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Near ground propagation model for pine tree forest environment

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ABSTRACT

A propagation model experimentally derived from both free space and near ground plane earth path loss models for pine tree forest with foliage depth lower than 400 m has been proposed. It is a piecewise model taking foliage depth of 200 m as a boundary. The model is compared with several well-known models, namely Weissberger, ITU-R and COST235. Different from other models, the proposed one takes into account trunk height gain *k*. Observed average error is about 6 dB for proposed model whereas it is about 32 dB, 16 dB and 20 dB for COST235, Weissberger and ITU-R models, respectively. Also, it is observed that COST235 estimates the highest path loss among the models and it has the highest absolute errors especially in a forest with low foliage density.

1. Introduction

New wireless technologies rapidly grow resulting in an increase in popularity of mobile communication. This popularity requires that development of a proper propagation model is essential for uninterrupted communication in both urban and unsettled areas including forests and hilly territories. Use of a proper model is not only required for personal cell phone communication but also vital for military, governmental and unmilitary personal radiotelephone communication especially in forest areas. These requirements force scientists to investigate propagation mechanisms in forested area [1–6].

Meng et al. [1] proposed a modified ITU-R model taking into account the lateral wave effect. Their modified model was verified using measured and published data, and found to have higher accuracy for large foliage depth in the VHF band as compared to current models. Dias et al. [2] investigated a measurement campaign of land mobile HF/VHF radio signal in a typical urban sample of the Brazilian Atlantic Rainforest. They compared their measurements with calculated values from Tamir's model [7] in order to assess its variation with frequency and distance, and confirmed the good performance of Tamir's model.

Azevedo and Santos [6] proposed a model developed from an extensive measurement campaign carried out for different vegetation densities and types of trees. They pointed out the importance of the vegetation density in addition to distance and frequency effect on path loss calculation, and included a comparison with other methods in order to evaluate the performance of the model.

The foliage loss models proposed so far [1–7] present general formulas for wide frequency ranges and applications. Although they estimate path loss within an acceptable error margin for general conditions, they fail for specific conditions. Most of the forested areas in Turkey are covered by pine trees, and there are civil and governmental based issues which require development of specific propagation models. This requirement motivated us to generate a new model for such an environment where personal or vehicular communication is necessary. Therefore, only antenna heights of 2 m and only three frequencies, GSM900, GSM1800 and CDMA2100, have been examined.

In this study, the procedure of new model development has been presented starting with plane earth measurements. In Section 2, theoretical background is given. In Section 3, test setup and measurement campaign are described. In Section 4, comparison of the proposed model with Weissberger [4], ITU-R [8] and COST235 [9] models has been presented. This is followed by conclusion in Section 5.

2. Theoretical background

2.1. Free space and plane earth path loss models

In radio wave propagation, path loss gives an important idea about performance of a system. The free space path loss model can be used as a lower bound [1] to estimate path loss.

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The decrease in signal strength of an electromagnetic wave which would result from an unobstructed line of sight path through free space is called free space path loss [10]. Free space path loss model can be obtained by the help of Friis transmission equation [11]. The ratio of received power P_r from a radiated transmit antenna to base station transmit power P_t is given by the formula

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

where G_t is isotropic transmit antenna gain, G_r is receive antenna gain, λ is signal wavelength in meters (m), d is distance between transmit and receive antennas in meters (m) and L is system loss factor not related to propagation ($L \geq 1$). The formula is valid when d is much larger than λ.

If the radio wave propagates near the earth surface rather than through free space, plane earth path loss model, which includes the effect of ground reflection, can better be adopted [1]. After including the ground reflection effect, the plane earth path loss model is formulated as

$$\frac{P_r}{P_t} = \frac{G_t G_r h_t^2 h_r^2}{d^4 L} \quad (2a)$$

where h_t and h_r are the heights of the transmit and receive antennas in meters (m), respectively. Derivation of (2a) requires some assumptions [11] and it is valid when d is much larger than h_t and h_r.

$$\frac{P_r}{P_t} = 2\frac{G_t G_r}{L}\left(\frac{\lambda}{4\pi d}\right)^2 \left[1 - \cos\left(k_\omega \frac{2h_t h_r}{d}\right)\right] \quad (2b)$$

On the other hand, (2a) is invalid and (2b) can better be adopted especially at small distances, after adding L and antenna gains to the expression in [12], where k_ω represents the wave-number in reciprocal meters (m^{-1}). For d very large, it can be seen that (2b) converts to (2a), which is frequency independent.

2.2. Empiric models for forest areas

Although the free space and plane earth path loss models are good starting points for path loss estimation, such simple models for the path loss [13] only exist in a few special cases.

To estimate path loss in forested environments, some empiric models have been developed. Weissberger's modified exponential decay model, ITU Recommendation (ITU-R) model and COST 235 model are three well-known examples of empiric models applicable to foliage loss estimation.

In all models mentioned above, the foliage induced excess loss consists of the effect of both frequency and foliage depth, and can generally be represented as

$$L_{foliage} \ \ (\text{dB}) = A \times f^B d^C \quad (3)$$

where A, B, and C are all constant numbers and determined empirically according to foliage type [1].

Weissberger's modified exponential decay model is suitable when the propagation path is blocked by dense and dry trees with leaves within 400 m depth. This model is applicable in situations where propagation is likely to occur through a body of trees rather than by diffraction over the top of the trees [14]. The model is represented by the formula

$$L_{Weiss} \ \ (\text{dB}) = \begin{Bmatrix} 1.33 \times f^{0.284} d^{0.588} & 14 \text{ m} < d < 400 \text{ m} \\ 0.45 \times f^{0.284} d & 0 \text{ m} < d < 14 \text{ m} \end{Bmatrix} \quad (4)$$

where L is the loss due to foliage, f is the transmission frequency in gigahertz (GHz) and d is the distance between transmitter and receiver in meters (m).

ITU-R model was developed from measurements carried out mainly at Ultra High Frequency (UHF), and was proposed for cases where either the transmitter or the receiver is near to a small (d < 400 m) grove of trees such that the majority of the signal propagates through the trees [8]. The model is represented by

$$L_{ITU\text{-}R} \ \ (\text{dB}) = 0.2 \times f^{0.3} d^{0.6} \quad (5)$$

where f is the transmission frequency in megahertz (MHz) and d is the distance in meters (m).

COST235 model which was proposed based on measurements made in millimeter wave frequencies (9.6–57.6 GHz) [1] through a small (d < 200 m) grove of trees is

$$L_{COST} \ \ (\text{dB}) = \begin{Bmatrix} 26.6 \times f^{-0.2} d^{0.5} & \text{out-of-leaf} \\ 15.6 \times f^{-0.009} d^{0.26} & \text{in-leaf} \end{Bmatrix} \quad (6)$$

where f is the transmission frequency in megahertz (MHz) and d is the distance in meters (m). In COST235 model (6), measurements were performed over two seasons, when the trees are in-leaf and when they are out-of-leaf.

The models (4)–(6) present estimation of path loss in all types of forests and applicable at whole frequency range between 0.23 GHz and 95 GHz [1]; however, transmission medium and propagation characteristics between the transmitter and receiver have great significance in determining the exact value of the path loss [13].

In this paper, an empiric model, which is more efficient than Weissberger, ITU-R and COST235 models, is developed for pine tree forest areas. It has been examined at GSM900, GSM1800 and CDMA2100 for dry weather. Also, it has been verified in pine tree forests when foliage depth d is smaller than 400 m.

2.3. Derivation of new empirical model

Comparison of measured and simulated data suggests using both models in piecewise manner. In Fig. 1, simulated results of (1) and (2b), as well as measured data for 900 MHz, 1800 MHz and 2100 MHz are shown. Measurements were conducted on an uncultivated area, which is covered only by grass, where no obstruction exists on line of sight between the transmitter and receiver, the heights of which were both 2 m. For different frequencies, measurements had not been conducted on the same path and random paths had been followed to include the near ground effect in measurements in a path-independent manner and not to be bounded by similar data in model derivation, resulting in different maximum distances for each path. Analysis of Fig. 1 suggests that free space model predicts path loss better than plane earth model up to certain distance; however, it is not expected especially for large distances. To investigate the intersection distance of both models, they have been simulated up to 500 m, as shown in Fig. 2. Path loss predictions of both models intersect at 150 m for 900 MHz, 280 m for 1800 MHz and 330 m for 2100 MHz. In proposed model, a distance of 200 m has been selected as boundary; the model adopted as a starting point for model derivation is free space model for distances below 200 m and plane earth model for distances above 200 m.

Path loss (PL) in a forest environment can be expressed in dB as

$$PL \ \ (\text{dB}) = -10\log(G_t G_r) - 20\log(\lambda) + 20\log(4\pi d) + L_E \quad (7)$$

by using (1), and as

$$PL \ \ (\text{dB}) = -10\log(G_t G_r) - 20\log(h_t h_r) + 40\log(d) + L_E \quad (8a)$$

by using (2a), and as

$$PL \ \ (\text{dB}) = -10\log\left[2G_t G_r\left(1 - \cos\frac{2k_\omega h_t h_r}{d}\right)\right] - 20\log(\lambda) + 20\log(4\pi d) + L_E \quad (8b)$$

by using (2b), where L_E stands for the excess loss in both cases.