PLANNING TOOL FOR LMDS COVERAGE USING 3D GEOGRAPHIC INFORMATION SYSTEM DATA

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Abstract: Local Multipoint Distribution Services (LMDS) Network operating in 40.5 – 43.5 GHz band in Europe requires relevant planning tool for its deployment. An accurate knowledge of the propagation environment (buildings, trees…) is necessary especially in urban areas. This paper presents software based on Ray Tracing method using 3D Geographic Information System (GIS) database. Several series of simulations were done and the effects on propagation issues of some parameters were interpreted. Measurements were also achieved and were compared with simulation curves. Finally, cosecant-squared and switch beam antennas are briefly presented as solutions to avoid shadowed zones and to improve coverage area.

1 INTRODUCTION

Some years ago, Local Multipoint Distribution Services (LMDS) is revealed as a real asset to provide broadband and high capacity access services to end users. Its deployment needs to develop a relevant planning tool as it exists for others wireless systems such as GSM. Furthermore, the assigned frequency band can be different from a country to another. To facilitate the design of LMDS network, we elaborate a computer program based on Ray Tracing method. This program uses 3D Geographic Information System (GIS) data.

This paper presents the principles and the algorithm of the software. The simulation results and the comparison with measurements are also showed. Finally, some solutions to enhance and to improve the coverage area are presented. Cosecant-squared antenna and switch beam antenna are some of them.

2 A SIMULATION SOFTWARE PACKAGE

Nowadays the fixed wireless systems such as LMDS are not to be any more presented. Nevertheless some advantages are useful to be reminded. These advantages include the ability to connect with users in remote areas without laying new cables and the capacity for broad bandwidth that is not impeded by fibber or cable capacities. Furthermore, the fixed wireless networks are easy and fast to be deployed with incremental infrastructure investment.

Even though, LMDS network is one of the simplest networks in installation and operation, we still need to simulate its design to reduce the installation time and to increase the coverage area by using the minimum base stations that will reduce the installation costs and will increase the network efficiency.

2.1 3D-GIS data with Ray Tracing method

Geographic information system databases enable telecommunication professionals to integrate maps and information to make better decisions. They are composed by different layers which give geographic information (where things are) with descriptive information (what things are) (What is GIS). LMDS operates at high frequencies (40.5 – 43.5 GHz in many European countries) for which any physical obstructions effectively block the signal. GIS data requirements are therefore based on line-of-sight parameters.

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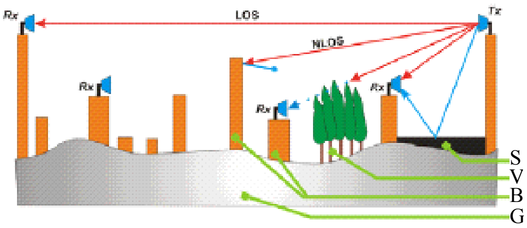
a. Modelling of a 3D environment

b. Main GIS layers used in LMDS design



S = Street B = Buildings

V = Vegetation G = Ground

Figure 1: Example of 3D GIS data visualization with some main layers

To meet these requirements, a virtual metropolis must be constructed for each city depicting all buildings and vegetation with a resolution and an accuracy less than 1 meter. In our case, we use only some GIS layers that can affect the LMDS link; these layers are depicted in the *figure 1-b*.

The building layer is the most important with two main effects. The direct effect appears when there are obstacles between the transmitter and the receiver. The indirect effect is the reflected signal caused by the construction materials of buildings (such as: glass, wood, stone, metals...). The building models must have an incredible level of detail – elevator shafts, air conditioning ducts, and peaked roofs are possible obstacles in the design of LMDS network.

The second important layer is the vegetation layer that represents the trees areas and forests. This layer can reduce the quality of service or even disconnect the LMDS service. Also, we have to notice that the effect of this layer is seasonal and it can be changed according to the four seasons of the year unlike the buildings layer which remains unchanged all over the year.

Using 3D GIS data can dramatically improve the reliability and efficiency of a network design. Our software package makes able to know all effects of the buildings materials, weather conditions and terrain textures on the LMDS network, and how many users will be able to use this network and what quality of service they will expect.

The computer program is based on Ray Tracing method (Jensen et al., 1990) stems from Geometrical Optics (GO) and Uniform Theory of Diffraction (UTD). It provides several advantages over other prediction methods (Rappaport, 1997)

- Precise Signal power level prediction
- Incorporation of 3D pattern of antennas
- Angle of arrival information
- Multipath time delay information

The program traces rays in a digital cityscape. The total power level is obtained by combining incident power with reflected power from the sides of buildings and rooftops across the simulation zone.

2.2 The Simulation Algorithm

The first step is to choose the coverage area and on this area the optimal location of the base station (BTS). Then, the Point-to-Region visibility is tested between the BTS and the subscribers' out door unit (ODU) located on households. Two cases are possible:

- Line-Of-Sight (LOS) areas are corresponding to 60 % of the potential single cell coverage area. The reflection paths are found using method of images which consists to place iteratively virtual transmitters behind each surface in computer 3D database. Each path contains the same signal with a different time delay. The total received power is calculated as follows:

$$P_r^t = \frac{1}{2}\frac{{E_r^t}^2}{\eta_0} - A_p^t \qquad (1)$$

$$E_r^t = E_r^i + \sum_{j=1}^{N} E_r^{rj} \qquad (2)$$

Where:
P_r^t = Total received power
E_r^t = Total received field
A_p^t = Total rain attenuation
E_r^i = Incident received field
E_r^{rj} = Reflected received field
N = number of reflected rays
η_0 = Wave impedance

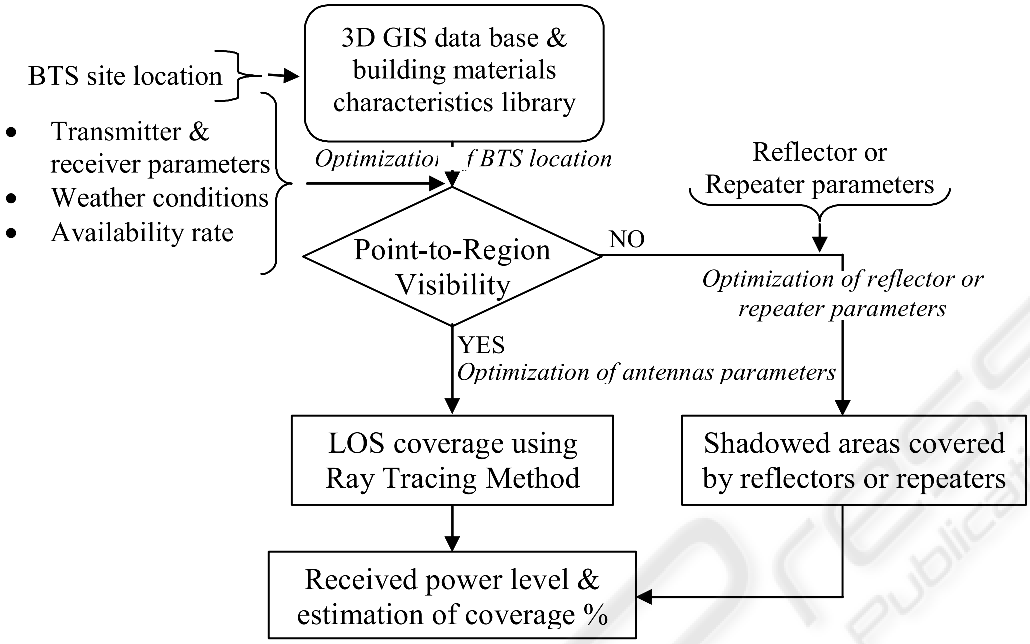


Figure 2: Scheme of LMDS planning tool

The rain attenuation (dB) over a path is given by relation (3). (ITU-RP 530-7)

$$A_p = kT^{\alpha} \bullet d_{eff} \bullet 0.12 p^{-(0546+0.043\log_{10}(p))} \qquad (3)$$

Where:
T is the rain intensity (mm/h), d_{eff} is the distance (km), p is the percentage of connection availability. The values of k and α are frequency and polarization dependent factors given in ITU-R Recommendations. (ITU-RP 838)

- No Line-Of-Sight (NLOS) or shadowed areas. The use of reflectors or repeaters will dramatically reduce these areas and increase the single cell coverage percentage to more than 90%. The following formula (Ruck, 1970) is used to calculate the received power level which depends on the passive reflector cross section.

$$P_r = P_e G_e G_r \left(\frac{\lambda}{4\pi R_1 R_2} \right)^2 \left(\frac{\Sigma}{4\pi} \right) - A_p \qquad (4)$$

Where:
Σ = Reflector cross section, its calculation depends on the geometrical shape of the reflector and the working frequency.
Pe, Pr = Transmitted and the received powers
Ge, Gr = Transmitted and the received Gains
R_1 = Distance transmitter - reflector
R_2 = Distance reflector - receiver
λ = wavelength

The chart (Figure 2) describes the main steps of our coverage prediction model. It’s important to notice that this planning tool can be used for any other system operating at frequencies above 20 GHz.

The total power level can be depicted as power curves or power maps. Somme simulation results with measurements comparison are presented in the following paragraph.

3 SIMULATION RESULTS AND MEASUREMENTS

The results obtained using our planning tool allow to interpret the effects of some parameters on LMDS network design especially on the coverage prediction. The figures (3-a, 3-b) show that the power level is deeply connected in one hand to the difference of height between the BTS and an ODU and in the other hand to the weather conditions.

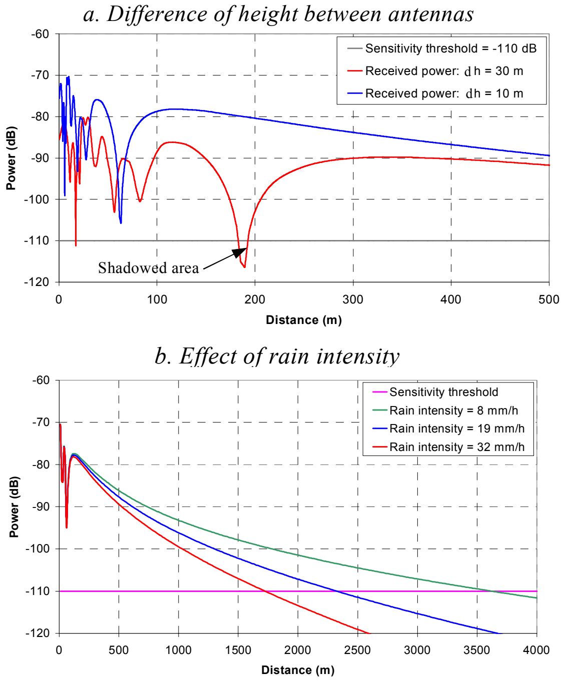


Figure 3: Effects of some parameters on LMDS link budget.

The shadowed zone indicated on the *figure 3-a* is only due to the gap between the main lobe and the side lobes when a directional transmitting antenna in elevation plane is used. The maximum coverage range decreases when the intensity of rain increases, as it is showed on the *figure3-b* with 99.99 % of the availability rate. Some time, the improvement of the coverage range is possible by a little reduction of this rate.

On different sites located in Limoges-France, several series of measurements were achieved using a Panoramic Field Measuring Device (MCP3000). The description of measurement conditions and the comparison of curves are depicted on the following figures 4-5. The comparison of power levels shows a good agreement between simulations and measurements. It is confirmed by the standard deviation (SD) and the average error percentage of the two cases presented below.

$$Error\_\% = \frac{SD \times 100}{Average\_of\_measurements} \qquad (5)$$

With SD = STDEVPA (MS-Excel function)

Error % of measurements: Case n°1 = 8.8%
Error % of measurements: Case n°2 = 3.1%

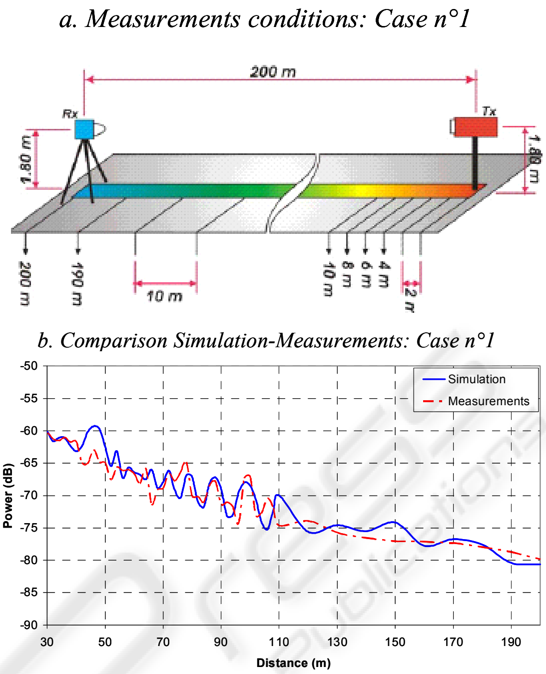


Figure 4: Measurements achievement: Case n°1

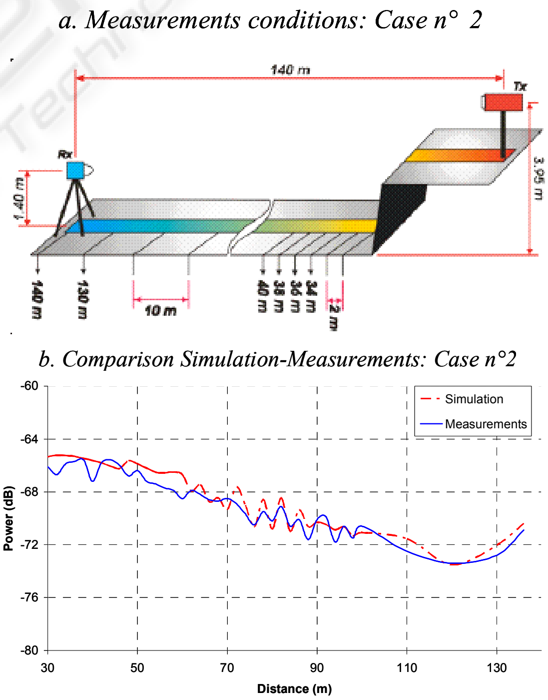


Figure 5: Measurements achievement: Case n°2

We successfully carried out studies of coverage prediction around ESTER site located in Limoges.

The figure 6 is an example of the power level map with its corresponding coverage area.

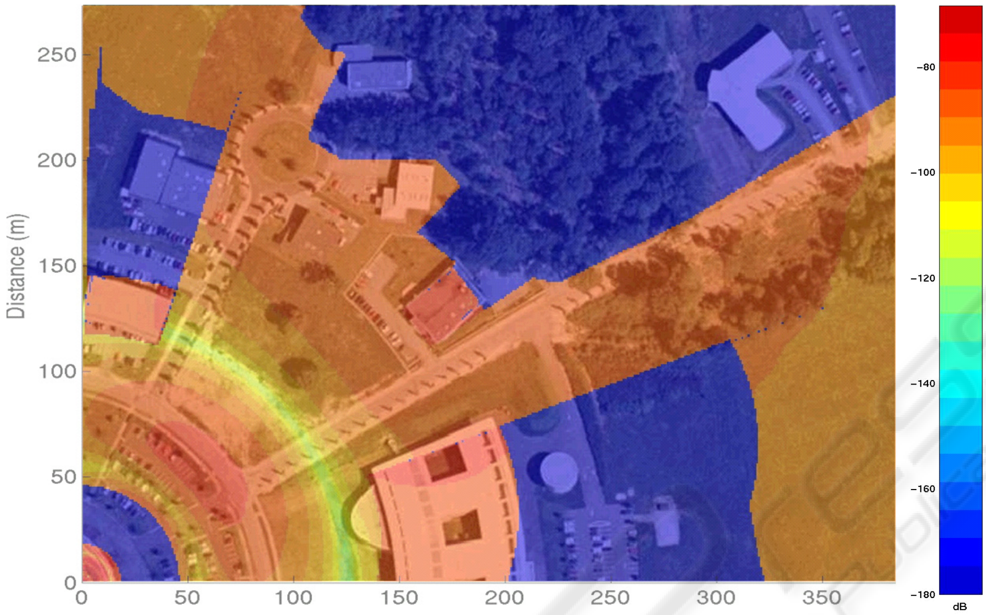


Figure 6: Example of coverage with power level map around ESTER site

4 TWO WAYS TO IMPROVE THE COVERAGE AREA

A solution to overcome the shadowed areas *(see figure 3-a)* is to design a new antenna with cosecant-squared pattern in elevation plane. (Freytag and Jecko, 2002) The cosecant-squared diagram is given by:

$$G(\theta) = \frac{Co\sec^2(\theta)}{Co\sec^2(\theta_0)} \qquad (6)$$

The principle *(figure 7-a)* is to compensate the propagation effect especially in the shadowed areas near the transmitting antenna of the BTS. At 40 GHz, the coverage area is up to 2 till 3.5 Km from the base station depending on weather conditions *(see figure 3-b)*. To increase this range, a switch beam antenna is designed using Butler matrix 4*4 and its working principle is illustrated on the *figure 7-b* (Dall'omo, 2003)**.** The pointing direction of each beam is given by:

$$\varphi_m = \frac{2\pi d}{\lambda} \mathrm{Sin}(\theta_m) \qquad (7)$$

Where:
φ_m = phase gradient between 2 consecutive patches
θ_m = Angle between the beam m and the normal direction of the array
d = Distance between 2 patches
λ = Wavelength

The effects on propagation issues of cosecant-squared and switch beam antenna are respectively depicted on *figure 7-c* and *figure 7-d.* The shadowed zones disappear with cosecant-squared antenna and the coverage area is gone from 50% to 90% by using switch beam antenna.

5 CONCLUSION

A computer program using Ray Tracing method for coverage prediction has been implemented based on 3D GIS databases. This planning tool is applied to LMDS by making several series of simulation in order to have better understanding of propagation phenomena in frequencies ranges around 40 GHz. The comparison between simulations and measurements was also presented. Finally, the design of new antennas was carried out to improve the LMDS coverage area.

Planned on-going research will be focused on repeaters and will be investigated precisely in the near future.

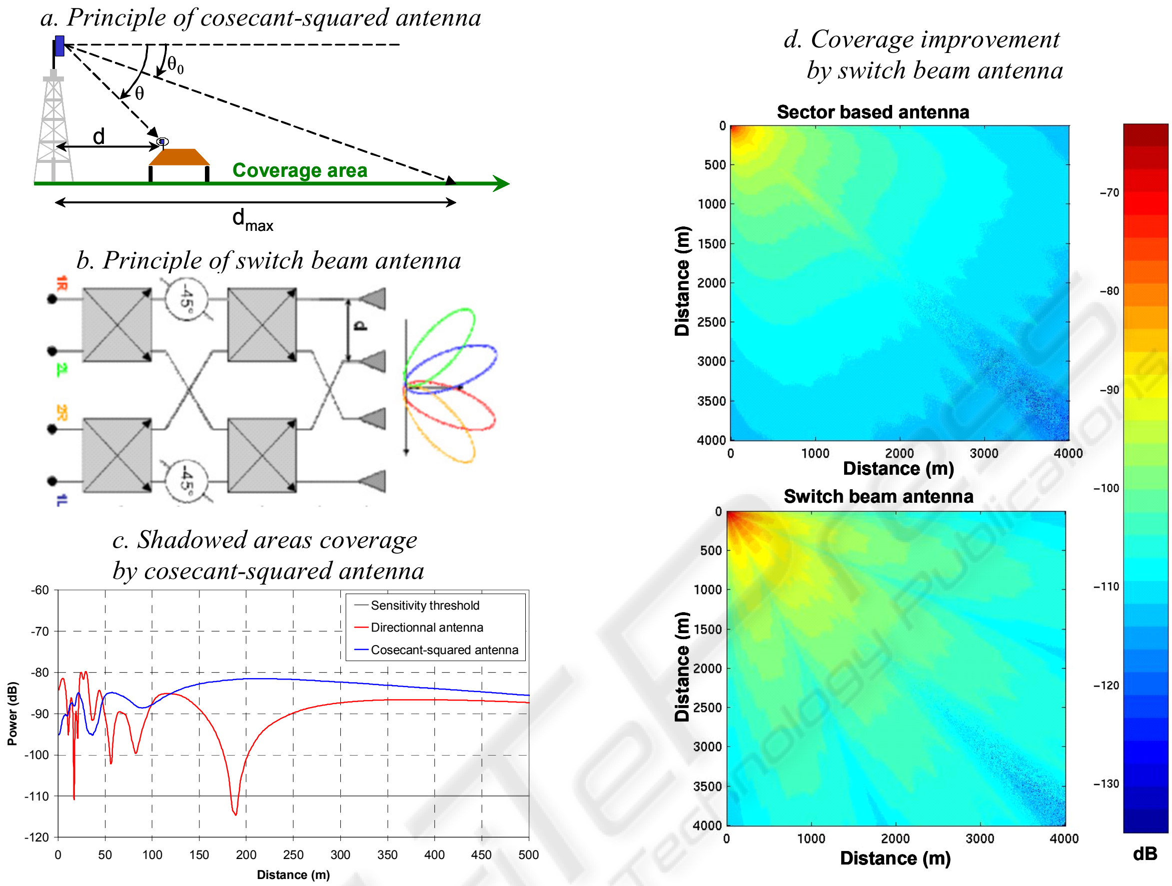


Figure 7: Principle and effect of cosecant-squared & switch beam antennas

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