# A GIS-based Environment for Telecommunications Engineering

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## ABSTRACT

This work describes a large GIS-based environment for the support of planning and design activities in Telecommunications Engineering. This environment supports various activities such as the acquisition of geographic and engineering data, the design of outside plants for telecommunications companies, and the design of wireless transmission systems. To support such activities, the geographic information system must be customized. This paper focuses on tools for the customization of the geographic information system, on the design of wireless transmission systems and on the lessons learned during the development of the whole environment. Among these lessons, we distinguish: (a) workstations are not always the most appropriate platform, (b) the GIS environment might require the implementation of special purpose software modules if acceptable performance is to be obtained, (c) a requirements analysis phase must be concluded in the very beginning if users are to be kept satisfied with the system, and (d) application of methodology to the software engineering process is an absolute must.

**Keywords**: geographic information systems, telecommunications engineering, computer graphics applications, software engineering, spatial data bases.

## 1   Introduction

Telemig, the telecommunications company for the state of Minas Gerais, in Brazil [Telemig, 1997], is responsible for the operation and engineering of a large network of telecommunications systems. Such communication network includes wired networks and long-distance wireless links. The geographic area of operation covers a territory of roughly 500000 km2 in which approximately 15 million inhabitants live.

To support planning and design activities in its large telecommunications network, Telemig adopts a GIS-based engineering environment which was developed in partnership with the Computer Science Department of the Federal University of Minas Gerais (CS/UFMG). The

development of this environment began in 1993, and is expected to continue at least until the end of 1998. The effort has required so far an outlay of a few million dollars and has involved telecommunication engineers and a number of graduate students in Computer Science. These students have worked under the supervision of faculty members of the CS/UFMG department.

In a previous paper [Paula Filho et alii, 1996], a preliminary description of the whole GIS-based telecommunications designing environment was presented. In this paper, we focus the discussion on the computer-aided design of wireless telecommunications systems. We aim at describing the design process, the tools developed for assisting with that process, and the main difficulties we encountered.

The paper is organized as follows. First, we provide historical notes to situate the reader. Second, we discuss the computer-aided design of wireless telecommunication systems with emphasis on two particular systems: (a) networks of radio-links and (b) mobile telephone systems. Third, we discuss the lessons we have learned in the process. At the end, we provide some final remarks.

# 2 Historical Notes

## 2.1 GIS Environment

The first steps taken by Telemig towards computer-based management telecommunications engineering happened near the end of the 80's, using tools based on CAD environments. The available CAD environments, however, were unable to perform the required association between graphical and non-graphical data, as well as to execute the necessary spatial data management functions. To overcome such defficiency, Telemig decided to adopt an environment based on a geographic information system (GIS) for support of its telecommunications engineering activities.

In 1991, Telebrás, the Brazilian company which oversees operation of all subsidiary state phone companies in the country (including

Telemig), felt the need to standardize the GIS environment to be used by its subsidiaries. Through a benchmark, Telebrás opted for GIS-Vision[1] as that standard. In the end of 1992, GIS-Vision was installed at Telemig running on Sun Sparcstation platforms.

## 2.2 Digital Relief Modeling

In the design of wireless transmission systems, the basic activity is the calculation of radio-links performance and interference. The input data for these calculations are composed of engineering data and geographic relief data, which, in this case, should cover the relief of the whole area served by the telecommunications company. However, the geographic relief data had to be first digitized.

The choice of the relief digitization process was not easy, due to several limitations including hardware, software, availability of qualified staff, and legal issues. For instance, extraction of the relief from satellite imagery was discarded as an option, given its high cost at the time. In the solution adopted, the relief data base was populated through the digitization of the cartographic maps of the State of Minas Gerais. This straightforward approach proved to be a feasible, low-cost solution, yielding adequate data quality. The construction of the relief data base was finished in the beginning of 1993. It contains 418 charts, covering the whole State of Minas Gerais, as well as neighboring areas. It is a continuous data base, organized in five layers: contours and summits, water basins, road network, urban spots and textual mapping information.

## 2.3 Tools for Computer-Aided Design: Assisting the Engineering Process

The development of adequate application software is fundamental to the deployment of a GIS environment for telecommunications engineering. Often, it is quite difficult for the end users to learn to use the GIS native command languages in a correct and productive way [Egenhofer and Frank, 1990]. Moreover, many de-

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[1] Now a product of MCI System House Ltd.

sign engineering tasks require complex algorithms. In many cases, it is not possible to implement these algorithms efficiently, using a data base query language, because they are computation-intensive. Further, it is often necessary to reuse legacy code from existing stand-alone applications.

To overcome these difficulties at Telemig, a suite of application tools for supporting common telecommunications engineering tasks was built. These tools are integrated in the GIS environment, as shown in Figure 1, so that the work of the engineers revolves around a single spatial data base. The applications are organized in two main groups: outside plant systems (wire-based) and wireless transmission systems.
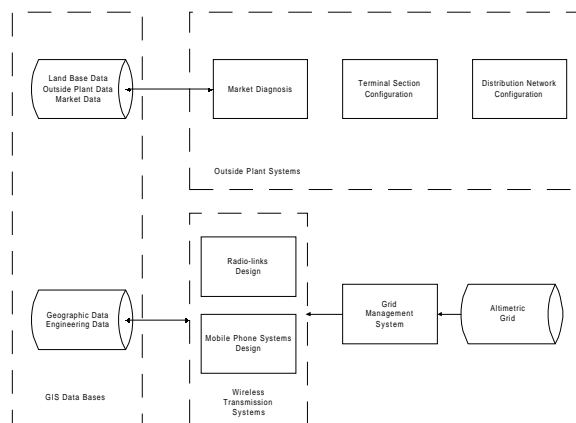


**Figure 1 -- Engineering process sub-systems**

Applications concerned with wireless transmission systems involve mainly designing tasks and are the focus of the remaining of this paper. Thus, from this point on our discussion concentrates on tools for computer-aided design of wireless transmission systems.

## 3 Computer-Aided Design of Wireless Transmission Systems

In this section we discuss some of the tools we developed for assisting the design of wireless transmission systems. We focus on two particular types of wireless systems: (a) networks of radio-links and (b) mobile telephone networks. Both systems depend on accurate altimetric data to perform properly. However, extracting such data from the GIS environment on the fly proved to be excessively expensive. As a compromise, an altimetric grid was pre-computed. The management of such grid is discussed in the immediately below. Following, we discuss the support for networks of radio-relays and mobile telephone systems.

### 3.1 Altimetric Grid Management

Part of the geographic information needed in the design of wireless transmission systems is extracted on demand, directly from the GIS data base. This includes data such as terrain types, water basins and urban spots, which are used for calculations or for reference. For altitude data, however, a performance problem had to be solved.

The engineering algorithms employed in the design of wireless systems assume that altimetric data are organized as a regular square grid. The main GIS data base, however, contains altimetric data organized as a collection of contour lines and summit points which are suited for the presentation of regular geographic charts. Thus, the altimetric data has to be converted from the contour-summit representation to the regular grid. Unfortunately, such conversion proved to be prohibitively time consuming, making on-line generation of the square grid impossible, even for restricted areas of interest.

To overcome this difficulty, a special-purpose **grid data base** was pre-computed. In this grid, the altitude information is kept in a rectangular array, indexed via the $x$ and $y$ coordinates. The points in this array have a regular spacing of 2 seconds of arc. This array was generated by the GIS system itself, using its built-in interpolation procedure, in an off-line process. It was then exported by the GIS system and stored in special-purpose files. **SGG** (Grid Management System) is a library that manages these files and supplies requested rectangular portions of the grid, given the rectangle corners, expressed in either spherical or UTM coordinate systems.

## 3.2 Computer-Aided Design of Radio-Links: the SPREAD System

At Telemig, the design of a new radio-link is a process composed of three phases as follows. First, the interference of the relief with the new radio-link is computed. Second, the performance of the new radio-link is evaluated. Third, the interference of radio-links in the plant with the new radio-link is quantified. For assisting the telecommunications engineer with each of these phases, three computer-aiding tools were designed and implemented. Recently, these three tools have been integrated in a single designing tool named SPREAD which stands for *System for the Planning of Radio-links Analogical and Digital*. The portion of the SPREAD system which concerns analogical design is basically finalized. The portion concerning the design of digital radio-links is under development with the inclusion of two additional modules: one for computing the performance of a digital radio-link and one for computing interference among digital radio-links.



**Figure 2 -- Screen for radio link design, including profile graph**

Figure 2 illustrates the main screen for the Spread system. The interference of the relief with the new radio-relay is computed by the module *Perfil*. The performance of the new radio-relay is computed by the module *CalcDes*. The interference among the new radio-relay and the radio-relays in the plant is computed by the module *Safra*. Notice that the modules CalcDes and Safra have distinct versions for the cases of radio-relays analogic and digital. The sixth module shown, called *Emaps*, is simply a radio-relays visualization tool and is not discussed in this paper.

The Perfil (Profile) system generates the altimetric profile between two given points which are being considered as candidates for the placement of a new radio-link. Also, it analyzes the transmission performance between these points, considering the altitudes of the points, the engineering data for candidate antennas, and the signal loss due to diffraction or absorption by terrain obstacles. For the engineering calculations, it employs proprietary algorithms, based on studies performed both by Telemig and outside consultants.

The CalcDes system computes the electromagnetic performance of the new radio-relay. Such performance depends on wheater data, characteristics of the antennas, power of the radio equipment, and data generated by the module Perfil which is passed through automatically. The calculations use proprietary algorithms implemented at Telemig.

The Safra system determines the interference of the new radio-relay with the radio-relays already present in the telecommunications network. The computation of the interference uses data generated by the module CalcDes which is passed through automatically. Usually, the interference occurs only among radio-relays in the same frequency band. The computations consider the electromagnetic characteristics of the radio-relays but also take into account the impact of the relief. For instance, the influence of a new radio-relay on a given radio-relay in the plant might be completely masked by a summit point in the relief. Additionally, it is given to the designer the flexibility of selecting which interfering radio-relays should be considered. This is useful in cases where additional evidence is known to the designer but not registered in the system (for instance, a given radio-relay might be inactive).
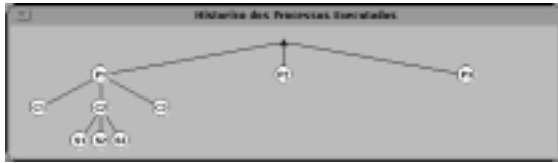
**Figure 3 – Planning session provided by the Spread system.**

To the whole design cycle of a new radio-realy, the Spread system assigns a planning session. In this session, the designer has the flexibility of computing several instantiations of the modules Perfil, CalcDes, and Safra. Figure 3 illustrates a planning session in which the module Perfil was executed three times. Each of them corresponds to a small variation of the initial setting (for instance, the positions of the antennas might be distinct). The designer liked the execution labeled P1 and decided to explore it. Three instantiations of the module CalcDes were then performed. For the instantiation C2 of the module CalcDes, three instantiations of the module Safra were done. The importance of the concept of a planning session is that the designer has greater flexibility in exploring the space of plausible solutions. Further, due to the automatic communication among the three modules, the interactiveness of the Spread system is much higher than before. The main effect is that the whole design cycle can be conclude in a much shorter time which allows the designer to concentrate on characteristics of the various solutions.

### 3.3 Computer-Aided Design of Mobile Telephony: the Arcomov/X System

The Arcomov/X system (meaning Area Coverage by Mobile Systems, X-Windows version) helps the telecommunications engineer in the design of Radio-Base Stations (RBSs) for mobile telephone systems. Besides the altimetric grid data base, described above, its algorithm uses a matrix of terrain types. Spatial reference data, such as street coordinates, help the engineers with the placement of the RBSs.

The area to be covered by the RBSs (interest area) is viewed as a matrix of squares, whose side length is specified as the desired spatial resolution. The application forecasts the average attenuation of the RBS signal, for every

square in the interest area. Signal propagation is strongly influenced by the natural terrain irregularities, by the kinds of terrain (water, vegetation, several kinds of urban settlement), and by environmental conditions; which are all factors considered by the program.
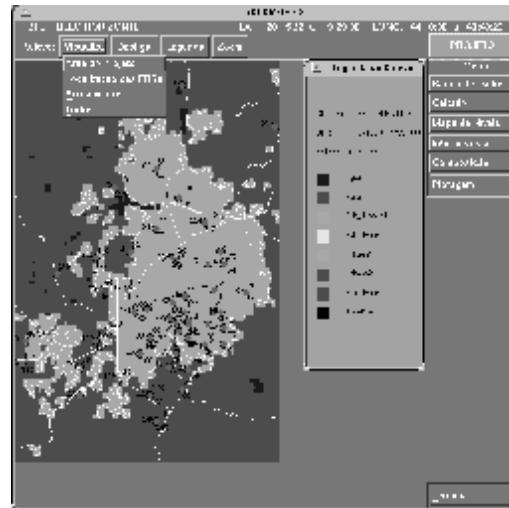


**Figure 3 -- Reference map for mobile telephone system design**
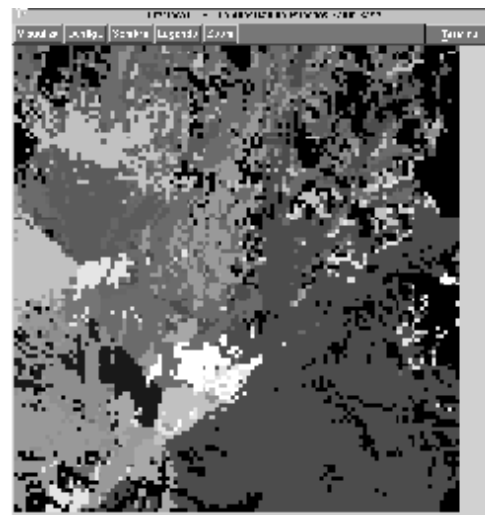


**Figure 4 -- Composition map for mobile telephone system design**

The waves generated by the RBS stations arrive at the receiving antenna following different paths, at different times. As the cellular telephone end-user displaces himself in the interest area, the received signals change, and the re-

ception quality can vary significantly. Shadow areas may be created by the topographical obstacles or by vegetation. The coverage model yields an average reception level per square of the interest area. There are different versions of Arcomov, corresponding to the different frequency bands that are used for cellular telephone systems. Figure 3 shows a reference map for Arcomov/X. Figure 4 shows an Arcomov/X composition map, where the color of each square encodes an index to the RBS whose signal is strongest in that square. Details of this system are discussed in [Menezes et alii, 1996].

## 4   Lessons Learned

### 4.1   On Data

The deployment of a large GIS-based environment requires a major investment in data entry and checking. Data quality is essential to system accuracy. Alternatives such as manual digitization, map scanning, aerial photography and satellite images have their pros and cons, which must be carefully evaluated. In some cases, lower-technology solutions may be more adequate than highly automated procedures.

The behavior of the data base management portion of GIS-Vision has not been entirely satisfactory. Changes to graphic entities may cause side effects on other entities or attributes. Updates of geographical data are slow, since they require splitting data among the tables of the relational model. Also, integrity issues are not completely solved by the system: exceptions such as hardware failures or power outages have sometimes corrupted geometrical data. On the other hand, the problems found so far did not justify searching for alternative systems.

### 4.2   On Platforms

GIS applications such as the ones described here require workstations with at least middle-range performance, such as SparcStations 20. To attend multiple users, they must be connected in a well-dimensioned network, and the appropriate number of licenses must be bought,

for each tool. The administration of such a network is a challenge in itself, and requires frequent support by specialized staff. Since the data bases are large, critical performance problems have to be solved at the system level, rather than in the software design. Sometimes, significant performance increases are achieved with system tuning, without software changes.

On the other hand, many activities are better handled by microcomputers. These include data entry and checking, and support activities such as documentation and engineering process workflow. Microcomputers and their software are much less expensive than workstations, and the pervasive microcomputer culture allows a less steep learning curve.

One problem that has to be solved, in such heterogeneous environments, is the transport of data between the different subsystems. Future applications in this environment are expected to profit from the client-server orientation of GIS-Vision 4.0. In the near future, they are also expected to benefit from Internet standards, which are inherently portable. As a first step, most of the user documentation was ported to HTML, and it is therefore accessible on-line, via Internet browsers.

### 4.3   On Performance

Performance considerations required the deployment of a special-purpose grid data base, as described earlier. Problems in this area were also found in the development of the graphic user interfaces.

In the case of the applications related to the outside plant, and also of the module Perfil, the necessary graphic output is mostly polygons and text. In this case, the graphics output facilities provided by GIS-Vision proved to be satisfactory. However, Arcomov/X presented harder problems in relation to graphic output. Drawing the result maps as collections of polygons prove to be unacceptably slow. It was found that part of this delay resulted from the underlying X-Windows protocol, which normally requires a handshake for every graphic primitive, due to its structure, designed to support remote graphic devices.

Because of this, a small special-purpose graphics library had to be written. This graphics library was built upon Xlib[2], using a function that allows to draw sets of polygons of the same color, in a single operation. Special caution had to be taken to remain compatible with the UIMX widget structure, in order to allow the integration of the map picture with other elements of the user interface. The graphics library is responsible for the conversion between world coordinates and screen-window-widget coordinates, allowing arbitrary zoom-in and zoom-out of the output maps.

### 4.4 On Users

It is generally difficult for the users to learn how to make the most of a GIS-based application. It was found that this happens even in a company where most users have a high degree of computer literacy. In a utility company, many users of a GIS system are often under strong pressure to deliver new systems and services to the public. Since they work in areas with very stable engineering processes, they are not generally aware of the difficulties in estimating software costs and schedules.

These problems are compounded if projects are started without a requirements' analysis phase. Novel requirements creep easily in, as work progresses, sometimes invalidating previous developments. The practice of this project has confirmed the importance of thorough requirements analyses. These are now a required part of the software life cycle, and the resulting documents must undergo peer reviews [Freedman and Weinberg, 1982].

User documentation, on-line help and training programs must be planned beforehand, as an integral part of each application project. Maintenance activities must also be planned as part of the software life cycle. An on-line maintenance application was developed, in the Lotus Notes environment, in order to help streamline the handling of maintenance requests, and to preserve historical maintenance data. A recent version of this application supports also configuration management procedures.

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[2] X-Windows low-level graphic library.

### 4.5 On Software Engineering

The development of application-specific software requires a deep understanding of the application area, user requirements and system aspects, besides good software engineering practices. Tight project control, supported by a project management tool, is necessary, in order to control costs and schedules.

Configuration management is a significant problem, since in a large organization the successful applications tend to evolve quickly, to satisfy changing user requirements. Also, they tend to spawn variants with minor configuration differences, either in application or system features. These changes must be kept consistent across the variants.

In our case, a quality program was deployed, in order to address these issues in software engineering. This quality program is intended to reach CMM maturity level 2 [Humphrey, 1990; Paulk et alii, 1995] in the short term, aiming a further evolution towards level 3.

## 5 Final Remarks

Developing a large GIS-based environment is a major undertaking, but it can be done in a context of partnership between a university and a corporation. Most of what has been described here is now used in routine production, and maintenance is supplied on a professional basis.

Given the high cost of telecommunication systems, this is an investment with quick return. A comprehensive survey of the benefits remains to be done. As an example, however, the RBSs saved by designs based on Arcomov/X have already paid several times for the whole project.

Besides the authors, many other persons worked in the design and development of the products mentioned here. These are described further in a number of technical reports (mostly in Portuguese). A list of these is available in [DCC, 1997].

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