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DIFFRACTION THEORIES AND MICROCELL PROPAGATION

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ABSTRACT

Mechanisms for the propagation of radio waves in a street microcell when the transmitter and the receiver are separated by a street corner have been considered. A ray model based on rigorous diffraction theory has been used to predict the signal levels in the side streets. A comparison between a rigorous and a heuristic diffraction coefficient has also been made. Good agreement between the measured and predicted signal profiles was obtained.

I. INTRODUCTION

One of the special types of propagation environments analysed in the development of future high-capacity mobile communication systems is the street microcell, in which a mobile user communicates with base stations mounted at lamp-post height. This environment involves regions from which the base station is not visible from the mobile port. The received power levels in these shadow regions are much lower in comparison with those of the illuminated regions from which there exists an optical path to the base station. The real task here is to estimate the electric field observed – in terms of the received power – by a mobile user approaching a street junction and then proceeding into a crossing street where the optical path is obstructed. A deterministic model based on ray-optic approximations has been adopted, this being an efficient technique for dealing with high-frequency wavefields.

The geometry of the problem is shown in Fig. 1. The field radiated at S – with the electric field vector perpendicular to the plane of the paper – is observed at P. We will assume that high buildings are erected along the street sides – suppose, therefore, that no signal transmission occurs over the roof tops. Suppose also that no transmitted energy is propagating through the walls of the buildings. Radiated energy reach the point P either directly, by reflection or by diffraction. Note that geometrical optics fails to account for energy transported into the shadow zone; diffracted rays emanating from all the corners carry part of the energy. Contributions arise also from multiple reflection and multiple diffraction.

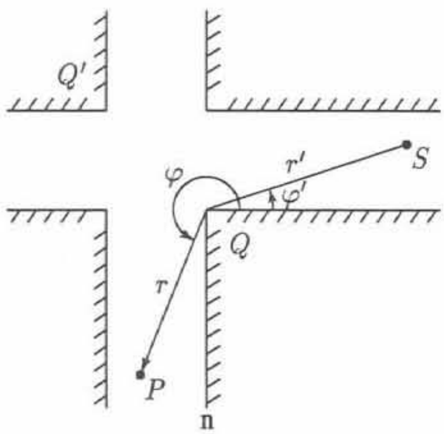

Figure 1 The geometry of the problem.

Diffraction coefficients for a wedge with impedance faces are solutions to a canonical problem that can be used for the geometry described above. The buildings surrounding the street junctions can be viewed upon as four homogeneous rectilinear impedance wedges with conductivity σ and permittivity ϵ. The application of wedge diffraction coefficients to communication links involving diffraction propagation has been investigated by others [1], but the coefficients used were based on a heuristic solution. The diffraction coefficients treated in this paper are derived from a rigorous solution.

In the first part of the paper results from a comparison of a rigorous and a heuristic wedge diffraction coefficient, both valid for plane wave incidence, are described. The application of the rigorous coefficients to the street junction scenario is analysed in the later sections; a good agreement between measured and predicted signal levels for that case is shown. A time dependence of $e^{-j\omega t}$ is assumed and suppressed throughout.

II. Rigorous Diffraction Coefficient

A solution to the problem where a wedge with impedance faces having a large refractive index is illuminated by a plane wave perpendicularly incident on its edge is given by Maliuzhinets [2]. Asymptotic evaluation of the solution ($kr \to \infty$, r being the distance from the edge to the observation point) yields the scattered far field from the wedge as a sum of a geometrical optics field (the incident field and the fields reflected from the wedge surfaces), a diffracted field and a surface wave field. The diffracted field E_d in the far zone can be written as

$$E_d = D\, E_Q, \tag{1}$$

where E_Q is the field at the edge and D is the diffraction coefficient. With the source S and the observation point P situated at (r', φ') and (r, φ), respectively, one finds

$$D = -\frac{e^{j\frac{\pi}{4}}}{2n\sqrt{2\pi k}} \cdot \left\{ \frac{\Psi(n\frac{\pi}{2} + \pi - \varphi)}{\Psi(n\frac{\pi}{2} - \varphi')}[\mathcal{D}^-(\beta^-) - \mathcal{D}^-(\beta^+)] + \frac{\Psi(n\frac{\pi}{2} - \pi - \varphi)}{\Psi(n\frac{\pi}{2} - \varphi')}[\mathcal{D}^+(\beta^-) - \mathcal{D}^+(\beta^+)] \right\} \cdot A(r, r')\, e^{jkr}, \tag{2}$$

with

$$\mathcal{D}^{\pm}(\beta) = \cot\left(\frac{\pi \pm \beta}{2n}\right) F^*[kL\alpha^{\pm}(\beta)], \tag{3}$$

where Ψ is a special function introduced by Maliuzhinets [2] and $\beta^{\pm} = \varphi \pm \varphi'$, while F (the Fresnel transition function), $\alpha^{\pm}(\beta)$, L and the attenuation factor $A(r, r')$ are defined in [1]. The wedge angle equals $(2 - n)\pi$ so that for a perpendicular wedge one has $n = 1.5$. The effect of the surface wave poles on the diffracted field has been neglected in the derivation of (2). It should be noted that Maliuzhinets only provided a solution valid for plane wave incidence ($r' \to \infty$), but the solution can be extended to treat other wave incidences. The problem analysed in this paper assumes spherical wave incidence.

III. Comparison with a Heuristic Coefficient

The diffraction coefficient for an incident wave on a perfectly conducting wedge is given within the context of the uniform geometrical theory of diffraction (UTD). This solution can be modified to include finite conductivity [1]. The result is an ad hoc solution (heuristic); it is not based on any formal solution. The heuristic diffraction coefficient and the rigorous counterpart (2) have a similar form so it might be thought that fields derived from the two coefficients would be nearly the same. This is not so.

Suppose that an E-polarized (the electric field vector being parallel to the edge) plane wave is incident on a right-angle impedance wedge. Figure 2 depicts the electric field obtained from the rigorous and the heuristic coefficients along with that derived from the exact solution [3] when the incident field is close to gracing, $\varphi' = 5°$.

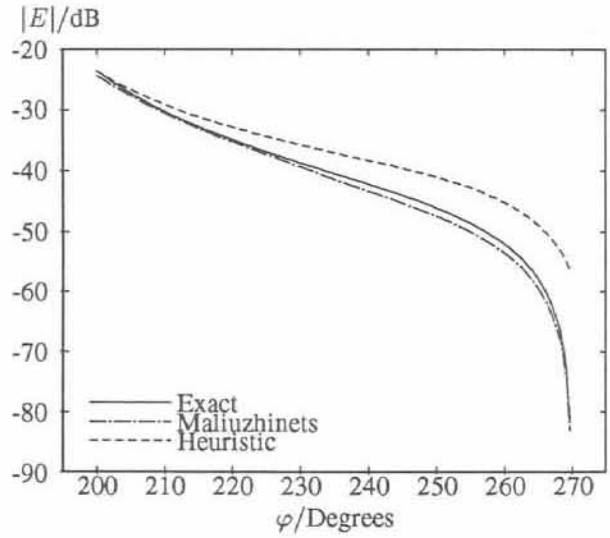

Figure 2 Total field excited by an E-polarized plane wave.

The electrical properties of the wedge medium are $\epsilon_r = 8$ and $\sigma = 0.001$ S/m, which is equivalent to dry soil. The observation point lies in the region $200° < \varphi < 270°$ with $kr = 100$. Upon comparing the field patterns, one observes that Maliuzhinets' solution is a reasonably good approximation to the exact solution: the error is within 2 dB for the whole region considered. The accuracy of the heuristic solution is very poor, notably in the region close to the wedge face. No surface wave is launched.

To sum up: Maliuzhinets' solution is in good agreement with the exact solution provided that the refractive index of the wedge is large compared to unity. The heuristic solution is accurate only in the transition regions across the reflection and shadow boundaries. Finally, it is worth mentioning that other values of the wedge impedance can give rise to an even greater difference between the diffracted fields derived from the rigorous and the heuristic coefficients.

IV. Street Microcell Measurements

Measurements have been taken in a central district of Stockholm, Sweden. The streets of this district form a rectilinear grid pattern and the variation in street altitude is small. The streets are bordered by buildings of about 4-7 storeys. Thus, most of the assumptions made for the problem discussed in this paper were fulfilled. A map of the measurement area is shown in Fig. 3.

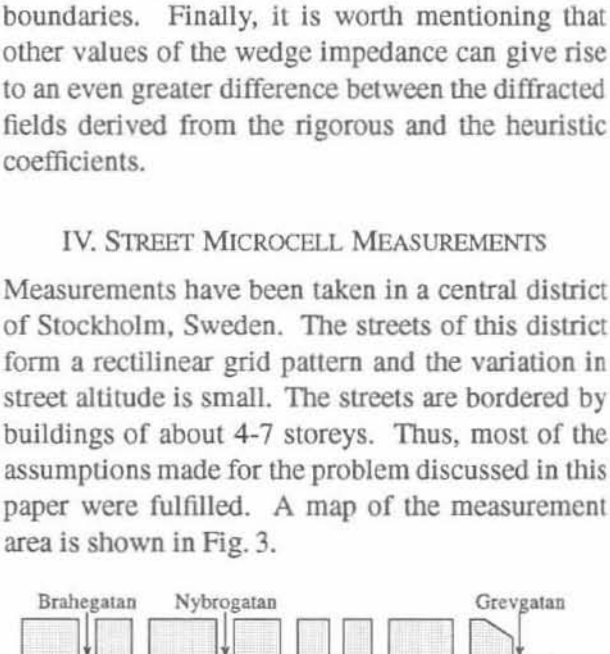

Figure 3 Map of the measurement area.

The measurement equipment consisted of fixed transmitters and a mobile receiver housed in a van with an antenna mounted on its roof. The transmitters generated CW signals in the range of 1700-1710 MHz with an output power of 43 dBm. The transmitter antennas were mounted on top of masts with a height of 5 m, i.e. well below the roof tops.

V. Results

Figure 4 shows predicted and measured results for the case where the transmitter was located at site A (Fig. 3) and the mobile moved along trace 1. The distance from the transmitter to the street junction was approximately 600 m. The predicted signal profile (the upper curve) has been shifted by +30 dB to enhance clarity. In the figure, $d = 0$ m corresponds to the street junction, where a Line-of-sight (LOS) path was present. The signal level dropped con-

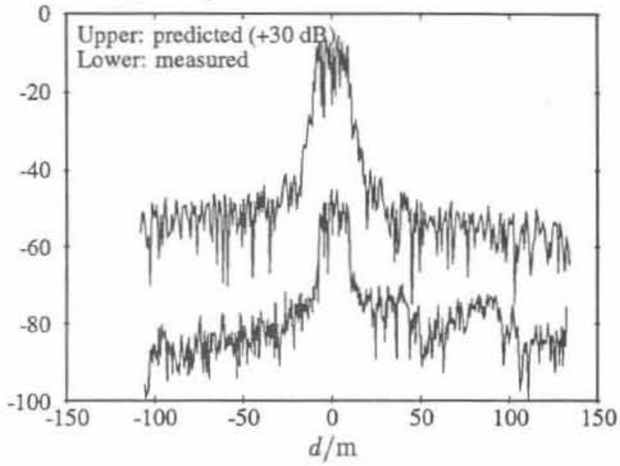

Figure 4 Measured and predicted signal levels along trace 1.

siderably and the fall-off rate was very large in the beginning as the mobile went into the shadow zone. In this zone the LOS path was blocked. A good agreement between predicted and measured signal level is obtained except for $d > 50$ m. This is probably due to a slight ascent of the side street on this side of the street junction (repeated measurements have shown the same behaviour), which is not in conjunction with the initial assumptions made.

The rigorous diffraction coefficient (2) was used for the prediction. This coefficient is only applicable when the plane of incidence is perpendicular to the edge. However, in this case the transmitter and the receiver were located far from the diffracting edges at roughly the same height. Therefore, the incidence was almost perpendicular.

A multitude of rays and ray combinations have to be taken into account to get an accurate prediction. The prediction shown in Fig. 4 involved single diffraction, double diffraction from succesive edges and ray combinations of reflection and diffraction; the highest order ray type included was reflected-reflected-reflected-diffracted-diffracted-reflected-reflected-reflected. The geometrical optics fields (the incident and the reflected fields) dominate in the the street junction (LOS region), whereas diffraction dominates far into the side street. All four diffracting edges at the street junction contribute to the total field in the shadow zone. However, the major contributor to the diffracted field far into the shadow zone is the field constituent scattered from corner Q' in Fig. 1, assuming that the transmitter is located at S and that the receiver is located at P. Reflected paths may extend into the shadow zone, but when the transmitter is located far from the street junction they only reach a few meters into the side street.

In Fig. 5, a case where the transmitter was located close to the street junction is shown (site B in Fig. 3). The mobile moved along trace 2. The distance from the transmitter to the nearest diffracting edge was 40 m, which is about twice the street width. Predicted levels (the upper curve) are again in good agreement with measured levels. The slopes of the signal profiles are not as steep as in the previous case. This is owing to the fact that reflected paths extend well into the shadow zone, where the direct path is blocked.

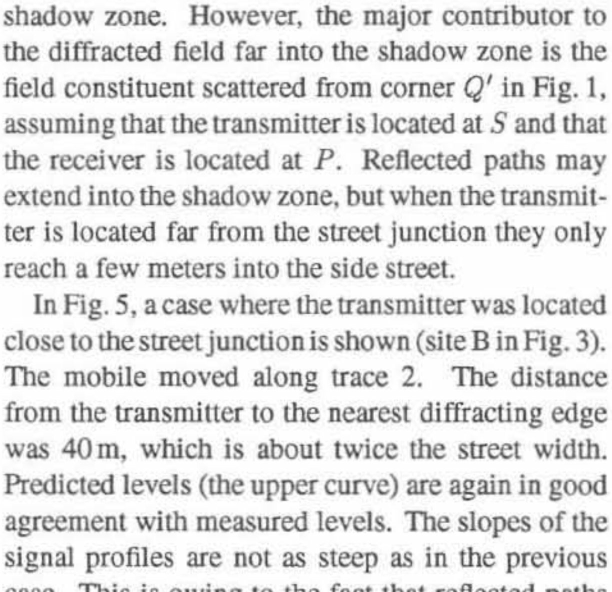

Figure 5 Measured and predicted signal levels along trace 2.

For both cases considered above the predicted and the measured signal profiles are in good agreement; the slopes and the signal levels are about the same – though not identical. (However, it should be noted that all the initial assumptions were not fulfilled during the measurements. The walls of the buildings were not perfectly flat and the streets were not empty.) The interference lobes of the predicted and the measured profiles show a similar behaviour, which shows that propagation into a side street can be described by a multi ray mechanism.

VI. Discussion

The problem of propagation in a street microcell when the transmitter and the receiver are separated by a street corner has been considered. A ray model based on rigorous diffraction theory was used to predict the received signal levels in the side streets, where the direct path from the transmitter was blocked. The predicted signal levels were represented as sums of a multitude of combinations of reflected and diffracted ray fields. Good agreement between measured and predicted signal levels was obtained and the slopes of the measured and predicted signal profiles were about the same.

Rigorous and heuristic wedge diffraction coefficients were compared for a given value of the wedge impedance. The magnitude of the diffracted field yielded by the two coefficients differed significantly — the difference was of the order of 10dB — in certain regions around the wedge.

References

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