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LOSS CHARACTERISTICS IN URBAN ENVIRONMENT WITH DIFFERENT BUILDINGS' OVERLAY PROFILES

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ABSTRACT

In this work we continue the analysis of a probabilistic approach and the corresponding stochastic multiparametric model of wave propagation in built-up areas with randomly distributed buildings. We concentrate on the influence of buildings' overlay profile on signal decay within the UHF/X-band urban propagation channels. Using different buildings' overlay profiles, the field loss characteristics are examined taking into account single scattering and multiple scattering phenomena, and diffraction from buildings' corners and rooftops, for various positions of receiver and transmitter antenna with respect to surrounding obstacles. The comparison between experimental and theoretical predictions is presented.

1. INTRODUCTION

The prediction of propagation characteristics has become an essential part of radio wireless network planning. To successfully predict the design of these local networks, detailed experiments and theoretical investigations have been carried out to examine wide band radio channel characteristics and their dependence on the various real urban environment parameters. In reality many towns and cities sprawl over irregular terrain and one needs to simultaneously account for the presence of rough terrain and obstructing buildings in the propagation model. Because of complexity of radio propagation theoretical prediction in built-up areas, up today does not exist and cannot be proposed some general algorithm to predict loss characteristic in urban scene. Each concrete model describes a special situation in urban environment [1-4]. We consider below a case of non-regularly distributed rows of building and use a parametric model [4], which combines both deterministic and stochastic approaches. In [2, 3, 5] based on this model, three-dimension case (3D) was analysed taking into account the diffraction from rooftops as well as the multiscattering effects (side effects), to predict the loss characteristics in urban propagation channels. In our work we improve existing *multiparametric* model [2, 3, 5] by taking into account the real buildings' overlay profile. We present a comparison between the theoretical predictions and the results of experiments carried out in urban area with non-regularly distributed buildings.

2. PROPAGATION OVER BUILT-UP TERRAIN

Description of buildings' overlay profile. Earlier, in [2-5], we have considered the case of the homogeneous built-up profile that is, the case of buildings' overlay with non-uniformly distributed buildings' height from its minimum h_1 to its maximum h_2 . Let us now consider the influence of the city buildings' profile on the average field intensity for the case of stochastically independent waves, singly scattered from buildings lying along the radio path linking transmitter and receiver. Taking into account the fact that the real areas of urban environment are inhomogeneously distributed, we present the built-up layer profile $F(z_1, z_2)$ for two cases: when the higher antenna height z_2 is above the rooftops' level, i.e., $z_2 > h_2 > h_1$ (z_1 is the lower antenna height),

$$F(z_1, z_2) = H(h_1 - z_1) \left[(h_1 - z_1) + \frac{(h_2 - h_1)}{(n+1)} \right] + H(z_1 - h_1) H(h_2 - z_1) \frac{(h_2 - z_1)^{n+1}}{(n+1)(h_2 - h_1)^n} \quad (1a)$$

and when higher antenna height is below the rooftops' level, i.e., $z_2 < h_2$,

$$F(z_1, z_2) = H(h_1 - z_1) \left[(h_1 - z_1) + \frac{(h_2 - h_1)^{n+1} - (h_2 - z_2)^{n+1}}{(n+1)(h_2 - h_1)^n} \right] + H(z_1 - h_1) H(h_2 - z_1) \frac{(h_2 - z_1)^{n+1} - (h_2 - z_2)^{n+1}}{(n+1)(h_2 - h_1)^n} \quad (1b)$$

From (1) we can also determine the average buildings' height h , as building heights non-uniformly distributed in the range h_1 to h_2 .

$$h = h_2 - n(h_2 - h_1)/(n+1) \quad (2)$$

which reduces to $h = (h_1 + h_2)/2$ for the case of uniform distributed built-up profile investigated in [2-5], where polynomial parameter n in (1) is unity, i.e., $n=1$. Because there are several geometrical factors of the build-up layer profile: the antenna heights z_1 and z_2 , the maximum and minimum building heights h_1 and h_2 and the building relief appear in formulas (1a) and (1b), let us consider their effect on the function $F(z_1, z_2)$ separately.

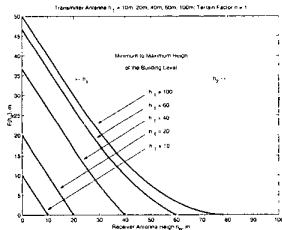


Figure 1: $F(h_R)$ distribution versus the receiver antenna height h_R with increase of transmitter antenna height h_T from 10m (bottom curve) to 100 m (top curve) for $n=1$.

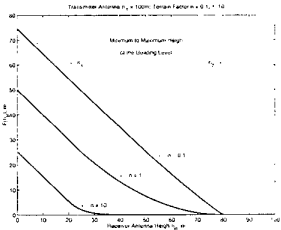


Figure 2: $F(h_R)$ distribution for concrete elevation of base station, $h_T=100$ m, for various parameters $n=0.1, 1, 10$.

In Fig. 1 $F(h_R; h_T, n) = F(z_1, z_2)$ given by (1a) or (1b), for $z_2 > h_2 > h_1$ or $z_2 < h_2$, respectively, is depicted as a family of curves versus the receiver antenna height. The parameters are the transmitter antenna height, ranging between 10 m (bottom curve) to 100 m (top curve), and n . The minimum and maximum heights of the buildings' overlay are indicated by dotted vertical lines. We have chosen $n=1$, corresponding to a uniform distribution of buildings' heights. By inspection of the displayed curves it is obvious that for a constant transmitter antenna height, with increasing receiver antenna height the value of $F(z_1, z_2)$ becomes smaller and the effect of the building layer on the path loss is reduced, as intuitively expected. A more regular decrease of $F(h_R)$ is evidenced with the increase of the higher transmitter antenna, e.g., see curves for $h_T = 60$ m and $h_T = 100$ m.

In Fig. 2 we examine the role of the parameter n on $F(h_R; h_T, n)$, at a constant transmitter antenna height $h_T=100$ m, with three typical values $n=0.1, 1, 10$ for the polynomial parameter, describing predominantly tall buildings, uniformly distributed heights, and predominantly low building heights, respectively. This provides a transition of the built-up area from that of a typically residential area with predominantly small building centers (the bottom curve in Fig. 2 corresponding to $n=10$), to that of a dense city center with predominantly tall buildings (the top curve in Fig. 2 corresponding to $n=0.1$). Obviously the relief plays a significant role.

Coherent and incoherent average field intensity. Upon using the expressions (1a) and (1b) for the functions $F(z_1, z_2)$, one can move on to the actual calculation of the pertinent field intensity. The expression for the incoherent part of the total field intensity can be presented,

taking into account single scattering and diffraction from buildings' corners and rooftops, as follows:

$$\langle I_{mc1} \rangle = \frac{\Gamma \lambda l_v}{8\pi \left[\lambda^2 + (2\pi l_v \gamma_0 F(z_1)) \right]^2} \cdot \sqrt{(\lambda d / 4\pi^3) + (z_2 - h)^2} \quad (3)$$

The corresponding formula for double scattering and diffraction is given by:

$$\langle I_{mc2} \rangle = \frac{\Gamma^2 \lambda^3 l_v^2}{24\pi^2 \left[\lambda^2 + (2\pi l_v \gamma_0 F(z_1, z_2)) \right]^2} d^3 \quad (4)$$

Here Γ is the absolute value of the reflection coefficient, l_v is its vertical correlation scale and d is the range between two antennas (the detailed definitions of these parameters can be found in [2, 3]). The parameter γ_0 determines the average horizontal distance of line-of-sight (LOS) $\langle \rho \rangle$, where $\langle \rho \rangle = \gamma_0^{-1}$. According to the analysis presented in [2-5] the parameter γ_0 can be defined as $\gamma_0 = 2\langle L \rangle v / \pi$, where v is the density of buildings per km^2 and $\langle L \rangle$ is the average building length dimension in the investigated area.

The difference between the formulas presented here by (3) and (4) and those obtained in [2-5] is that here we introduce a new relief function $F(z_1, z_2)$, given above by formulas (1a), (1b), better suited to describe realistic and general cases of terrain and buildings' overlay, and for different configurations of transmitter and receiver antennas. The coherent part of the total field intensity can be obtained in the same manner:

$$\langle I_{cv} \rangle = \exp \left\{ -\gamma_0 d \frac{F(z_1, z_2)}{z_2 - z_1} \right\} \frac{\sin^2(kz_1 z_2 / d)}{4\pi^2 d^2} \quad (5)$$

Hence the total average field intensity is present by sum

$$\langle I_{total} \rangle = \langle I_{cv} \rangle + \langle I_{mc1} \rangle + \langle I_{mc2} \rangle \quad (6)$$

and path loss expression, given in dB, is

$$L = 10 \log(\lambda^2 \langle I_{total} \rangle) \quad (7)$$

3. COMPARISON WITH EXPERIMENTAL DATA

We compare now the results of theoretical predictions for the total field intensity attenuation, according to the proposed multiparametric model described in Section 2, with results of the experiments carried out in different sites in Jerusalem [6]. In each experiment, the stand-alone radio port unit (RPU) with height 42 m played the role of the transmitter. The terminal unit, called fixed access unit (FAU) with height 6 m, was used as the receiver, which during the experiment was moved from point to point. According to the FAU specification, its measurement accuracy in all experiments does not exceed 3 + 4 dB [6]. The terrain in Jerusalem according to the topographic maps can be characterized as *hilly*. The notion of the medium urban area is relevant to the Jerusalem propagation conditions. Two or three samples there were taken at each experimental point along the vehicle route and the average values based on these measurements have been found. To determine radio signal strength indication (RSSI) L_{RSSI} values from the above expressions of path loss, we sum (7), receiver G_R and transmitter G_T antenna's gain, that is

$$L_{RSSI} = 10 \log(\lambda^2 \langle I_{total} \rangle) + G_R + G_T \quad (8)$$

In further calculations we added the ground heights to the building heights as well and then determined, according to (2), the average building height. Moreover, we obtained from the topographic map that the parameter n is in ranged between 0.1 and 10. From the topographic map of the experimental site of Jerusalem we obtained the following parameters of the built-up terrain: the building density $v = 1039 \text{ km}^{-2}$; the average building length $\langle L \rangle = 18 \text{ m}$; the average building height (not including the local ground height) $h = 8.3 \text{ m}$; average reflection coefficient $\Gamma = 0.73$ [6]. The measurements were made at frequency 930 MHz. The results of numerical calculations are presented in Fig. 3a by curves both for uniform built-up terrain, i.e., $n=1$, and non-uniform built-up terrain with predominant number of tall ($n=0.1$) and small ($n=10$) buildings, respectively. In Fig. 3a, the measurement results, denoted by circles, are compared with the double scattering and diffraction model according to formulas (3)-(8). The indicated number pairs are the

standard deviation value (STD) and the pertinent prediction error (Err) between two point sets. In Fig. 3a it is seen that the discrepancy between the theoretical prediction and experimental data can be decreased by at least $3 + 4$ dB. In Fig. 3b a comparison between the experimental results obtained in Jerusalem, denoted, as in Fig. 3a, by circles, and the calculations according to the Hata small-medium model, presented by the solid line curve, is shown. As follows from illustrated in Fig. 3a and 3b, the Hata model gives less accuracy (with mean error of 6 dB) compared with that obtained from the parametric model.

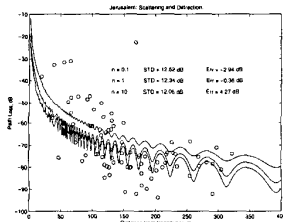


Figure 3a: Jerusalem. The results of Path Loss prediction by stochastic model (continuous curves) and comparison with measurements data (circles).

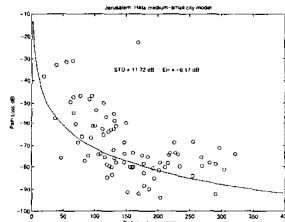


Figure 3b: Jerusalem. The results of Path Loss prediction by Hata small-medium model (continuous curves) and comparison with measurements data (circles).

4. CONCLUDING REMARKS

In this work we continued the investigation of the 3D-model of wave scattering and diffraction from randomly distributed buildings and similar obstacles placed on a rough terrain, taking into account a more general and realistic terrain and overlay buildings' profiles. It follows from comparison of the theoretical predictions and experimental data obtained for measurements in different kinds of built-up areas, that the 3D-model is very good predictor (with mean error of $3 + 5$ dB compared with experimental data, which cannot be higher than $6 + 7$ dB) for the loss characteristics in built-up areas for various kinds of terrain profile and for different position of transmitting and receiving antennas with respect to rooftops, as long as the receiver antenna position is not within deep shadow zones in the vicinity of the obstructing object. The proposed multiparametric stochastic model, is a general approach which uses data acquired for terrain and buildings' overlay geometry, and takes into account terrain input parameters, such as the buildings' height distribution characteristics and their density over the terrain.

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