UHF Ray Tracing Propagation Model for Corridors

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Abstract: Wave propagation for rectangular corridors is studied. Ray theory and uniform theory of diffraction (UTD) were combined to predict wave strength. The model was checked doing measurements at 1 GHz. The results show good agreement between theory and measurements for different locations. Since some parts of corridors have different properties(e.g. constructed by glass, wood and/or cement e.t.c). We prepared a useful database considering all possible effects at any point of reflection.

Keywords: UTD, RF Propagation, Corridors, Model, Simulations

Introduction

Wireless mobile communication in closed platforms (e.g. corridors) is going to be very important for microcellular communications in urban area. Especially, both the wireless communication in an urban street and the wireless communication in corridors ray theory are used. The accurate signal strength prediction will play an important role for an interference control. In this study, ray tracing models are used and some important parameters that effect the prediction is determined. Namely, these parameters are reflection and diffraction coefficients, number of rays and diffracting corner characteristics. Propagation characteristics were measured at 1 GHz in corridors for Line-off-Site(LOS) at different locations.

Studies for underground streets and corridors were done by some scientists. Yoshio Yamaguchi has modelled underground streets and/or corridors as a waveguide [1] and A. Emslie [2] has modelled the coal mine tunnels as waveguides. While we were modelling corridors, we followed reference [3] at the beginning, and we modified their study using [4-5]. Modified formulas were applied to previous studies and checked with their results.

Measurements were made by transmitting a continuous wave (CW) signal from a semi-mobile source to a fixed base, and recording the signal level for every location of transmitter. Base antenna was placed at the centre of corridor at height of 120 cm. The semi-mobile system was driven along the corridor to reach the distance 2-3m far from the receiver, and level of detected signal for every position of transmitting antenna is recorded at PC memory. These records were used directly in computer analysis since they were already digitised. At 1 GHz data were transmitted by half-wave dipole antenna and received by a conical-log-spiral antenna, and stored at memory card of EMI Receiver. E-polarisation was used during the measurements and theory also based on the E-polarised fields.

Background and Theoretical Model

The orientation of the corridor is shown in Figure 1 for LOS calculations. As shown in Figure 1a, X and Y points are diffracted points and the main corridor (has a width of 2.2m) and the sub-corridor (has a width of 2.2m) were made up of same materials. In the reference, measurements were done through the main corridor but some part of measurements cover the sub-corridor. Sub-corridor also causes rays to be diffracted and some part of rays radiates through that corridors that will never reach the receiver. The distance d between transmitter and receiver is 9.6m. Figure 1b shows side wiev of corridors that consists 10cm width metal plates at every 120cm interval of its ceiling (shown by filled square at the top side view). Here we use half-wave dipole antenna as a transmitter. It moves towards the receiver located at the end point of corridor. During this work, mainly three groups of rays are considered. The first group is the reflected-reflected (RR) group, which consists of rays reflected along corridor. The second group is the combination of reflections (R) from floor and ceiling. The third group of rays is the diffracted (D) rays, which consists of rays diffracted at both corners.

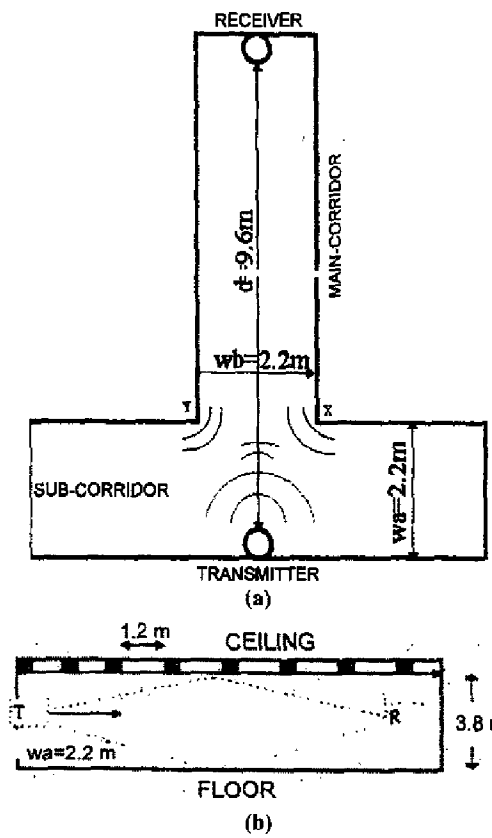


Figure 1. Geometry of the Corridor. (a) View of the Corridor from the Top (b) Side View of the Corridor.

The reflected electric field of a ray at the receiving antenna is calculated using [6]

$$E_r = E_0 \, R \, e^{-jkd} \tag{1}$$

and diffracted field is calculated by the following equation.

$$E_d = E_0 \, D \frac{e^{-jk(s+s')}}{\sqrt{s}} \tag{2}$$

Where k is the propagation constant, E_0 is a constant field strength, λ is the wavelength, d is the propagation path length from the transmitter to the receiver antenna, D is the diffracting coefficient, s' and s are the propagation path lengths from the diffracting wedge to the transmitter and the receiver antenna respectively, and R is the Fresnel reflection coefficient for E-polarized or H-polarized fields.

R value is changing from point to point where reflection occurs and also depends reflecting numbers, polarization and incidence angle of fields. The Fresnel reflection formulas at any point of surface for TE and TM cases (ith reflection point) can be calculated using [6]

$$\Gamma_{\perp} = \frac{\eta_1 \cos\theta_0 - \eta_0 \cos\theta_1}{\eta_1 \cos\theta_0 + \eta_0 \cos\theta_1} \quad \text{for TE case} \tag{3a}$$

$$\Gamma_{\parallel} = \frac{\eta_1 \cos\theta_1 - \eta_0 \cos\theta_0}{\eta_1 \cos\theta_1 + \eta_0 \cos\theta_0} \quad \text{for TM case} \tag{3b}$$

where i denotes the ith reflection point of surface, η_0 and η_1 are wave impedance of free space and of the surface at which reflection occurs, θ_0 and θ_1 are the incident angle and transmitted angle between refracted field and normal to the wall respectively.

$$R = \prod_{i=1}^{N} \Gamma_i \tag{4}$$

R is the total reflection coefficient where N is the number of reflections and it equals to the value of biggest i that is 10 in our formulation. It can be increased to obtain exact result. Increasing the value of i 10 times changes the result not more than 1%, but computer time increases more than 10 times. That's why we choose 10 as an optimum value.

The new wedge diffraction coefficient (D) formula was taken from reference [4] as:

$$D = \frac{jk\mathrm{Sin}\theta(jk\,D_h\,\mathrm{Sin}\phi - \xi_1 D_{g2}) - \xi_2(jk\,D_{g1}\mathrm{Sin}\phi - \xi_1 D_s)}{(jk\mathrm{Sin}\theta - \xi_2)(jk\mathrm{Sin}\phi - \xi_1)} \tag{5}$$

Surface impedances (ξ_1, ξ_2) for an incident vertically polarized wave and an incident horizontally polarized wave are given in equation (6a) and (6b) respectively.

$$\xi_1 = \xi_2 = \frac{-jk}{\sqrt{\varepsilon_r - j60\lambda\sigma}} \tag{6a}$$

$$\xi_1 = \xi_2 = -jk\sqrt{\varepsilon_r - j60\lambda\sigma} \tag{6b}$$

where

$$D_{g1} = -\frac{\mathrm{Exp}(-j\frac{\pi}{4})}{2n\sqrt{2k\pi}} \left\{ \begin{array}{l} 2\mathrm{Sin}\frac{\pi}{2n}\left[\mathrm{Cos}\frac{\beta^-}{2n} + \mathrm{Cos}\frac{\beta^+}{2n}\right] \\ + \left[\alpha_g^+(\beta^-)F(Ka^+(\beta^-)) + \alpha_g^-(\beta^-)F(Ka^-(\beta^-))\right] \\ + \left[\alpha_g^+(\beta^+)F(Ka^+(\beta^+)) + \alpha_g^-(\beta^+)F(Ka^-(\beta^+))\right] \end{array} \right\} \tag{7}$$

$$D_{g2} = -\frac{\mathrm{Exp}(-j\frac{\pi}{4})}{2n\sqrt{2k\pi}} \left\{ \begin{array}{l} 2\mathrm{Sin}\frac{\pi}{2n}\left[\mathrm{Cos}\frac{\beta^-}{2n} - \mathrm{Cos}\frac{\beta^+}{2n}\right] \\ + \left[\alpha_g^+(\beta^-)F(Ka^+(\beta^-)) + \alpha_g^-(\beta^-)F(Ka^-(\beta^-))\right] \\ - \left[\alpha_g^+(\beta^+)F(Ka^+(\beta^+)) + \alpha_g^-(\beta^+)F(Ka^-(\beta^+))\right] \end{array} \right\} \tag{8}$$

where

$$\alpha_g^{\pm} = \frac{\mathrm{Cos}^2(\frac{\pi \pm \beta}{2n})}{\mathrm{Sin}(\frac{\pi \pm \beta}{2n})} \tag{9}$$

$$D_s = \left[\alpha^+(\beta^-)F(Ka^+(\beta^-)) + \alpha^-(\beta^-)F(Ka^-(\beta^-))\right] - \left[\alpha^+(\beta^+)F(Ka^+(\beta^+)) + \alpha^-(\beta^+)F(Ka^-(\beta^+))\right] \tag{10}$$

$$D_h = \left[\alpha^+(\beta^-)F(Ka^+(\beta^-)) + \alpha^-(\beta^-)F(Ka^-(\beta^-))\right] + \left[\alpha^+(\beta^+)F(Ka^+(\beta^+)) + \alpha^-(\beta^+)F(Ka^-(\beta^+))\right] \tag{11}$$

where

$$\alpha^{\pm} = \mathrm{Cot}(\frac{\pi \pm \beta}{2n}) \tag{12}$$

Note that D_s and D_h are the two dimensional Keller diffraction coefficients in uniform version for the horizontal and vertical polarization for a perfectly conducting wedge. In the preceding equations

$$\beta = \beta^{\pm} = \phi \pm \phi' \tag{13}$$

$$K = ks\sin^2\beta_0 \tag{14}$$

$$F\left(Ka^{\pm}(\beta)\right)=2j\sqrt{Ka^{\pm}(\beta)}\ Exp\left(jKa^{\pm}(\beta)\right)\int_{\sqrt{Ka^{\pm}(\beta)}}^{\infty}Exp(-jt^{2})\,dt \quad (15)$$

where the positive branch of the square root is taken, and

$$a^{\pm}(\beta)=1+Cos\left(-\beta+2nN^{\pm}\pi\right) \quad (16)$$

The value of $N^{\pm}$ is determined by the integer which most closely satisfies the equation:

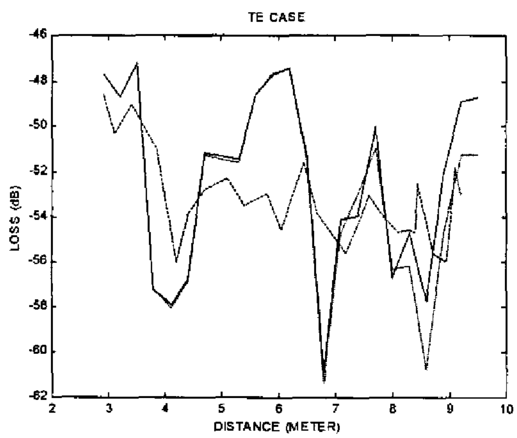
$$2n\pi N^{\pm}-\beta=\pm\pi \quad (17)$$

Each ray, either direct (for LOS case) or reflected N-times by corridor walls, has a paired ray that also reflected by the floor and the ceiling of corridors. These pairs of rays are more affective for LOS than for NLOS (Non-LightOf-Site).

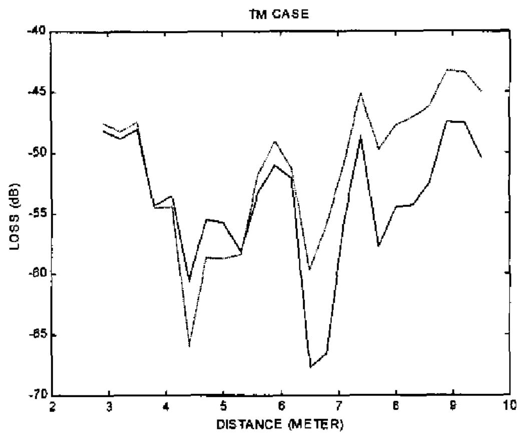
Simulation Results and Analysis

Computer evaluation of received electric field was performed for a main-corridor and sub-corridor width of 2.2m and height of 3.8m. Half wave dipole transmitting antenna height of 120cm and conical-log-spiral antenna height of 120cm located in the middle of corridor. For the Fresnel reflection coefficient $\varepsilon_r = 9$ and $\sigma = 0.1\ S/m$ were used [4-5]. For modelling, we assumed that 10 rays reflected from one side of corridor, 1 ray reflected from ceiling and 1 ray reflected from floor and 2 rays diffracted from both corner of corridor for each position of transmitting antenna.

Figure 2 shows path loss curves at 1 GHz for LOS propagation for TE and TM cases. Continuous line and dotted line are for theoretical results that computed using 3D and 2D UTD for the diffraction parts respectively, and dashed line is for measurement results. As easily seen from the figure 2 that theory and measurement results close to each other. The continuous lines are calculated from the new diffraction coefficients, whereas the dotted lines are from Keller's diffraction coefficients and dashed line is measured results. Keller's result for perfectly conducting wedge is ploted to illustrate the effect of the impedance boundary conditions. The new formulation show a lower fluctuation of the total field.



(a)



(b)

Figure 2. Simulation Results (a) TE Case (b) TM Case (continuous and dotted lines, that contain 3D and 2D UTD respectively, show theoretical results and dashed line shows measurements)

Conclusions

Ray theory and UTD were combined to specify wave propagation characteristics for corridors. Modelling approach was presented and compared with experimental results at different locations of transmitters. Because of geometry of the corridor, the effect of diffracted waves is seen above 7 m. In the region where diffraction occurs, we saw that ignoring diffracted waves cause 2-4dB difference in theory, and this result adds more deviation from the experimental results.

Very good agreement was achieved for different locations at fixed frequency. The ability to predict loss and interference levels of each waves using computer simulation will allow engineers to determine efficiency of their systems. It will also allow them to specify future strategies for the communication systems.

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