COMPARISON OF INDOOR PENETRATION MEASUREMENTS WITH GEOMETRIC AND PHYSICAL OPTICS PREDICTIONS

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INTRODUCTION

In the planning of microcells for mobile communication systems, the received signal level and the possibility to accurately predict it, play a significant role. Field strength measurements at GSM frequencies have been performed by *Mobilkom AG* in a modern office building in Vienna. Two different propagation models have been used for the simulation of the radio wave propagation in this environment. The first model was a Geometric Optics (GO) ray tracing model and the second was a Physical Optics (PO) ray tracing model. Both models are implemented in the EPICS propagation prediction tool developed at ESAT/TELEMIC [1].

PHYSICAL OPTICS VERSUS GEOMETRICAL OPTICS

Traditionally, the method of geometric optics is implemented in most ray tracing tools. This method has been shown to give reasonable results and is computationally very efficient to implement. However, the GO reflected field has some shortcomings. Since only the specular direction is considered, it is possible that with a fixed transmitter the reflection point belongs to the reflecting surface for a single receiver position and not for any other receiver position. Also, the value of the reflected field doesn't take into account the finite dimensions of the reflecting surface: it is calculated for an infinite reflecting surface. These GO shortcomings can be overcome by the theory of Physical Optics. Referring to Fig. 1, the radiated electrical field from the reflecting surface *S'* can be computed [2] as

$$\vec{E}(\vec{r}) = -\frac{j}{\omega\varepsilon}\int_{\Sigma}\left[(\vec{J}.\vec{\nabla})\vec{\nabla} + k^2\vec{J}\right]\frac{e^{-jkR}}{4\pi R}dS' \qquad (1)$$

with $\vec{J}$ an electrical surface current.
The evaluation of (1) requires the computation of the PO radiation integral

$$\iint \vec{J}(r')\frac{e^{-jkR}}{R}dS' \qquad (2)$$

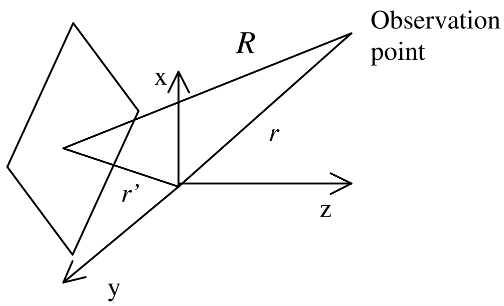

Fig. 1: Geometry for the PO radiation integral

With a well chosen center, the resulting phase of each point on the reflecting surface can be written as an expansion around the phase of the center as a second degree polynomial in $x' = x - x_{center}$ and $y' = y - y_{center}$ without crossterm. The radiation integral thus reduces to

$$\frac{\vec{J}_0}{R_{TC}R_{RC}}e^{-jkR_{TC}}e^{-jkR_{RC}}\iint e^{-jk(ax'+by'+cx'^2+dy'^2)}dx'dy' \qquad (3)$$

a, b, c and d are real valued and can be deduced from the position of both transmitter and receiver. R_{TC} and R_{RC} are the distances of the transmitter and receiver to the chosen center. As can be seen from (3), the PO radiation integral can be written in terms of Fresnel integrals. The same reasoning can be made for the electrical field due to a magnetic current. Both electric fields are included in the EPICS propagation prediction tool.

It has been shown [3] that the procedure described above leads to much less subdivisions as in the Beckmann case, where the approximation is done with a plane wave. The number of subdivisions needed depends on the distance of both transmitter and receiver to the reflecting surface as well as the angles of transmitter and receiver with respect to this plane. In general the minimum far field distance is much smaller than the traditional $\frac{2D^2}{\lambda}$.

The PO reflection model has been validated by multiple measurements under controlled circumstances in the anechoic chamber of ESAT/TELEMIC. These measurements were done for different materials, both for flat and corrugated structures. The PO simulations fit very well these measurements in amplitude and phase, both under nearly grazing incidence and nearly perpendicular incidence, also in situations where the GO reflection point doesn’t belong to the reflecting surface and the GO model consequently fails.

MEASUREMENTS IN AN OFFICE BUILDING AND PREDICTION

Since the PO model was proved to be correct, it is interesting to investigate measurements in a typical indoor situation. Field strength measurements at 951 MHz inside a modern office building of *Mobilkom AG* in Vienna were used for this purpose. During these measurements, the transmit antenna was attached to the ceiling. The antenna pattern was simulated as that of a vertical dipole because this a standard antenna pattern in the software and because this is a good approximation for the omnidirectional, vertically polarized antenna that was used. The receive antenna was a GSM handset connected to a laptop with measurement software. The receiver moved over the whole floor.

A floor plan of the floor where the measurements were done is shown in Fig. 2. Most of the inner walls are made of plasterboard, except some which are made out of brick or concrete. The material parameters (permittivity ε and loss tangent tanδ) were taken from measurements in Telemic at 2.4 GHz [4]. We know from earlier investigations ([5], [6]) that there is no significant difference in transmission through plasterboard, concrete, for both 2.4GHz and 950MHz.

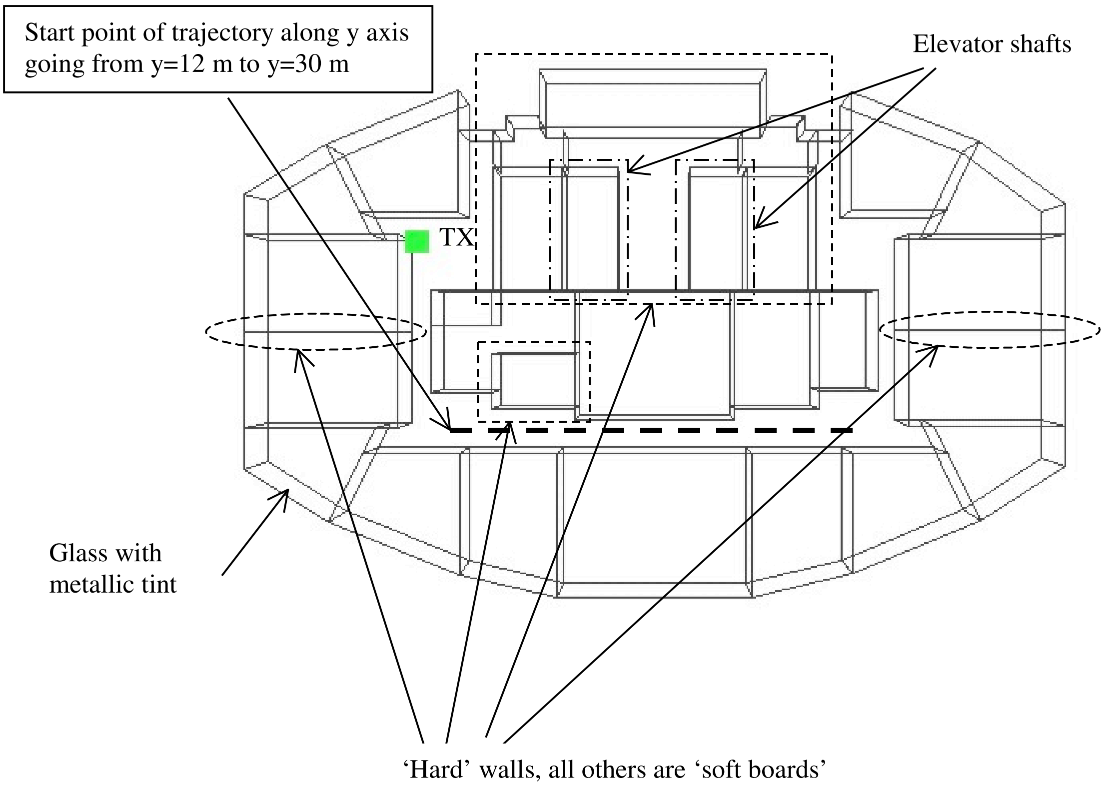

Fig. 2: Bird eyes view on the measured floor

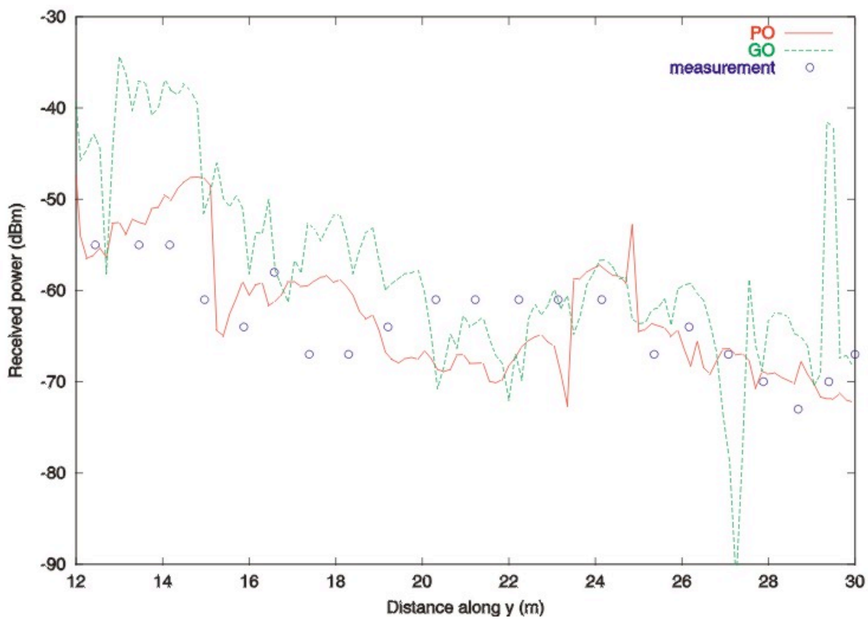

Fig. 3: Comparison of measurements and their predictions

Two prediction models have been used for the simulation of the received power in the case of the investigated building. Both models take into account a combination of penetration and reflection. More specifically the computed rays are the direct ray, single reflected, double reflected and triple reflected rays. Fig. 3 gives the result for the measurement and prediction for the trajectory indicated as the stripe line in Fig. 2. Both models predict the general trend of the measurements. It is seen that the PO prediction is generally better than the GO prediction. Only between y=20 m and y=23 m this is not true. It is thought that one of the rooms which is simulated as concrete is in reality not as 'blocking' as in the simulations. Due to the fact that we only have plasterboards, there are a number of multiple reflections, which can be from any direction, also from the windows with the metallic tint. The ensemble of those multi-reflections in the simulations doesn't lead to the higher signal values measured.
Due to the properties of the PO model, the changes in the PO predicted fields are less sharp as the GO case. For the chosen trajectory, the mean error and the standard deviation of the error are given in Table 1. The PO model indeed gives a good improvement in both mean and standard deviation. The improvement of the mean error with more than 1 dB and of the standard deviation with more than 3 dB is typical for all measurements.

Table 1: Statistical results

	(dB)	σ (dB)
GO	3.5	11.7
PO	2.4	7.5

The extra computation time needed by the PO model for a whole trajectory is on average only in the order of 10%-15%. This figure may vary from point to point depending on the circumstances. Cases with nearly grazing incidence are more time consuming since more subdivisions have to be taken into account, as explained before. It should be pointed out that the extra computation time does not only consist of extra time needed for the electromagnetic computations, but als for the extra rays which are taken into account by the PO version compared with the GO version.

CONCLUSIONS

It can be concluded that the field strength can be well predicted with our models. The prediction using the PO model is better than the GO model but remains efficient: with no more than 15% extra calculation time, the mean and standard deviation improve by respectively more than 1 dB and more than 3 dB. This accurate prediction is important in site planning and allows to draw conclusions about effectiveness of indoor communication systems [7].

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