An Architecture for Delivering Location-Based Services

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Summary

Location-based services (LBS) denote services provided to mobile users according to their geographic location. Such services are emerging as value-added services, and their implementation requires a secure and reliable wireless architecture. This paper identifies technical challenges related to LBS technologies, and presents a cost-effective wireless network architecture which can efficiently support LBS applications. Such an infrastructure contains a geolocation server which uses a geolocation database for gathering information required to compute user location, and transmits information to be displayed on the mobile terminals. Several scenarios related to emergency services, context-aware services, navigation and proximity services demonstrate the feasibility of this proposal, and show that the proposed architecture can rapidly provide location-dependent information access in a changing environment.

Key words:

Context-aware service, emergency service, GIS technology, location-based service, mapping applications, navigation service, web mapping, wireless architecture.

1. Introduction

The increasing need for mobility and recent advances in wireless technology have created one of the most promising mobile services: location-based services (LBS). Location-based services denote services provided to mobile users according to their geographic locations [2, 15]. Such services use the ability to dynamically determine and transmit the location of persons within a mobile network by the means of their terminals [25]. These services include capabilities to search information about physical location, and have features that support finding routes to specified destinations. Currently, a wide range of LBS are available. Examples of such services include:

- mapping applications, providing mapping directions to a vehicle driver ;
- city guides, providing information for travelers about a given area;
- mobile yellow pages, assisting mobile users to locate the services they need;
- location-aware marketing, triggering advertisements based on proximity to an area.

LBS types may be classified according to their functionalities and use of location information [25]. The basic class is *location-based information* service which informs the user about its current location. This service is usually combined with a digital map associated to the user location, which is a *map service*. Because of the limitations on the screen size of mobile terminals, a digital map only contains basic information on the street network, such as some street names and attraction points. When this map is augmented with an access to some point of interest information, the service type becomes a *city guide service*. A city guide service may provide an additional level of assistance by displaying routes to reach specific destinations. When such a service includes capabilities to search information about physical services and a possibility to contact them, it becomes a *yellow page service*. The latter may have features that support finding the most appropriate routes from the current user location to specified destinations. This service is called *navigation service*. Nowadays, most cars use a navigation system which can find routes and display information about stores and gas stations [10].

Also, a wireless network may use the knowledge about the user position to provide information about the area and nearby objects, or to trigger certain actions [8]. This service is called a *location/context-aware information service*. One example is *location-based marketing* which enables ads to be sent to the terminals approaching a restaurant. Schilit and Theimer (1994) developed a prototype system, called active-map service, which provided users with information about the location of objects in areas such as buildings or small campuses. Also, location-aware services are able to determine and transmit the locations of the mobile users to third parties [13]. However, to deal with privacy issues, the interface of the service should enable a user to define to which degree other users can access information belonging to him [8].

Moreover, a number of papers discussed various problems related to LBS, such as service design [1], [4], [8], [13], as well as spatial data modeling and management [8], [13], [14], [21], [25], [27]. However, few of them directly tackled architectural problems when designing a wireless network which has to deliver LBS. This paper presents a wireless network architecture that supports LBS applications in a cost-effective manner while reflecting the current and future status of wireless technologies. It is organized as follows. Section 2 identifies technical

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challenges related to LBS technologies, such as standardization and interoperability problems, data integration and distribution, real-time generalization of cartographic data, and web mapping. Section 3 presents a cost-effective architecture which can efficiently deliver LBS. Section 4 presents several scenarios which show how the proposed architecture can support LBS applications, whereas Section 5 gives some concluding remarks.

2. Background and technical challenges

A functional architecture of an LBS system is illustrated in Figure 1 [15]. In this architecture, the terminal location must be accurately estimated and shared with the service provider's infrastructure. Technologies for location estimate are categorized into *network-based* methods and *handset-based* methods [14]. Network-based methods enable receivers at known positions to compute the location of a mobile terminal using the measurements of the distance or direction of this terminal from each of the receivers. Such methods, also called network-centric positioning methods, have the advantage that the mobile terminal can be implemented as a simple transceiver with small size and low-power consumption. In this category are the following techniques: time difference of arrival (TDOA), angle of arrival (AOA) and multipath analysis [14], [15].

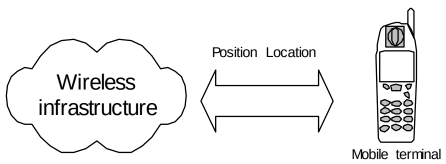

Fig. 1 Functional architecture of a location-based system

In a self-positioning system, the mobile terminal determines its position using measurements of its distance or directions from known locations of transmitters. Self-positioning methods are often referred to as mobile-based or terminal-centric positioning methods. This category includes the most successful and well-known global positioning system (GPS), developed by the US military for defense purposes [14], [15], [20]. This system is based on 24 satellites which orbit the earth, enabling 4 of them to be viewed from any point of the earth's surface at any time. Users wishing to know their position must have a GPS receiver capable of receiving signals from the satellites. If the user can receive signals from at least 3 satellites, the exact location can be found, and it is expressed in terms of latitude and longitude [4]. The main advantage to using GPS is its global coverage, as GPS receivers are relatively compact and relatively inexpensive. However, to obtain an accurate position, a GPS receiver must be able to locate at least 3 satellites, which precludes using the technology inside buildings and in areas where tall buildings block the satellite signals [4]. In fact, GPS-based systems are useless indoors [20].

Another category of LBS is called *on-demand mapping* [3]. These services enable users to define by themselves the content, coverage, scale and visual appearance of the requested products. In order to create on-demand maps at arbitrary scales, it is necessary to use cartographic generalization techniques. The GiModig Project (Geo-spatial Info-Mobility service by real-time Data-integration and generalization) addresses real-time generalization of spatial data suited to mobile terminals with different display resolutions [18]. In this context, methods such as on-demand mapping, real-time and object-oriented generalization of the content of geo-databases may be used to address the challenge of better delivering the location-related information to mobile users [7]. Since most current cartographic generalization techniques are known to be time-consuming [16], they need to be significantly improved in order to be applied in the context of LBS.

Moreover, LBS can take benefit from current capabilities of *geographical information systems* (GIS). GIS are information systems which enable to collect, convert, represent, analyze, and visualize geographically referenced entities, such as rivers, forests, roads and houses [25]. Such systems work with large scale spatial areas, such as a city or a country. Data collection and conversion capabilities of GIS systems have produced large and expensively collected information contents that can be used for LBS. In fact, a lot of data are available in different coordinates systems worldwide. A GIS enables to integrate any data set and convert it into one model of the reality.

In the same vein, GIS analysis is making a major transition from simple geometry and topology-based analysis tools towards advanced computational methods called GeoComputation [25]. Considering geographic data presentation, the traditional 2D map visualization methods have evolved into interactive and animated 3D models, with sound and text. While an increasing number of services will need to display maps on wireless terminals, the reduced screen size and low display resolution of mobile terminals is a challenge that needs to be addressed. Given the display limitations of mobile terminals, it is necessary to select, simplify and apply geometric transformations to the required information, using generalization mechanisms.

However, a critical question arises when considering the capacity of GIS servers to efficiently process queries submitted by a very large number of wireless terminals. Because of the processing limitations of mobile terminals, it is necessary that most of the processing operations be run on servers. Considering that geographic data processing requires a lot of computing power, there is a need for GIS architectures to support such complex operations. In this context, Takino [22] proposes a system architecture that allows a single database to be accessed by personal computers and mobile terminals. In this architecture, workstations are considered as fat client systems supporting a large part of the processing workload, whereas mobile terminals are thin clients mainly supporting input/output operations, and application programs are stored and run on the server side. Another solution to this problem is to take advantage of networked GIS servers and distributed computing [12].

Another aspect to take into account when designing a network for delivering LBS is the standardization and data integration. In fact, for LBS development, it is essential that new standards support a common representation of geographic information so that geo-spatial data delivered to mobile users might be accessible and interpretable by any location-based application [5]. Vanttinen [24] considers the problems of standardization and interoperability as the main reasons for the poor handling of users' privacy, restricted LBS architectures, the lack of common data structures and compatible positioning methods. In this context, the Location Interoperability Forum (LIF) promotes common and ubiquitous solutions for Mobile Location Services (MLS) by defining interoperable location-services solutions that are open, simple and secure in the context of spatial data modeling and processing [21]. Its goal is to provide common protocols to transmit the mobile device location [17]. In addition, the Open Location Services (OpenLS) Initiative envisions a successful integration of geo-spatial data and geo-processing resources into location services and telecommunication infrastructures. The OpenLS Testbed aims at developing candidate interface specifications in support of interoperable location services to be made available through mobile terminals [11]. Moreover, it is essential that the proposed standards support a common representation of geographic information so that location information may be transparently integrated with other sources of geospatial data. In this context, the Open GIS Consortium (OGC) suggests a format to transmit location information based on the Geographic Markup Language [6].

In the same vein, the Geographic Data File (GDF) model which has been recently proposed by digital map providers contains road data in a specific format. Such a situation makes it difficult to integrate heterogeneous data from different sources. The Nexus project is one of several initiatives that address this problem, by developing a platform which provides a generic data model for different kinds of location-based applications [26]. Also, the GiMoDig Project tackles the lack of common data and methods to transfer and process data in location-based applications among European countries [18]. This project investigates the problems encountered when trying to integrate heterogeneous geo-spatial databases from different countries, and aims at developing methods to harmonize real-time data.

3. The proposed Architecture

Figure 2 gives an overview of a typical mobile network [19] which essentially consists of 2 subsystems: the radio subsystem (RSS), as well as the network and switching subsystem (NSS). The RSS comprises all radio specific entities, *i.e.* the mobile terminals (MT) and the base station subsystem (BSS). The BSS contains the base stations (BS) and the base station controllers (BSC). It performs all functions necessary to maintain radio connections to an MT, coding/decoding of voice, and rate adaptation to network part. Each BS comprises all radio equipment, *i.e*. antennas, signal processing, amplifiers necessary for radio transmission. The BSC reserves radio frequencies, handles the handover from one BS to another within the BSS, and performs paging of the MT. The latter comprises all user equipment and software needed for communication (*e.g.* a PDA: Personal Digital Assistant). A typical LBS MT has a screen with many components, such as a camera, pen/finger interface, audio input/output interface with speech generation and voice recognition, calendars, address books and Internet browsers [1]. In this context, the camera may be pointed at the user to interpret his gestures, or pointed at the environment to interpret objects or symbols in the environment.

Moreover, the heart of a mobile network is the *network and switching system* (NSS). The NSS connects the wireless network with standard public networks (PSTN: Public Switch Telephone Network) and the Internet. It performs handovers between different BSS, comprises functions for worldwide localization of users, and supports charging, accounting, and roaming of users between different providers in different countries [19]. It essentially consists of a *home location register* (HLR), *visitor location registers* (VLR) and *mobile switching centers* (MSC). The HLR is the most important database in the system, as it stores all user-relevant information, *i.e.* static information, such as subscribed services, and dynamic information, such as the user location. It can manage data for several million customers [19]. Visitor Location Registers are dynamic databases which store all important information for mobile users in the location area they control. Each VLR is associated with an MSC which handles all signalling needed for connection setup, connection release and handover to other MSC. Each MSC performs all functions needed for supplementary services, such as call forwarding, multi-party calls, and reverse charging.

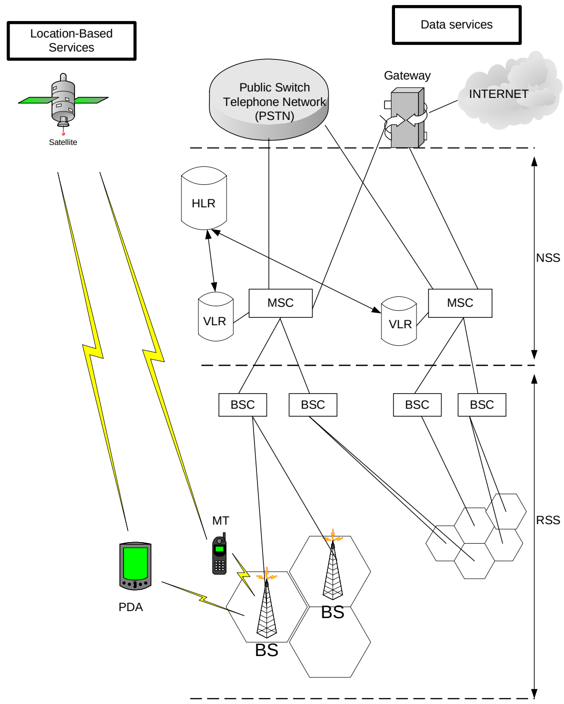

Fig. 2 Typical architecture of a mobile network

When designing a wireless infrastructure which has to support LBS, a number of mobile environment constraints must be taken into account [25]. These are:

- The service has to provide information of different types, covering different geographic regions, and coming from different sources;
- The service has to provide dynamic information;
- Interoperability of different LBS components must be managed;
- Mobile terminals have limited memory, limited computational power, limited screen size and resolution;
- Mobile networks have high cost, limited bandwidth, high latency, low connection stability and low availability.

To cope with these constraints, we propose to include into the architecture presented in Figure 2 a *geolocation server* (GLS) that contains a *geolocation database* (GLDB). Such a server is connected to each MSC/VLR via high-speed wireline, which is illustrated in Figure 3. The GLS constitutes a wireless information server and a data manager used to compute information requested by an MT. It manages and facilitates interaction between each VLR which contains location information and the GLDB which contains user profiles and available services. This enables to efficiently deliver LBS. In this case, each service request from an MT to the GLDB is managed by the GLS which sends back the response (*e.g.* location information) to the MT.

The GLDB provides the functionality of storing and retrieving geo-related information in relation to geographic objects, and carries out appropriate geo-processing anytime, anywhere and on any terminal. By using the GIS technology, the GLDB contains geographical information in the form of stored digital maps. In order to keep such information as precise as possible, the GLDB is continuously updated. It can collect, analyze and store dynamic geographic data coming from heterogeneous sources, including GIS databases. This enables a user to visualize geographic information and to propose a route, or to perform spatial queries, like searching for objects of a given type within a certain distance in the context of navigation services delivery. Note that all personal data transmitted by the MT to the GLDB pass through the MSC/VLR. In this context, data management is assured by the GLS.

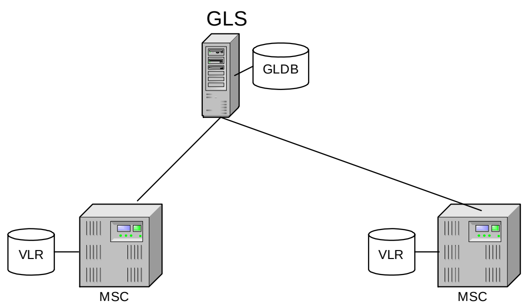

Fig. 3 Proposed architecture for delivering LBS

Moreover, the addition of new equipments at the NSS level requires implementation of new methods at the terminal level for spatial data handling, such as web mapping and real-time generalization [9]. In fact, dynamic web mapping capability must be used by LBS operators to provide mobile users with specific geo-referenced data and other real-time information. Furthermore, because of display constraints of an MT, cartographic data must be displayed in a generalized form. However, it has been recognized that generalization algorithms are time-consuming [16]. A solution to such a problem is to use multi-scale databases, where time-consuming generalization algorithms are preprocessed off-line and the results stored as levels of detail (LOD) in a multi-scale database [23]. At run-time, when users require cartographic information, efficient generalization algorithms are used to refine the nearest LOD to the requested map scale. As a result, the proposed architecture is cost-effective in the sense that we make use of the existing components with the addition of equipments dedicated to efficiently deliver LBS.

4. Scenarios and applications

A number of LBS applications are already available [2], such as emergency services, mapping services, as well as information services that provide local news, weather, traffic and leisure information. In this section, we present several scenarios which show how the proposed architecture can support LBS applications.

4.1 Emergency services

Nowadays, emergency or E-911 services are among the most popular LBS applications supported by the Federal Communication Committee (FCC) to assist mobile users in distress or needing help. In order to improve emergency response, the FCC mandated that all operators should provide geolocation services and that 95% of mobile terminals should be location-compatible [14]. The mandate requires that a public safety answering point (PSAP) be able to locate the mobile terminal within 50 m for 67% of E-911 calls and 150 m for 95% of the calls if a handset-based geolocation technology is used, and within 100 m (300 m) for 67% (95%) of calls if network-based geolocation technology is employed [15].

The following gives an example of operation of the proposed architecture in the context of providing E-911 services to subscribers. Upon a request from a mobile subscriber to the service provider for location information about an MT, a query is sent to the GLS, requesting it for the MT coordinates. The GLS gathers information required to compute the MT location. Depending on past information about the MT, a set of BS may be used to page the MT and to obtain the location parameters with accuracy. Once this information is collected, the service provider transmits it to the PSAP, which enables to rapidly find the mobile user in distress.

4.2 Context-aware applications

Context-aware applications take advantage of contextual information, such as position, to offer services to users. In this section, we show how the proposed architecture enables to offer such services. For this, we take a scenario in which the MT becomes a personal guide to visiting a museum, which is reported in [1]. In this context, a mobile user (*e.g.* a tourist) may take personalized tours in the museum, watching any desired exhibits in any order. The terminal may allow the tourist to go anywhere in the museum and be able to receive information in function of its current location. To evaluate such a location, the MT sends a request to an MSC/VLR via the nearest BS. Then, position measurement systems, such as indoor beacons or GPS, are used to locate the user, whereas electronic compass or inertial navigation system may be used to find his orientation. In function of the user position and orientation, the GLS/GLDB sends information on objects of interest to be displayed on the MT. Such a process is illustrated in Figure 4. Objects of interest could be marked with visual makers or active beacons or recognized using computer vision. Note that a personal guide may also assist a mobile user in route planning, providing directions.

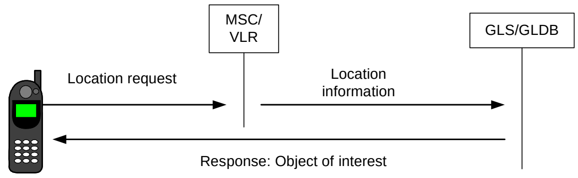

Fig. 4 Location request in a context-aware application

4.3 Navigation services

Currently, navigation services offer basic functionalities, such as “finding a restaurant”, or “giving assistance to a tourist” [25]. However, the trend is to determine the location and the fastest route to a point of interest (bank, restaurant or restroom facility), using an MT with the possibility of visualising a map and having voice help. To do that, the service provider has to monitor traffic conditions on all major highways, by maintaining in the GLDB potential areas of traffic congestion. When traffic congestion is detected, it informs any mobile user who is about to enter a heavily jammed highway so that this mobile user can avoid the congestion. Then, it proposes alternate route directions. The implementation of such services offers the benefits of optimized routing, avoiding traffic congestion. Note that such applications rely on handset-based positioning techniques.

Another navigation scenario, described in [25], concerns proximity services, allowing passengers to request the nearest business of a particular type relative to their current location and compatible with their profiles. This scenario supposes that a mobile user wants to find a near-by restaurant. Using his MT, he may query for closed moderate-priced restaurants offering a certain kind of food.

This request goes to the GLS which consults the GLDB. As a response, a map is presented on the user MT, displaying his current location and locations of a few closed restaurants offering the requested sort of food. By selecting a particular restaurant, the mobile user can get information about that restaurant, and can ask for turn-by-turn navigation instructions to drive to the restaurant. Again, both GLS and GLDB contribute to provide the requested information, using the GIS technology.

5. Conclusion

In this paper, we presented an infrastructure that supports LBS applications in a cost-effective manner with no major additional equipments to the current wireless network architecture. Such an infrastructure contains a geolocation server (GLS) which uses a geolocation database (GLDB) for gathering information required to compute user location and transmit information to be displayed on the mobile terminal. Several scenarios concerning emergency services, context-aware services, navigation and proximity services have demonstrated the feasibility of our proposal and shown that the proposed architecture could rapidly provide location-dependent information access in a changing environment. Further work must tackle problems related to the implementation of the architecture in real-world conditions, such as the scalability of dynamic data collection and the standardization of the interfaces between the additional equipments. From a software perspective, new software will take advantage of location information to increasingly offer more sophisticated location-based services in the near future, as we are evaluating the potential of employing mobile agent technologies to support LBS queries.

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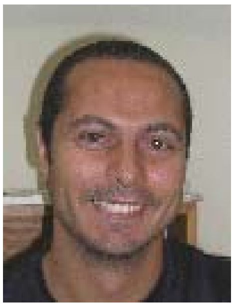

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