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Propagation Model for the Land Mobile Satellite Channel in Urban Environments

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1 Abstract

This paper presents the major characteristics of a simulation package capable of performing a complete narrow and wideband analysis of the mobile satellite communication channel in urban environments, for any given orbital configuration. For the RF frequency range the model has been designed to be applicable (1 up to 60 GHz), the wavelength-to-average urban geometrical dimension ratio has required the use of the Geometrical Theory of Diffraction (GTD) [1], extended to include effects of non-perfect conductivity and surface roughness. Taking advantage of the inherent capabilities of such a high frequency method, we are able to provide a complete description of the electromagnetic field at the mobile terminal. Using the information made available at the ray-tracer and GTD solver outputs, the Land Mobile Satellite (LMS) urban model can also give a detailed description of the communication channel in terms of power delay profiles, Doppler spectra, channel scattering functions and so forth. Statistical data, e.g. cumulative distribution functions, level crossing rates or distributions of fades are provided too. The user can access the simulation tool through a Design-CAD user-friendly interface by means of which he can effectively design his own urban layout and run consequently all the envisaged routines. The software is optimised in its execution time so that numerous runs can be achieved in a considerable short time.

2 Introduction

Urban areas will likely represent a significant market for the conventional mobile communication services and for the new concepts of personal communications through hand-held terminals. The propagation of an electromagnetic field in such environments is, on the other hand, a very complex phenomenon to simulate. To date the analyses of the link impairments and the estimation of their impact on the LMS system performance have been mainly based upon experimental data and empirical models, [2]-[4]. The development of a deterministic model not directly related to specific environmental urban scenarios and designed on canonical electromagnetic laws is therefore strongly needed.

Based on this sort of considerations and having in mind to develop a user-friendly prediction tool to be used not only by propagation engineers but also by LMS system planners, the

European Space Agency (ESA) decided to place a study contract with two Italian companies, Space Engineering and Ingegneria dei Sistemi (IDS), in 1992, [5]. The main features of the LMS prediction tool developed under this contract are hereafter described.

3 The LMS urban prediction tool

The GTD-based prediction tool for LMS systems in urban environments can be considered as the result of the interaction of several functional blocks, each of them properly designed in order to save computational time and increase modularity and transportability. The core of the simulation package is represented by the Ray Tracer and the GTD Solver codes. In addition we also have an Urban Area Modeler, an Electromagnetic (E.M.) Mesher and a Post Processor Unit. A functional block diagram of the package is reported in Fig. 1 while a detailed description at subsystem level is given in the following sections.

3.1 The Ray Tracer

In most of the existing GTD prediction packages (e.g. NEC-BSC) ray tracing and electromagnetic field computation are performed in the same logical step; the ray tracing parameters calculated at any observation point are not saved for further processing (e.g. at a different RF frequency) and this inevitably results in a great computational inefficiency particularly in complex environments such as urban areas. In our LMS prediction tool, the two operations are kept separate and are performed by two distinct modules. All the ray tracing parameters are saved in a file before actually starting the e.m. calculation. This software architecture implies a sensible reduction of the CPU time and is naturally suitable for optimization and upgradability.

The input parameters for the Ray Tracer are: the satellite position, the urban area model, the vehicle speed and path and the number of electromagnetic interactions to be considered. The model has in-built the opportunity to generate orbital configurations other than the conventional geostationary one; this feature is extremely important to simulate a large variety of LMS constellations, from Low to Medium and Helliptical Earth Orbiting multisatellite systems (LEO, MEO, HEO). The urban geometry of the vehicle path is given through a set of straight lines with a user-assigned speed for each of them. As for the number of the electromagnetic interactions, the LMS urban prediction tool has been to date designed to include up to the second order, i.e. double reflected or diffracted and all the different combinations with the direct and single scattered rays.

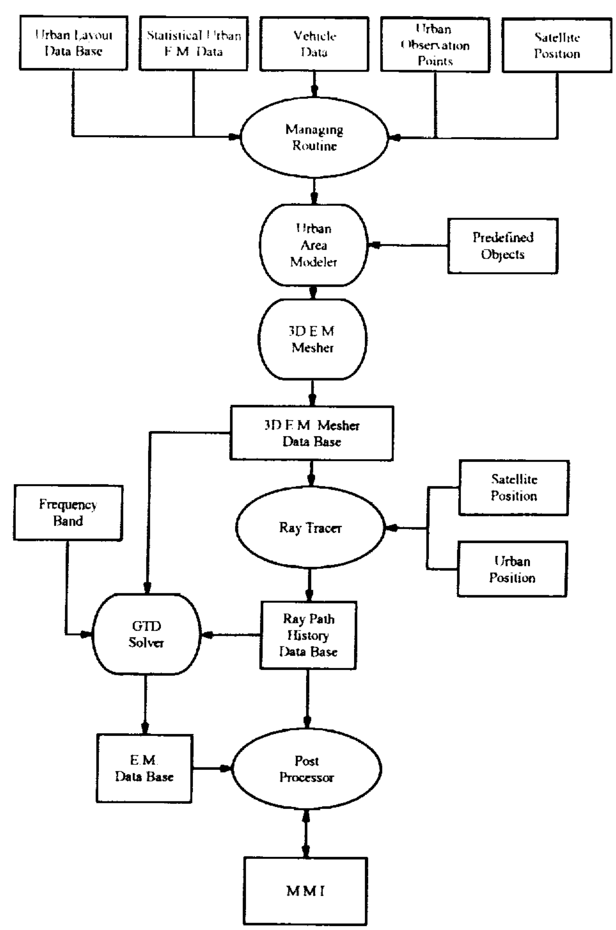

Fig. 1 LMS prediction tool block diagram

The software architecture has been anyhow conceived to be easily upgradable for any higher order of contributions.

In order to reduce the computational time, the Ray Tracer considers as *active* part of the user-defined urban layout the boolean combination of the portions contemporarily seen by the satellite and the mobile terminal. Once all the ray paths relevant to a certain observation point are computed, they are stored on a high capacity hard disk and the mobile position is updated. In Fig. 2 a sketch of the Ray Tracer active area for a typical urban area is reported where all the relevant rays (reflected, diffracted, etc.) are clearly visible.

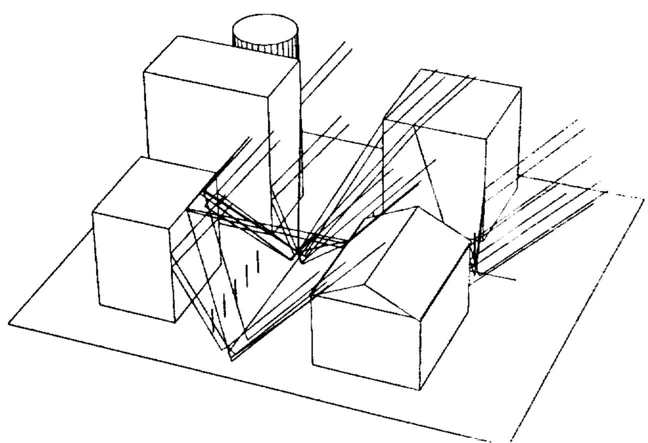

Fig. 2 Typical Ray Tracer output

3.2 The GTD solver

This unit performs the actual electromagnetic computations according to the uniform theory of diffraction and using, where applicable, the geometrical optics and the Fresnel coefficients for the reflection ray paths. The extension to non perfectly conductive materials and surface roughness is achieved through heuristic formulations and user-defined look-up tables for the complex reflection coefficients. The effect of leafage absorption is also modeled directly by the user introducing weight functions or empirical relations.

The input parameters for the GTD Solver are, for any given satellite position and observation point: the ray path history file, the e.m. urban model and auxiliary information, e.g. RF frequency. The direct, reflected, diffracted and refracted field components are then computed in amplitude and phase. This information is stored in a file and handed over to the Post Processor Unit.

3.3 The Urban Area Modeler and E.M. Mesher

The urban layout is characterised by a set of large and small objects representing urban parameters, such as buildings, tunnels, overpasses, trees, street lamps, phone booths, parked cars, etc. Through the Urban Area Modeler implemented in Design-CAD, the user is able to create a fully controlled urban environment placing building by building; it is envisaged, for future developments, also an automatic generation procedure based on a set of statistical parameters (urbanization factors). The urban layout previously considered for the computation of the active Ray Tracer area is reported in Fig. 3.

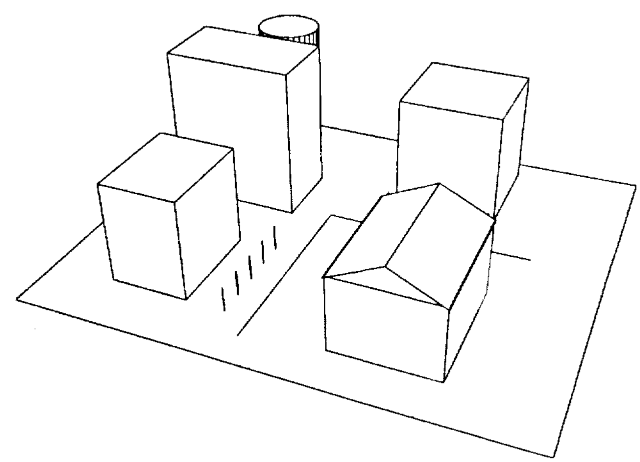

Fig. 3 Urban Modeler output

The Urban Modeler has also the possibility of accepting as input file the layouts of actual cities (Paris, London, Rome, etc.) if given in forms of digital terrain data bases.

Large objects are defined mainly by boxes and cylinders of predefined dimensions; more complex urban objects can be built using flat panels. Trees are characterised by a spherical leafage and a cylindrical trunk while other small objects (nearby vehicles, dust bins, phone booths, etc.) are accounted for with spheres of given radius, scattering isotropically. All the objects materials are defined with their complex permeability and permittivity.

The E.M. Mesher is the unit interfacing the urban layout modeler with the electromagnetic solver. It performs all the required verifications and manipulations on the CAD file, in ASCII format, and translates it into a solver acceptable input format. The objects' electromagnetic properties are included at this stage.

3.4 The Post Processor Unit

Under the supervision of a managing module interfacing the solver output database with the user control screen, the Post Processor Unit performs the following tasks: extraction of the time series of the received e.m. field, field weighting by the preselected mobile terminal antenna pattern, computation of the narrowband statistical functions and wideband channel parameters. It is important to stress that the user has the opportunity to select his mobile receive antenna within a large set of predefined radiation patterns; a computed weight function can also be user defined to take into account the effect of the vehicle roof. In Fig. 4, the time series for the test case presented in Fig. 3 is reported.

The set of statistical narrowband analyses available to the user includes Probability and Cumulative Distribution Functions (PDF and CDF), Average Fade Durations (AFD), Level Crossing Rates (LCR), Distribution of Fades and Connections, Time-share of Fades and Connections.

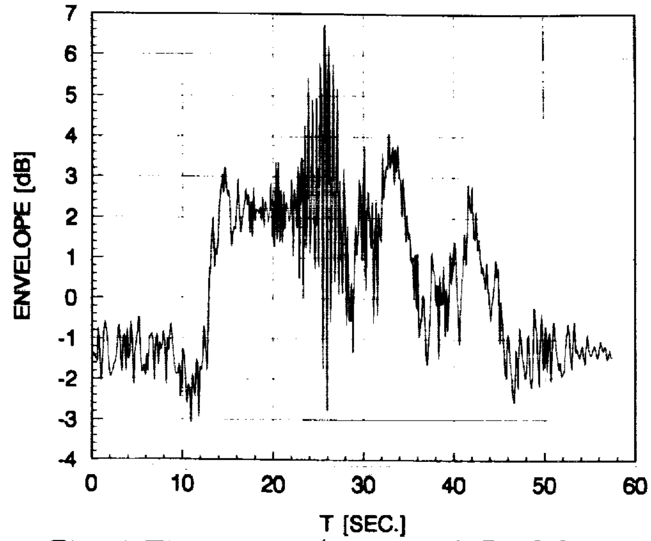

Fig. 4 Time series (segment A-B of the trajectory)

The list of wideband channel parameters is also quite exhaustive: Doppler and power delay profiles, channel scattering function, delay spread and coherence bandwidth. Through the use of these routines the LMS system engineer can effectively achieve a very detailed characterisation of the narrow and wideband channel, ([6]-[7]). Fig. 5 reports, on the base of the previous urban layout, the corresponding PDF and CDF; it is clearly visible the multipath effect due to the strong reflecting buildings (perfect conductivity) along the trajectory considered.

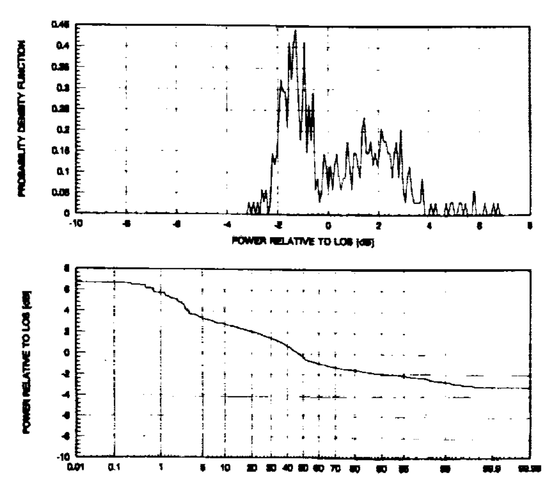

Fig. 5 PDF and CDF

In Fig. 6, the scattering profile of the urban channel computed in several observation points along the selected trajectory is presented. It is very interesting to observe the mutual interaction between different ray contributions generated by the urban area elements.

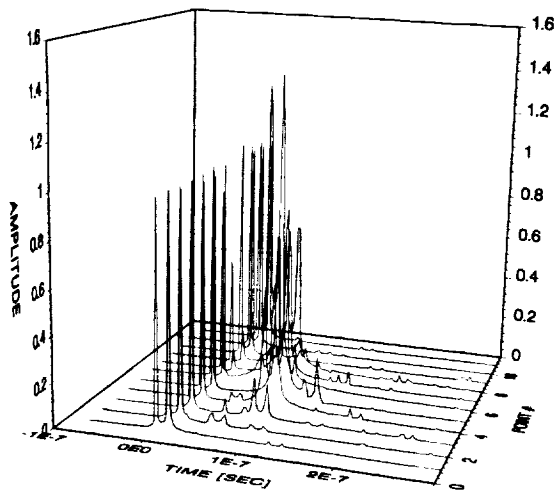

Fig. 6 The Scattering Channel Profile

Finally, the cumulative distribution functions of the average delay and delay spread are given in Fig. 7. The segmented shape of the curves is due to the limited number of observation points considered in our test case. It is fairly easy to notice that the maximum average delay is around 76 ns while the delay spread is always less than 40 ns.

4 The hardware and software platforms

The LMS prediction tool for urban environments has been presently designed to run on PCs with MS-DOS operating system. The requirements for the hardware platform are an 80486 processor, 8 Mbyte of memory and 200 Mbyte of hard disk, a VGA or better EGA graphic card. FORTRAN has been used to develop all the model units but the Man Machine Interface running under Windows environment through Microsoft Visual Basic. The user can visualize and interact with the Urban Modeler via a DesignCAD-3D tool, incorporating a large set of commands and macros.

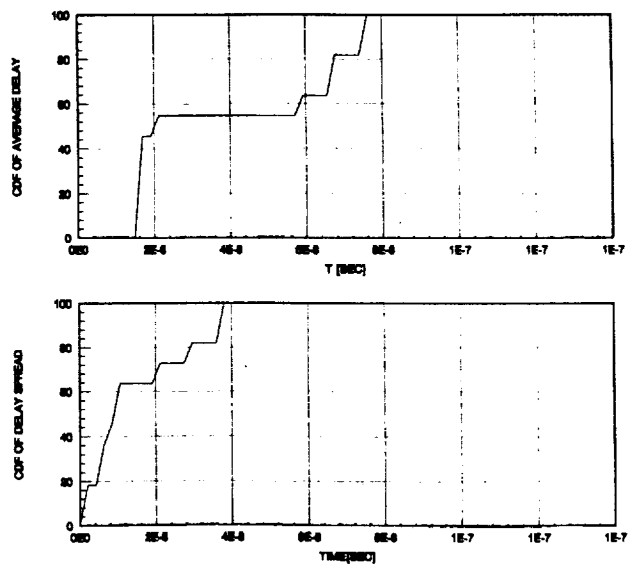

Fig. 7 Average Delay and Delay Spread CDFs

5 Conclusions

A brief summary and description of the main features of a GTD-based LMS prediction tool for urban environments has been presented in this paper. The model can be effectively used to simulate and estimate the behaviour of the narrow and wideband channel for any given mobile satellite system in built-up areas. The user can define his own urban layout through a DesignCAD tool inserting buildings, tunnels, phone booths, parked vehicles and many other typical urban items. The model itself is suitable for simulating moving vehicles at given speed as well as personal communication network users equipped with hand-held terminals. The set of wideband parameters and statistical functions available to the user, being a propagation engineer or an LMS system planner, is fairly comprehensive.

In the next future, the LMS prediction tool will be upgraded insofar as higher orders of electromagnetic contributions and the transmitter located inside the urban layout will be taken into account and implemented. With proper but minor modifications of the Ray Tracer and the GTD solver and with the consequent update of the MMI, the model itself will be then able to estimate channel parameters also for in-building and cellular radio communication networks. In addition to the afore mentioned improvements, the LMS prediction tool will also undergo fairly extensive and comprehensive validation campaigns in the ESA Compact Antenna Test Range, on a scaled model of urban environment, and using actual experimental data.

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