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INVESTIGATION OF GSM SIGNAL VARIATION DRY AND WET EARTH EFFECTS

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Abstract—This work proposes a site attenuation method to calculate the intensity of the field received by a mobile phone on a two-lane highway. To validate the model, radio propagation measurement was carried out through the intercity connection highway of the City of Isparta. The measurement system consisted of live radio base stations transmitting at 900 MHz and 1800 MHz. Downlink signal strength level data were collected by using TEMS test mobile phones, and were analyzed by TEMS Investigation, MapInfo and Google earth. Transmitted power-into-antenna was 14 W for both 900 MHz and 1800 MHz. Both base station sectors are facing towards the same direction having a 14 dBi gain. A proposed approximation was compared with real data. The results indicate that wet white pine trees cause 3 dB to 6 dB extra loss at 1800 MHz and about 1 dB to 3 dB extra loss at 900 MHz. Although 1800 MHz transmitter is 10 m higher, it loses its advantage in signal strength at longer distances.

1. INTRODUCTION

Signal quality and drop calls of mobile communication operators in buildings have been studied extensively for the last five years [1–6]. Helhel et al. [7, 8] proposed indoor ray tracing propagation model, and propagation through forest into the building model at previous studies, and showed that 1800 MHz operators have disadvantage in comparison to 900 MHz operators. Teh et al. [9] studied a path-correction technique for modeling walls in a ray-tracing framework without increasing its complexity. The walls, earth in our sample, are treated as infinitesimally thin slabs in ray-tracing. Intercity connection ways as well as highways are important for GSM operators for site planning for competitive high quality service. This type of area is generally covered by one or two sites, and perfect planning may bring advantage to 1800 MHz operators when compared to 900 MHz operators.

During latest studies, forest has been assumed to be a homogeneous block attenuating the radio signal. The propagation of radio waves over irregular surfaces is of great importance to design of fixed and mobile radio systems. The behavior of propagating electromagnetic waves through forests and thick woods has been extensively studied in the last decade [10–14].

Cavalcante et al. [12] proposed a simple model using ray trace techniques for mixed paths in forest environment. The model makes use of diffraction and/or reflections on abrupt discontinuities caused by the presence of a road inside the forest environment [15]. Cavalcante et al. [12] utilized a small number of rays paths contributing to the received electromagnetic field, and shown that those analytical results can be described in terms of ray paths, which permit the calculation of mobile radio loss in a large class of forest environment.

Hsieh [15] proposed that dielectric constant of leaves (trees) depend on the dry mater fraction, and it almost independent of frequency at very high frequencies. Similar study was carried out by Helhel et al. [16] and similar results were obtained. The scope of Georgiadou et al. [17] is the incorporation of rainfall rate effects on pulse propagation along Line-Of-Sight (LOS) Fixed Wireless Access (FWA) paths, and the applied model reveals higher distortion for shorter initial pulse widths, higher rainfall rates and longer paths of propagation.

These results say that dielectric properties of trees vary by seasons, and depending on their saline water of leaves. Rogers et al. [18] reported a static single white pine attenuation as 10.6 dB in the average and 12.1 dB at maximum, and the attenuation coefficient as 1.2 dB/m in the average and 1.5 dB/m at maximum at 900 MHz using circularly polarized antennas. From the same study it can be concluded that attenuation coefficient is 2 dB/m in the average at 1800 MHz. Li et al. [19] proposed an analytical expression in which equivalent permittivity for rain medium is presented by utilizing system identification to investigate the electromagnetic wave attenuation induced by rain. Their results show that the permittivity is a function of both the frequency and the rain rate.

In this study, an approximation of site attenuation approach has been used for calculating propagation loss, and compared with real data obtained at both 900 MHz and 1800 MHz on the highways. Wetness of earth (tree) effects on radio propagation and penetration loss capabilities of single line trees have also been analyzed and discussed.

2. MEASUREMENT SETUP AND GEOMETRY

Measurements were made by using Ericsson K600i at 1800 MHz, and Ericsson T610 at 900 MHz. Both mobile phones were loaded by Ericsson test software. Normalized received signal power given by Martijin et al. [20] was measured. $RxLev$ and P_r are defined as the measured average received signal level, and received signal level given by Eq. (1) that the propagation loss (L_p) between receiving and transmitting antennas was calculated by using Eq. (2), where P_t is the transmitted power. The accuracy of TEMS telephone measured RxLev is ± 1 dB, and the received signal measurement range is from 0 dBm to 110 dBm, where 110 dBm is the noise floor. P_r is the average received signal power measured within one slow associated control channel (SACCH) multi-frame of approximately 480 ms. In total approximately 100 samples are taken within one SACCH multi-frame [20]. Car speed was maintained at 40 km/h for collecting enough numbers of SACH frames.

$$RxLev = P_r\,(\text{dBm}) + 110\,\text{dB} \tag{1}$$

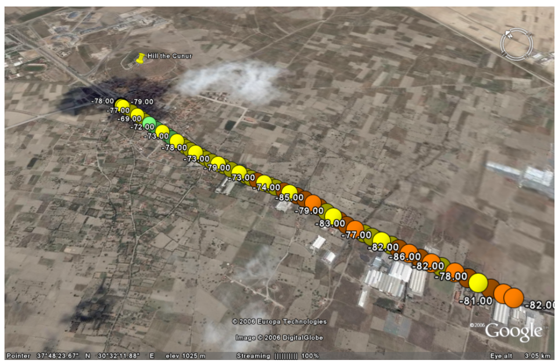
$$L_p = P_t - RxLev \tag{2}$$

Intercity has two directions that each direction has 15 m wide and 5 m apart from each other as shown in Fig. 1(a) and Fig. 1(b). South-North direction has been assumed as no obstructed, as well as north-south direction is single line white pine obstructed. In this study, 900 MHz transmitter antennas are mounted at the top of 20 m height tower as well as 1800 MHz antennas are mounted at the top of 30 m tower. Both 900 MHz and 1800 MHz antennas have same electrical down tilt of 6 degree, 14 dBi antenna gain, and same power into antenna values of 14 W.

3. FORMULATION OF THE PROBLEM

Received signal strength level by mobile phone is the vector summation of plane waves originated from main source and secondary sources which is described as Huygens principles [21]. Geometry of data collection area is demonstrated by Fig. 1.

(a)



(b)

Figure 1. Drive-Test/model area view. (a) View of intercity road. (b) Collected data presentation on Google earth map.

3.1. Ground Reflection Contribution

An LOS path may have adequate Fresnel zone clearance, and yet still have a path loss which differs significantly from free space under normal refraction conditions. In paths over relatively smooth ground or bodies of water, however, ground reflections can be a major determinant of path loss. In a radio path consisting of a direct path plus a ground-reflected path, the path loss depends on the relative amplitude and phase relationship of the signals propagated by the two paths. In extreme cases, where the ground reflected path has Fresnel clearance and suffers little loss from the reflection itself (or attenuation from trees, etc.), then its amplitude may approach that of the direct path. Then, depending on the relative phase shift of the two paths, one may have an enhancement of up to 6 dB over the direct path alone, or cancellation resulting in additional path loss of 20 dB or more. The amplitude and phase of the reflected wave depend on a number of variables, including conductivity and permittivity of the reflecting surface, frequency, angle of incidence, and polarization.

Beroual et al. [22] studied and analyzed concrete materials for assessment of cavities and water contents in it, water contamination affects on dielectric materials has also been reported by Helhel et al. [16], previously. They have reported that real part of dielectric permittivity varies between from 7 to 35 ($\varepsilon_r = [7-35]$), and imaginary part of it varies between 0.2 to 3 ($\varepsilon_r'' = [0.2-3]$) with respect to water content between 0% to 50%. Throughout this study, since the experiments were carried out on asphalt/concrete mixed roads, these dielectric coefficients have been selected for ground reflection calculations.

3.2. (No) Diffraction Contribution

At west side of intercity road, which is assumed as without obstructed zone, it has to be checked that a diffracted contribution is either there or not. A Fresnel zone is a simpler concept to understand a diffraction affect: it is the volume of space enclosed by an ellipsoid, which has the two antennas at the ends of a radio link at its foci. The two-dimensional representation of a Fresnel zone is shown in Fig. 1. For the first Fresnel zone, $n = 1$ and the path length differs by l/2 (i.e., a 180° phase reversal with respect to the direct path). For practical purposes, only the first Fresnel zone need be considered for calculation. A radio path has first Fresnel zone clearance if no objects capable of causing significant diffraction penetrate the corresponding ellipsoid. This means that geometry can be assumed as with no diffraction contribution in the case of having 60% of the first Fresnel clearance.

For first Fresnel zone clearance, the distance h from the nearest point of the obstacle to the direct path must be at least as in Eq. (3), where f in GHz, d_1 and d_2 are in km, and h in meters [23].

$$h = 17.3\sqrt{\frac{d_1 \cdot d_2}{f(d_1 + d_2)}} \tag{3}$$

For this problem, since $d_1 \gg d_2$ square root term goes to $\approx \sqrt{1/f}$ and $h \approx 18\,\text{m}$ for 900 MHz and 14 m for 1800 MHz. A clearance of

8 m is about 55% of 900 MHz and 45% of 1800 MHz, so it is sufficient to allow negligible diffraction loss. Finally, received electric field can be described as a combination of direct wave propagation and ground reflected wave propagation given below as in Eq. (4) [24, 25]. While the measurements have been carried out behind the tree, a penetration loss of white pine of 10 dB was added to the final loss calculation

$$E_r^{\max}=\frac{\sqrt{49.2}\left[r_2^2+r_1^2\cdot|\rho_h|^2+r_2\cdot r_1\cdot|\rho_h|\cos\left(\phi_h-\beta\left[r_2-r_1\right]\right)\right]^{1/2}}{r_1\cdot r_2} \quad (4)$$

where

$$\begin{aligned} r_1 &= \sqrt{R^2+(h_t-1.5)^2} \\ r_2 &= \sqrt{R^2+(h_t+1.5)^2} \\ \rho_h &= \frac{\sin\gamma-(K-j60\lambda\sigma-\cos^2\gamma)^{1/2}}{\sin\gamma+(K-j60\lambda\sigma-\cos^2\gamma)^{1/2}} \end{aligned} \quad (5)$$

K is the relative dielectric constant

σ conductivity, in Siemens/meter

γ angle of incidence

λ wavelength, in meters.

Power equivalent of this electric field can be expressed by using Eq. (5) [24, 25]

$$P_r=\frac{|E^r|^2}{30\cdot G_1(\theta)}\cdot\left|\frac{l}{e^{-jkl}}\right|^2 \quad (6)$$

where P_r is the received signal power which is also given at Eq. (1), $G1(\theta)$ is the directed antenna gain and l is the total propagation path length in meter. Finally path loss can be calculated by using Eq. (6), Eq. (1) and Eq. (2) by using electric field calculation.

4. MEASUREMENTS AND PREDICTIONS

Figure 2 demonstrates the measurements taken at 900 MHz. A line of white pine as an obstacle causes a penetration loss of 10 dB to 15 dB as given by Rogers et al. [18]. As seen from the figures that between 750 m and 1000 m, signal at both sides are almost at the same level. It is because of wider gabs between trees which area is reserved for further crossing roads.

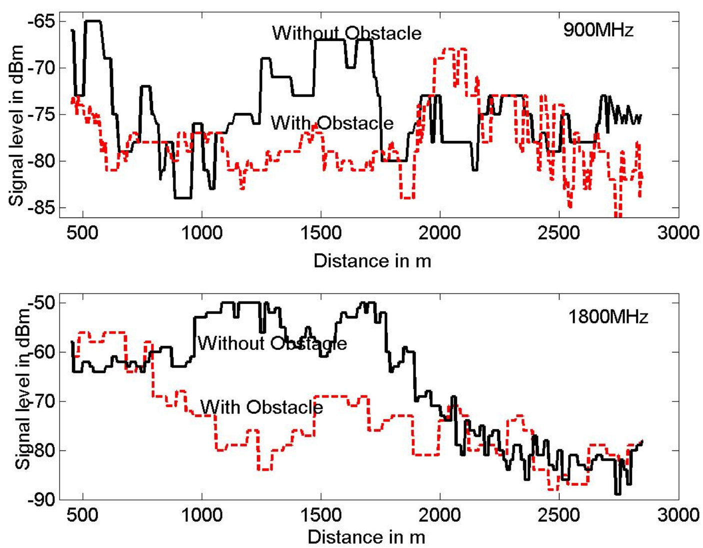


Figure 2. 900 MHz measurements.

Behind 2000 m distance, because of folded road, both sides behave as without obstruction. Subplot of Fig. 3 demonstrates the measurements taken at 1800 MHz. A line of white pine as an obstacle causes a penetration loss of about 20 dB as given by Rogers et al. [16]. Behind 2000 m distance, because of folded road, both sides behave as without obstruction, and signal levels at both sides are almost at the same level.

Figure 3 demonstrates both 900 MHz and 1800 MHz measurements. Instead 1800 MHz serving signal level is 15 dB better than 900 MHz up to 1000 m distance; 900 MHz overcomes 1800 MHz at longer locations as expected. Advantage of 1800 MHz at closer points is because of 1800 MHz operator is using a 10 m higher tower than 900 MHz operator. At longer locations, 900 MHz operator overcomes as expected.

Figure 4 demonstrates the signal variation at 900 MHz and 1800 MHz through the obstructed region. There dry modified-site attenuation approximation for 900 MHz and 1800 MHz has also been proposed. It is seen that at 900 MHz, wet tree causes extra 1 to 3 dB penetration losses while reaches up to 10 dB of extra penetration losses. Dry-site attenuation approximation model for 1800 MHz and experimental data are good in track, as well as it is not that much of fit in 900 MHz.

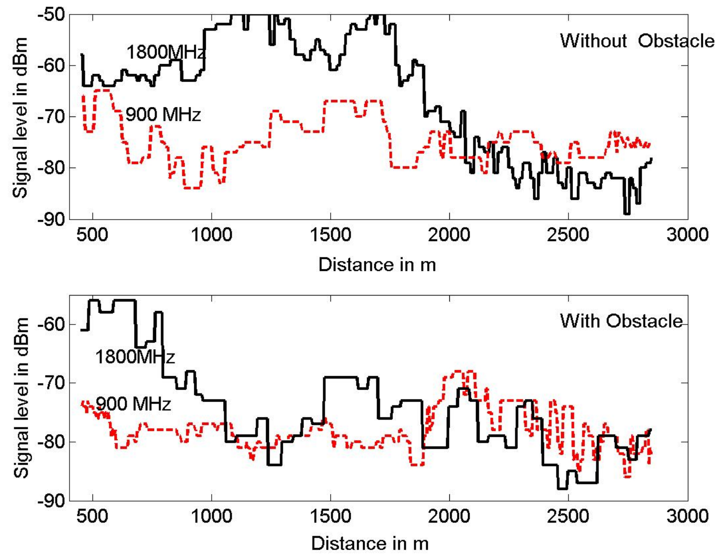


Figure 3. 900 MHz and 1800 MHz measurements.

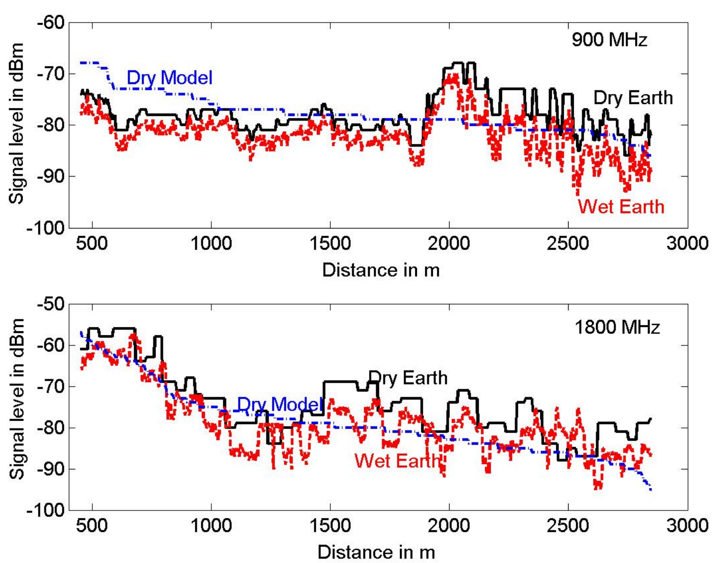


Figure 4. 900 MHz and 1800 MHz after rain and dry model.

5. CONCLUSION

Dry earth measurements say that white pine has a penetration loss capability of 5 dB to 10 dB at 900 MHz and 10 dB to 25 dB for 1800 MHz. higher penetration loss regions are the locations where two lines of white pines are present.

Comparison of 900 MHz and 1800 MHz from Fig. 4, at both sides of intercity road, gives us that at longer distances 900 MHz signal level becomes stronger then 1800 MHz even 1800 Hz is transmitting from higher tower. Subplot of Fig. 4 shows that in the case of obstruction higher frequency (1800 MHz) loose it is energy sharper then lower frequency (900 MHz).

Figure 4 gives us a conclusion about the effect of wet earth on radio propagation. Increased earth conductivity with heavy rain was assumed that ground reflection contribution would have been increased, but it is not! Actually, this expectation was true, but wet tree caused extra penetration loss is bigger than extra earth reflection gain. This is because that wet earth effect with wet tree obstruction gives us extra losses instead of extra gain.

For a big conferences, big organizations and national days; planners are asked to design a "mobile base station" for a period of week or weeks. These results show us that especially for winter times, meteorological data has to be taken into account for such a temporary site design.

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