An adaptive polynomial path loss model at UHF frequencies for mobile railway communications

K Ravindra & A D Sarma
R & T Unit for Navigational Electronics, Osmania University, Hyderabad 500 007

and

M V S N Prasad
Radio & Atmospheric Science Division, National Physical Laboratory, New Delhi 110 012

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Study of channel behaviour for efficient spectral usage has been the key aspect in the design of third generation (3G) mobile communications systems. This paper deals with modelling of UHF signals acquired in a moving train corresponding to a distance of 180 km in northern India starting from New Delhi to Sharanpur, covering various environmental zones. A new sixth order adaptive polynomial model is proposed to further model the deviation of earlier adaptive three coefficient model. The standard deviations of the predictions made by the proposed model from the experimental data are within 2.1 dB throughout the region of experimentation in contrast to a maximum of 24 dB reported earlier.

1 Introduction

Cellular mobile telecommunications and the world wide web are growing at an exciting pace. The tremendous success of second generation cellular systems, especially of the global system for mobile communication (GSM), is closely related to the urge for voice communication anywhere, anytime, with anyone. The third generation (3G) wireless systems are currently under development around the globe and are likely to be deployed with limited capabilities by the end of this year with major deployment at least a couple of years later. The migration to third generation mobile communication systems has to open up a vista of entirely new services. All limitations of second generation technologies have to be overcome; whatever prevents efficient deployment of wireless e-mail, web browsing and corporate local network access as well as videoconferencing, e-commerce and multimedia among other applications still beyond our imagination. The universal mobile telecommunications system (UMTS) will integrate the currently separate worlds of mobile and fixed telecommunications services in a digital data environment to serve the user as a comprehensive personal tool for unlimited communications. This means that the user can and will conduct any and all communication activities from a mobile platform, receiving similar services regardless of location or environment.

In order to support these services, a thorough understanding of mobile telecommunication channel characteristics in different environments is an essential prerequisite for optimizing future mobile communication systems. The initial step for optimization is the prediction of path loss for narrow band mobile systems and path loss and channel dispersion for wide band systems. Propagation prediction modelling via mobile channel initially aims at the development of models which provide an accurate estimate of the mean received power or path loss for a specified frequency band based on limited geographical information about the environment. Prediction models for the optimum prediction of path loss are very helpful to mobile radio service providers, because they allow optimization of the cell coverage area of a base station, help to minimize the interference problems and reduce the need for costly measurements. It is imperative to understand the effect of wave propagation on digital transmission quality in a wide variety of mobile environments. A number of deterministic and statistical propagation models are available to predict path loss over irregular terrain. Multiple ray models developed by Barger were able to provide reasonable prediction of probability distribution of the dynamic parameters of the land mobile multipath channel. Recently, a robust ray tracing technique called vertical plane launch method, which gives
propagation predictions in a heterogeneous building environment of a city with base station antennas situated at various heights above the ground has been proposed\textsuperscript{11}. The model has been validated with measurements at 900 and 1900 MHz.

In the present work, path loss measurements data acquired in a moving train\textsuperscript{12} in northern India (New Delhi-Sharanpur) have been used. A sixth order adaptive polynomial model (APM) is proposed to simulate the communication channel behaviour. The total signal path covers different environmental zones. The main aim of this paper is to study how well the existing microwave network situated along the railway track can be utilized for mobile communication. Very limited mobile train measurements are reported from this region of the world. The microwave towers were utilized as base station antenna masts. Assuming the average spacing of microwave stations to be 35 km, the train radio system should be able to provide coverage for at least 20 km radius under good propagation conditions in open/flat terrain.

2 Measurement details
The frequency range allocated to Indian Railways is from 314 to 322.6 MHz. Train radio network occupies a bandwidth of 2×850 kHz, in the range from 314 to 314.85 MHz and from 321 to 321.85 MHz. Base stations situated along the track continuously transmit the carrier at 320 MHz. Some of these are at a height of 30 m with telescopic masts and some others have utilized the trackside microwave towers located at a height of 40 m. A test coach is equipped with a calibrated receiver and computerized data logger. Also, a chart recorder was used to record the carrier level. A vertical monopole antenna was used for reception at the roof of the coach. The height of the mobile antenna\textsuperscript{13} is 3 m. Block diagram of the receiver is presented in Fig. 1.

3 Environmental description
In the northern railway zone, the measurements were conducted between New Delhi and Sharanpur. The base stations are situated at New Delhi, Ghaziabad, Meerut, Muzaffarnagar and Sharanpur. The total distance between New Delhi and Sharanpur is 180 km. Between New Delhi and Sharanpur, the terrain is flat with small obstacles except for the urban areas of New Delhi and Ghaziabad. The region extending from the New Delhi base station up to 6 km can be classified as urban region with high degree of urbanization. Many multi-storeyed buildings with six to seven floors are situated on one side of the track up to the first 2 km. The region from 6 km up to the Ghaziabad base station is sub-urban and beyond it can be considered as open area with green fields and intermittent trees\textsuperscript{12}.

4 Model description
A number of deterministic and statistical path loss models are available to predict path loss. The deterministic models such as free space and plane earth models have several limitations in the context of mobile communication such as multiple reflections and
effect of the movement of mobile unit. Okumura et al.\textsuperscript{4} developed a method for propagation prediction based on RF field strength measurements that employs curves instead of parametric equations. To overcome this shortcoming, Hata\textsuperscript{5} derived parametric equations which describe Okumura's curves. As Hata's empirical formulas of received signal strength are based on Okumura's measurements taken within a particular geographical region, these empirical formulae are to be validated for other regions. Stern et al.\textsuperscript{6} proposed an adaptive propagation prediction technique similar to Hata's model but based on measurements from the region where one is interested. In the propagation model suggested by Walfrisch and Bertoni\textsuperscript{7} street width and building height are input parameters, reducing the need for empirical correction factors. However, this model is cumbersome, as it needs geometry of the environment under consideration. Though, several propagation prediction models have been developed over the last decades for mobile communication network planning, they are all limited in one way or the other. The one presented here is a starting point for developing a better model.

In mobile communication links, the destructive interference between direct signal and signal due to shadowing or multipath conditions is one of the causes for transmission loss. Using an adaptive three coefficient model (ATCM), path loss can be expressed as\textsuperscript{8}

\[ p = c_0 + c_1 \log_{10}(r) + c_2 \log_{10}(f) \]  

... (1)

where, \( p \) denotes the path loss in dB, \( r \) the distance between the base station and the receiver in metres, \( f \) the carrier frequency in Hz, and \( c_0, c_1 \) and \( c_2 \) are the adaptive coefficients. These adaptive coefficients can be obtained by solving the following parametric equations.

\[ n c_0 + c_1 \sum \log_{10}(r) + c_2 \sum \log_{10}(f) = \sum p \]  

... (2)

\[ c_0 \sum \log_{10}(r) + c_1 \sum \log_{10}(r) + c_2 \sum \log_{10}(f) = \sum p \log_{10}(r) \]  

... (3)

\[ c_0 \sum \log_{10}(f) + c_1 \sum \log_{10}(f) + c_2 \sum \log_{10}(f) \]  

... (4)

where, \( n \) in Eq. (2) denotes the number of data points. The coefficients thus obtained are used to calculate the path loss for a fixed mobile antenna height. To achieve better prediction results, the following sixth order adaptive polynomial model is proposed.

\[ p_{pol} = \sum_{m=0}^{k} a_m \cdot l^{k-m} \quad k = 6 \]  

... (5)

Here, \( a_m \) denotes the coefficients of the polynomial and \( l \) denotes the error between the measurements and theoretical values [Eq. (1)]. This APM along with ATCM is applied in this paper for all the base stations. The overall path loss due to these models is found by adding Eq. (5) to Eq. (1).

5 Results and discussion

Initially, the measured data are processed using ATCM path loss prediction model [Eq. (1)]. The adaptive coefficients have been calculated using the whole data acquired from New Delhi to Sharanpur and are presented in Table 1. Due to lack of multi-frequency data we are restricted to use single frequency data for this purpose. These coefficients are used to model the path loss due to different base stations. The deviations due to this modelling are further modelled using sixth order adaptive polynomial model. Even though several methods, such as Tchebyschev or a cubic spline, are available, for simplicity, we have chosen polynomial model here\textsuperscript{9}. The main objective of APM is to obtain coefficients using experimental data and to predict path loss at a frequency where measurements are not available. The inputs to the ATCM are measured signal strength, operating frequency and distance. The carrier frequency of the experiments is 320 MHz. Even though the data at other frequencies are not available, we deliberately kept frequency as a variable. In this way, we can obtain rough approximation. This can be refined further using APM, which again uses measured data. So this can be applied to estimate the path loss at neighbouring frequencies more accurately. For prediction of path loss at unknown frequency, a frequency correction factor is to be included\textsuperscript{10}. The theoretical results obtained using APM and ATCM due to different base stations are depicted in Figs 2-9. The path loss between New Delhi and Ghaziabad with the base station located at New Delhi is presented in Fig. 2. The increase in the path loss up to 6 km from New Delhi is

<table>
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<th>Table 1—Values of adaptive coefficients</th>
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due to the high degree of urbanization. The variations in the path loss from 6 km to about 15 km are due to terrain variations. Beyond 15 km, the monotonic increase in the path loss could be due to the local structural terrain at Ghaziabad. With the base station located at Ghaziabad as a central point, the measurements have been recorded separately by moving towards New Delhi in one direction and in the other direction towards Meerut. The experimental data are superimposed on the results due to APM and ATCM and are shown in Figs 3 and 4 for the path covering Ghaziabad-New Delhi and Ghaziabad-Meerut, respectively. Practical data have been acquired from Meerut to Ghaziabad and from Meerut to Muzzafarnagar by keeping Meerut base station as a reference location. The corresponding modelled data along with the practical data are presented in Figs 5 and 6. The reason for the path loss crests at about 24 km from Meerut towards Ghaziabad (Fig. 5) and at about 32 km from Meerut towards Muzzafarnagar (Fig. 6) is ascertained due to the destructive interference of signals reflected from the local huge structures. The results obtained between Muzzafarnagar and Meerut path and Muzzafarnagar and Sharanpur, with Muzzafarnagar base station as a reference location are given in Figs 7 and 8. As this region is open and flat terrain, the absence of undulations is evident. Similarly, the results due to Sharanpur-Muzzafarnagar path with the base station at Sharanpur are presented in Fig. 9. It is obvious from Figs 2-9 that APM

![Fig. 2](image1.png)

**Fig. 2**—Path loss between New Delhi and Ghaziabad with base station at New Delhi

![Fig. 3](image2.png)

**Fig. 3**—Path loss between Ghaziabad and New Delhi with base station at Ghaziabad
Fig. 4—Path loss between Ghaziabad and Meerut with base station at Ghaziabad

Fig. 5—Path loss between Meerut and Ghaziabad with base station at Meerut

Fig. 6—Path loss between Meerut and Muzaffarnagar with base station at Meerut
Fig. 7—Path loss between Muzaffarnagar and Meerut with base station at Muzaffarnagar

Fig. 8—Path loss between Muzaffarnagar and Sharanpur with base station at Muzaffarnagar

Fig. 9—Path loss between Sharanpur and Muzaffarnagar with base station at Sharanpur
predicts significantly better than that due to ATCM. The details of path travelled, location of the base station, height of the base station antenna and standard deviations between the predictions and experimental data for the railway network are presented in Table 2. The earlier reported standard deviations are in between 1 and 24 dB (Ref. 12), whereas in the present case it lies between 0.7 and 2.1 dB. It is evident from Figs 2-9 that the theoretical curves compare well with the experimental data. The model can be made superior and universal for different environmental conditions, if more data at different carrier frequencies and varying heights of transmitting as well as receiving antennas are available.

6 Conclusions

A sixth order adaptive polynomial model is proposed to model the deviations of earlier models. It is evident from the results that the model is well in agreement with the measurements. The standard deviations between the measurements and the model are ranging between 0.7 dB and 2.1 dB, which are very much better than earlier reported results. However, the effects of variations in the heights of transmitting and receiving antennas on the field strength are to be investigated. The results presented in this paper would be useful in exploring the usage of conventional microwave towers in designing the future mobile communication systems. The model can be made universal for different environmental conditions if more practical data at several frequencies are available.

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