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PREDICTION OF VHF/L-BAND RADIO WAVE PROPAGATION IN URBAN AND SUBURBAN ENVIRONMENT

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1. Introduction

The MultiGain-Wireless (MGW) system proposed by Tadiran Communication Ltd. is the system used in local networks serving as an alternative to conventional loop distribution networks. It complements the multigain family of pair-gain digital multiplex systems [1], adding the radio media as an additional means of providing economic connection to the customer in the local access area. To design the system successfully itis very important to investigate the characteristics of urban/suburban radio channels, to define optimal locations of the radio ports and to make performance predictions for the individual subscribers.

Below the effectiveness of a wireless local loop system are examined theoretically and experimentally in two different propagation conditions: of line-of-sight along the street level, when both radio ports were below the rooftop level, and of the "clutter" conditions, when one of the radio ports was below the rooftops. In first case when an urban area was constructed as a grid with regularly planned buildings, a two- and three-dimensional multislit waveguide models according [2] are developed. In second case, when the buildings are regularly distributed as a rows in crossing-street grid, the 2D-model of multi-diffraction from the building roofs [3] is used in conjunction with actual variations of building heights, the distances between them and the actual base station antenna height variations.

2. Propagation in line-of-sight conditions at the street level

Let us consider that the buildings on the street are replaced by randomly distributed non-transparent screens with scales L_n; the gaps between the buildings (slits) we define as l_n. The laws of their distribution are determined as independent and exponential, ones with mean values $<L>$ and $<l>$ respectively:

$$<L>^{-1} \exp\{-L_n/<L>\}, \quad <l>^{-1} \exp\{-l_n/<l>\}, \quad n=1,2,3... \tag{1}$$

In Fig. 1 there a 3D-waveguide model of city region with regular planned building and with receiver and transmitter at street level below the rooftops is presented. The resulting reflected field is considered as a sum of mirror reflecting imaginary sources. The reflection from the flat ideal conducting ground surface is also considered using an imaginary source (Fig. 3). We use the approximation of geometrical theory of diffraction (GTD) for the evaluation of all the kinds of wave: direct from the source, reflected from the walls and ground surface, and diffracted from the edges and roofs of buildings. This approximation is valid when the first Fresnel zone~$(\lambda d)^{1/2}$ does not exceeds the width of the street "a", where λ is the wavelength. In most measurements for VHF/UHF waves this condition is correct for distances d<2-3 km [3-5]. In this assumption, all the kinds of ray have the same nature and are described by geometrical optics theory, which successfully includes elements of GTD.

Let us now to introduce the characteristic functions $f_1(y)$ and $f_2(y)$ which equal 1 when reflection or diffraction from the walls (screens) takes place and zero when rays pass through the spaces between the buildings, i.e. fall into the slits of the waveguide. Thus segments with $f_{1,2}(y)=1$ represent screens including their edges, but segments with $f_{1,2}(y)=0$ represent slits (see Fig. 2). We now consider that the vertical electric dipole is placed at the point (0, 0, h) on the z-axis (Fig. 4). For each reflection from the walls we substitute an image sources Π_n^+ (for the reflection from the left-hand walls of the street waveguide) and Π_n^- (for the reflection from the right-hand walls).

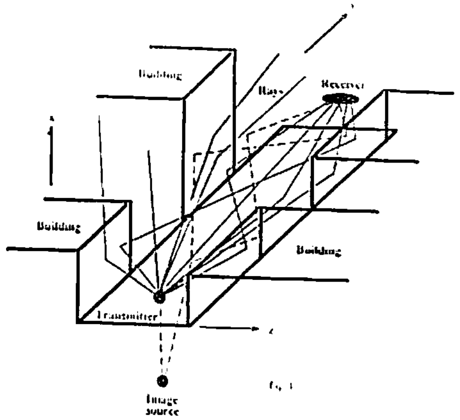

Fig. 1

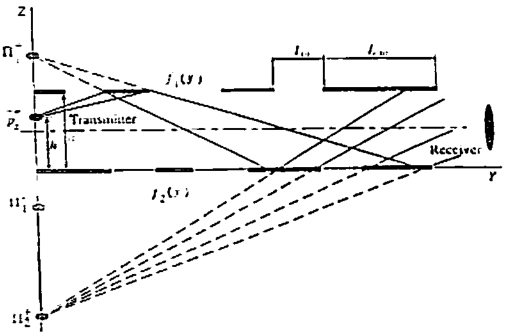

Fig. 2

Taking into account the Poison screens distribution (1), the following form of direct field from the source presentation as a vertical electric dipole [2], the simple evaluations from the GTD, and the correlation law from arbitrary order moments of "telegraph" functions $f_1(y)$ and $f_2(y)$ [2], we finally obtain the average total field intensity inside the multislit sreet waveguide for the case r>>a:

$$\langle I\rangle \approx C^2[1+D_{mn}]^2 r^{-1}\exp\{2[\rho_n^{(0)}r - |\ln M|(\pi n/a)r/\rho_n^{(0)}a]\} + D^2[(1-M)/(1+M)]^2 r^{-2}, \qquad (3)$$

where $M=\langle L\rangle/(\langle L\rangle+\langle l\rangle)$ is the parameter of brokenness; $\rho_n^{(0)}=\sqrt{k^2-(\pi n/a)^2}$; C is the constant which determines properties of the vertical electric dipole; n=0, 1, 2,....; is the coefficient of diffraction which can be estimated from formulas evaluated in [5].

3. Propagation in the clutter conditions

Let us consider that an elevated antenna (base station) radiates a field that propagates in an environment with regular distributed non-transparent buildings with various heights h_i and different separation distances d_i (i=1,2,3...) between them (see Fig. 3). The height of base station antenna, H, can be greater or smaller than the first (near the antenna) building's height, h_1. Below we consider that the base antenna height H is more than the first building height, i.e. $H>h_1$. In this case the radiating field propagates over the rooftops by a process of multiple diffraction past rows of buildings (Fig. 3). As all buildings are non-transparent, the majority of the propagation path cannot lie through the buildings Moreover when there is propagation between buildings the rays reflected from the ground after a second diffraction from the roofs (path 3 in Fig. 1) are attenuated very quickly (according to the estimation obtained in [3]). As a result, the majority of the paths cannot be associated with propagation between the buildings. We therefore conclude that the primary propagation path lies over the top of the buildings, as indicated by path 1 in Fig. 3. Then the propagation over the rooftops involves diffraction past a series of buildings with dimensions larger than wavelength λ, i.e. h_i, $d_i >> \lambda$.

Treating the base station as a transmitter and assuming that the receiver is at the street level, we can obtain the path loss in dB as the sum of the free space path loss

$$L_0 = 32.44 + 20\log_{10}f_0 + 20\log_{10}R \qquad (4)$$

and excess loss L_{ex}. The last can be presented for the case $H>h_i$ and for the case when angle α_N (see Fig. 3) is small, i.e. $\alpha_N \approx [H - (1/N)\Sigma h_i]/R$, as [3]:

$$L_{ex} = 57.1 + 5\log_{10}\{[(1/N)\Sigma d_i/2]^2 + [(1/N)\Sigma h_i - h_r]^2\} - 9\log_{10}[(1/N)\Sigma d_i] +$$
$$+\ 20\log_{10}\{\tan^{-1}[2((1/N)\Sigma h_i - h_r)/(1/N)\Sigma d_i]\} - 18\log_{10}H. \qquad (5)$$

Here R is a distance from transmitter to receiver; f_0 is an operated frequency; other parameters are presented in Fig. 3.

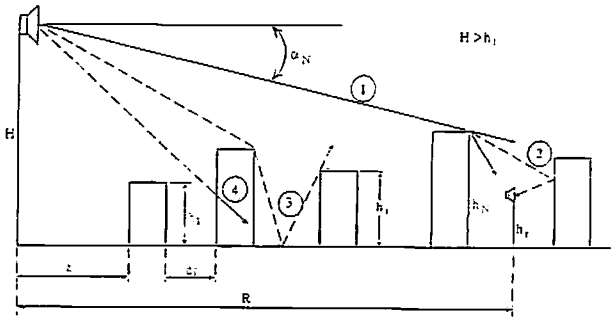

Fig. 3

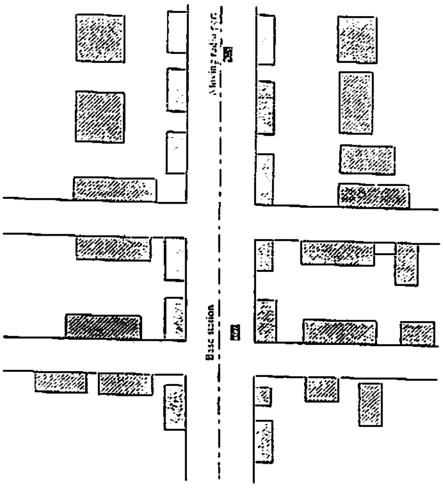

Fig. 4

4. Comparison with experimental data

Let us now compare the theoretically obtained formulas (3)-(5) with the Tadiran's experimentally measured path loss distribution in the investigated urban area. The first measurements were taken in Kfar Yona, Israel, where the Tadiran MultiGain Wireless Local Loop is under trial in conditions of direct visibility and in the obstructive conditions. The omni directional base station antenna was located at a distance of 4-5 m from the corner building surface. The mobile radio port antenna (also omni directional) moved along the street in the middle of the road.The tested system operates in the frequency band f_0~902-928 MHz. The tested site is suburban with buildings' heights h≈6-7 m and with a right-angle crossing straight street plan. The first experiment was carried out in conditions of direct visibility when the receiver and transmitter were along the street (Fig. 4) and the base station was at the rooftops level and lower (h_T~4-6 m), but the radio port antenna was lower than roof tops ($h_r \approx$2-3 m). The measured relative intensity of received fieldin dB (to intensity in free space at distance of 100 m) is presented as a set of points in Fig. 5, where also the field intensity attenuation according to the approximate formula (3) in dB, evaluated from 2D-waveguide model [2] (dashed line) and that, obtained from numerical calculations of 3D-waveguide model [2] (continuous curve), versus the distance from the source are presented. As can be seen, both waveguide models give a closed intensity loss in the conditions of line-of-sight at the street level, as those observed experimentally. But from 3D-model one can predict the change of law of field intensity attenuation and existance of break point at the distance ≈200-250 m from the source (see Fig. 5). Moreover this model as "two-ray" model [4] gives a good explanation of field intensity oscillations in the range before the break point with intensity fading $\sim r^{2}$. Using 3D-waveguide model one can also predicts the exponential attenuation of average field intensity beyong the break point up to 1-2 km from the source, as were observed experimentally, and what cannot be understood from "two-ray" model" [2, 4]. The second experiment was carried out in the conditions of existing shadow zones between receiver and transmitter ("clutter" conditions). In this experiment the base station antenna was above the rooftops level ($h_T \sim 7$-8 m), but moving radio port antenna was lower than roof tops ($h_r \approx 2$-3 m). From measurements the "dimond"-shape of coverage curves in the suburban region was obtained, as presented in Fig. 6. In this picture the values of intensity loss obtained theoretically according to formulas (3)-(5) (in the circles) and obtained experimentally (near every experimental curve), are also presented. From comparison between theoretical predictions and experimental data, we notice that in a grid-street-planned urban/suburban microcell having radius less than 1-2 km in the conditions of line-of-sight and in clutter conditions we can with great accuracy use formulas (3)-(5).

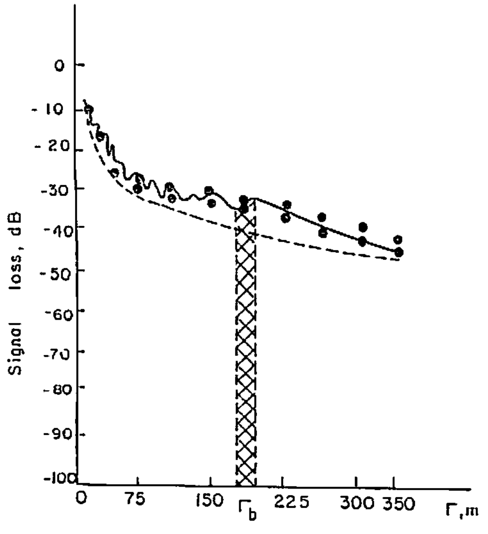

Fig.5

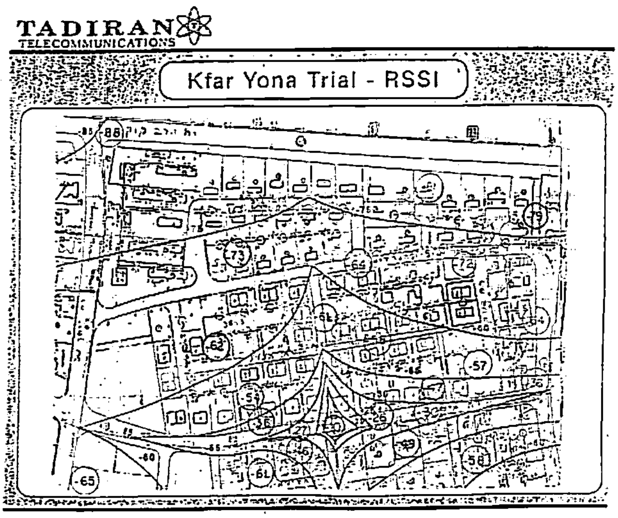

Fig. 6

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