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A Deterministic Model for the Planning of Microcellular Mobile Radio Communication Systems

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Abstract - In this paper a ray model for field strength prediction for the planning of microcellular mobile radio communication systems is presented. The already developed software at Eindhoven University of Technology for LMSS has been adapted for application in microcellular mobile radio communication systems. The adaption consists of using simple shaped objects and higher order contributions. The simulation results of the new model are compared to measurements which were performed in The Hague.

I.   INTRODUCTION.

The continuously increasing demand for cellular radio services means that network operators will have to greatly increase the capacity of their cellular radio networks. Currently the only way to significantly increase the capacity of cellular radio networks is to reduce the sizes of cells (eg. micro-cells). Such massive usage of small cells increases the complexity of the network and subsequently its frequency and capacity planning.

An important part in frequency and capacity planning is the accurate estimation of the radio power distribution and interference levels between reused channels. For this purpose propagation models must be used. In the past statistical-empirical models have been developed for use in the planning of 'large' cells (eg. diameter > 3km). These models can successfully predict the statistical distribution of signal levels within grid-areas with resolution of about 500 x 500 m². These models perform well as long as the base station antenna is placed well above the rooftop of buildings, which is the case when using 'large' cells.

The reason for the success of such models is not wholly known. This success probably stems partly from the fact that the propagation over larger distances from the base station, involves a process of statistical averaging of the propagation effects of random objects. Also, the large size of grid areas used by the planner means that only the number of occurrence and magnitude of specific propagation effects (eg. shadowing) need to be predicted and not the exact locations, within such area, where these effects take place.

Unfortunately such statistical-empirical models are inadequate for use in the planning of small cells. In the first place the usage of small base station height in small cells implies that some modes of propagation (such as diffraction round corners of building) which in the case of high base station antenna give only a secondary contribution to the received power, may now be the prime mechanism by which power is transferred from transmitter to receiver. In the second place because the cells are small the planner must use grid area of very high resolution (probably some 25 x 25 m²). This negates the use of statistical models since the power associated with each such area is mostly produced by a few   dominant propagation modes (out of a large number of possible modes). The received power can therefore only be determined accurately in a deterministic way.

PTT Research and Eindhoven University of Technology (EUT) are   currently   working   jointly   to   develop   a deterministic   model   for   planning   of   micro-cellular networks. The approach used is based on the model FiPre [1] developed at the EUT. In this paper we present the results of the research to adapt and further improve the model for usage in a microcellular environment. The paper also presents results of testing of the new model with data measured using direction sensitive antennas.

II.   DESCRIPTION OF THE PREDICTION MODEL.

The model described in this paper is based on the existing model FiPre. Like FiPre the new model also uses Geometrical Optics (GO) complemented with the Uniform Theory of Diffraction (UTD) [2] to account for the bending of electromagnetic (EM) waves around edges. In these high-frequency theories, the EM wave is assumed to travel in space along straight lines which are called rays. Hence, the medium in the urban environment is assumed to be homogeneous.

The major difference between both models is the number of steps to take before obtaining a field strength prediction. Instead of tracing the rays and calculating the field strength in one step, these features are separated (Figure 1).
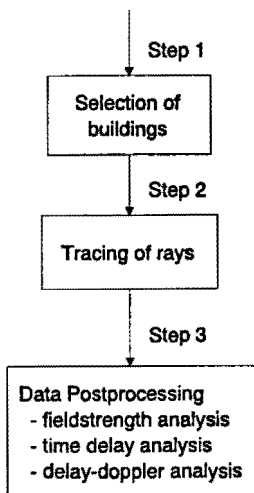

Figure 1: Three steps towards channel analysis.

The first step is the selection of the buildings. It is obvious that the number of buildings considered determines the total calculation time. In our case we manually select the buildings in the vicinity of the transmitter and receiver. Furthermore, the new model considers only three types of buildings: buildings with three and four corners and a finite width screen. The rooftops of the buildings are considered to be flat. The vertical sides of these objects are perpendicular to the earth's surfaces. This constraint gives considerable more computational efficiency.

The second step is finding the paths from the transmitter to the mobile. Since these waves propagate along straight lines and we use simple shaped buildings, it becomes very easy to find diffraction and reflection points. Originally, the model FiPre was developed for land mobile satellite services (LMSS). The new model must be applied in a microcellular communication system such as GSM. Figure 2 shows the major difference between both applications.

Obviously, in most cases the edges and surfaces of the buildings in the vicinity of the mobile can be seen by the satellite due to the relatively large elevation angle. As Figure 2 clearly shows, this is not the case for microcellular systems. Since FiPre only takes single diffraction and reflection contributions (and possible combinations of diffraction and reflection) into account, we can assume that FiPre is not applicable for field strength prediction in the microcellular environment. Therefore, the
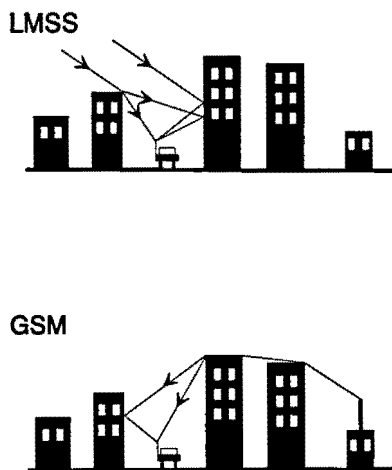

Figure 2: LMSS versus GSM.

ray tracing procedure must be extended. The following classes of contributions are defined (see Figure 3).

1. The direct wave of order k^0, where k is the free space wavenumber;
2. The diffracted wave of order $k^{-1/2}$. The ray tracer is able to locate possible combinations up to three edges;
3. The reflected wave of order k^0. The ray tracer is able to locate possible combinations up to three surfaces;
4. Combination of a reflected wave and diffracted wave. The ray tracer is able to locate possible combinations up to three surfaces/edges.
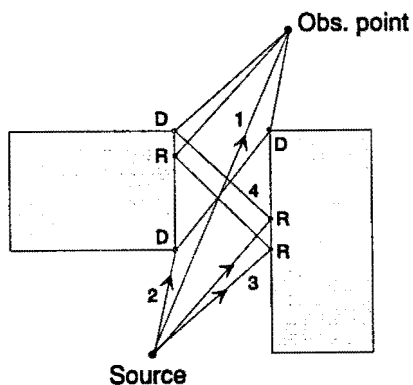

Figure 3: Some possible combinations.

Before the ray tracer can actually be invoked some input data has to be defined.

1 The classes of contributions included;

2 The source position;

3 The trajectory of the mobile and the number of sample points.

The only task of the ray tracer is to find the paths from the source to the observation point, either direct paths or paths obeying the laws of Snell and/or Keller [3]. If a ray is not blocked the path data is put into a file. Hence, after the second step we have obtained a file which contains all possible paths from the source to the observer point(s).

The third step towards a field strength prediction is the data postprocessing. In this step the file containing all the paths is translated into a field strength pattern along the trajectory. Figure 1 shows that besides field strength prediction, also time delay and delay-Doppler analysis can be performed. Since all paths are known, the excess path length and the direction of the arriving wave at the mobile, which are the necessary parameters for the aforementioned analysis, can easily be found. In this paper we only consider field strength data postprocessing. This postprocessing tool translates every path into a field strength using the formulas defined by GO and UTD. At the observation point the total electric field E^{obs} is given by

$$E^{obs} \propto \sum_l E_l \qquad (1)$$

where E_l is a wave arriving at the observation point.

Before this translation can be performed the following input data must be defined.

1 The type of transmitting antenna;

2 The type of receiving antenna;

3 The frequency;

4 The source polarisation; included are only linear (H/V) polarisation;

5 The building material (perfect conductive or dielectric).

III. DISCUSSION OF THE MODEL.

Obviously, the basis of the new model corresponds to FiPre. However, the new approach of producing a field strength prediction has some important advantages. First of all, for a particular configuration of buildings the ray tracing only needs to be performed once. With the path data file all kinds of analysis can be performed: the analysis regarding different materials of buildings or different frequencies for example. Furthermore, the analysis of the mechanism scattering, which is not (yet) implemented, can also be performed afterwards. Scattering objects, such as trees and fences, can be positioned in the configuration. If one of the paths intersects with these objects an additional attenuation can be inserted.

Besides postprocessing of the path datafile, also preprocessing the input building file has been applied. Since multiple diffraction/reflection contributions are taken into account, the number of possible combinations grows exponentially. Using preprocessing such as determining the edges or surfaces in sight of one another or in sight of the source, the number of combinations and hence the calculation time is limited. Due to this preprocessing and using only the aforementioned restricted building input format, the new model is approximately a factor ten faster than FiPre. However, a disadvantage of the new approach is that large disk space is required to store the (preprocessed) data.

IV. COMPARISON OF SIMULATIONS WITH MEASUREMENT RESULTS.

In Figure 4 a map is given of the area where the measurements have been performed. All coordinates are given in the Dutch "Rijksdriehoek" cartesian coordinate system.

The transmitting antenna is positioned in the AB building marked by the circle and cross at a height of approximately 25 metres. We have used a patch antenna with a gain of 5 dB and a 3 dB beamwidth of 90 degrees. The main beam is directed perpendicular to the right vertical surface of the AB building. This antenna generates an EM wave of 910 MHz with a power of 40 dBm.

The trajectory driven starts at the beginning of the "Louise-Henriettestraat" and after turning right the "Marijkestraat" is entered. In Figures 5 and 7 the x-axis is given by the distance driven. The total length of the Louise-Henriettestraat is about 235 metres, whereas the
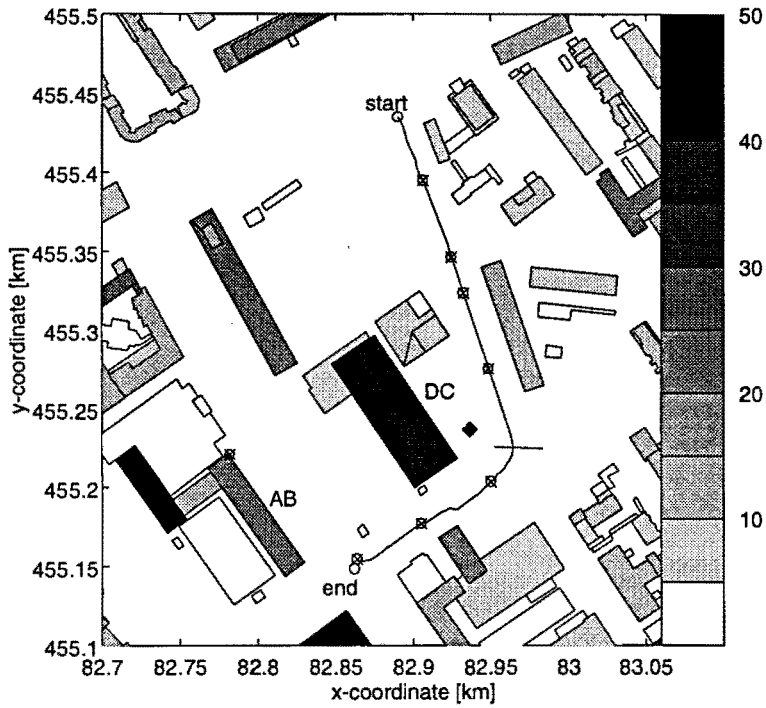
Figure 4: Area of measurement setup in The Hague. The solid line represents the trajectory driven on the Louise-Henriettestraat (start to crossed line) and the Marijkestraat (crossed line to end).
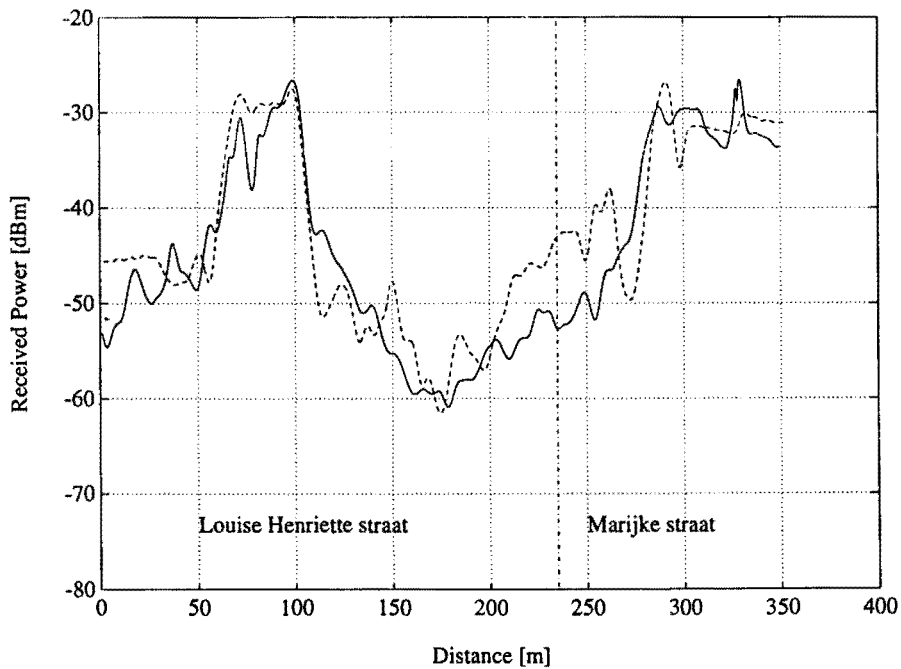

Figure 5: Comparison monopole measurement results (solid line) with simulations (dashed line).

length of the Marijkestraat is approximately equal to 120 metres. The marked points at distances 50, 100, 125, 175, 250, 300, and 350 metres on the trajectory refer to Figures 8 and 9.

We have used two different receiving antennas, which were both mounted on top of the van at a height of approximately 2.5 metres. The first antenna was a $\lambda/4$-monopole with a gain of 2 dB. The second antenna we have used was a phased array, which is able to scan in twelve directions.

Figure 5 shows the measurement results with the monopole as receiving antenna compared with simulations. We have considered the buildings between the trajectory driven and the transmitting antenna and the buildings within 50 metres apart from the trajectory. All buildings are considered to be perfectly conducting. The fast fading has been removed using a low pass filter [4]. It can be seen that a good agreement is found. However, there are some notable discrepancies. The first can be found at the start of trajectory where the simulation results are overestimated. This can be explained by the fact that the area north from the DC building is a parking area with many trees and obviously cars. In [5] is shown that these trees can have a significant influence on a propagating EM wave. The second difference occurs in the part from 110 to 130 metres. In this case we have received more power than the simulation results predict. From the simulation we have found that the received power in this area consists mainly of double diffraction contributions (see Figure 8 at distance 125 metres). The last major discrepancy lies in the region from 200 to 275 metres where again the simulation overestimates the received power. The reason for this is that surfaces of the buildings are clearly not smooth. According to the simulation results the received power in this area comes from combinations of reflecting and diffracting waves. Obviously the reflection mechanism is not sufficient well modelled.

Figure 7 shows the monopole measurement results compared with the phased array measurement results. As already mentioned, the phased array antenna is capable of scanning in twelve directions. Hence, each beamwidth is equal to 30 degrees. The gain of this antenna is approximately 6 dB. The zero degrees direction of this antenna is defined as the direction the car is driving. When looking on top of the phased array antenna the other scan directions are clockwise oriented as can be seen in Figure 6. Hence, considering contributions arriving at the right hand side of the mobile, the 90 degrees position must be used to receive them.

In Figure 7 can be seen that the received power with the phased array switched on the 60 degrees

direction, follows the monopole measurement in several parts of the trajectory. This is rather obvious since in these areas there is a line of sight (LOS) in exactly that direction. More interesting is the measurement results with the phased array switched on the 180 degrees direction. Especially in the part from 150 to 200
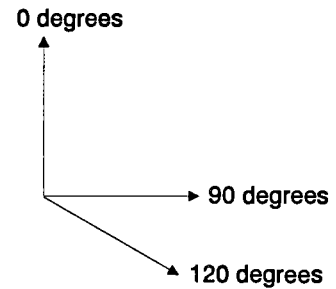
Orientation Phased array

Figure 6: Orientation of the phased array.

metres we see that most of the received power comes from behind of the car. In the simulation results however, these rays cannot be found. Note that this part lies in the deepest shadow of the DC building. Hence, the received power from 180 degrees must be due to other propagation phenomena (e.g. scattering or transmission through buildings).

In Figure 8 the relative magnitude (normalized to the strongest contribution) and the direction of individual rays can be found at several positions of the mobile on the Louise-Henriëttestraat. Note that the relative magnitude is on a linear scale. The distances 50, 100, 125, and 175 metres refer to the marks on the trajectory in Figure 4. At distance 50 metres we see that most of the power comes from directions 30 and 60 degrees. According to the simulation these contributions are due to diffraction. At distance 100 metres the LOS is clearly visible. The next subplot represents the received power when just entering in the shadow region of the DC building. We see that most of the power comes from the north side of the DC building, what agrees with the results obtained from the ray tracer. The last picture shows clearly that the total received power at that specific position is due to multipath propagation.
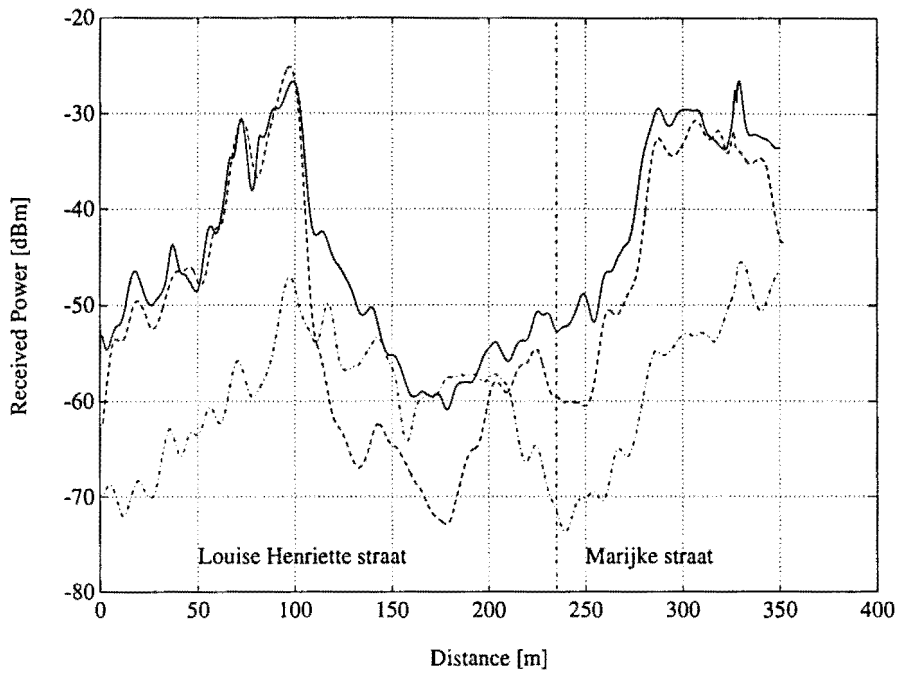
Figure 7: Comparison monopole measurement results (solid line) with phased array measurement results; -- 60 degrees; -. 180 degrees.
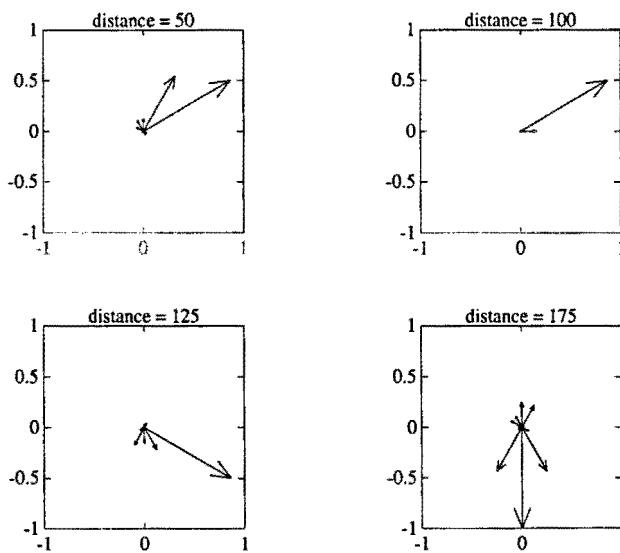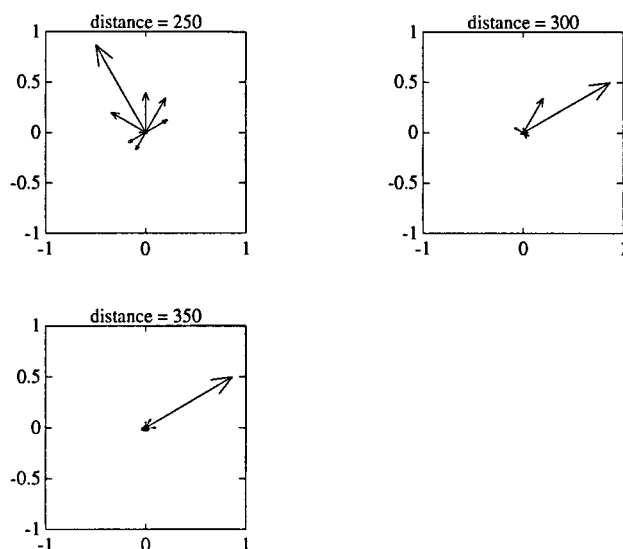

Figure 8: Relative magnitude and direction of the individual rays on the Louise-Henriettestraat at distances 50, 100, 125, and 175 metres.

Figure 9: Relative magnitude and direction of the individual rays on the Marijkestraat at distances 250, 300, and 350 metres.

Figure 9 representing the Marijkestraat shows that at distance 250 metres the received power is also mainly due to multipath propagation. Driving further on we can see again the LOS coming from direction 60 degrees.

V. CONCLUSIONS.

In this paper the major features of the prediction tool developed for the simulation of the most significant parameters of a microcellular communication channel have been presented and discussed. The new tool holds the same features as FiPre, but is much faster and can be applied in LMS Services as well as in a microcellular environment. Furthermore, the new approach in determining a field strength prediction offers some advantages to analyse various phenomena. A disadvantage of the new approach is that there is trade-off between speed and disk space. More speed in determining the field strength requires more disk space.

The comparison of the measurement results with the simulations has shown that a good agreement was found. However, more effort must be spent in the scattering phenomena of trees and buildings. Hence, this will result in a deterministic model containing several statistical properties to model these phenomena.

Using the sectorial antenna for verification of the direction and relative magnitude of the arriving waves has shown interesting results. These results has also shown that such measurement equipment is very important for the verification of a deterministic model.

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