A NEW ROOF MODEL ON RANDOMLY PLACED BUILDINGS IN MOBILE COMMUNICATION

N. Altın and E. Yazgan

Electrical & Electronics Engineering Department
Hacettepe University
06532, Beytepe, Ankara, Türkiye

Abstract—Multiple diffraction propagation path loss due to the successively located different shaped building roofs are important for mobile communication. In the literature, building roofs are considered as wedge shaped structures. In this paper, building roof is modelled with a more realistic structure and the propagation path loss between the transmitting antenna and the receiving antenna is calculated.

1. INTRODUCTION

The extended uniform geometrical theory of diffraction has been applied to the problem of investigating the effects of intervening terrain on the propagation path of high frequency electromagnetic waves [4, 8]. The new diffraction coefficient was applied to calculate the diffraction due to the perfectly conducting roofs and rough lossy roofs. Also the path loss predictions due to the various shapes of terrain profiles with varying conductivity, permittivity and surface roughness were obtained. Successful results have been obtained for frequencies between 100 MHz and 10 GHz. In this work, surface waves haven't been taken into consideration [4].

Another important problem, being of the second roof is in the shadow region boundary of the diffracted fields of the first roof, discontinuity occurrence is seen in the results obtained for the electric field strength. Heuristic slope diffraction correction term has been used for removing this discontinuity. The slope diffraction term provides continuity on both perfectly conducting roofs and rough lossy roofs for both polarizations. For grazing incidence between roof vertices and lossy roof, diffraction coefficient is multiplied by a special gain factor [5].

In this study, the comparison of the diffracted fields for the perfectly conducting and rough lossy roofs are given for both polarizations by depending on interior angles of building roof changes. The chosen geometry is more realistic one for the exact calculation of the path loss due to roofs of building in the urbans.

2. FORMULATION

In the formulation, three kinds of rays have been taken into formulation in the new uniform geometrical theory of diffraction [2]. These rays are

a) Direct ray
b) Reflected rays from the roofs surface
c) Diffracted rays from roofs vertices of roofs.
The expressions of rays as shown in Figure 1.
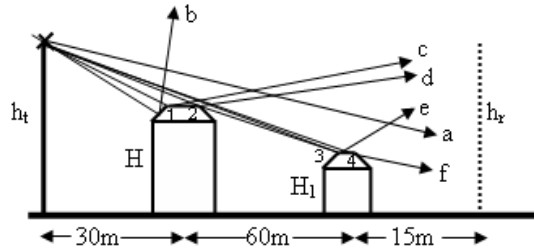
Figure 1. Propagation model between the transmitting and the receiving antenna.

a) Direct ray: This ray is the ray between the transmitting antenna and the receiving antenna. The expression of direct ray is given as below

$$E_i = \frac{e^{-iks}}{ks}U_1 \tag{1}$$

Where U_1 is the unit step function related to direct ray. s is the total path between the transmitting antenna and the receiving antenna.

b) Reflected rays from roof surface: This ray is the ray that arrives to the receiving antenna form the transmitting antenna by reflecting from the roof surface. Reflected ray from the roof surface is given as below

$$E_r = R\frac{e^{-ik(s_1+s_2)}}{k(s_1 + s_2)}U_2 \tag{2}$$

Where U_2 is the unit step function related to reflected rays region. s_1 is the distance from the transmitting antenna to the reflection point

on the roof surface, s_2 is the distance from the reflection point on the roof surface to the receiving antenna. R is the reflection coefficient from roof surface for the appropriate polarization. In the perfectly conducting roof surface is taken -1 for horizontal polarization and $+1$ for vertical polarization. In the rough and lossy roof, the reflection coefficient is given as

$$R = R_s \cdot \rho \tag{3}$$

Where R_s is the plane wave reflection coefficient, ρ is the surface roughness attenuation factor. Here

$$R_s = \frac{\sin\varphi - \sqrt{\hat\varepsilon_r - \cos^2\varphi}}{\sin\varphi + \sqrt{\hat\varepsilon_r - \cos^2\varphi}}, \quad R_s = \frac{\hat\varepsilon_r \sin\varphi - \sqrt{\hat\varepsilon_r - \cos^2\varphi}}{\hat\varepsilon_r \sin\varphi + \sqrt{\hat\varepsilon_r - \cos^2\varphi}} \tag{4}$$

are the reflection coefficients for horizontal and vertical polarizations, respectively.

$$\rho = e^{-\delta^2/2}, \qquad \delta = \frac{4\pi\Delta h}{\lambda}\sin\varphi \tag{5}$$

With Δh is the standard deviation for the normal distribution of the local surface roughness and λ is the wavelength.

$$\hat\varepsilon_r = \varepsilon_r - i\sigma/\omega\varepsilon_0 \tag{6}$$

$\hat\varepsilon_r$ is the complex permittivity and σ is the conductivity. Diffraction coefficient is multiplied by a special factor for the grazing incidence between vertices of the roof those have finite conductivity [4].

c) Diffracted ray: This ray is the ray that is diffracted by striking vertices of roof and reaching the receiving antenna. Diffracted ray from vertices of the roof is expressed by

$$E_1^d = E_2^i = E_1^i D_1(\phi_1, \phi_1')\sqrt{\frac{s'}{s''(s'+s'')}}e^{-iks''}U_3 \tag{7}$$

Where $s' = |\overline{s}'|$ is the distance from transmitting antenna to the corner of the roof. $s'' = |\overline{s}''|$ is the distance from the corner of the roof to the receiving antenna. ϕ_1' is the angle between s' and left surface of the roof. ϕ_1 is the angle between s'' and the left surface of the roof. D_1 is the diffraction coefficient for the uniform geometrical theory of diffraction [1]. Here U_3 is the unit step function related to diffracted ray region.

d) Doubly diffracted ray: This ray is the ray that is diffracted again form the second tip of the roof and reaching to the receiver antenna after diffracting from first tip of roof. Slope diffraction term

is added for this ray. The expression for doubly diffracted field is given by

$$E_3^i = E_2^d$$
$$= \left[E_2^i D_2(\phi_2, \phi_2') + \frac{1}{2ik} \frac{\partial D_2(\phi_2, \phi_2')}{\partial \phi'} \frac{\partial E_2^i}{\partial u_2} \right] \sqrt{\frac{s'+s''}{s'''(s'+s''+s''')}} e^{-iks'''} U_4 \tag{8}$$

Where $s' = |\overline{s}'|$ is the distance from transmitting antenna to the corner of the roof. $s'' = |\overline{s}''|$ is the distance between two tip points of the roof. $s''' = |\overline{s}'''|$ is the distance from the second tip of the roof to the receiving antenna. ϕ_2' is the angle between s'' and left surface of the roof. ϕ_2 is the angle between s''' and left surface of the roof. D_2 is the diffraction coefficient in the uniform geometrical theory of diffraction in [1]. Open expression of the slope diffraction term is given in [5]. Here U_4 is the unit step function related to diffracted ray region.

e) Triply diffracted ray: This ray consists of diffracted-diffracted ray and addition diffraction of this ray from the single tip of the roof. Explanation of the doubly diffracted ray is given above is valid also for this case. Diffracted-diffracted-diffracted field will have the following form.

$$E_4^i = E_3^d = E_3^i D_3(\phi_3, \phi_3') \sqrt{\frac{s' + s'' + s'''}{s^{\iota v}(s^{\iota v} + s' + s'' + s''')}} e^{-iks^{\iota v}} U_5 \tag{9}$$

Here U_5 is the unit step function related to triply diffracted field region.

f) Four times diffracted ray: This ray consists of four successive diffraction from the tips of the roof. Explanation that is given above is valid also for this situation. E_4^d is given by

$$E_4^d = \left[E_4^i D_4(\phi_4, \phi_4') + \frac{1}{2ik} \frac{\partial D_4(\phi_4, \phi_4')}{\partial \phi'} \frac{\partial E_4^i}{\partial u_4} \right] \sqrt{\frac{s^{\iota v}+s'+s''+s'''}{s(s+s^{\iota v}+s'+s''+s''')}} e^{-iks} \tag{10}$$

Total field that is the sum of these rays can be found as below. 14 different types of rays are examined in the formulation with the consideration of various points due to their special features.

$$E_{toplam} = E_i + E_r + E_{k1} + E_{k2} + E_{k3} + E_{k4} + E_{k1k2} + E_{k2k3}$$
$$+ E_{k2k4} + E_{k3k4} + E_{k2k3k4} + E_{k1k2k4} + E_{k1k2k3} + E_{k1k2k3k4} \tag{11}$$

Here, subindexes; i represents incident, r represents reflected and k represents the singly and doubly diffracted fields.

3. THE CALCULATION OF PROPAGATION PATH LOSS WITH HEURISTIC SLOPTE DIFFRACTION METHOD THAT IS APPLIED CONSECUTIVE ROOFS WITH VARIOUS ANGLES

Results can be observed as given in the Figure 2 and Figure 3 by calculating the diffracted field loss between the transmitting and the receiving antennas with the aid of the total field which is expressed by above formulas for the geometry seen in Figure 1. Here receiver antenna height is considered as a parameter.

Slope diffraction correction term corrects the discontinuity problem that is caused by a perfectly conducting roof with a horizontally polarized incident field and a rough lossy roof for both polarizations. In this study, reflections from the ground weren't included so as to show the effect of the diffracted fields in the path loss computations clearly. These reflections must be included in any actual path loss computations.

Rough and lossy parameters are given as relative permittivity 15, conductivity $0.012\,\mathrm{S/m}$ and local surface roughness $23\,\mathrm{cm}$. The comparison of the losses those are caused by the diffracted fields on the perfectly conducting or rough and lossy roofs for both polarizations are given by changing the angles ($95°$–$115°$) between the tips of the building roofs in Figures 2 and 3.
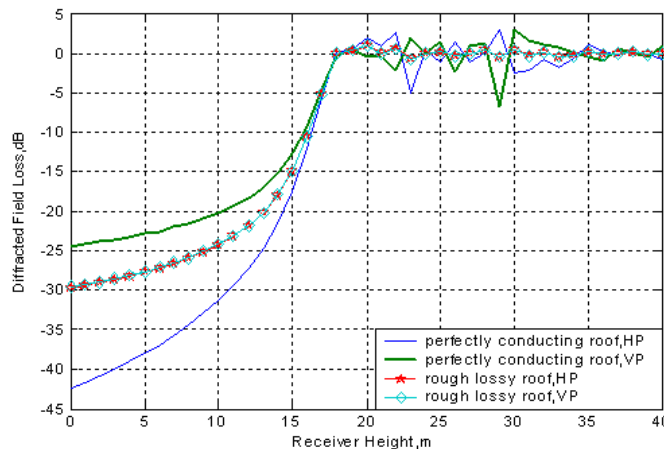
Figure 2. Diffracted field loss while angles of building roof vertices are $95°$. Frequency is $900\,\mathrm{MHz}$, 1. building height $30\,\mathrm{m}$, 2. building height $20\,\mathrm{m}$ and thickness $10\,\mathrm{m}$, height of transmitter antenna (h_t) $45\,\mathrm{m}$.
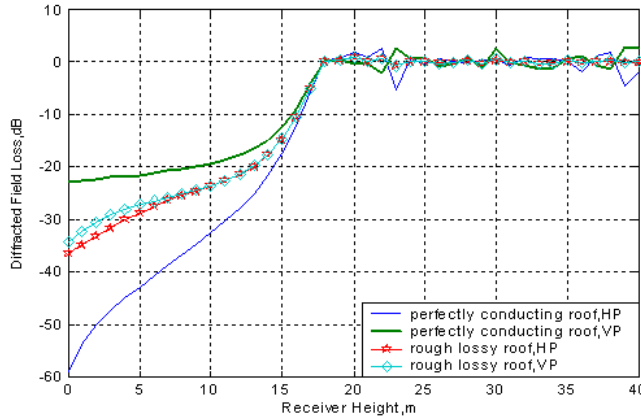
Figure 3. Diffracted field loss while angles of building roof vertices are 115°. Frequency is 900 MHz, 1. building height 30 m, 2. building height 20 m and thickness 10 m, height of transmitter antenna (h_t) 45 m.

Attenuation of the received waves is increased in the perfectly conducting roofs for horizontal polarization and in the rough and lossy roofs for both polarizations when the angle between the tips of the building roof is increased, as seen in Figures 2 and 3. There is no difference between horizontally and vertically polarizations for lossy surfaces, however there are some differences between horizontally and vertically polarisations in the perfectly conducting roofs. In the Figure 3, when the angle between the tips of the building roof is increased, for rough lossy roof and receiving antenna height is low, differences between horizontally and vertically polarizations can be observed more obviously, for example for $h_r = 0$ m, when the angle between the tips of rough lossy roof is 95°, total loss is 30 dB for horizontally and vertically polarized waves. When the angle is 115°, total loss is 37 dB for horizontally polarized and 35 dB for vertical polarization as shown in the figures. When waves are horizontally polarized for the perfectly conducting roof, attenuation is greater than the others since the ray is parallel to the ground. While the angle between the tips of the roof is 95°, attenuation is 43 dB.

4. CONCLUSION

Calculation of the propagation path loss between the transmitting and receiving antennas becomes possible with the contribution of the SD (Slope Diffraction) terms to the heuristic wedge diffraction

coefficients. By changing interior angles of the tips of the building roof, for both polarizations, loss is increased as expected for rough lossy roof compared to perfectly conducting roof. Indeed, the building roofs are rough and lossy, in practice, diffracted field losses the derived formulation as given above, those are leads more realistic results for rough and lossy rough roofs.

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