path loss models for urban, suburban and other environmental conditions [1]. Propogation of the radio waves in urban areas is quite complex because it consists of reflected and diffracted waves produced by multipath propagation. In general, radio wave propagation consists of three main modes (a) Reflection : It occures when radio wave propagation in one medium impinges upon another medium with different electromagnetics properties. Part of radio wave energy may be absorbed or propagated through the reflecting medium, resulting [2, 3] in the reflected wave that is attenuated. (b) Diffraction : It is a phenomenon by which propagating radio waves bend or deviate in the neighborhood of obstacles. (c) Scattering : It occures when radio waves hits a rough surface or an object which is having a size much smaller than the signal wave length.

Prediction of path loss is an significant element of system design in any communication system. A reliable propagation model is one which calculates the path loss with small standard deviation. Suitable models must be chosen for measurements of field strength and path loss as well as other parameters. An accurate and reliable prediction methods helps to optimize the coverage area, transmitter power and eliminates interference problems of other radio transmitters as well. This will help network engineers and planners to optimise the coverage area and to use the correct transmitted powers. All the prediction methods are divided into empirical and deterministic/physical models [4]. The preference for the coverage prediction model depends on the propagation environment and the area to be covered. Since it is clear from above discussion that the propagation takes place through multiple diffraction, reflection and scattering from the extremely large number of objects. Since it is very difficult to locate scatterers deterministically therefore characterisation of the signal within the coverage zone is done statistically. For this reason, prediction models have been developed using empirical or statistical methods [5].

The critical factor that affects path loss is the distance between the transmitter and receiver [6]. It is known that signal power decreases as distance increases. The path loss represents the mean signal attenuation at a certain distance from the transmitter and can be predicted by the distance and other macroscopic parameters [7, 8] such as carrier frequency, transmitter and receiver antenna heights, terrain contour and buildings concentration. In our present work, one of the main reason for understading the the various elements affecting radio signal path loss is to predict the coverage area that may be achieved for a particular broadcast station [9-13] and also to predict the suitability of model as well.

II. A BRIEF STUDY OF VARIOUS PROPAGATION MODELS

The two basic propagation models (Free-Space and Plane Earth Loss) have all the mechanisms which are encountered in macrocell prediction. Many researchers use these models and predict the total signal loss. Other models require detailed knowledge of the locations, dimensions and parameters for every tree or building and terrain feature in the area to be covered. The models are complex and yield an unnecessary amount of details as the network designer is not interested in the particular locations covered, but the overall extent of the coverage area. One appropriate way of removing these complexities is to adopt an empirical model. These models use all the parameters like the received signal strength, frequency, antenna heights and terrain profiles which were derived from a particular environment by the use of extensive measurements and statistical analysis as well. These models then can be used to design the systems which operates on similar environmental condition as the original measurements [14].

2.1 Free Space Propagation Model

The 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) [15]. Since in most large-scale radio wave propagation models, the free space model predicts that received power decays as a function of the separation distance between Transmitter-Receiver raised to some power (i.e. a power law function) (Saunders 2005). 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).

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

where P_t is the transmitted power, P_r (d) is the received power, Gt is the transmitter antenna gain, Gr is the receiver antenna gain, d is the transmitter-receiver separation distance in meters and λ is the wavelength in meters.

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

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

Where c is the speed of light ($3\times10^8\ ms^{-1}$)

2.2 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 extrapolated up to 3000 MHz. Okumura's models is developed for macrocells with cells diameters in range from 1 to 100 km. The height of the base station antenna is kept between 30-100 m [16]. 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 (hb) of 200m and a mobile antenna height (hm) of 3 meters. These curves were developed from extensive measurements using vertical omni-directional antenna at both the base and mobile. In this cas 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 [17] :

$$L_{50}(dB) = L_F + Amu_{(fd)} - G_{(hb)} - G_{(hm)} - G_{AREA} \quad \text{.........(3)}$$

where $L_{50}(dB)$ is the median value (i.e. 50^{th} percentile) of path (propagation) loss, L_F is the free space loss and can be calculated using either Equation (5) or Equation (6). The value of Amu is the median attenuation relative to free space, G(hb) is the base station antenna height gain factor, G(hm) is the mobile antenna height gain factor, and GAREA is the gain or correction factor owing to the type of environment. Amu(f; d) and G_{AREA} are determined by observing the Okumura curves.

The term G(hb) and G(hm) can be calculated by using these simple formulas :

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

$$G_{(hm)} = 10 \log_{10} (hm/3) \;\; hm \leq 3m \quad \text{........(5)}$$

$$G_{(hm)} = 20 \log_{10} (hm/3) \;\; 10m \leq hm \leq 3m \quad \text{.........(6)}$$

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 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.

2.3 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 in this model. This is one of the main advantage of this model. However, the model neglects the terrain profile (condition) between the transmitter and receiver i.e. hills or other obstacles that exists between the transmitter and receiver were not considered. This is because both Hata and Okumura models have made the assumption that the transmitters would normally be located on hills.
The basic formula for the median propagation loss given by Hata is :

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

where f_c is the carrier frequency (in MHz) from 150 MHz to 1500 MHz, h_b is the base station antenna height (in metres) ranging from 30m to 200m, h_m is the mobile antenna height (in metres) 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

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

2.4 Extension of Hata Model to Longer Distances

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

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

where

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

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

2.5 The Hata-Davidson Model

The Telecommunications Industry Association (TIA) recommends 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:

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

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

distance	A(h1,dkm)	$S_1(d_{km})$
$d_{km} < 20$	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 $d_{km} > 64.38$

2.6 Extended COST-231 Hata model

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 received antenna, height of a base station and distance between the base station and the received 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 has seen it widely used for path loss prediction at this paricular frequency band.

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

$$L(urban)(dB) = 46.33 + 33.9logf_c - 13.82logh_{tx} - a(h_{rx}) + (44.9 - 6.55logh_{tx})\log d \quad \text{..........................(10)}$$

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, f is 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 metres. 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.

III. COMPARSION IN TERM OF DIFFERENT MEASUREMENTS

3.1 Results and discussion

Field measurement data has been taken with the help of Anritsu site master and anritsu dipole antenna with fixed receiving antenna height of 4 meters. The Anritsu receiving antenna has isotropic gain of 2.15 dB. The measurements have been taken from two radio stations one is situated at Gurdaspur (State : Punjab) which is operating at RF power of 100w, transmitting frequency of 100.1 Mhz and transmitting antenna height of 45 m. In this case transmitting antenna gain is 2 dB which is referred as gain of dipole antenna. For this low power station, measurents have been taken at two radii route at the distance of Approx. 50 Km from transmitter as :

- Gurdaspur to Pathankot
- Gurdaspur to Talwara

For the second field strength measurements we have taken Kathua FM radio station situated in jammu i.e. at adjoining area of Punjab border. This is a high power (10 Kw) transmitter working at frequency of 102.2 Mhz at the transmitting antenna height of 100 m. In this case, the transmitting antenna gain of 5 dB referred as dipole antenna gain. The field strength measurements for Kathua (State: Jammu) has been taken only for one radial distance (approximately 50 Km from high power transmitter) and route is given below:

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

Now from the measured values of field strength at different distances, the other parameters values can be calculated by using the available formulas.

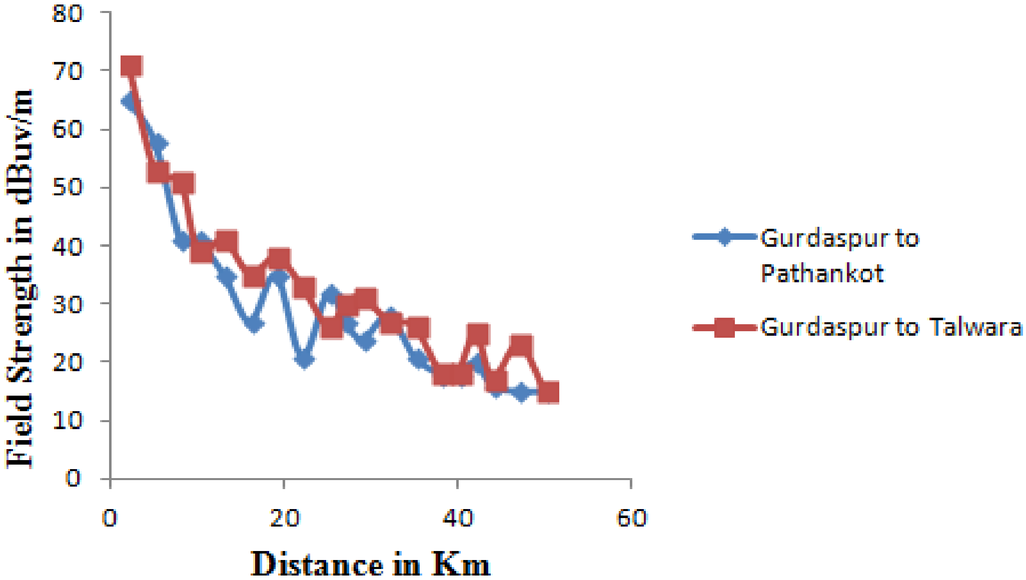

Fig 1. Field Strength v/s Distance for Gurdaspur FM 100 w Transmitter

Fig. 1 shows the measured field strength values for Gurdaspur FM 100 w Transmitter, this given field strength has been converted into path loss in dB by using formula as given below :

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

Where P_{iso} is received power in watts

This received power in watts has been converted into dBm values and then path loss value is given as :
Path loss = Transmitted power + Transmitting antenna gain + Receiving antenna gain – Received power.
Fig. 1 clearly shows that due to low power (100 W) of this transmitter in both routes (Gurdaspur to Pathankot & Gurdaspur to Talwara) at approximately radial distance of 50 Km the field strength value decrease more drastically due to less power of the transmitter.
While Fig. 2 shows the measured field strength value for high power transmitter situated in Kathua (State: Jammu)

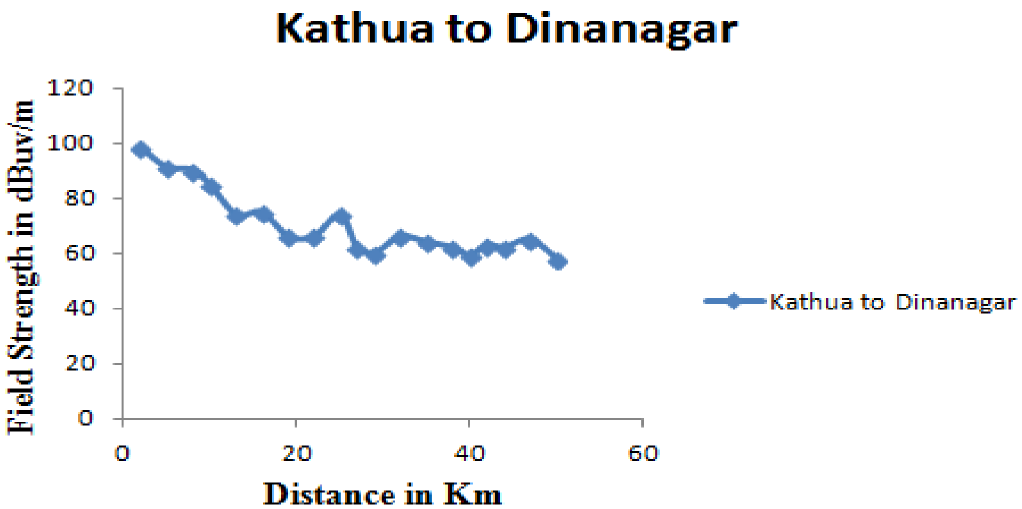

Fig 2. Field Strength v/s Distance for Kathua FM 10 Kw Transmitter

This figure 2 clearly shows that value of field strength with respect to distance (appr. 50 Kms) for high power transmitter situated in Kathua (State: Jammu) will decrease at much less rate as compared to low power transmitter (100 W). This will evidently due to high power of transmitter.

3.2 Suitablity of model for both high power and low power transmitter

Fig. 3 shown below gives the variation of path loss with distance for low power (100 W) for Gurdaspur FM station at transmitting antenna height of 45 meters. From the graph we have clearly seen that Cost – 231 model shows comparitively better results than the other models. Free space path loss model is also less accurate because it has taken only the consideration that RF wave becomes weak as the distance increases because of diffraction of signal. Apart from that fact there are so many other environmental factors that can effects the signal strength. Infact Hata Davidson model shows better results than Hata model but not better than cost – 231 model. Hence we conclude that Okumara model is not suitable for plane area like the border district of Punjab.

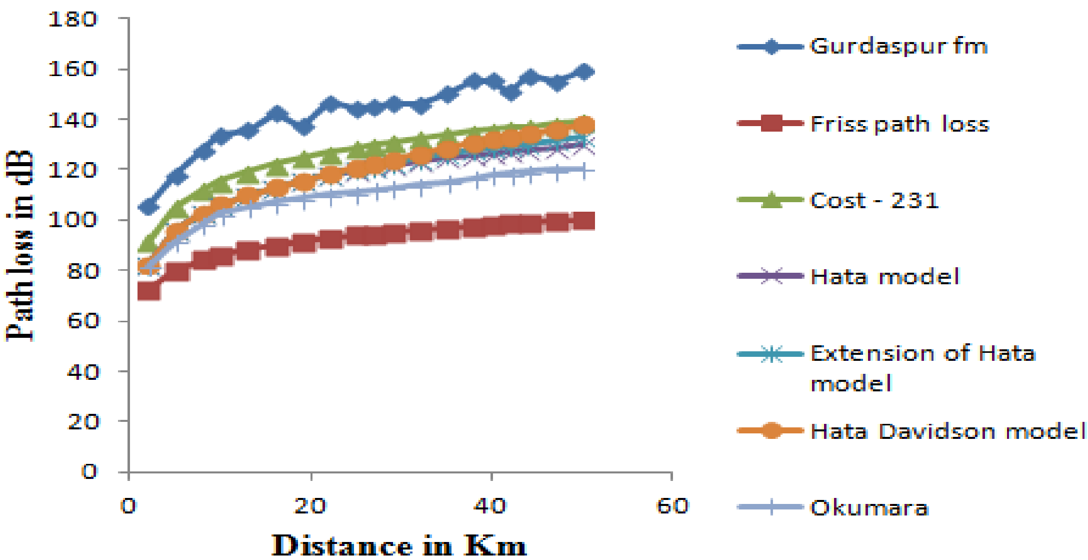

Fig 3. Path loss in dB v/s distance for Gurdaspur fm 100 w, transmitting antenna height of 45 meters

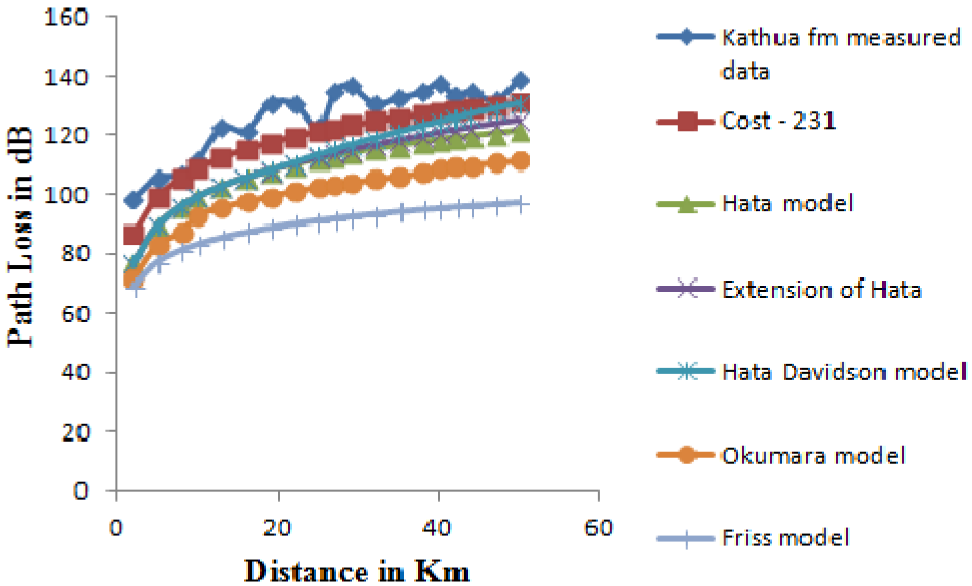

Fig 4. Path Loss in dB v/s Distance in Km for Kathua FM 10 kw, transmitter antenna height of 100 meters.

Fig. 4 shows ths measured value of path loss with respect to distance (appr. 50 Kms) for high power transmitter situated in Kathua (State: Jammu) at greater antenna height (100 meters) and hence has been compared with the available models. Here we are getting the same results as that of low power Gurdaspur FM station. But in contrast, we observed that for high power transmitter (Kathua, State: Jammu) the value of path loss of Cost – 231 model is very close to measured value of path loss as compared to Gurdaspur FM station.

IV. CONCLUSIONS

Here in present work, first we compared different available path loss models with the measured data for low power (100 w) FM RF transmitter working on 100.1Mhz at transmitting antenna height of 45m and used second high power RF FM transmitter (10kw) working at 102.2 Mhz at transmitting antenna height of 100 m. The path losses obtained is plotted graphically in order to achieve better results. By observing the different graphs we conclude that Cost – 231 has shown comparatively better results than other models. Although, we observe that Hata davidson model shows reasonably better results than the extension of hata and Hata models but the value of mean square error obtained in Cost – 231 found to be minimum. Therefore, lastly we conclude that for plane area like border district of Punjab Cost – 231 model is found to be best suited for broadcasting applications.

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