Location-based services:
A framework for an architecture design

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Abstract

Location awareness describes applications in computing and telecommunications, which alter their behaviour in dependence on the location of an entity, such as the user of an application, a person the user of the application wants to communicate with, or an object capable of changing a location. Such location presents a major category of context and it is derived by various methods of positioning. Over the past two decades, positioning has been a driving factor in the development of ubiquitous computing applications demanding such location information. Many devices and techniques have been developed; however, very few of them are actually used commercially. This is because the precision is limited to specific applications, and the availability limited to the provider of specific services. Obviously, to support efficient and effective development and deployment of innovative Location–Based Services (LBSs), namely, services able to deliver personalized location-aware content to subscribers on the basis of their positioning capability of the wireless infrastructure, a flexible middleware should be build as the enabling infrastructure.

This work examines various systems of LBSs focusing on their architecture characteristics and the different governing platforms and technologies on which they are based. The goal is to contribute towards the development of an architecture that combines numerous individual positioning technologies to obtain more precise and more reliable results according to the various needs of the whole range of LBSs. The general concepts of these systems are discussed by presenting a first level of classification which depends on the positioning infrastructure namely, indoor, satellite or network-based configuration. Several specific LBS architectures are categorized by means of the various characteristics regarding the design and functionality of each one. Position is combined with spatial information so as to integrate a system of LBSs with Geographical Information Systems (GIS) or other location dependent information. Finally, to increase interoperability among the various systems and technologies, standardization and homogenization is also taken under consideration.

Keywords - Location-Based Services (LBS), Location awareness, Positioning, Geo-locatation, Internet GIS.

1. INTRODUCTION

Context-aware computing is an emerging computing paradigm that exploits information about the user context to provide added value services. Today, there exist a huge variety of systems which take into account the current context. The major aspects of the infrastructure of building location-aware applications include positioning in various environments using different locating mechanisms, location modelling, location-dependent query processing, tracking, information delivery model, privacy issues, and intelligent location-aware message notification. For this reason context-awareness is a key issue in the area of mobile and ubiquitous computing.

The emerging convergence and integration of digital communication technology based on mobile networks, driven by the success of Internet technology, are now focused on offer services that are related by the location of individuals. Such services are generally referred to as Location Based Services (LBSs) and can be defined as services that integrate a mobile device’s location or position with other information so as to provide added value to a user (Schiller and Voisard, 2004). They can be seen as the convergence of mobile services, location aware technologies (positioning) with the Internet and GIS (Figure 1). Obviously, the various systems of LBSs must be able to integrate information related to geographic position and information (mapping), routing, searching, multimedia content and address location functionalities with user-specified profile and content.

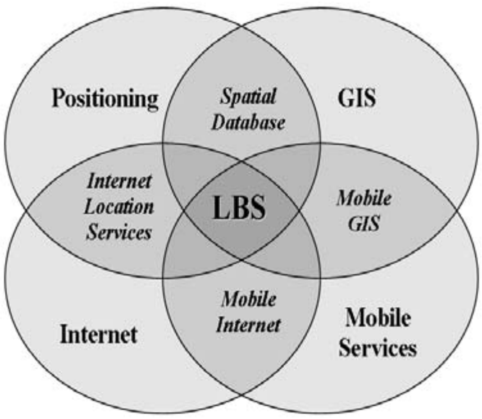

Figure 1: Convergence of technologies to create LBS

The premise of the new generation LBSs is a distributed mobile computing environment where the geographic locations of the clients in space are utilized for computing and application-related optimization. LBS architectures feature location-aware devices, which are equipped with geo-positioning systems, interconnected through wired and wireless networks. For example, mobile users often require information depending on their current context, e.g. their location, their environment or available resources, such as ‘telephone follow me’, ‘everywhere printing’ and ‘intelligent tourist’. Examples of LBSs reported in the literature are a guidance system with caching function (Davis et.al., 1999), a context-aware tour guide system (Cheverst et.al., 2000), a LBS framework using Cellular Digital

Packet Data (Jana et.al., 2001), a nearest available parking lot application (Chon, et.al., 2002). However, today, only isolated LBS like car navigation systems or mobile tourist guides are offered by different providers. They are restricted to certain data formats, certain mobile communication techniques and certain sensor technologies.

An interesting feature of LBSs is that they provide semantic information about the current location and its neighborhood. This enables users to orient themselves and to find other locations. Several infrastructural components are vital in order to offer LBSs. These include a method to locate the position of the user, a network that connects the user to the service, a centralized or decentralized database to store the necessary information and an algorithm to extract the information which is stored in the database by using location of the user. Note that the first two requirements are provided by the hardware of the mobile device and/or the network provider. For a Wireless Local Area Network (WLAN), the limitation in the signal strength allows users to estimate their position by using the position of the wireless access point. For a cell phone network, the location information can be provided either by locating the cell phone position which uses the time of arrival information can be provided either by locating the cell phone position which uses the time of arrival information of several transmitters in different cells of the phone network in city areas with good cell coverage, or by a Global Positioning System (GPS) in rural areas.

Current LBSs utilize information about locations of users to determine such services as the nearest features of interest from a location. The general assumption in these systems is that the area centered at the current location of the user is where the services are needed. Although this assumption is valid and used as the basis of many computing strategies in LBSs, there are additional benefits when future locations (e.g., locations at later times) are also predicted. Location prediction provides a longer time available to prepare and present services, especially services involving complex and time consuming tasks, such as mobile electronic commerce, and to ensure that only desired services are delivered. For example, location-based predictive caching strategies have been proposed to deal with handoff latency in mobile IP (Campbell et.al., 2002). In addition, having the priori information about locations where the user will visit at later times during a trip will extend the location management capability of LBSs and will facilitate the generation of new services that were not possible previously. For instance, a service that allows the user to plan a purchase stop for a later time.

LBSs are met in multiple fields and applications. They have been seen as a key for differentiating between the mobile and fixed Internet worlds since LBS capitalize on the nature of mobility by bringing together the user and his/her immediate environment. According to Schiller and Voisard (2004), the most interesting approaches distinct LBS applications into person/device oriented and the push/pull services. It has been realized that a flexible and resilient middleware should be built as the enabling infrastructure to support the different players, so that a service provider can efficiently, effectively, and quickly develop and deploy LBS applications and support innovative location-aware applications. The location-aware infrastructure should address the key challenges in location-aware computing. These include technology-independent location sensing, end-to-end control of location information, tracking and predication, and other research challenges involving geospatial information processing and human interaction with this information.

This paper aims to address some of the challenges listed above in order to develop an infrastructure supporting LBSs. Several key components of the infrastructure are introduced to show issues of the location-aware computing we address and to explain how the composition of components could facilitate the development of various location-aware services. The quality of the services provided depends on the utilized architecture that would support differentiated service levels, each of which guarantees a specific Quality of Service (QoS). The purpose is to provide a framework for designing such a location model able to capture the location operation semantics. The work is organized as follows. Section 2 describes the geo-location technologies, Section 3 presents the architecture, Section 4 deals with the integration of LBSs with GIS, Section 5 presents the LBSs platforms, and lastly, Section 6 some conclusions are drawn.

2. GEO-LOCATION TECHNOLOGIES

2.1. Location identification technologies

Knowledge about locations of mobile devices is the basic requirement for LBSs. The design of a system of LBSs focuses on the degree of accuracy in targeting a user's location. Geo-location technologies promise an accurate pinpointing of an object or person's position on earth (Rao and Minakakis, 2003). Choosing and deploying geo-location technologies is not always an easy task. Significant factors to be taken under consideration include the range of coverage and scalability of applications, the degree of service quality that can be established and maintained at a reasonable cost, and the careful alignment of the overall technology costs. Note that systems that determine the location of a mobile user can be *tracking* or *positioning*. In the case a sensor network determines the location the term that is used is tracking. Otherwise, if the mobile system determines the location itself, the term positioning is used.

Today, there are a number of approaches for determining location of a mobile client, each requiring a different infrastructure and resulting in a different accuracy level. Of these, time difference of arrival (TDoA), angle of arrival (AoA), location pattern matching (LPM), and the Global Positioning System (GPS) are widely used. A typical GPS receives signals from multiple satellites and employs a triangulation process to determine physical locations with an accuracy of approximately 10 m. While GPS is only for outdoor LBSs, TDoA and AoA can be used for indoor LBSs. The types of location identification technologies are summarized and compared in Table 1.

Technology	**Description**
User Input	User enters an address
Cell ID	The network knows which cell the handset is in.

(Cell Identifier)	Works well in cities where cells are small.
GPS (Global Positioning System)	It based on 24-satellite network. Outdoor precision within five-meter range. User device must be in direct line of sight.
A–GPS (Assisted GPS)	Like GPS. More accurate. Enhancement over GPS. No “cold starts”. Faster fix on location.
DGPS (Differential GPS)	Similar to GPS. More accurate relative to GPS. A reference receiver computes corrections for each satellite signal received.
CoO (Cell-of-Origin)	No modifications needed to networks or handsets. Relatively low accuracy.
TDoA (Time Difference-of-Arrival.)	The network uses its base stations to triangulate a fix on the handset, based the time of arrival of signals from the handset.
E–OTD (Enhanced-Offset Time Division)	Use the triangulation technique to calculate the position. Software modified handsets needed.
ToA (Time of Arrival)	Uses existing CDMA network features.
AoA (Angle of Arrival)	Complicated antennae required.
IN (Intelligent Network)	Location Finding System independent.

Table 1: Location identification technologies

2.2. Taxonomy of Positioning Systems

Positioning systems are divided into three classes: satellite positioning, indoor positioning, and network-based positioning systems.

- **Satellite positioning**

Satellite-based systems can be used for wide area location tracking. One such system is GPS, where 24 satellites broadcast coded location information. The information is received and processed by GPS receivers to determine their locations. The location precision achieved is in the range of a few millimeters to several hundred meters depending on equipment and procedure. To improve location accuracy even further, differential GPS systems can also be deployed. GPS systems can operate effectively mostly in outdoor clear space environments.

Using satellites for positioning has important advantages, such as the following:

- Positioning can in principle be carried out everywhere on the earth.

- Environmental conditions, such as the weather, have only minimal influence on the positioning process.
- A high precision is obtained.

NAV-STAR GPS system is a most popular world-wide positioning system. There also exists the GLONASS system, and the GALILEO system. To reduce the complexity of user devices, assisted GPS system could be used.

- **Indoor positioning**

Indoor positioning systems require cost-intensive installations and are restricted to buildings or even some rooms inside a building. Although the mechanisms of the satellite navigation systems are very similar, indoor positioning systems are very different concerning the basic mechanisms, precision, and costs. For example, indoor GPS technique is based on generating a GPS-like navigation signal from a number of local area pseudo-satellites to allow compatibility with GPS receivers with minimal adaptation to simulated signal (Salaur, 2005). For an indoor environment, several systems based on various technologies such as infrared (Azuma, 1993), ultrasound (Priyantha, et.al., 2001), video surveillance (Krumm et.al., 2000), and radio signal (Patwari, et.al., 2003; Bach et.al., 2002) are emerging.

- **Network-based positioning**

Existing wireless networks can be used for positioning services. The network-based positioning may be subdivided by infrastructure into the following three subclasses:

- *Positioning in cellular networks*: The GSM is a world popular standard for cellular phone service. Without any further installations, a simple positioning is possible within the GSM network, which knows exactly in which cell which mobile telephone is registered. Ericsson developed a system called the Mobile Positioning System (MPS) (Schiller and Voisard, 2004), which makes more exact positioning possible in large cells. Before such systems can be used for positioning, they may be needed to be trained.

  In cellular, PCS, and GSM, location tracking is done as follows: as long as the user stays in a certain location area, it does not update the location. However, once the user moves to a different location area, update messages are sent. In general, the network knows the location of users with accuracy equal to the size of the location area. To achieve even higher accuracy a smaller location area with a reduced cell size and number of cells may be used. The reduced number of cells allows accurate location information to be found quickly by paging fewer cells. In case an immediate tracking is needed with near-zero response time, or when a user is inactive, or is in an area out of the network coverage, the network may return the last known location of the user.

- *Positioning in WLAN*: Positioning is based on WLAN infrastructure and uses the measurements of signal strength of wireless LAN access points or bridges to compute physical location of the target device equipped with WLAN card -

network adapter. It is mostly useful in indoor environments but, it may also work for outdoor environments. There has been proposed various WLAN positioning systems that use different algorithms, differ in performance and target environments. Among these systems, radio-signal-based approaches—more specifically, the wireless local-area network (WLAN) (IEEE 802.11b, also named Wi-Fi) radio-signal-based positioning system—have drawn great attention in recent years (Bahl and Padmanabhan, 2000; Myllymaki et.al., 2001). A WLAN-based positioning system has distinct advantages over all other systems. It is an economical solution because the WLAN network usually exists already as part of the communications infrastructure.

Some of the cellular/PCS location schemes can be used in indoor location tracking. Since many indoor applications require higher location precision, a smaller wireless local area networks (WLANs) and Personal Area Networks (PANs) may be used. Note that base stations can be kept closer and may co-operate in location tracking of radio-enabled devices, users, products, and services. The radius of a cell can be determined as the minimum of location accuracy.

The last component which can be included in the infrastructure is Radio Frequency IDentification (RFID). It uses wireless links to uniquely identify objects or people using dedicated short-range communications. When a product or person with a tag enters the read zone of a reader, the address and data stored on the tag is read and can be sent to a server for location-tracking purposes. Since RFID readers have limited coverage (15–30 meters), our proposed architecture includes a multidimensional grid of RFID readers to cover the whole area (such as a warehouse). This would detect both horizontal and vertical location of components, products and people with RFID tags. The maximum distance between two neighboring readers can be based on the range of readers and the location accuracy require.

- *Positioning in ad hoc sensor networks*: Positioning is based on sensor networks and uses short distance signal propagations to determine mobile user's location with accuracy up to the coverage of short-range signal-emitters. The examples of this subclass of systems include Bluetooth, IrDA, Active Badge, Cricket, Dolphin, Active Bat, Cyberguide, and others. One of such systems uses RFID tags. Table 2 provides the main characteristics of the above and others positioning systems.

Name	**Category**	**Tracking/ Positioning**	**Mechanism**	**Medium**	**Precision**
GPS	Satellite	Positioning	TOA	Radio	25m horizontal 43m vertical
DGPS	Satellite	Positioning	ToA	Radio	3m
A-GPS	Network/ Satellite	Positioning		Radio	

WAAS	Satellite	Positioning	ToA	Radio	3m
Active Badge	Indoor	Tracking	CoO	Infrared	Cell
WIPS	Indoor	Positioning	CoO	Infrared, (+ WLANS)	Cell
SpotON	Indoor	Tracking	Signal Strength	Radio	3m
Active Bat	Indoor	Tracking	ToA	Ultrasound/ Radio	0.1m
Cricket	Indoor	Positioning	ToA	Ultrasound/ Radio	0.3m
RFID	Indoor	Tracking	CoO	Radio	Cell
Visual Tags	Indoor	Both	Video	Optical	Depends on camera resolution
GSM	Network	Both	CoO, AoA, ToA	Radio	Cell, 155m-35km
MPS	Network	Both	CoO, AoA, ToA	Radio	~100m
Nibble	Network	Positioning	Signal Strength	Radio	~2m

Table 2: Characteristics of positioning systems.

3. LBS ARCHITECTURE

3.1. General concept

The LBS architecture basically comprises the following components:

- *Mobile positioning system*.
- *Wireless network*, which delivers the service to users. Their function is to connect positioning systems with the wireless network and the LBS application.
- *LBS application* itself. This consists of an application server and a spatial database.
- *LBS middleware*, which facilitates the development and deployment of LBS applications in heterogeneous network environments.
- *Application server*, which is the processing centre for a LBS platform that handles user interface functions and communicates with the spatial database.

3.2. Client/server architecture

Most of the LBS applications have client/server architecture and can be abstracted into three main parts: Client, server, and wireless communication to connect client and server. Client is responsible for sending the user's request and the geographical location of the mobile device to server, and server is responsible for providing services based on the geographical location of the mobile device. Client can make contributions to information acquisition by collecting data in the field. Server will put the information collected from the field into the database and will then provide services for all clients based on the database. In fact, the role definitions of server and client are becoming more and more ambiguous. Server can analyze this critical information and put it into the database for service. Although it is a trend for LBS to collect information at the client side, there are still some problems caused by wireless communication (Liu, 2002). The architecture of LBS is shown in Figure 2.

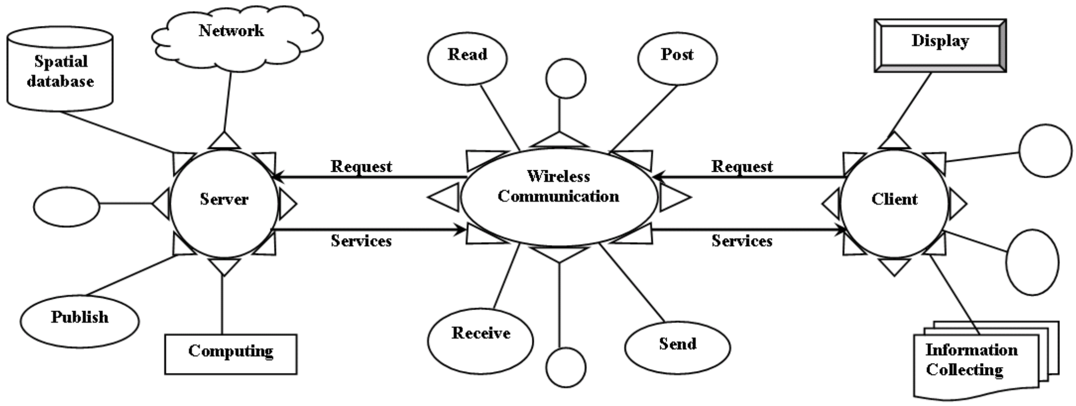

Figure 2: *LBSs Architecture.*

client, server, and wireless communication of LBS can be further divided into an aggregation of functions, which for a certain application will fall into a subset of the following function pools:

- Client functions: *Display, Information Collecting, Peripheral Control, Computing, Wireless Connection, Save* and *Multimedia*.
- Server functions: Network: *Database, Computing, Multimedia, Business Logic,* and *Wireless Connection*.
- Wireless Communication functions: *Receive, Send, Real-time, Post, Read, Encryption,* and *Information Security.*

The above classification is the first step for client, server, and wireless communication to pursue reusability. However, the methods and the procedures used to realize reusability for each of them are different in each case. At the client side, hardware compatibility which is the core problem for application developers to realize reusability is now available. Considering power consumption, computation ability, size, hardware interface, and screen issues, there is not a universal solution to meet the requirements of all users. At the server side, the crucial problem lies in network compatibility. The program running on the server side should support multiple operating systems, web browsers, and protocols that are proliferating rapidly on the Internet and Intranet. The most common and dominant method of wireless communication available today is the commercial cellular telephone system. Compared to server, the protocols for wireless communication are much less. Moreover, different types of wireless communication are highly complementary and easily merged (Liu, 2002).

3.3. Middleware perspective

LBS middleware has to bridge protocols and network technology with wireless and Internet technology. Standards that are emerging in this domain are the Wireless Access Protocol (WAP) and interoperability standards (OGC, 2005). LBS middleware is either deployed within the network operator's network or hosted by an application service provider. The middleware integrates with the network infrastructure, including location servers, WAP gateways, subscriber portal services, customer care, customer activation services, billing systems, accounting systems, and operational systems. An end-to-end system architecture is presented in Figure 3.

LBS middleware differ in the kind of services offered to the subscriber, the network operator, and the application provider. Applications are layered on top of the middleware, without much concern for the lower-level services. There is not one standard architectural reference model that uniquely describes the components of LBS middleware available to date.

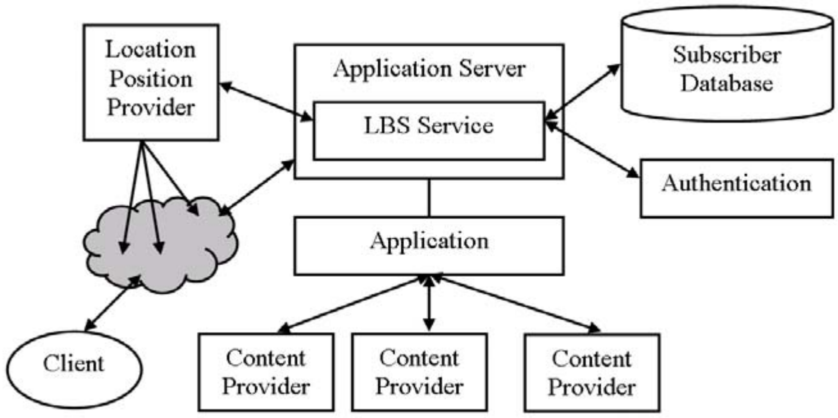

Figure 3: LBSs Architecture.

3.4. Mobile Communication

The concept of LBS rests on the ability to communicate while being mobile. Different requirements lead to different architectures and LBS can be built on top of many of these different system architectures. Their common task is to provide communication among different entities, whether they are mobile or fixed, and LBS use this facility to communicate. But the differences in system architectures will affect the type of communication support LBS can expect.

The most common architectures of mobile communication systems that their functionality can offer to the realization of LBS are: Cellular-based Mobile Communication, Wireless LANs, Internet-based Mobile Communication and Ad-hoc

Networking.

4. INTEGRATION WITH GIS

4.1. GIS and LBS

LBSs is an information system that processes geographic data. The presentation of maps in various forms is based on the development of cartographic knowledge on map design. Clarke (2001) and Casademont et al. (2004) have presented the technology currently available for use in wireless GIS systems and its capabilities by reviewing portable devices that can run mobile cartography and GIS applications. Spatial data usually consist of complex spatial objects (Shekhar et al., 1999), while an LBS spatial index contains a large number of simple spatial objects (points) that are frequently updated. These “moving object databases” pose new challenges to spatial data management (Prasad Sistla et al., 1997; Wolfson et al., 1998; Pfoser and Jensen, 2001). There are several important aspects of a GIS, which have to be analyzed when trying to enhance an advanced LBS with GIS features, such as geographic data collection, conversion, management, analysis and presentation (Longley et al., 2001). The power of LBSs lays in delivering GIS functionality and location-based information across fixed and mobile Internet-based networks, to be used by anyone, anywhere, at any time and on any device.

4.2. Mobile GIS architectures

Mobile GIS and LBS have special demands on the presentation of maps and on the interaction with spatial objects, which result from the varying position and orientation of the user and from the typical applications performed on mobile devices (Brinkhoff, 2005). The characteristics of a mobile GIS are mobility and interconnectivity through wide area wireless networks, while utilizing certain Spatial Information Servers (SIS). The analytic, data storage and retrieval and data collection technology are just background serving technologies as LBS

The main architectures of a Mobile GIS system are:

- *Stand-alone client architecture* (Figure 4): It is the simplest architecture where the application resides entirely on the mobile device which stores geo-data, out-of-the box mobile GIS software to interpret and display that data, and the application, which is built on top of the GIS software. The limitations inherent in the architecture lie within the restrictions posed by the hardware and the lack of communication between systems using the same application.

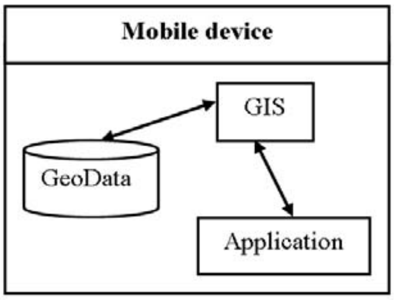

Figure 4: Stand-alone client architecture

- *Client-Server architecture* (Figure 5): This model addresses limitations of the Stand-Alone Client architecture. The geo-data are moved to a separate computer and served to the client by a GIS server software. The advantages over the Stand-Alone Client architecture are that the hardware, being an enterprise server, has virtually limitless resources. Moreover, several applications can concurrently access the server. A disadvantage of this architecture arises when the connection with the server cannot be realized.

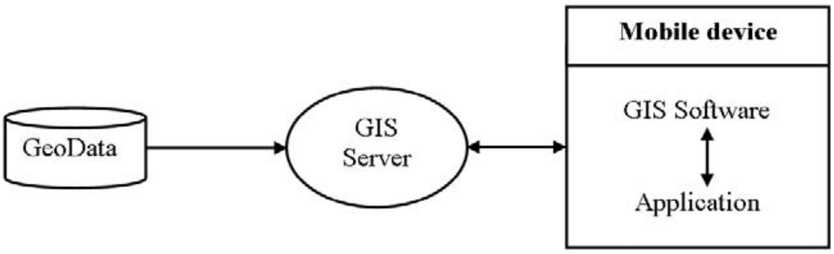

Figure 5: Client-server architecture

- *Distributed Client-Server architecture* (Figure 6). To address the above connectivity problem, two key distributed system concepts must be employed: Persistence in connection tries and resource management in the form of locally cached data. This architecture will support most mobile GIS applications in a robust, reliable way, but it does not allow for extensibility on the back end.

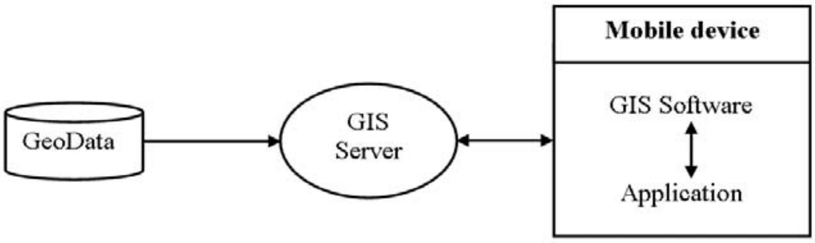

Figure 6: Distributed Client-Server architecture

- *Services architecture* (Figure 7). The GIS server is viewed as a web service and other web services are part of the application as well. As long as the same communications protocol is used, the mobile device(s) can communicate with them while the services can also communicate with each other. A natural fit for this common communications protocol is SOAP XML, the industry standard for passing messages between software components. This architecture is not suitable for collaboration in remote areas where connectivity to servers is unavailable.

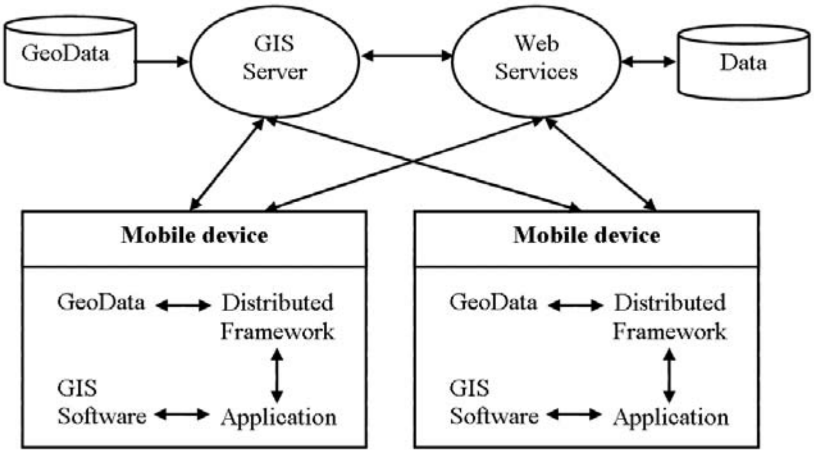

Figure 7: Services architecture

- *Peer-to-Peer architecture* (Figure 8). Each mobile device houses just a subset of the geo-data making the use of a server needless, while still addressing the shortcomings of the Stand-Alone Client architecture.

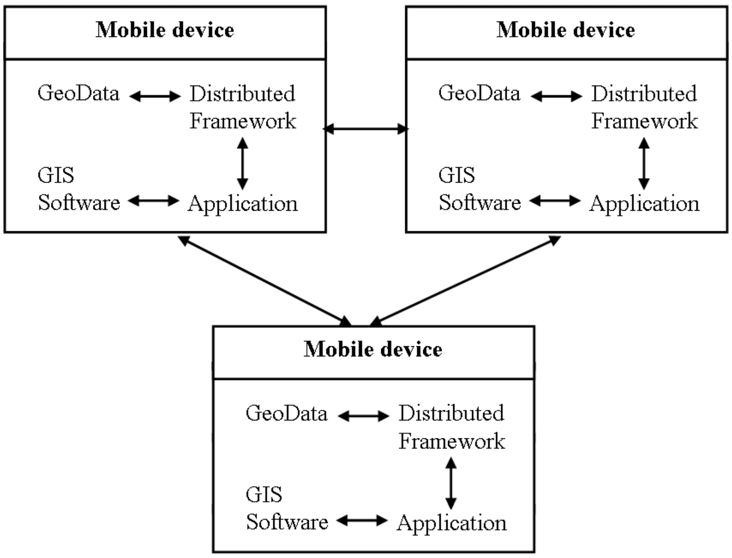

Figure 8: Peer-to-Peer architecture

4.3. Internet GIS and LBS

The various Internet information systems have evolved from static natured systems, which provided users with limited interactive view of information, into the contemporary 3-tier information systems (client, application and data server tiers), assembled of self-contained, self-describing modular applications (services) which can be published, located and invoked across the Web using computing devices. There are two basic approaches to development and deployment of GIS on the Internet: the server- and the client- side applications (Gifford, 1999).

- In server-side Internet GIS, a Web browser is used to generate server requests and display the results. An Internet GIS server usually combines a standard Web (HTTP) server and a GIS application server, and the GIS databases and functionality reside completely on the server(s). The disadvantages encompass poor performance on one hand and limited user interface or interaction on the other.

- In client-side Internet GIS, the client is enhanced to support GIS operations, while the middle tier, represented by the application server, is populated with application logic (Figure 9). In such systems either a substantial amount of GIS functionality is moved to the client, or only the user interface is enhanced slightly to enable specific user interaction. The advantages of this approach are the enhanced user interfaces, the improvement in performance and the implementation of advanced solutions using both raster and vector data. The main problems relate to distributing software and data. ISO TC 211 (ISO/TC 211, 2001) and OpenGIS (OCG, 2005) are working on open standards for interoperability within geo-information infrastructure, which have to be the foundation of contemporary Internet based GISs.

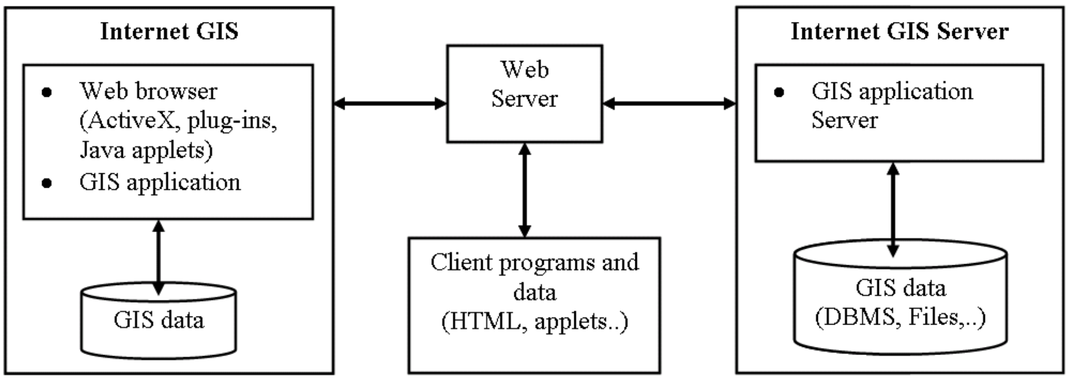

Figure 9: Client-side Internet GIS architecture (3-tiers)

The Internet GIS technology behind LBSs will empower an increasingly diverse range of applications, since they provide access to spatiotemporal information by utilizing various GIS components, this way enabling the dissemination of even more valuable information.

5. PLATFORMS

Location-based solutions are of major interest in the wireless domain, invoking many corporate vendors to develop software tools and middleware platforms to handle their delivery. Table 4 enumerates the key characteristics of the most common location-based platforms available today, most of which are based on JAVA/J2EE technologies. Some of them are of general-purpose, while others are oriented to specific application domains.

Location Platform (Source/Provided by)	**Key characteristics**
ALBS (Ibach *et al*. (2005))	o Utilize their ability of location-awareness to simplify user interactions and adapt to the specific context. o WSDL, GPS, WLAN, Bluetooth.
ArcLocation Solutions (ESRI)	o WAP/SMS/HTTP/GMLC connectivity.
AROUND (José *et al.* (2003))	o Enables the discovery of LBS over the Internet. o Distance-based and scope-based models. o GPS/GSM.
Autodesk Location Services (AutoDesk)	o Service deployment through java or web services APIs.
Cellocate (Cell-Loc Inc.)	o Proprietary positioning hardware for delivering LBS.
Celltick Platform (Celltick Technologies)	o GSM and GPRS networks using SMS or WAP connectivity.
Cloudberry (Air-Trak)	o GPS-enabled vehicle tracking system.
Dumb Pipe (Spinney (2003))	o Assumes all spatially enabled applications residing outside the network firewall in the IP domain exploit the wireless network as a resource from which to collect location information. o MPC/GMLC, LES, and GIS.
GeoMobility Server (OGC (2005))	o Open LBSs platform.
GiMoDig (GiModig, (2005))	o Develops test methods for delivering geospatial data to a mobile user.
LOC-AID.net (Datumcom Corporation)	o Location tracking for CDMA and GSM networks.
Location Engine (Kivera Inc.)	o No interface to positioning infrastructure.
LocationAgent (Mapflow)	o Service deployment over 2G/3G networks.
MapInfo MapXtreme Java Edition (MapInfo)	o Java middleware for LBS but without positioning interface.
Mobile Positioning System (Ericsson)	o LBS for 2G/3G networks.
PanGo Proximity Platform (PanGo Networks)	o Proximity services for WLAN environments.
PLM (Karimi and Liu (2003))	o Predicts locations in LBSs with road-level granularities. o Geometrical and topological techniques allowing users to receive services on time. o GPS positioning. o Client-Server architecture.
POLOS (Spanoudakis *et al.* (2003))	o Component-based. o Accommodate new transport protocols. o Open interface.

	o 2G/3G networks, WLAN, GPS, SOAP, SCL language.
SpatialFX (ObjectFX Corporation)	Java enabled software for performing spatial queries.
The Cellpoint MLS/MLB architecture (cellpoint)	2G/3G Networks.
Webraska Products (Webraska Mobile Technologies)	GMLC positioning interface, SOAP HTTP/XML APIs for service development.
Xypoint Location Platform (XLP) (TeleCommunic ation Systems)	GSM, CDMA, TDMA and 3G support.

Table 4: LBS platforms

6. CONCLUSIONS

With the advance in wireless Internet and mobile computing, LBS offer the capability to deliver location-aware content to subscribers on the basis of the positioning capability of the wireless infrastructure. There are some open problems that need to be addressed:

- Context is often ambiguous. As a result, some times the context perceived by context providers might be wrong. Therefore it is important for users to be able to correct any context misperception. Moreover, the architecture needs to learn from user's response in order to provide better context information in the future.

- The privacy and security of a user's context information needs to be strictly enforced. The enforcement should be at both the entity level and at the individual context data level as well.

- In most of the cases, platforms do not directly support the comparison of data entries. Better support is needed in maintaining and searching through context history. Future work will evaluate different types of context storage to see if they better meet the needs of context –aware computing. Ultimately, it may be necessary to develop customised context storage if a suitable alternative could not be found.

- To support efficient and effective development and deployment of innovative location-aware applications, a flexible and resilient middleware should be built as the enabling infrastructure. Three key components of the infrastructure—the location server, a moving object database, and a spatial publish/subscribe engine—need to be addressed in detail. The location server should have a common location adapter framework that will support heterogeneous positioning techniques and industry standard location Application Program Interfaces (APIs). The moving object database should manage the location stream and processes the location-based queries. Finally, the spatial publish/subscribe engine will enable intelligent location-aware message notification.

- Because of the distributed, dynamic, ad-hoc, and energy-constraint nature of the sensor networks embedded into the LBSs, localized algorithms need to be developed for their scalability, robustness and energy-effectiveness advantages. Localized algorithms intelligently select necessary nodes for sensing, tracking, and reasoning to avoid flooding the network with useless or redundant data, and thus extend the lifetime of the sensor network. The selection of participating nodes can be most efficiently done if both the LBSs consider it.

- System issues such as distributed communications, dynamic configurations, constant availability, fault tolerance and mobile clients need to be addressed in the context-aware architecture. In addition, the performance of the context-aware architecture should also be evaluated.

- To evaluate better the different aspects of the context-aware architecture, more context-aware applications should be developed. Note that in the future, LBSs will benefit from real-time information acquisition at the client side. Thus, client will be equipped with sensors to collect information automatically and send it back to server.

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