Application of classical two-ray and other models for coverage predictions of rural mobile communications over various zones of India

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The development of various prediction tools requires the comparison of radio measurements with prediction methods. For a country like India where diverse terrain conditions exist, same prediction method might not hold good in all the regions. To identify the methods suitable to rural zones an attempt is made to compare the measured results with classical two-ray, Hata and ITM methods. Their efficacies have been evaluated in terms of statistical parameters like error distribution functions, etc.

Keywords: Rural mobile communications, Classical two-ray theory, Hata’s model, ITM model
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1 Introduction
With the increase in economic growth and the importance given to rural development, especially, wireless communications by the various governments and united nations, cellular communications are getting increasingly focussed on rural zones. In most of the urban zones there is saturation in the revenues of operators and, to generate more revenues, operators are focussing on rural cellular communications. Even there is a talk going on for shared cellular towers in rural zones for various operators and various technologies. This can lead to a lot of interference, and various studies are required to minimize this problem. Rural and sub-urban propagation is mainly dependent on the topography and land usage area. Network operators require fast and accurate models for cell planning and site optimization1-3.

To provide inputs for the design of future cellular communications in rural zones, various experimental data bases raised by the present group on road- and train-based mobile communication experiments in different contexts4,5 have been utilized. The carrier levels monitored from these experiments have been converted into path loss values and these are utilized to evaluate various models including classical two-ray theory6, irregular terrain model (ITM model)7, Hata’s model for open and sub-urban conditions8. Other experimental details were given in the respective references.

2 Environmental and experimental details
The track-side base stations utilized in the study are: (i) Meerut (ii) Muzzafarnagar (iii) Saharanpur located in northern India (iv) Vangani (v) Neral, (vi) Pangoli, (vii) Talegaon and (viii) Pune situated in western India. The base stations in the northern India are located at 40 m above ground level and those in western India are situated at 26, 25, 46, 115 and 45 m above ground level. The effective radiated powers of the base stations located in northern India are + 37 dBm, whereas the effective radiated powers of western India base stations are + 39.5 dBm .The recorded carrier levels are averaged over 100 m section. In the case of train measurements over northern and western India, low profile omni-directional antenna was used outside the coach to avoid the shielding effects. Slightly-directing transmitting antenna radiation patterns have been used for reduction of radiation in unwanted direction and obtain moderate antenna gain of 5 dB. When the track has minimum number of turns, slightly-directing antenna is used; when it is zig zag, omni-directional antennas are used and when it is straight, highly-directing antenna can be used. Antennas are vertically polarized with 50 ohms impedance.
The region extending from Meerut to Saharanpur can be classified as open area with intermittent trees and small villages and towns in between. The region extending from Vangani, Neral, etc. in western India is also open with agricultural lands and the region around the base station is of sub-urban in nature. Overall, both the northern and western regions represent typical rural Indian scenario. Microwave towers located by the track side were utilized as base stations. In the northern region the terrain is flat and open, whereas in the western region where measurements were conducted, the terrain is rough with some hilly(ghat) sections in between. In the southern region (near the coastal regions of Andhra Pradesh) where 150 and 440 MHz measurements were conducted, the region is sub-urban and mainly open.

In the case of southern India, transmitting antenna is an omni-directional monopole and receiving antenna is a yagi with 12 dBi gain and mounted on the vehicle and the antenna was oriented towards the base station. Here, the measurements were carried out for base station antenna heights ($h_b$) of 16, 30 and 40 m. Receiving antenna height ($h_m$) in all cases is 3 m.

3 Results

The comparisons of observed path losses for the above base stations with the three prediction methods have been carried out. Instead of presenting the comparison of prediction methods with the observed values for all the base stations, some typical comparisons one each with Muzzafarnagar base station in the north, Vangani base station in the west and 440 MHz and 150 MHz in the south are shown in Figs 1-4. In order to evaluate the efficacy of prediction methods, prediction errors for all the data points for all the base stations have been deduced and error distributions for all the prediction methods are presented. Here, briefly the comparisons of the prediction methods are described.

In the case of two-ray model, the path loss is predicted irrespective of visibility status. In the northern India, two-ray model gave reasonable agreement in the case of Meerut, Muzaffarnagar and Saharanpur base stations. In the western India, the same model gave good agreements in the case of Vangani and Pune base stations. The classical two-ray theory has been utilized to deduce the path losses throughout the range of measurement distance without considering the obstacles in between. The path loss at each point of measurement distance has been computed under the assumption that direct ray and ground based ray would exist.

In the case of Muzzafarnagar base station shown in Fig. 1 on the left hand side, the two-ray and Hata’s models for open conditions show good agreement overestimating (up to 15 km) by 2 dB and beyond this underestimating by more or less 2 dB for the remaining distances. The ITM model gives good agreement up to 10 km and beyond this underestimates the path loss by 10 dB for the remaining distances. On the right hand side of the base station, all the three models show a kind of

![Fig. 1—Comparision of Muzzafarnagar base station observed results with two-ray, Hata and ITM models (320 MHz, $h_b = 40$ m, $h_m = 3$ m)](image-url)
reasonable agreement up to 15 km, ITM model showing better than the remaining two models. Between 20 and 40 km, all the three models overestimate the observed losses around 10 dB. Beyond 40 km, observed values return to original trend and coincide with the models. The Hata’s method for sub-urban conditions deviated by large values. Hence, it is not included in the present study. In the case of Meerut base station, the two-ray theory and Hata’s method for open region have given good agreement as compared to the ITM method. In the case of Saharanpur also, same trend is exhibited.

Figure 2 shows the same comparison of Vangani base station of western India for the same models. On the left hand side, observed values also fluctuate by 10-20 dB at different distances. The two-ray model and Hata’s model with open correction factors give agreement on the average of observed values till 20 km. Beyond this, observed values steeply increase by 20 dB. The ITM model slightly underestimates the observed values than two-ray and Hata’s models. On the right hand side, Hata’s model for open region and ITM and two-ray theory underestimate the observed values. Hence, Hata’s method with sub-urban correction factors has been used. This gave good agreement at all distances and better agreement from 10 km onwards. In the case of Neral base station, Hata’s open model, two-ray model and ITM model underestimate the path loss. At 10 km distance the two-ray and Hata’s open methods underestimate the loss by 10 dB and at 18 km by 20 dB. The ITM method underestimates at 10 km by 25 dB and at 18 km by 27 dB or so.

In the case of Pangoli base station, the observed values fluctuate between 95 and 135 dB and all the model predicted values lie between 110 dB and 135 dB. Some kind of agreement is seen only between 30 and 35 km. The Hata’s model for sub-urban conditions underestimates by large values. In the case of Talegaon base station on the left hand side of the base station, the observed values steeply increase beyond 10 km. The Hata’s method for open conditions and two-ray model give good agreement up to 12 km and due to steep rise in path loss they could not give good agreement beyond 12 km. The ITM method underestimates beyond 10 km. On the right hand side, all the three methods give good agreement up to 10 km and beyond this observed loss increases steeply reaching 150 dB at 33 km. In the case of Pune base station, the two-ray and Hata’s open model give very good agreement with the observed values throughout the range of distances. The ITM method also gives good agreement throughout the range of distances with a deviation of 2-4 dB. This method underestimates the losses. This is a typical comparison where all the three methods predict very well the averaged observed values. The Hata’s method for sub-urban conditions overestimates by large amounts. In the case of these base stations an attempt is also made to compute the loss due to spherical diffraction following the approach of ITU-R methodology. In all the three north Indian base stations the line-of-sight distance comes to 32 km.

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**Figure 2**—Comparison of Vangani base station observed results with two-ray, Hata’s and ITM models (320 MHz, $h_b = 26$ cm, $h_m = 3$ m)
Beyond this, the losses computed from spherical diffraction were not tallying with the observed values. They were overestimating the observed values by 8-12 dB. In the case of west Indian base stations, diffraction zone was possible only in the case of Pangoli base station. Here also the predicted losses are greater than the observed ones by 10 dB. It seems that the two-ray theory and Hata’s method predicted the losses much better than those by spherical earth diffraction model.

Figure 3 depicts the comparison of above models with that of 440 MHz measurements for base station antenna heights of 40 m. In Fig. 3 only the ITM method comes closer to the observed values in the open region followed by two-ray, Hata’s open and Hata’s sub-urban models. The ITM model deviates more after 20 km and deviations of 4-5 dB are seen below 20 km. In the quasi-open case, the two-ray theory gives very good agreement throughout the range of distances. The ITM method underestimates by 3-4 dB and Hata’s open method overestimates by 5-6 dB. In the case of base station antenna heights of 30 and 16 m, similar trend is seen with the classical two-ray theory giving very good agreement with the observed quasi-open values, whereas the ITM model showed a moderate agreement with the observed open values. In the case of 150 MHz measurements for similar base station antenna heights of 40, 30, 16 m, the same trend is seen except for the fact that the deviation of ITM values with the observed open values is higher than that in 440 MHz case and shows good agreement with the observed quasi-open values.

4 Error distributions

After the above comparison, prediction errors for the above methods have been deduced. Here prediction error is defined as the difference between the observed and predicted loss values. Based on these errors, percentage values of error distribution have been deduced as a function of prediction error range. The prediction errors have been classified into various ranges like 0-5 dB, 5-10 dB, -5-0 dB, etc. These have been carried out to test the statistical stability of the above prediction methods. Figure 5 depicts the error distribution for all the north Indian base stations. Here the two-ray method shows highest percentages of 37 at -5-0 dB range and 27 at 0-5 dB range. Between -10 dB and -5 dB, a lowest percentage of 2 is seen. Hata’s method shows highest percentage of 43 in the range 0-5 dB and negligible errors in the range -10 to -5 dB. In the range 5-10 dB, an error percentage of 23 has been noticed. The ITM method exhibited 32 % in the range -10 to -5 dB and 27 % in the range 0-5 dB and 8% in the range 5 -10 dB. If the curve peaks at the centre and falls on both sides then it can be taken as the suitable method, since higher percentage of errors with minimum prediction errors are desirable. The two-ray theory is biased more on negative errors and Hata’s method is biased more on positive side of errors.

![Figure 3](image-url)
For western Indian paths, the error distributions have been shown in Fig. 6. The two-ray method showed 22% in the range 0 to 5 dB and 10% in the range -10 to -5 dB. Hata’s method exhibited 17% in the range -5 to 0 dB and 8% in the range -10 to -5 dB. The ITM method showed highest errors of 20 in the range -10 to -5 dB, 8 in the range -20 to -15 dB. In the range 0-5 dB, 4% and in the range 5-10 dB, 2% are observed. In the case of 440 MHz measurements shown in Fig. 7, the two-ray and Hata’s methods showed high error percentage of 50 in the range < -20 dB. Here the distribution is not balanced. Overall, in the case of north Indian base stations, Hata’s method and the classical two-ray appear to be performing equally well. There is not much difference between the two methods. In the case of west Indian base stations, both these methods are equally biased...
on left sides. Hata’s method is having edge over the two-ray method. For 440 MHz and 150 MHz measurements, all the methods are biased on the negative side and showed large percentage of errors.

5 Discussion
Though the environment near the base station is of sub-urban in nature, this would not extend to large distances. The region after 500 m of the railway base station appears to be totally open. Hence Hata’s method for open, classical two-ray gave better agreement. The ITM model followed with some kind of deviations. At some points the observed loss is more than the predicted loss due to two-ray. This could be due to the blockage of dominant path by terrain obstacles. If we consider the digital elevation map of the particular path and apply knife edge diffraction principles at the point of contact of obstacle, we would be in a better position to explain the greater observed loss. This can be classified as deterministic two-ray model, i.e. verifying if the direct ray and ground reflected ray are really existing at a given point. We could not carry out this process due to lack of digital elevation data. In the case of Saharanpur, Vangani base station’s two-ray predicted

Fig. 6—Error distribution for various prediction methods over western India. (f = 320 MHz base station antenna heights for Vangani = 26 m, Neral = 25 m, Pangoli = 46 m, Talegaon = 115 m, Pune = 45 m, h_m =3 m)

Fig. 7—Error distribution for various prediction methods for 440 MHz measurements (h_b = 40 m, 30 m, 16 m and h_m =3 m)

Fig. 8—Error distribution for various prediction methods for 150 MHz measurements (h_b = 40 m, 30 m, 16 m and h_m =3 m)
loss is less than the observed values. In these cases if clutter loss of 10-15 dB is added to the two-ray predicted values, it can give good agreement.

6 Summary and conclusions

A comparative analysis of various models has been carried out using measured train-based mobile data in northern and western rural zones and road-based data in Andhra Pradesh rural zones. Based on the prediction errors, the error distributions have been deduced to evaluate the suitability of the methods. In most of the cases the classical two-ray theory followed by Hata’s model for open region gave good agreements. The main reason for this could be the railway track (where measurements were conducted) having minimum number of turns and line-of-sight zone extended to large distances. The ITM model followed these two models with moderate deviations. In train-based environments where there are no obstacles, the classical two-ray theory and Hata’s model can be used to predict the losses with some confidence. The highlight of the present study is the deployment of classical two-ray theory to predict the losses along rail roads along with Hata’s method.

References