Wireless technology applied to GIS

Jordi Casademont*, Elena Lopez-Aguilera, Josep Paradells, Alfonso Rojas, Anna Calveras, Francisco Barceló, Josep Cotrina

Telematics Engineering Department—Technical University of Catalonia (UPC), Modul C3—Campus Nord, C. Jordi Girona 1-3, Barcelona 08034, Spain

Received 6 January 2003; received in revised form 19 February 2004; accepted 29 February 2004

Abstract

At present, there is a growing interest in wireless applications, due to the fact that the technology begins to support them at reasonable costs. In this paper, we present the technology currently available for use in wireless environments, focusing on Geographic Information Systems. As an example, we present a newly developed platform for the commercialization of advanced geographical information services for use in portable devices. This platform uses available mobile telephone networks and wireless local area networks, but it is completely scalable to new technologies such as third generation mobile networks. Users access the service using a vector map player that runs on a Personal Digital Assistant with wireless access facilities and a Global Positioning System receiver. Before accessing the information, the player will request authorization from the server and download the requested map from it, if necessary. The platform also includes a system for improving Global Positioning System localization with the Real Time Differential Global Positioning System, which uses short GSM messages as the transmission medium.

Keywords: PDA; DGPS; E-commerce; IEEE 802.11; GDF

1. Introduction

During the coming years, a significant rise in the use of small size mobile computers is envisaged: smartphones, Personal Digital Assistants (PDAs), tablet PCs and notebooks. These devices are currently reaching a level of development that enables them to support the first practical graphical applications. At the same time, industry is coming up with new, additional equipment embedded into PCMCIA cards: flash memory, hard drives, Wireless Local Area Networks (WLAN), Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS) modems and Global Positioning System (GPS) receivers. Also, enormous advances have taken place in GPS technology in the past years: GPS accuracy has improved, the receivers have become smaller and cheaper and the GPS integration with mobile devices as PDAs has been made possible (Wadhwnani, 2003).1 The cartographic market through Geographic Information Systems (GIS) is one of the sectors, which are interested in such an infrastructure. Actually, there is a great offer of GIS and mapping software for PDAs with different operating systems (Palm OS, Windows CE, etc.) (Mobile and Field GIS, http://gislounge.com).2 Moreover, user applications become more functional when they are connected to

*Corresponding author. Tel.: +34-93-401-60-01; fax: +34-93-401-59-81.
E-mail address: jordi.casademont@entel.upc.es (J. Casademont).


Mobile and Field GIS, http://gislounge.com
packet switched networks in order to obtain data from centralized servers, and nowadays, these networks are broadening their coverage and bandwidth.

The cartographic market through GIS applications is one of the sectors most willing to invest money in these technologies, due to the increase in efficiency that these represent. The advantages of distributing GIS information from a central server instead of having it stored in memory devices, that users have usually bought several months ago, are basically two. The first one is that the user only downloads maps of the areas in which he is really interested in, and it is not necessary to buy the map of the whole country because there is always the possibility of getting any needed information in real time. The second and most important advantage is that downloaded maps can be permanently updated. Any map modification can be immediately distributed to users that consult the map just after. These benefits can be combined with other type of applications as those that collect field data and transfer it from different mobile sources to the central system (Ryan, 1998; Dix et al., 2000). While these applications are very useful to update databases, the former provide a way to make use of this information immediately. The market sector that can get more benefits from this technology is that related with location-based services, since they need absolutely updated data. Also, in different geographic areas there can exist different service providers that use the same user application and exploit a distributed map service.

Nevertheless, semantic heterogeneity of geographic data sharing can cause some problems, such as semantic non-interoperability between applications and repositories. This non-interoperability may affect the data quality of the information collected (Pundt, 2002).

This article presents and analyzes different network systems, devices and options available for developing such applications and introduces, as an example, a prototype developed at the Technical University of Catalonia (UPC). This platform implements a system for commercializing cartographic information through PDA, using the concept of renting maps with micro-payments and with facilities for correcting GPS positioning using Differential GPS (DGPS). Fig. 1 shows the basic architecture of this system.

2. Mobile devices

Mobile devices have two main and contrasting characteristics: portability and capacity (memory, processing speed, display size and autonomy). On one hand, users want them smaller and lighter, but on the other hand, graphical applications need wide displays and high processing capacity to process all the information. The different models available include (Fig. 2):

2.1. Mobile phone-based smartphones

This group is the commonest and comprises devices mainly designed as mobile phones with advanced Personal Information Management (PIM), productivity tools, network and other computing capabilities. This kind of device has limited memory capacity (between 2 and 16 Mbytes) and processing speed (processors between 20 and 104 MHz), as well as limited display size, up to 180 x 220 pixels, due to their phone-based form. They provide connectivity to Internet through Wide Area Networks (WAN), such as GSM/GPRS, CDMA or 3G cellular systems, and depending on the model, connectivity to peripheral devices through the Bluetooth protocol, USB, or infrared port, even integrated VGA digital cameras.

Fig. 1. GIS application through PDA with wireless facilities architecture.
2.2. PDA-based smartphones

This group includes smartphone devices mainly designed as PDAs with mobile communications features built in. These devices have larger displays, which are more suitable for viewing hypertext pages, in Wireless Markup Language (WML) or Extensible HyperText Markup Language (XHTML) formats. Furthermore, the creation of e-mails, Short Message Service (SMS) or Multimedia Message Service (MMS) messages and even larger documents have become easier through handwriting recognition, touch sensitive on-screen keyboards and, in many cases, third party add-on folding keyboards. Memory (from 16 to 64 Mbytes), processing capabilities (up to 206 MHz) and display size (240 x 320 pixels) are higher than those of mobile phone-based smartphones, and these devices offer a richer variety of network connectivity and expansion possibilities.

2.3. PDAs

PDAs were originally conceived as small devices with the basic functions of organizers, providing management of contact lists, calendars, diaries, calculators, etc. PDAs first appeared in the market in 1993, shipped by Amstrad, Apple and Sharp. Since 1996, when they were pioneered by Palm, the category has exploded with products from most of the major players of the sector: Compaq, Hewlett-Packard, Casio and Handspring. Technical features are similar to those of the PDA-based smartphones, but they have more memory (up to 112 Mbytes) and more processing capabilities (up to 400 MHz); multimedia capabilities and greater connectivity possibilities through WLAN and through the Bluetooth protocol; and more expansion slots. In the early stages, PDA operating systems were completely controlled by the device maker and closed to third party applications. In recent years, open systems have appeared and applications can be executed from different sources. There are, at present, three major PDA operating system platforms: Palm OS, Windows CE and EPOC OS.

2.4. Handheld PCs

Handheld PCs are like laptop PCs but much smaller. They usually run one of the Microsoft Windows CE versions (though other platforms exist, such as EPOC or Linux) and have processing, storage, expansion and wireless connectivity capabilities similar to those of PDAs. Their built-in keyboard feature facilitates the user’s data-input process and allows these devices to have larger displays, up to 640 x 240 pixels.

2.5. Tablet PCs

Tablet PCs have high-speed processors (up to 1.5 GHz), large internal disk drives (up to 40 GB), industry-standard interface ports, extended battery life, good display resolution (up to 1050 x 1400 pixels), handwriting recognition software, a large memory capacity (512 Mbytes), expansion capabilities and WLAN access. These devices generally run one of the standard Microsoft Windows variants, though other possibilities, such as Linux platforms, are available.

2.6. Notebooks

These can be divided into several categories: full-size, thin-and-light, mini and subnotebooks. Most of them are almost indistinguishable from one another within the categories. Some notebooks are built to withstand more damage than a standard consumer product. For example, some of them are ruggedized or even water resistant. Others include special features needed for specific jobs. The notebooks’ processing capabilities, as well as their size and weight, are the highest among the mobile devices presented in this section. There are models available with processing speeds of 2.4 GHz and storage capacities of 1 GB of RAM and 60 GB hard disks.

3. Wireless access networks

GIS systems can be used in a wide variety of applications of different fields (GIS Development, http://www.gisdevelopment.net/application): agriculture, geology, military, urban planning, etc. Applications that run on portable devices will need access to GIS information and we can envisage two ways of doing this.

3 GIS Development. http://www.gisdevelopment.net/application
The first one is to store the information in local memory, which has basic limitations because most portable devices have a limited memory capacity. Typical memory devices and capacities as of 2004 are MultiMedia Cards (MMC, capacity up to 1 Gbyte), Secure Digital Cards (SD, capacity up to 1 Gbyte), Memory Sticks (capacity up to 1 Gbyte), Compact Flash Cards (CF, capacity up to 4 Gbytes), SmartMedia Cards (capacity up to 128 Mbytes) and Hard Disk Drives embedded into PC or PCMCIA Cards (capacity up to 5 Gbytes). A map of a big city, as for example Barcelona (SPAIN), using Geographic Data Files (GDF) format, including information about street and square names, number of lanes of a route, one-way streets, public transports and monument names, has an approximate size of 40 Mbytes. With an external memory card capacity of 1 Gbyte, it is possible to store about 25 maps of this size. Moreover, a map covering the same area, but including only street and square names, has an approximate size of 10 Mbytes. Thereby, with the actual external memory capacities it is possible to store a high number of maps.

The second is to download cartographic information on demand. This operation must be carried out in the most transparent way for the user; for instance, when the GIS platform detects that the required map is not stored locally, it tries to download it from the server after requesting confirmation from the user.

In order to connect mobile devices to a fixed network in which the cartographic server will be set, we can use two kinds of wireless networks: WLAN and Wireless Wide Area Networks (WWAN). WLANs, as the name expresses, have a limited coverage, from few meters to some kilometers. Their main characteristics are that they provide high transmission rates and usually are privately owned. WLAN appeared first as office data networks, then gave coverage to university campus, hospitals or other private and public institutions, and nowadays, there are some operators that give this service in other private and public institutions, and nowadays, there are some operators that give this service in strategic areas as downtown districts. On the other hand, WWANs are public networks, with national coverage and provide lower transmission rates, up to 2 Mbps for the third generation cellular networks as CDMA2000, UMTS or FOMA. In these networks, the transmission bandwidth is expensive and the network design is focused on the link utilization efficiency.

For the WLAN group, there are three basic possibilities:

- **IEEE 802.11** was introduced on 26 June 1997 as the first internationally recognized standard for WLANs. IEEE 802.11 specifies the physical and Media Access Control (MAC) layers. IEEE 802.11b has a rate of up to 11 Mbps, IEEE 802.11a and IEEE 802.11g a rate of up to 54 Mbps, and the forthcoming IEEE 802.11n a rate of 108 Mbps. The MAC protocol is a scheme called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Security features are also included in the standard, such as the Wired Equivalent Privacy algorithm (WEP) that prevents other stations from understanding data packets. Its main format is included into a PCMCIA, which makes it suitable for most mobile devices (Crow et al., 1997; Keiser, 2002; Prasad, 2002; Schiller, 2000).

- **Bluetooth** is a proposed radio frequency specification for short-range, point-to-multipoint voice and data transfer, which is intended to replace the cables connecting portable and/or fixed electronic devices. It is envisaged that it will allow for the replacement of the many propriety cables that connect one device to another with one universal radio link. Most mobile devices are equipped with this interface. It has a normal range of 10 m, which can be extended up to 100 m, reaching rates of 721 Kbps in asymmetric data transmission and up to 432.6 Kbps in symmetric transmissions (Bisdikian, 2001).

- **Infrared (IrDA)** stands for Infrared Data Association, which is an international organization that creates and promotes interoperable, low-cost infrared data interconnection standards that support point-to-point and ad hoc data transmission models that can be used in a broad range of appliances, computing and communications devices. Most mobile devices are equipped with this interface, whose range is 1 m and whose rates go from 9.6 Kbps up to 4 Mbps (Megowan et al., 1998).

WWANS, or commonly named mobile telephone networks, are cellular networks that firstly appeared as voice networks and, later, due to the social requirement of data transmission have been adapted to transmit any kind of data. This networks have evolved and according to their capabilities are classified in three generations: 1, 2 and 3G (De Vriendt et al., 2002; Mohr and Konhäuser, 2000).

- **IS-136 (Interim Standard 136)** also called D-AMPS (Digital Advanced Mobile Phone System) or simply TDMA (Time Division Multiple Access). This 2G system, that has been deployed as IS-54 and updated in 1994, provides circuit access mode and is mainly used in America. It offers data transmission rate of 9.6 Kbps. Because of its limited data rate, it is not appropriate for video streaming and for high volume data downloads (Sollenberger et al., 1999).

- **IS-95 (Interim Standard 95)**: This 2G system was the first Code Division Multiple Access (CDMA) system to gain widespread use and is found widely in America. Its brand name is cdmaOne and the initial

---

specification for the system was IS95A, but its performance was later upgraded under IS-95B. It is this later specification that is synonymous with cdmaOne. Apart from voice, the system is also able to carry data at rates up to 14.4 kbps for IS-95A and 115 kbps for IS-95B (Knisely et al., 1998).

- **PDC (Personal Digital Cellular)** also called JDC (Japanese Digital Cellular) is a 2G system, developed in Japan and based on D-AMPS. In order to improve its maximum data rate of 9.6 kbps, a new parallel packet switched network, named PDC-P (PDC mobile Packet data communication system) was developed. With this newer network data transmission can achieve rates up to 28.8 kbps. The main reason for PDC-P success is i-mode, a mobile Internet system developed by the largest Japanese operator NTT DoCoMo, which provides access to thousands of web sites specially adapted to fit onto the phone’s small screen (Maebara et al., 1998).

- **GSM (Global System for Mobile Communications)** is the second generation system developed by European Telecommunications Standards Institute (ETSI). It has another version working at higher frequencies named DCS 1800/1900 (Digital Cellular System). Both systems offer data rates up to 14.4 kbps in circuit access mode and charging is carried out in relation to the connection time (Prasad, 1999).

- **HSCSD (High Speed Circuit Switched Data)** constitutes an improvement of the data circuits provided by GSM and it is suitable for services requiring a permanent channel. With this solution, a transmission data rate of 57.6 kbps can be reached, although more realistic implementations offer a maximum rate of 28.8 and 43.2 kbps. The service is not fully available, and only several operators support it in Europe, Asia Pacific, South Africa and Middle East (Prasad, 1999).

- **GPRS (General Packet Radio Service)** has been designed to solve GSM and HSCSD limitations, and offers a data packet switched access suitable for bursty transfers. Theoretically, data rates of up to 170 kbps can be reached, although a more realistic limit is 115 kbps. In addition, GPRS is the first system offering the “always on” concept, which allows data to be sent and received without user interaction. Today the service is available in North America, Europe and Asia Pacific (Prasad, 1999).

- **EDGE (Enhanced Data rates for GSM Evolution)**: EDGE introduces a new modulation schema that is able to offer a threefold increase in data rates of GSM, HSCSD and GPRS. The usage of EDGE allows choosing between several coding schemes corresponding to different data rates according to the signal-to-interference ratio. Nevertheless, the area where the best coding schemes can be used is very restricted, thus limiting the availability of the improvement (Prasad, 1999).

- **IMT-2000 (International Mobile Telecommunications 2000)** is the third generation system standardized by the International Telecommunications Union (ITU) to be used worldwide. Two thousand implies three major features: user bit rates of up to 2000 Kbps (2 Mbps), frequency around 2000 MHz, and system introduction around year 2000. In order to have only one system for all continents, an open call for proposals was made. The response was very good and 17 proposals were presented. During recent years, these proposals have been more defined and most of them have been withdrawn. At beginning of 2004, two systems have already been developed: UMTS (Universal Mobile Telephony System) in Europe and Japan (where it takes the commercial name of FOMA: Freedom Of Mobile multimedia Access) and CDMA2000 in America and Korea (Knisely et al., 1998; De Vriendt et al., 2002).

4. GIS data formats

There are two basic map formats: raster and vector. In raster, the map is stored as a bitmap image and is sometimes compressed using Joint Photographic Experts Group (JPEG), Tagged Image File Format (TIFF), GeoTIFF, Graphical Interchange Format (GIF) or Portable Networks Graphic (PNG) algorithms. Vector formats are more complex because they store map information as a group of coordinates that are linked by points, lines and polygonal areas when displayed. Moreover, they are able to store points of interest and other kinds of information like street names, number of lanes of a route, one-way streets, thus making the map navigable for the user. This kind of maps are more interesting, because the correspondent player is not forced to show the information altogether, as happens with raster maps. Information in vectorial maps are stored as layers of information, and they can be displayed independently, so it is possible to show only the map topology or include some additional features as street and square names, public transports or services, at any moment, attending user’s requirements (Bernhardsen, 1999). This format is especially interesting for location-based services because it is much more configurable than the former.

There are different vector map formats on the market, there are proprietary formats from companies that also provide players and user applications, as AutoCAD, MapInfo or ESRI, and other that are international standards as the European GDF (Geographic data BC, 1999; CEN TC 278 WC7, 1996) or the American Spatial Data Transfer Standard (STDS) (Spatial Data Transfer Standard (SDTS), Information Site).5

The GDF format is an open standard used mainly to describe and transfer road-related data. GDF is much more than a generic GIS standard, because it gives rules on how to capture data and how features, attributes and relations have been defined. In Europe, GDF is not only a theoretical standard; the major digital road data suppliers also push it; EGT, Bosch, ETAK and Tele Atlas. These companies have committed themselves to building their databases according to GDF specifications. GDF’s main drawback is the fact that it uses text format. This is an inefficient way of storing digital information because it occupies more disk space and takes longer to read. The most immediate solution is compressing GDF files with a standard compression algorithm, which would solve the memory issue but not the reading speed. On the other hand it is important to use this kind of formats in order to guarantee semantic interoperability.

Another approach is pushed by Open GIS Consortium (OGC) (http://www.opengeos.org). OGC is a non-profit international trade association that is working in the development of open and extensible software applications programming interfaces for GIS. The specifications adopted by OGC are public and available at no cost. Its aim is to provide geographic information and services available across any network, application and platform.

Actually, OGD has standardized the Geography Markup Language (GML) (Open GIS Consortium, 2003). GML is an Extensible Markup Language (XML) grammar written language for the modeling, transport and storage of geographic information including both the spatial and non-spatial properties of geographic features. The specification defines the XML schema syntax, mechanisms, and conventions that provide an open, vendor-neutral framework for the definition of geospatial application schemas and objects; allow profiles that support proper subsets of GML framework descriptive capabilities; support the description of geospatial application schemas for specialized domains and information communities; enable the creation and maintenance of linked geographic application schemas and data sets; support the storage and transport of application schemas and data sets and increase the ability of organizations to share geographic application schemas and the information they describe. XML-based languages are suitable for data transfer between distributed, heterogeneous applications and platforms. In this way, XML is appropriate to GIS development and is being used to enable the integration of information from distributed information sources (Cottrell, 2001; Zaslavsky, 2000).

5. Positioning systems: GPS and differential GPS

The GPS has proved its reliability and continuity since the mid-90s. In May 2000, the government of the United States discontinued the Selective Availability (SA) of the GPS system and, consequently, absolute positioning showed a substantial improvement. Currently, the accuracy obtained with a quality receiver (optimum conditions) is about 3 m although it is also possible to get errors of more than 7 m for long periods of time (> 10 min) (Cartographic Institute of Catalonia, 2000).

Today the need for precise position and navigation aids in many commercial sectors is becoming increasingly apparent and the precision of absolute GPS is not enough. One solution to increase precision is the use of (DGPS), which reaches precisions of 1 m.

The main sources of GPS error are the ionosphere, the troposphere, satellite clocks, satellite ephemerides, code measurement, receiver clocks and multipaths (Arpin, 2003; Wormley, 2003). The purpose of DGPS is to eliminate or reduce the first four of these. The main idea of DGPS is that two receivers observing the same satellites will produce the same measurement errors, if the receivers are close enough. By setting one reference receiver in a well-known position and measuring the GPS position, it is possible to calculate the error and its associated correction vector. This correction vector is then sent to user receivers who use it to correct their absolute GPS position.

The protocol used between reference and user GPS receivers is called RTCM SC-104 (RTCM recommended standards for Differential GNSS (Global Navigation Satellite Systems) service, 1998). This messaging standard provides 64 messages related to GPS and marine navigation.

Real-time DGPS requires an appropriate method of data transfer. Currently, governmental organizations or foundations that carry out geographic studies use the Radio Data System (RDS), which comes with the frequency modulated (FM) radio broadcasting programs on 87–108 MHz to distribute DGPS information. In order to improve transmission of RTCM SC-104 over RDS channels, a multiplex technique called RASANT (Radio Aided Satellite Navigation Technique) is used. RASANT decreases error probability by adding parity bits for error detection and correction, and it also makes the transmission faster by using compression methods.

---

8 Open GIS Consortium (OGC), http://www.opengeos.org

---

In order to be able to exploit DGPS, the user needs a RASANT receiver connected to the GPS receiver. The flow of information from the RASANT receiver to the GPS receiver is coded with RTCM SC-104 format.

6. Wireless GIS platform

Having analyzed the state-of-the-art of nowadays technology, we present an application whose aim is to use all the technical possibilities in order to implement a commercial platform. It combines services that include e-commerce of digital navigable cartography on mobile devices with GPS receivers, and a distribution system for DGPS information using SMS messages.

The platform works in a client–server model, where the server is an Hyper Text Transfer Protocol (HTTP) (Stallings, 2003) server (an Apache Server in the first prototype) with additional functionalities to authenticate and authorize clients, and control radio devices such as RASANT and GSM receivers. The client’s hardware platform is a PDA connected through a wired network or through a wireless interface such as IEEE 802.11b, GSM or GPRS. It also needs a GPS receiver. The services offered are:

(a) **Representation of vector maps in GDF format**, with points of interest in several formats (audio, video and images). The player also has extra facilities and can calculate distances on the maps, make zooms, draw grids on the map, etc.

(b) **Server-side map storage**. Server cartographic information is stored in a database using a vector format. The stored geographic area can be of any size and when a client makes a map request, the server consults the database and builds a new GDF map with the specified coordinates.

(c) **Access to the cartographic server**. The storage of maps in small devices is quite a critical issue because of the size of the files and the limited memory available on PDAs. The application considers two ways of storing maps. The first is local storage of maps in local RAM or in memory PC cards, which can be exchanged depending on user requirements. The second storage model is a centralized server accessed through the available communication networks using the HTTPS (Secure HTTP) protocol. When trying to fetch a file, the player always looks in the local memory first and, if the required information is not there, it downloads it from the cartographic server using a coordinates system to identify the required map. In order to save memory space and speed up transmissions, all downloaded maps are compressed using the ZIP60 algorithm.

(d) **Information protection**. The platform guarantees the intellectual property of cartographic information selling maps encrypted with a personal key. Each player has been programmed to work with a different key, and therefore, when users buy a map they can only visualize it with their own player. If users try to open their maps with players owned by other users, these will not be displayed. The operation of decrypting the map is carried out internally and no original map is stored in the temporal memory to prevent unauthorized copies. The encryption algorithm used is Data Encryption Standard (DES) (Federal Information Processing Standards Publication, 1999).

(e) **E-commerce of cartographic information**. Two ways of selling maps can be considered. The first one is selling the map permanently, although this may result expensive to the customer because the creation of detailed maps with specific information is costly and these costs have to be applied to the final price. Furthermore, map features may become obsolete and therefore they should be updated periodically. The second way is renting map fragments in a micropayment model (Costello, 2003; Michel, 2001).10,11 This model consists in offering a temporal, specific service to users for a small amount of money. The benefits are obtained from a high volume of transactions at very low price. Applying this model, users do not own the maps, the server rents the fragments that users are interested in, for a certain period of time. This model has more advantages than the former, because users only pay for what they are really interested in and do not need to buy whole maps.

(f) **Information and user validation**. When the player is required to open an encrypted map, it has to verify whether the user has the right to use it or not. To do so, the player contacts the server, if the user has permission to see the map, it is displayed. This process is totally transparent to the user. If the user does not have permission, the player shows a pop-up window requesting the user to rent the map for a certain amount of time. When the user confirms this request, the map is displayed and the server database is updated with the new user parameters. Therefore, user intervention is needed for updating map subscription. It is worth noting that, in order to carry out this operation, the client must access Internet where the server is connected.

(g) **Navigation facilities**. The player gets input from a GPS receiver and is able to position the user on the

---


map. To achieve this, it is necessary to convert the World Geodetic System 1984 (WGS84) datum coordinates provided by the GPS receiver into Universal Transverse Mercator (UTM) coordinates, used by GDF maps. Moreover, if the user moves and his or her position exceeds the dimensions of the displayed map, the player will try to load the new, correct map automatically. If the user has permission to view the map, the process will be totally automatic, if not the system will use the micropayment model again.

(h) Position correction using DGPS. The GIS e-commerce platform offers the possibility of correcting the GPS position obtained by receivers set in players. In a standard tool, DGPS information is obtained through a RASANT receiver, but this requires FM radio receivers with RDS facilities in the client device. As we are considering devices with GSM facilities, a good option is to use them to send DGPS information. Thus, the solution adopted is to use SMS to send correction requests and replies. When the player requires the improvement of the GPS position, it sends a GPS correction request to the server using an SMS message. After a few seconds, it receives another SMS message with the answer, then the GIS client builds a RTCM frame and sends it to the GPS receiver. The GPS receiver corrects its GPS position with the information it has just received and sends it back to the player, which then displays the information to the user.

Fig. 3 shows the appearance of the player application on a PDA. In Fig. 4, the global architecture of the system can be observed. Three well-differentiated parts can be distinguished: the client side in different platforms (PDA and Laptop), the server side with four servers (HTTP, database, authorization and positioning improvement), and the transport network. Although GSM/GPRS terminals appear as mobile telephones, a better solution would be to have PCMCIA cards connected to the device directly.

6.1. Client-software requirements

The main objective of the wireless GIS platform is to provide a tool that enables mobile users to use navigable cartography by staying in contact with the system server that provides the required information and user control.
Main options for client hardware are laptop PCs and PDAs. The advantage of laptops is their better performance and the drawback their larger size. In contrast, PDAs are much smaller but have the problem of hardware limitations.

The methods used to connect these devices to the network vary according to the wireless system coverage. The systems tested are IEEE 802.11b at 11 Mbps, circuit-switched GSM and packet-switched GPRS. In the first prototype, GSM Wavecom modems (Wavecom web site: http://www.wavecom.com) connected to the serial port were used to access the GSM network and to send SMS messages. The GPRS connection was tested using a GPRS mobile telephone.

The client platform also requires a GPS receiver that can be connected to the serial port or integrated into a PC card.

### 6.2. Server-software requirements

Server requirements are based on the following tasks:

(a) **Provision of GDF maps.** These are provided using an Apache Web Server (The Apache Software Foundation, http://www.apache.org) on a Linux platform. The code is programmed with PHP (PHP: Hypertext Preprocessor, http://www.php.net) and the communication is conducted using an HTTPS connection in order to increase system security. PHP code consults the database, which in the prototype is an Oracle Server, then builds the required map and sends it to the client.

(b) **User authentication.** When users access the system, they are validated using a login name and a password. User parameters are maintained in a MySQL (MySQL: The World’s Most Popular Open Source Database, http://www.mysql.com) database consulted directly by the Apache Server.

(c) **Map authorization control.** The server provides the client with a list of maps available to a specific user. This information is stored in a MySQL database and sent to the client using a TCP/IP connection.

(d) **GPS position improvement.** The server receives client requests that are replied to with information obtained by the RASANT receiver connected to the server serial port. Communication between clients and server is carried out via SMS messages. Therefore, the server needs a GSM PC card or modem in order to receive and send SMS messages and a RASANT receiver.

The combination of Linux operating system, Apache Server, MySQL database and PHP language represent an open source web platform that is able to develop high performance web applications. In this way, there are many popular web sites running on an Apache Server with its PHP module installed (LAMP: The Open Source Web Platform, http://www.onlamp.com).

### 6.3. Network requirements

This application uses Internet as backbone, and wireless access networks that introduce bandwidth restrictions. We can consider the following requirements:

(a) **When downloading maps from the server to the GIS client player:** GDF maps can vary greatly in size, with data volume ranging from 50 Kbytes to several Mbytes. In this case, GSM has very little bandwidth and it is therefore more convenient to use IEEE 802.11 or GPRS. Nevertheless, it is not advisable to send maps larger than 300 Kbytes. This operation also requires user authentication.

(b) **When requesting authorization:** the amount of information to be transferred is less than 1 Kbyte, so bandwidth is not critical and the use of GSM does not involve any problems.

(c) **When requesting improvement of position:** this operation only requires the sending of two packets, one for the request and one for the response, both of which are less than 200 bytes. In this case, the transport is implemented using SMS.

### 7. System performance

One of the most critical factors for the application’s success is the response time. In order to evaluate this parameter, several tests have been conducted. Table 1 presents the access times obtained for two client platforms in seconds.

The client devices are the iPAQ 3660 by Compaq and a Pentium III PC laptop at 500 MHz with 320 Mbytes of RAM. The downloaded encrypted map has a size of 172 Kbytes when uncompressed and of 53.9 Kbytes when compressed. However, the map is always sent compressed. We have to bear in mind that time is very dependent on the client device’s capacities.

The speed of the connections is 11 Mbps for the WLAN, 40 Kbps in the downlink and 25 Kbps in the uplink for GPRS, and 9.6 Kbps in both directions for GSM.

The different tasks shown in Table 1 are the following:

- **Establishment Time.** This is the time taken to establish the connection with the Internet Service Provider (ISP).

---

12 Wavecom web site: http://www.wavecom.com
In a WLAN environment, this occurs when the client device boots, and it lasts until it is shut down. In a GPRS environment, it occurs the first time the user wants to connect to the Internet, and with the “always on” option it is possible to remain connected without extra monetary charges, as GPRS is mainly charged according to the amount of data transferred. In a GSM environment, it occurs every time the user wants to connect to the Internet and the user usually disconnects when the session ends, because the operator charges according to connection time.

- **Authentication procedure.** This task consists in authenticating the user and validating the server through a Certification Authority. The whole process involves sending several messages in both directions. In this case, it is important to note that GPRS is slower than GSM, because while GPRS transmits faster than GSM, once both systems have established the connection, GPRS takes longer to gain access to the data channel than GSM. The access channel time begins when the data to be transmitted reach the transmission interface, and ends when the system begins to send it after having assigned a transmission channel. This operation is faster in GSM than in GPRS.

- **Map authorization download.** To be able to accept or deny user requests to open and display maps, client application downloads from the server a list of all maps available and their expiration time. This occurs once, when the application starts.

- **Map download + memory store procedure.** When the user wants to display a map not stored in the client’s local memory, this has to be downloaded from the server. The operation response time can be divided in two parts: download time, which depends on the bandwidth available on the transmission medium, and the time taken to read the incoming data and save it to local memory. When carrying out these operations we can see the big computational differences between PDAs and standard laptops and between different wireless networks. It is worth highlighting several aspects:
  - **Differences in the memory storage procedure.** A PDA takes 13 s and a laptop only 1 s.
  - **Differences in data transmission management.**
    - **Table 1**
    | Tasks                                      | WLAN | GPRS | GSM |
    |--------------------------------------------|------|------|-----|
    | Establishment time                         | 0    | 7    | 28  |
    | PDA: authentication procedure              | 1    | 17   | 16  |
    | PDA: list with map authorizations download | < 1  | 5    | 5   |
    | PDA: map download + memory store procedure | 10 + 13 | 37 + 13 | 72 + 11 |
    | Laptop: authentication procedure           | 1    | 12   | 13  |
    | Laptop: list with map authorizations download | < 1  | 4    | 3   |
    | Laptop: map download + memory store procedure | 2 + 1 | 26 + 1 | 67 + 1 |

These response times are critical from the user’s point of view, although, depending on his or her requirements, they can be more or less tolerant. However, in improving the position service using real-time DGPS, the accuracy that can be achieved decreases as the age of the correction increases, because the conditions existing when the corrections were computed change over time. To limit this lack of precision, most GPS receivers will not accept RTCM data older than 20 s. **Geographic data BC (1999)** presents a study about the impact of the RTCM information age over the improvement on the position correction using a DGPS system. This work concludes that correction information can be considered valuable up to an age of 20 s.

The size of a full RTCM message is greater than 256 bytes and will not fit into a single SMS. As the transmission time is critical, the application develops a protocol between the client and the server in order to transport RTCM replies in a single SMS message. In order to do this, the client request contains the identification of those satellites that it really sees. The server then, looks at the RTCM flow provided by the RASANT system, which contains the corrections of all GPS satellites available, and extracts only the correction vectors from those satellites indicated by the client. It codifies this data and sends it to the client in one SMS message. The client extracts the received information and builds several RTCM frames, which are introduced to the GPS receiver, which then displays the corrected position. Several measurements of RTCM age information have been carried out, and more than 95% of answers were younger than 20 s. It is important to note that RTCM age information comprises four time periods: RASANT system delay, extraction of information from the original RTCM flow, SMS reply message transmission delay and RTCM frame reconstruction in the client before they are sent to the GPS receiver.
8. Implications of this work

The aim of this work has been to present a possible GIS commercial platform that integrates the major number of the technical advances available nowadays and the new trends on e-commerce, security and ubiquity of services.

Micropayments are getting more significance nowadays because users are more ready to pay a small amount of money for a service that they really need, although it has to be paid many times, than to pay a large sum for a whole volume of information that they do not know if many of this data will be useful sometime. Therefore, the presented solution, where users do not buy the maps, but they rent fragments for a certain period of time, seems to be commercially interesting. Also this methodology makes possible for the service providers to sell completely updated information, which is an added value for the user.

Another relevant aspect in e-commerce is security; service providers have to be sure that their information will not be copied illegally. This issue can be solved authenticating the user when he accesses the system, although this action will require user intervention, and encrypting downloaded data. We have presented a feasible solution where users authenticated themselves by a login and a password, directly to the server, and map fragments, which are encrypted with a personal key, can only be displayed with the player that this specific user owns. Therefore, users can only visualize their maps with their own player, and map interchanges between different users are not possible.

Another tendency of nowadays services is their ubiquity, in the sense that they could be reached in any place of the world any time the user wants. This fact becomes each day more possible because of the development of new wireless networks, which are faster and cover more areas year after year. So new services are being developed and offer new market opportunities. The presented platform presents one of such services, users of this system are able to obtain the required cartographic information from a centralized server, connecting their mobile devices to a fixed network using a wireless access network, either WLAN or WWAN (Axis communications, 2002; Lody, August, 200117, 18, Geng and Whinston, 2001).

Future technology evolution affects positively to the system because user devices will be more powerful and networks faster, so system response time will be shortened without software updating. Also new improvements are being achieved in GIS data collection, as satellite data transformation into precise and useful geographic information, radar interferometry or LIDAR methods to acquire information about the elevation or the deformation of the ground. Thereby, this high-resolution data could be employed for GIS applications, and additional GIS products could be offered, such as weather and agricultural forecasts, environmental monitoring, mineral resource exploration, etc. (Earth Satellite Corporation, http://www.earthsat.com)19.

9. Conclusions

In this paper, we have presented the technology currently available for use in wireless GIS systems and its capabilities. We have reviewed devices that can run mobile GIS applications, basically PDAs and laptops; wireless access networks that can be used to connect them to the fixed network where system servers will be located; communication protocols used for these networks; GIS file formats; and positioning systems (GPS and Differential GPS).

A wireless GIS platform developed at UPC has been presented as an example of how to integrate all these systems. Its problematic points were stated, along with an explanation of the adopted solutions. This platform provides services of localization and navigation using vectorial maps over mobile devices with wireless capabilities (WLAN, GSM, GPRS, SMS), for use in multiple fields. Mobile communications are required because client devices need to interact with a centralized server whose tasks are to provide and authorize access to cartographic information. This information is intended to be sold by means of micropayments. Finally, some measurement results have also been presented.

Acknowledgements

This work was partially funded by the CICYT project TIC2003-01748.

References


