Mobile Radio Propagation Path Loss Studies at VHF/UHF Bands in Southern India

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***Abstract*—Field strength measurements at 200, 400 and 450 MHz (VHF/UHF band) were conducted with the field strength meter placed on board of a vehicle in Southern India. Observed field strength values were converted into path losses and are compared with different path loss prediction methods like Hata, Egli, Blomquist–Ladell, COST 231 Walfisch–Ikegami, Walfisch–Bertoni and ITU-R. These path loss studies are carried out in urban, suburban and open areas in this region. The results showed that Hata's method gave better agreement with observed values in urban, suburban and open regions. COST 231 Walfisch–Ikegami model is also in good agreement with the observed values in urban and suburban regions. Egli and Blomquist–Ladell methods showed moderate agreement in open region only. The agreement of Walfisch–Bertoni and ITU-R methods with observed values is not good.**

I. Introduction

DURING the last couple of years mobile communications has developed from a narrow and specialized field with limited interest to one of the most important parts of the telecommunications field. Mobile communications has changed from being the businessman's tool to the means of communications used by the consumers and is the fastest growing area of telecommunications. VHF/UHF band mobile radios especially for land use are highly convenient for police communications, reporting services and traffic control [1].

As the demand for mobile communication services increases, deterministic propagation prediction techniques play an important role in the optimization of the coverage and the efficient use of the available resources. The ability to predict the minimum power necessary to transmit from a given base station at a given frequency, and to provide an acceptable quality of coverage over a predetermined service area, and to estimate the effect of such transmissions on existing adjacent services, is crucial for the improvement of frequency reuse and the implementation of band sharing schemes between different services and for the success of cellular systems. There is a need for a better understanding of the influence of the different urban and terrain factors on the mobile radio signal and its variability [2].

In mobile communications one of the major parameters of interest is path loss [3]. Prediction of path loss assumes even greater significance in view of the constantly changing environment conditions [4]. There is still a great need for more narrowband and wideband measurements at frequencies of interest to put proper bounds on the statistical values [5]. Any prediction model which is useful for most applications must consider all the important modes of propagation; model selection must also consider the extent to which the method is convenient to use [6]. Irrespective of the prediction models deployed, estimated values always have to be verified by measurements. If necessary, correction factors have to be derived and introduced in further predictions [7].

To identify suitable narrowband methods in Southern India and to study various propagation phenomena affecting mobile radio communications, propagation measurements were conducted around 200, 400 and 450 MHz. Observed results were converted into path losses and are compared with different path loss prediction methods given by Hata [8], Egli [9], Blomquist–Ladell [10], COST 231 Walfisch–Ikegami [11], Walfisch–Bertoni [12] and ITU-R [13]. The results are presented in this paper. Field strength prediction is a requirement for planning modern mobile communication system improvements in flexibility, accuracy and reliability [14].

II. Experimental Details

Keeping the above, propagation measurements were conducted in the Tirupati (Lat 13° 39′ N, Long 79° 22′ E) region of southern parts of India utilizing TV video transmissions at 189.25 MHz in the year 1998 in pre-monsoon months. Tirupati is a medium sized city surrounded by hills known as Tirumala Hills. The height of these hills are 1000 m above mean sea level (msl). Also 385.15 and 368.15 MHz UHF transmissions from two places known as Sriharikota (Lat 13.7° N, Long 80.2° E, hereafter written as SHAR center, as the Indian space research center is situated here) and Sullurpet are also monitored. Both these places are located at a distance of 90 and 70 km from Tirupati, respectively. One more UHF transmission, at 468 MHz, available from Renigunta, which is located 10 km from Tirupati, is also monitored for the purpose of the present study.

Field strength was measured continuously in a moving vehicle, converted into path loss, and studied as a function of distance for the first time in this region of globe. A massive expansion of mobile radio communications is going on in this region and these inputs will help to design the communication systems and to understand the propagation mechanisms. The purpose of signal level measurements is to give a realistic picture of the situation. In India, Prasad [4] made extensive measurements at VHF/UHF frequencies for different base station heights in Indian coastal zones, but no continuous monitoring of signals was

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done. Except for this, not much work of this sort is reported in India.

The signals were monitored continuously at a sampling rate of every second, averaged to one minute using a field strength meter (FSM).[1] The instrument was mounted on a jeep and the field strength measurements were taken during the motion of the vehicle. The FSM antenna is kept at a height of 3 m above the ground. The FSM has a facility for data storage and transfer to a PC for further analysis. In the present work a digital terrain data base is not used, but city topographic sheets have been used.

III. Comparison with Prediction Methods

An accurate and reliable prediction method helps to optimize coverage area, transmitter power, eliminates interference problems of other radio transmitters etc. All the prediction methods are divided into empirical, semi-empirical and deterministic models. The major advantage of empirical and semi-empirical methods is the low computation time for large coverage areas. But at the same time these can lead to errors due to lack of precise terrain data and propagation environments which is the decisive advantage of deterministic models [4].

The choice of the coverage prediction model depends on the propagation environment and the extent of the coverage area. In mobile communications, propagation takes place through multiple diffraction, reflection and scattering from an extremely large number of objects. Since it is very difficult to locate scatterers deterministically, characterization of the signal within the coverage zone is done statistically. The effects of multiple reflections of the transmitted signal arriving at the receiver, the irregular distribution of man-made structures, scatterers and vegetation within the area, the effects of movement of the mobile unit and the irregular distribution of terrain characteristics and their random nature suggest that a deterministic approach to propagation prediction in a land mobile radio environment may prove intractable. For this reason, many practical mobile radio propagation prediction models have been developed using empirical/statistical methods [15].

The accuracy of a particular model in a given environment depends on the fit between the parameters required by the model and those available for the area concerned [16]. In the present study, the experimentally observed path losses are compared with different prediction methods in order to identify a suitable prediction method. The prediction methods employed are 1) Hata [8], 2) Egli [9], 3) Blomquist–Ladell [10], 4) COST231 Walfisch–Ikegami [11], 5) Walfisch–Bertoni [12] and 6) ITU-R [13].

The simple modeling of path loss is still dominated by the Hata empirical model, where the propagation results are fitted to a simple analytical expression, which depends on antenna height, environment, frequency and other parameters. Hata's method is basically an extension of Okumara's method (which is somewhat cumbersome due to numerous correction factors) and employs curves instead of parametric equations. These type of models are well suited for large cell mobile systems, in which the base station is elevated with respect to the surrounding environment. The Hata model does not have any of the path-specific corrections which are available in Okumara's model.

In the empirical model of Blomquist-Ladell, the total attenuation is the sum of free space loss, a weighted sum of smooth spherical earth loss and obstacle diffraction loss, urban loss and vegetation loss. In the present case we have used methods like Hata, Egli, Blomquist–Ladell and the approximate models [17] like COST 231 Walfisch–Ikegami and Walfisch–Bertoni, which do not require precise information on the environment. Hence topographic sheets of the city were sufficient.

Euro-COST 231 group has recommended a combination of the Walfisch–Bertoni [12] model and Ikegami *et al.* [18] for urban area propagation prediction. COST 231 Walfisch–Ikegami model is valid for both 900 and 1800 MHz, it is applicable to large, small and micro cells. A steep transition of path loss occurs, when the base station antenna height is around the same height as local-roof tops. In the present case, base station antenna height is much higher than the rooftop building height, hence such transition problem is not expected

Walfisch–Bertoni method considers the impact of rooftops and building height by using diffraction to predict average signal strength at street level. These methods describe urban propagation loss as a sum of three terms: free space losses, rooftop-to-street losses and multiple diffraction losses. The approaches of Walfisch–Ikegami and Walfisch–Bertoni are restricted by definition to radio paths that are obstructed by buildings. They are not applicable if a free line-of-sight (LOS) exists between base and mobile antennas within a street canyon. The model accounts for local terrain slope in the vicinity of the mobile. It does not, however, incorporate terrain roughness factors or treat obstructing terrain features, such as hills. We have applied these methods at 200 MHz in the urban and suburban environments to see how they works at this frequency in a medium sized city and much below the lower frequency limit of 900 MHz.

Though this type of comparison was attempted by earlier researchers Grosskopf [19], Aurand and Post [20] their conclusions cannot be adopted to our region. Grosskopf compared various prediction techniques with the measurements in hilly and mountainous terrain of Germany, the terrain was built up area with buildings of 5 floors, each floor with 4 m or so. In the present case the buildings were 2 to 3 floors in urban region and in suburban area the buildings were 1 to 2 floors and no changes in terrain elevation. In Grosskopf's case there was no classification of urban, suburban and open areas, where as in our study we measured field strength continuously in motion covering the urban, suburban and open areas. Hence it is not proper to adopt his conclusions to Indian conditions.

Similarly our studies are different from those conducted by Aurand and Post, their experimental studies were not mentioned explicitly. In the present study path loss was studied as a function of distance. In all these methods effective antenna height is used. According to ITU-R [21], base station antenna height is usually taken as the height of the center of radiation above the average terrain elevation between 3–15 km in the direction of interest. The antenna height of a mobile is taken as its height above ground. In the present work, there is not much variation in

[1]The FSM used is model R-505 of Z-Technology Inc, U.S.A. The frequency range of the meter is from 3–1000 MHz, the measurement range is 0–110 dBμV, and the measurement accuracy is 2 dB. It is battery operated and highly portable with LCD display.

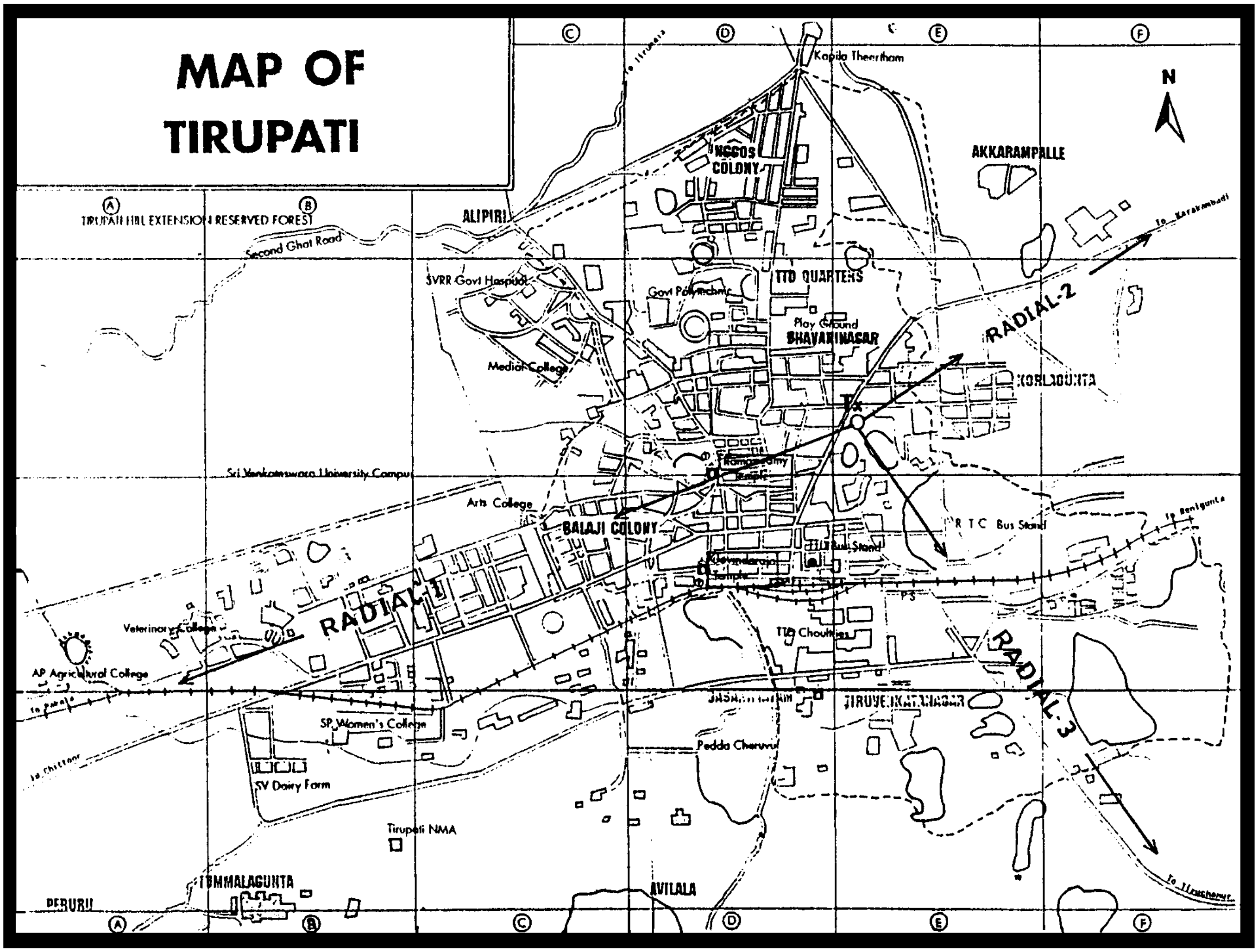

Fig. 1.

TABLE I
CHARACTERISTICS OF VHF TRANSMITTER AT TIRUPATI AND UHF TRANSMITTERS AT SULLURPET, SHAR AND RENIGUNTA

PLACE	TIRUPATI	SULLURPET	SHAR	RENIGUNTA
Transmitting Frequency (MHz)	189.25	368.15	385.15	468
Transmitting Power (W)	100	10	10	10
Transmitting Antenna gain (dB)	4	17	17	8
Transmitting Antenna Height (m) (above the ground level)	30	40	40	20

terrain elevation and the area has moderate dry ground. Hence effective height of the base station $h_{\text{eff}} = h_b$ (antenna height above ground at base station) has been used for calculating path loss values. In the present study the mobile antenna height is 3 m, the average buildings height in urban areas has been taken as 10 m and the average buildings height in suburban areas is 6 m.

IV. ENVIRONMENTAL DESCRIPTION

In the present study, a video signal from a low power TV transmitter (189.25 MHz) situated at Tirupati is monitored in different environments radially along the transmitter. A map of Tirupati is shown in Fig. 1. The transmitter is located in a thickly populated zone surrounded by congested 3 story buildings, markets and somewhat narrow roads. The characteristics of the transmitter are shown in Table I.

The measurements were conducted radially from the transmitter in 3 different routes, which are designated as Radial 1, Radial 2 and Radial 3. Radial 1 started from a temple situated near the transmitter and terminated at the Agricultural University via Balaji colony, Engineering college etc. In the case of Radial.1 the measurements were taken up to a distance of 6.5 km from the transmitter. The first 2 km is densely populated with 3 story buildings and roads of width 25 feet, denoting urban conditions. The zone between 2–4 km from the transmitter is less populated, with typical suburban conditions, and the region between 4–6 km can be classified as quasiopen area with palm trees of 20 feet in height on both sides of the road. The measurements were taken in the months of February to March.

Radial 2 started from Municipal office and covered a distance of 6.5 km. The distance of 2 km from transmitter is densely populated, denoting urban conditions. Beyond 2 km, conditions changed to suburban and after 3 km the environment resembled quasiopen. There are some open lands with trees of 10 feet in height having leaves. Around 3 km some banana plantations are also seen. Beyond 4 km distance tall trees with height of 20 ft are seen and a tiny village called Mangalam is located at 5 km distance; beyond that the area looked like complete open.

Radial 3 started around the transmitter and followed the road known as Karakambadi road and ended at another small temple town called Tiruchanur, covering a distance of 4.5 km. As in the previous cases, the region up to 2.5 km distance represented urban conditions. After 2.5 km, the area looked like suburban area with road widths of 25 feet and some dry tanks. Between 3–4 km some small bushes with dry land is seen with no obstructions. The measurements ended at 4.5 km at Tiruchanur, which has small population and single story buildings denoting suburban conditions. During the time of measurements, the nearby roads are filled with heavy traffic.

UHF signals originating from SHAR (385.15 MHz) and Sullurpet (368.15 MHz) transmitters were also monitored. In the case of the SHAR transmitter the region where the measurements were taken is completely open (7 km zone). The region up to a distance of 1.5 km around Sullurpet transmitter is suburban region and the remaining region is completely open zone. In this case the signal was monitored up to a distance of 11 km. Also, UHF signals from Renigunta Transmitter (468 MHz) were also monitored. In this case the region is completely open, signals were monitored up to 5 km. The area surrounded by the transmitter is suburban, up to 0.5 km only. The characteristics of the transmitters are shown in Table I.

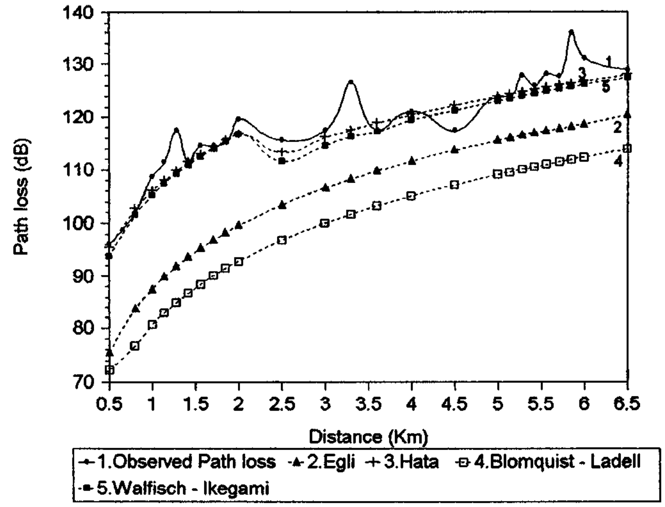

Fig. 2.

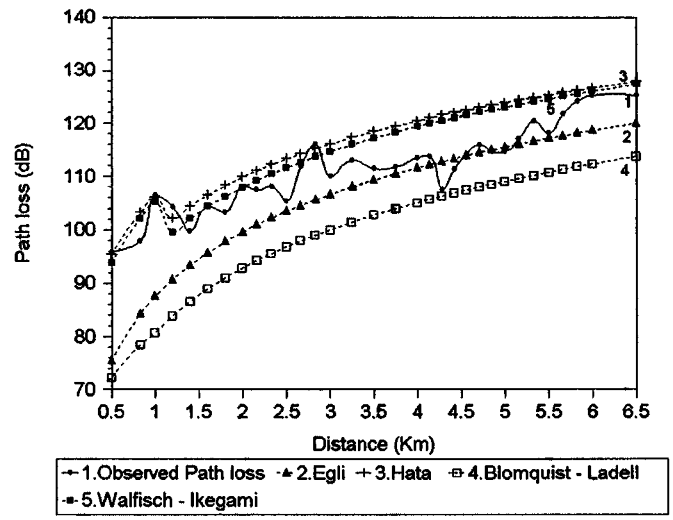

Fig. 3.

V. Results and Discussions

Fig. 2 shows the comparison of observed path losses with those predicted by the above prediction methods as a function of distance for Radial 1. Here Hata's method gives better agreement than other methods up to approximately 2 km. Up to 2 km Hata's method with urban factors has been used and beyond 2 km Hata's method with suburban correction factors have been employed. As described earlier in the environmental section, urban conditions exist up to a maximum distance of 2 km and beyond this the conditions resemble those of suburban. The maximum deviations observed by Hata's method are 9 dB at 3.5 km and 10 dB at 6 km distance.

The Walfisch–Ikegami method, with urban and suburban correction factors, gives good agreement with observed values and follows the same trend as observed path loss. The maximum deviation observed is around 10 dB at 3.5 and 6 km. Egli's method underestimated the path loss throughout the range of interest. At 2 km distance, the deviation is 20 dB and at 6 km the deviation is 18 dB. Blomquist–Ladell's method also underestimated the path loss. The deviations observed are 27 dB at 2 km and 24 dB at 6 km distance.

The results of radial 2 are depicted in Fig. 3 Here also Hata's method gives reasonably good agreement compared to the other methods. Here Hata's method with urban correction factors have been employed up to 1 km and beyond that suburban correction factors were used. The agreement is good up to a distance of 3 km and thereafter the observed path loss curves shows a little bit steady nature up to a distance of 5 km. After 5 km again the observed path loss shows increasing tendency and Hata's method gives better agreement after 5.5 km. The maximum deviation observed is 14 dB at around 4 km. COST 231 Walfisch–Ikegami method with urban and suburban correction factors is also in good agreement up to 3.5 km. The maximum deviation observed is around 13 dB at around 4 km respectively. Egli's method underestimates at smaller distances and coincides with the observed path loss between 3–5 km. Blomquist–Ladell's method underestimates throughout the

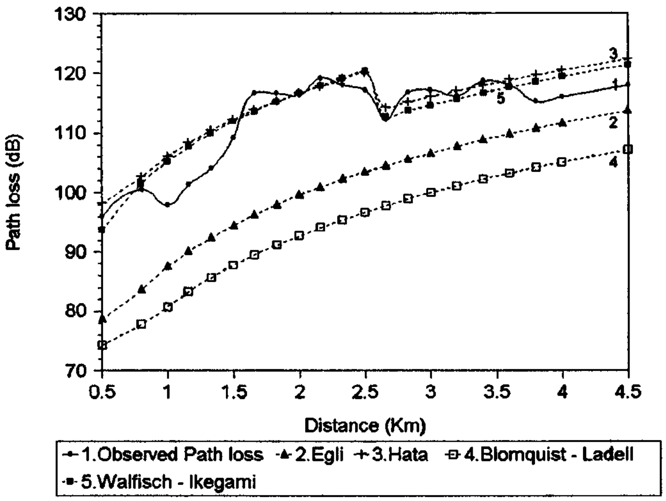

Fig. 4.

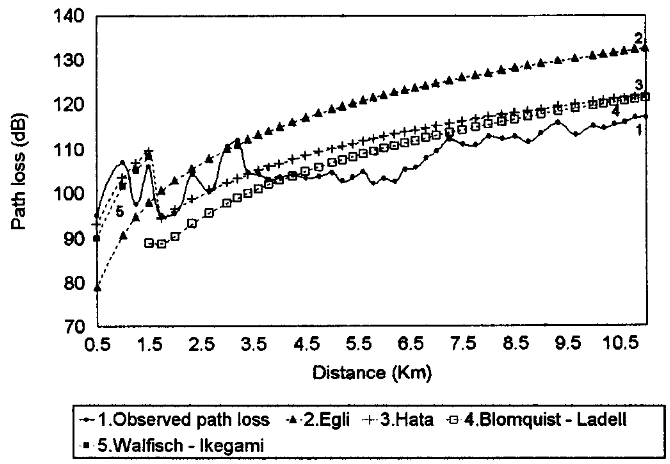

Fig. 5.

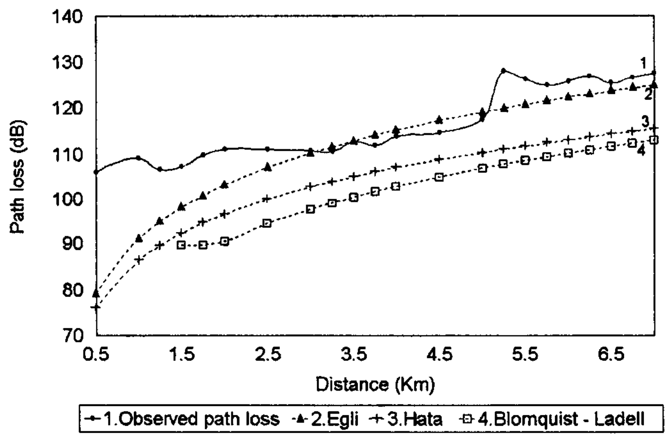

Fig. 6.

range of distances, with deviations of 15 dB at 2 km and 13 dB at 6 km distances.

Fig. 4 shows the results of radial 3 along with the predicted values. Here also Hata's method follows the trend of observed path loss better than the other methods. In this direction up to a distance of 2.5 km urban conditions prevailed and thereafter the region depicted suburban conditions. Hence Hata's method was employed for urban conditions up to 2.5 km and for the remaining distances suburban correction factors were employed. The maximum deviation observed is 6 dB at 1 km. At 4 km the deviation is 4 dB. Here Walfisch–Ikegami method with urban and suburban correction factors follows the same trend as observed path loss. The maximum deviation was observed around 8 dB at 1.6 km. After 3.5 km Walfisch–Ikegami's method is agreeing well with the observed values. Both Egli and Blomquist–Ladell methods underestimated the observed path losses.

We have tried to compare the observed path loss values with the method of Walfisch–Bertoni also. This method was formulated for predicting urban loss in the UHF band, and is based on direct numerical evaluation of the Kirchhoff–Huygens integral to evaluate the fields diffracted past a series of half screens. The deviations of observed values from Walfisch–Bertoni method in radial 1 at 2 and 6 km are 36 dB, in radial 2 the deviations observed at 2 and 6 km are 40 and 42 dB respectively, and in Rradial 3 the deviations observed at 2 and 4 km are 39 and 44 dB respectively. For frequencies in the UHF band, d/λ varies from 30–600. Here "d" represents center-to-center spacing of the rows of buildings and is in the range of 30–60 m. In the present case at 200 MHz with "d" values of 15, 20 and 30 m, d comes to around 10 to 18 which is much lower than the values used in the Walfisch–Bertoni method. This could be the reason why Walfisch–Bertoni's method deviated appreciably from the observed path loss values.

In the case of Walfisch–Bertoni method the path loss comprises three terms: 1. free space loss; 2. the reduction $Q(\alpha)$ of the roof top fields due to scattering, where α is incident angle; and 3. diffraction of roof top fields down to ground level. The last two terms are more appropriate in a dense environment, where as in the present study the environment is medium small size city. So there could be strong LOS path and less diffracted signal in the urban zone,explaining the deviation of the observed values from the predicted values of Walfisch–Bertoni method. However, this study shows the Walfisch–Bertoni method can be used effectively in areas where diffraction from roof tops is the dominant contributing factor. In places where diffraction is weak e.g., in medium sized cities, Hata's method could be a better prediction method to the design of mobile communication systems. COST 231 Walfisch–Ikegami method, though developed for 900, 1800 MHz, gives reasonable agreement in the urban and suburban zones in the present study.

Figs. 5 and 6 show the comparison of the path losses from the prediction methods with the observed path loss deduced from 400 MHz transmitters situated at Sullurpet and SHAR regions of Southern India. Fig. 5 shows the comparison with observed values of Sullurpet transmitter operating at 368.15 MHz. In this case the signal was monitored up to a distance of 11 km. The region from the transmitter up to a distance of 1.5 km can be classified as suburban and the remaining part is completely open. Hence in Hata's method for first 2 km suburban correction factors were deployed.

As in the earlier cases Hata's method gives reasonably good agreement throughout the range of distances. The deviations

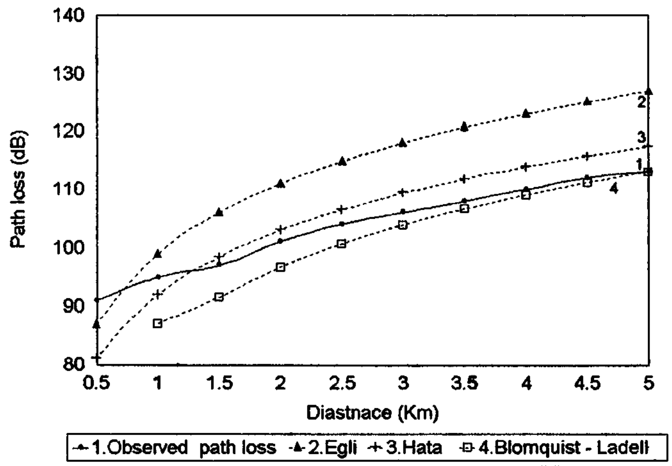

Fig. 7.

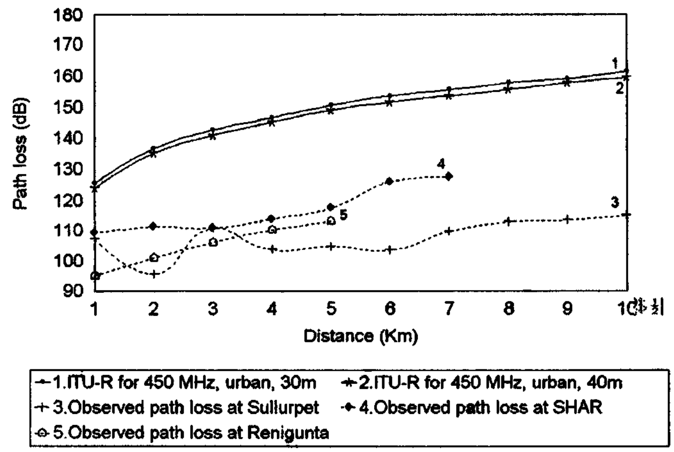

Fig. 8.

observed are 9 dB at 3 km and 10 dB at 6 km. Here also the Walfisch–Ikegami method with suburban correction factors follows the same trend as observed path loss. This method is not applicable for open areas, hence Walfisch–Ikegami method is not applied for open region. Egli's method gives close agreement from 3 km onwards. It has been observed that in completely open regions, Egli's and Blomquist–Ladell's methods give somewhat good agreement rather than in urban and suburban regions. This could be due to lack of appropriate environmental correction factors.

In Fig. 6 path losses deduced from the UHF transmissions originating from SHAR transmitter at 385 MHz are shown with prediction methods. The signal was monitored up to a distance of 7 km and the region between transmitter and the last point of monitoring is completely open. In this the variation in observed path loss is less between 1.5–4.5 km. It could be due to complete openness of the region. When the region is open, without buildings and obstacles, signal loss due to multipath effects and scattering from buildings would not be present. Here Hata's method for open conditions has been employed throughout the range. The agreement is not that good, with deviations of the order of 15 dB at 2 km and 7 dB at 5 km distance. Egli's method gives closer agreement between 3–5 Km and after this also the deviation is not much. Here Blomquist–Ladell's method underestimates the observed losses appreciably.

Fig. 7 shows path losses deduced from UHF transmitter from Renigunta at 468 MHz along with prediction methods. Here also Hata's method for open conditions has been employed throughout the range. The maximum deviation is 4.5 dB observed at 5 km. Blomquist–Ladell method gave closer agreement between 3–5 km. The maximum deviation observed with Egli is 14 dB at 5 km.

Fig. 8 shows the comparison of observed values at 400 and 450 MHz with those of ITU-R values at 450 MHz. Here the comparison is carried out for urban region and for antenna heights of 30 and 40 meters as there are no values available from ITU-R curves for suburban and open regions. No good agreement is found due to the above limitations.

Both theoretical and measurement based propagation models indicate that average received signal power decreases logarithmically with distance [22]. The average large scale path loss for an arbitrary transmitter–receiver (T–R) separation is expressed as a function of distance by using a path loss exponent, "n," which indicates the rate at which the path loss increases with distance.

In our present study, the path loss exponent value for free space is 2.0 and in urban areas is 3.3. These are agreeing with typical path loss exponents obtained in various mobile radio environments, 2.0 (free space) and 2–4 (urban) [22], [23]. The path loss exponent values obtained from the present study for suburban and open areas is 2.5 and 2.2, respectively. In experimentally based traditional propagation models which utilize a power law, $n = 4$ has been used. The value of "n" depends on the frequency and the environment. It has been found to vary between 2.8–5.3 for different environments and frequencies [24].

In our present measurements, the standard deviation of observed path loss values in urban and suburban areas at 200 MHz is 3.4 and 4.6 dB respectively, and the standard deviation of the observed path loss values at suburban and open areas at 400 MHz is 6.0 and 7.7 dB, respectively. Standard deviations in urban area have been reported by a number of authors. Okumura *et al.* [1] suggested a standard deviation of 5.8 dB at 400 MHz and 5.5 dB at 200 MHz in urban areas, and in suburban areas 7 dB at 200 MHz. Rowe *et al.* [25] measured standard deviation as 5.2, 4.4, 5.4 and 5.2 dB for rural, suburban, light urban and urban environments at 465 MHz. Parsons and Ibrahim [26] cited a standard deviation of 5.7 dB at 455 MHz and 5 dB at 168 MHz, while French [27] measured 5.0 dB at 462 MHz. Kozono and Watanabe [28] measured standard deviation as 4.5 dB at 450 MHz in Tokyo. Meno [29] measured standard deviation of 5.8 dB, in urban at 450 MHz.

In our present study, the standard deviation of errors (error = observed path loss—calculated path loss) of Hata, Walfisch–Ikegami, Egli and Blomquist–Ladell methods are shown in Table II. It can be seen from the table, that the standard deviation of errors of Hata method is less in all environments, urban, suburban and open areas, while that of Walfisch–Ikegami method is also less in urban and suburban areas. Other methods depict relatively higher values.

TABLE II
STANDARD DEVIATION OF ERRORS IN THE PREDICTION METHODS

	200 MHz		400 MHz
Method	Urban	Suburban	Open
1. Egli	3.9	4.3	6.5
2. Hata	1.9	2.5	5.4
3. Blomquist-Ladell	3.5	4.2	6.5
4. Walfish-Ikegami	1.7	2.4	--

VI. CONCLUSIONS

Field strength measurements were conducted in the Tirupati region of India at 200 MHz (VHF band), and at 400 MHz (UHF band) from SHAR & Sullurpet, which are 90 and 70 km away from Tirupati, respectively and also at 450 MHz (UHF band) from Renigunta which is 10 km away from Tirupati. The choice of these places was mainly dictated by the availability of transmissions. A comparison of different prediction methods with the observed path losses showed that Hata's prediction method gave better agreement in all cases. The advantage of this method lies in its adaptability to different environments by incorporating correction factors for various environments. COST 231 Walfisch–Ikegami method is in agreement in urban and suburban areas.

The novel feature of this study is the application of Walfisch–Ikegami method in VHF band in urban and suburban environments. The path loss exponents obtained from the present study in urban, suburban and open areas are 3.3, 2.5 and 2.2 respectively. The standard deviations of observed path loss values in urban and suburban areas at 200 MHz are 3.4 and 4.6 dB respectively, and the standard deviations of the observed path loss values in suburban and open areas at 400 MHz are 6.0 and 7.7 dB respectively.

In the case of paths where VHF measurements were conducted, the conditions were completely urban close to the transmitter changing slowly into suburban as distance from the transmitter increased. Walfisch–Bertoni and ITU-R methods deviated appreciably from the observed path loss values. Egli and Blomquist–Ladell's methods deviated appreciably in the urban and suburban zones. In the case of UHF measurements open region is dominated, Egli and Blomquist–Ladell's methods gave moderate agreement in open zones.

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