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Wireless Campus LBS: A Test Bed for WiFi Positioning and Location Based Services

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ABSTRACT: The Wireless Campus LBS project is designed to provide a test bed for location-based services (LBS) research, and it is a valued service for the University of Twente (UT) campus community. Initiated in early 2005, the project's research team is comprised of members from the University of Twente Computer Architecture Design and Test for Embedded Systems group, the UT department of Information Technology, Library and Education, and the International Institute for Geo–Information Science and Earth Observation. The research has focused on Wireless LAN positioning techniques and contextually aware data management systems for ubiquitous computing. The system delivers mapping information for LBS and mobile applications through the use of adaptive, cartography-aware database objects. In this paper, we describe the theoretical background of LBS and positioning services in location-aware GIS and database technology, the University of Twente Wireless Campus, and the prototype we developed for providing positioning and location-based services using that Wireless Campus environment.

KEYWORDS: Wireless and WebGIS, location based services, WiFi positioning

Introduction

In recent years, cartography and GIS have been more and more involved in the use of spatial database technology. Whereas in the past, GIS technology used to be file based or was using databases only for non–geometric data, general DMBS systems have become spatially aware and GIS technology and "general" database technology have become intertwined.

In the database world there is a growing focus on *context awareness* of database objects. One of the most cited definitions of context is probably from Dey et al. (Dey and Abowd 1999), "context is any information that can be used to characterize the situation of an entity." An entity can be a person, place, or object that is considered relevant to the interaction between a user and application, including the user and applications themselves. According to Dey and Abowd, a system is context-aware if it uses context to provide relevant information and/or services to the user, and the relevancy of the information depends on the user's task. Building upon this definition, Gray and Salber (2001) clarify the term "interaction" further by specifying whether it points to what is being achieved by doing this interaction (e.g., the task), or the interaction itself (e.g., the user interface or dialogue), and provide a definition for *sensed context as being the* "properties that characterize a phenomenon, are sensed, and are potentially relevant to the tasks supported by an application and/or the means by which those tasks are performed." One of the important sensed context parameters is *location awareness*, which is important for all spatial applications, and is currently being dealt with in research as well as implementations (see e.g., Bunningen et al. (2005), from which the overview above was summarized, or (Virrantaus et al. (2001) and Peddemors et al. (2003)).

In our research at the International Institute for Geo–Information Science and Earth Observation (ITC), the goal is to extend context and location awareness with the idea of database objects that are *cartography aware*. Traditionally, cartographers have been focusing on methods and techniques for visualizing spatial phenomena. When more and more these spatial phenomena were being stored in GIS systems and spatial databases, the DLM–DCM paradigm was developed (see, for instance, Kraak and Ormeling (2003)): On the one side of the paradigm is a Digital Landscape Model that models the geographic world in geographic objects (point, line, polygon, or raster) with attached thematic attributes, and on the other is a Digital Cartographic Model which models the various representations of the DLM in graphic objects (point symbols, lines, patches) using their graphic attributes (color, width, etc.). The theoretical work on this paradigm usually does not describe the practicalities—how these two models should or could be connected, if or how the DCMs are to be derived from the DLM, and so forth. Not surprisingly, implementations have been patchy too. Most GIS systems give little or no support to achieve the DLM–DCM model other than "by hand," or by providing some templates and default settings. Truly "automated cartography" using this concept has in fact hardly been made possible, other than in large customized systems, usually specially built for manufacturers of extensive map series, such as the topographic map series of national mapping organizations.

Connecting this problem with the context awareness research in databases might provide a way forward. As a simple example we conducted experiments with location maps in the Wireless Campus LBS, as described in this paper.

The Wireless Campus LBS

The Wireless Campus LBS project was initiated in early 2005, as an informal cooperation among the University of Twente (UT) Computer Architecture Design and Test for Embedded Systems group, the UT Department of Information Technology, Library and Education, and the International Institute for [?] Geo–Information Science and Earth Observation (ITC). The concept behind Wireless Campus LBS was described in Köbben et al. (2005), and the project's first test phase was executed during SVG Open 2005, the 4th Annual Conference on Scalable Vector Graphics. A report on its outcome can be found at http://www.svgopen.org/2005. The Wireless Campus LBS project is intended to serve as a test bed for research as well as a benefit to the University of Twente. The research reported on in this paper goes deeper into Wireless LAN positioning techniques, into context awareness of ubiquitous data management system, and into adaptive delivery of mapping information for LBS and mobile applications by using cartographically aware database objects.

The University of Twente's Wireless Campus

The "wireless campus" was inaugurated at the University of Twente in June 2003, enabling cable–free internet access to staff and students anywhere on campus. The University of Twente is a fairly young university with a 140–hectare campus located between the cities of Enschede and Hengelo in eastern Netherlands. There are 650 individual wireless network access points at the UT campus, making it Europe's largest uniform wireless hotspot. Anyone with a PC, laptop, PDA, or other WiFi (*Wireless Fidelity*) enabled device can access the university's network and the internet from any building, the campus park, or any other facility without cabling.

University of Twente's wireless campus aims to accommodate a broad range of research and applications of wireless and mobile telecommunication. Research projects investigate the technology and the applications of wireless and mobile communication in several ways, mostly in cooperation with industrial and other knowledge partners. The wireless campus has become a 'test bed' for wireless and mobile applications. The major part of this research takes place at the Centre for Telematics and Information Technology (CTIT). Its Computer Architecture Design and Test for Embedded Systems Group became interested in using the WiFi technology in the wider framework of the SmartSurroundings research program. This program is "investigating a new paradigm for bringing the flexibility of information technology to bear on every aspect of daily life. It foresees that people will be surrounded by deeply embedded and flexibly networked systems… This presents a paradigm shift from personal computing to ubiquitous computing… Relevant knowledge areas include embedded systems, computer architecture, wireless communication, distributed computing, data and knowledge modeling, application platforms, human computer interaction, industrial design, as well as application research in different settings and sectors" (Havinga et al. 2004, p. 64). An important part of such systems is establishing the position of persons, services, and devices, and one of the possible strategies to achieve that is to use WiFi technology.

Positioning Using WiFi Technology

Using WiFi technology for positioning is just one of the many wireless techniques available for positioning of mobile users. There are various reasons to choose WiFi based localization. One is the fact that it is an economical solution. Because the wireless network infrastructure already exists, localization can be done by software-only methods, without adding any additional hardware. This argument is, of course, also true for GPS technology, which has almost worldwide coverage, but WiFi has the advantage of also being useable indoors. Secondly, compared to other techniques such as infrared, *Bluetooth,* sonar or RFID, the range covered by WiFi is larger. Thirdly, a WiFi positioning system is scalable and (re)useable in many situations, because wireless networks are currently being deployed all over the world in public as well as private spaces.

Positioning Methodologies

There are different basic methods of using WiFi signals for determining the location of users, as shown in Figure 1. Hardware-based systems use additional hardware on top of the existing infrastructure to determine characteristics such as *Time of Arrival* or *Angle of Arrival* of the signal received from known fixed locations of the WLAN Access Points (APs). Triangulation and other geodetic techniques can then be used to calculate positions. Apart from the disadvantage of the need of additional hardware there is also the problem that the signals are reflected from various objects, especially indoors. This a called a *multipath environment,* and because of it, the geodetic techniques are complex and difficult to obtain reliable results with.

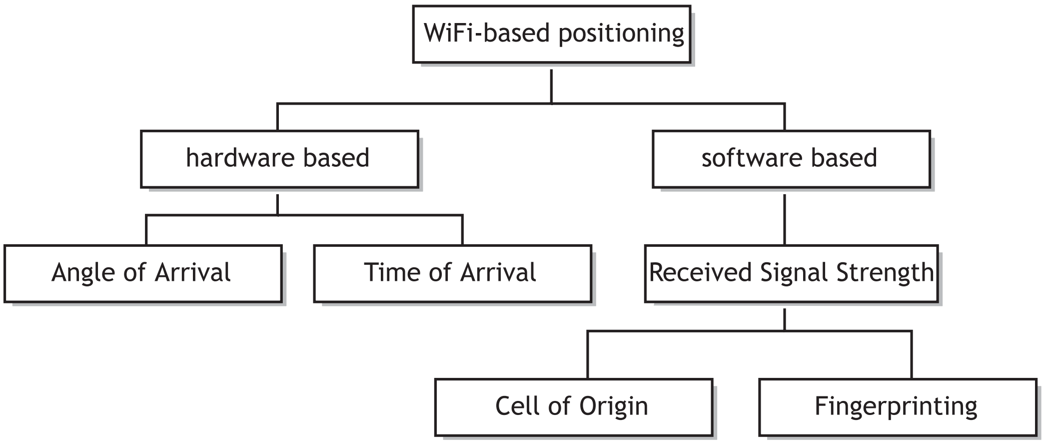

Figure 1. Simplified taxonomy of WiFi-based positioning systems, after (Muthukrishnan et al. 2005b).

The software-based systems mostly use the *Received Signal Strength* (RSS). The big advantage of RSS-based techniques is that we can use the existing infrastructure to deploy a positioning system without additional devices, other than the standard WLAN network card in the computer or PDA. A very simple method is to determine which AP's signal is the strongest one received and then assume the location to be in the area that is covered by this AP. This *Cell of Origin* method, which is similarly used in mobile phone networks, will generally result in very coarse-grained location information.

More accurate methods use the so–called *location fingerprinting* schemes, where selected characteristics of the signal that are location dependent are stored in a database. These fingerprints are then matched to the characteristics actually measured at the current location of a receiver. Unfortunately, the RSS is a highly variable parameter, and many issues related to positioning systems based on RSS fingerprinting are not yet understood well.

The fingerprint information can be obtained in two ways: first there are *Radio Map based* methods. They involve location fingerprinting at as many locations as possible and building up a fine-grained RSS map. When a device requests a location, it sends the signal strengths from all access points it can detect to the database, which finds the closest match and returns that as the probable location. The main drawback is the necessary calibration of signal strength as a function of a particular location, and even particular time (because the radio wave properties in an indoor environment can vary greatly, depending on the number of people inside the building). There is a trade-off between the amount of effort put into the calibration (it is time- and labor-intensive and must be performed repeatedly) and the accuracy obtained. Little research has as of yet addressed the issue of optimizing the calibration effort.

Second there are *Model based* approaches which generate fingerprint information based on models of the signal propagation and detailed information about the geometry and topology of the environment, including the materials used in walls, ceiling, etc., as these greatly influence the multi-path characteristics of the signal. Muthukrishnan et al. (2005b) defined the evaluation criteria for WiFi-based location systems which can be used as guidelines for comparing and evaluating indoor location/positioning systems. These are:

- *Accuracy* and *Precision* of an estimated location are the key metrics for evaluating a localization technique. Accuracy is defined as the deviation of the estimated position from the true position, and it is denoted by an accuracy value and precision value (e.g., 15 cm accuracy over 95 percent of the time). Precision indicates how often we expect to get at least the given accuracy. The accuracy of a positioning system is often used to determine whether the chosen system is applicable for a certain application.
- *Calibration*. Readings that are not calibrated are highly erroneous, and device calibration (the process of forcing a device to conform to a given input/output mapping) is needed. Often there is a trade-off between locational accuracy and the calibration effort.
- *Responsiveness* is defined in terms of how quickly the system delivers the required location information. It is an important parameter, especially when dealing with mobility.
- *Scalability* is important, because any WiFi-based design should be scalable to large networks. If an approach is calibration intensive then, eventually, it is not a scalable solution.
- *Self-organization* is highly desirable, as it is not feasible to manually configure the location determination processes for a large number of devices in random configurations with random environmental characteristics.
- *Cost*. This includes the cost of installation, deployment, infrastructure, and maintenance.
- *Power consumption* is of great concern when running the system in a real environment, especially for mobile devices.
- *Privacy* concerns. With localization-based approaches, it is very easy to create a “Big Brother” infrastructure that tracks user movements and thus makes it possible to deduce patterns of behavior. Though very important, this issue has generally been overlooked in the design of systems and, if it is considered, it is considered as an afterthought only. Centralized systems are particularly weak with regard to protecting privacy.

Wireless Campus LBS Positioning Algorithm

As in most WLAN-based indoor positioning systems, our localization algorithm relies on the observed signal strength distribution as its input to determine the location. Our localization component has been derived from an earlier project called “FriendFinder” (Bockting et al. 2004), which was executed in 2004 for one specific building on the UT campus. The FriendFinder pilot tests achieved an average positioning accuracy of about 5 m, for non-moving devices only. In the Wireless Campus LBS project, the positioning component was ameliorated as part of PhD research described in Muthukrishnan et al. (2005a), which was aimed at investigating and developing further a variety of positioning techniques for LBS. This research investigated the positioning algorithms, the filters and methods used in the Wireless Campus LSB project at University of Twente, and also the effects of signal-reflecting obstacles on the measurements. Obstacles such as walls and pillars are included in the geodatabase and its should therefore be possible to account for them in the positioning algorithm. An area of further research will be the self-learning abilities of the system, which should theoretically make the positioning more accurate over time. One of the main research goals in this regard will be to have calibration-free localization preserving quality and accuracy.

The Wireless Campus prototype works as follows. The WiFi device inside the laptop or PDA periodically scans its environment to discover access points in the vicinity. During the AP- scanning phase, the unique addresses of the access points and their RSS values are acquired and stored. At any unknown location n, the variation of the signal strength RSS will be:

$$0 >= \text{RSS} <= \text{MAX} \qquad (1)$$

However, the signal strengths are normally contaminated by noise. In order to have a better estimation of the actual location, an E*xponential Moving Average Filter* is employed to smoothen the signal strength:

$$\text{current RSS} = \alpha * (1 - \text{current RSS}) + \alpha * (\text{previous RSS}) \qquad (2)$$

where:

$\alpha = 0.125$, and

RSS = the observed signal strength.

To compute the user's location, the top three access points delivering the best signal strength are chosen. Because a trilateration/triangulation system is used, the localization will only be of sufficient quality if at least three access points are used.

Mapping the Access Points

The WiFi based positioning algorithm is dependent on an initial mapping stage at which the coordinates of all the access points in a 3D coordinate system had to be recorded in a database. For the FriendFinder pilot mentioned above, only a limited number of the APs had been used. As no geoscientists where involved at that stage, the positioning was done in a rather improvised way. The height of the APs especially was a problem; it was determined using an estimate of the building's ground floor height. This did not constitute a major problem in FriendFinder, as it involved only one building, but in the larger Wireless Campus project the elevation differences between the building bases (more than 5 m, which is a lot for the Dutch!) had to be taken into account.

The more than 650 individual wireless network APs that have been installed at UT's campus were shown on paper maps, one map per floor of each building at the campus. The base maps are printouts from CAD-drawn blueprints maintained by the Facility Management Services which have a high level of detail but they are not georeferenced and thus have a local, arbitrary, coordinate system that is basically a system of paper coordinates.

Furthermore, the location of the APs was indicated on these maps haphazardly by hand-drawn symbols at the time of the installation of the devices. The first task has thus been to digitally map the AP locations into a geodatabase. In order to do this, it was decided to digitize all locations using GIS software and digitally georeferenced versions of the CAD drawings. The georeferencing was achieved through a transformation of the CAD drawings using control points from an overview map of the whole campus available in the Dutch national coordinate system, the "Rijks Driehoeksstelsel." Using simple first-order transformations, a root mean square error of less than 0.1 m was achieved.

For all buildings, a base elevation was determined in meters above NAP (the Dutch vertical datum) by combining the campus map with the *Actual Height Model* of The Netherlands, a detailed elevation model of the whole country made by airborne laser altimetry, which has a point density of at least 1 point per 16 square meters and a systematic error of 5 cm at the most (Rijkswaterstaat AGI 2004). In order to get precise location measurements, it was necessary to physically visit all APs and use a laser measurement device to determine the relative location of the AP antenna with respect to the elements of the buildings present in the CAD drawings (wall corners, floors, windows). By combining these relative measurements with the georeferenced maps, a precise XYZ location was determined and input into a geodatabase. The added bonus is that all APs have been checked and additional attributes were gathered, such as antenna type and antenna connection length (for estimating signal loss).

The Wireless Campus Location Based Services

There has recently been much industry and research activity in the realm of location-based services. The purpose of the Wireless Campus LBS project is not the development of "the" (or even "a") Twente University LBS, but rather to set up the infrastructure necessary for LBSs based on it. The Wireless Campus LBS project is unique in that it combines input from several research projects concerned with the practical application of both new and established techniques to provide useful services for students and faculty at the UT campus.

FLAVOUR, a First Use Case

The first use case test of the Wireless Campus LBS was to provide the participants of a conference held at the UT campus (August 15-18, 2005) with a simple LBS to help them navigate the conference locations and locate fellow attendants. The conference, SVG Open 2005 (http://www.svgopen.org/2005), was deemed to be a good test bed as it drew a crowd of some 180 people from 20 countries, from a very wide range of applications: electronic arts and media, geospatial sciences, information technologies, computer sciences, software developers, web application designers. These professional communities all share an interest in Scalable Vector Graphics (SVG), the W3C open standard enabling high quality, dynamic, interactive, style-able graphics to be delivered over the web using XML. Most of them are technology oriented, and there is a high degree of interest in, and ownership of, mobile devices among them.

The pilot application *FLAVOUR* (Friendly Location–aware Conference Assistant with priVacy Observant architectURe) uses WiFi localization techniques to deliver 1) *pull services* for general navigation and to locate fellow attendants and conference facilities; and 2) p*ush services*, i.e., messenger-type peer-to-peer communication and notification by conference organizers.

The architecture, as shown in Figure 2 and described in more detail in (Muthukrishnan et al. 2005b), comprises a *Location Manager* for each mobile user logging onto the system, which provides *Lookup Services* using the *Jini* platform (Sun Microsystems, http://www.sun.com/jini). Jini is a Java–based open architecture that enables developers to create network-centric services. Each Location Manager offers the location of the user it represents. Interested users can look up the services offered and subscribe to the location of a given conference participant. This is done using a publish–subscribe mechanism. The Location Manager's privacy policy is used to decide if a client is allowed to subscribe to the location of the owner (publisher). The Location Manager provides to subscribers the relevant changes in the location of the owner.

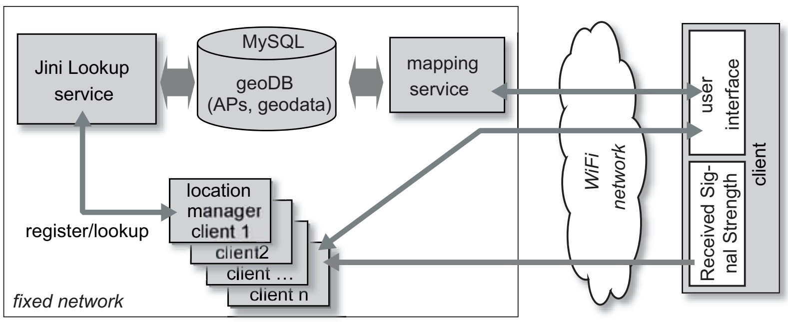

Figure 2. FLAVOUR architecture.

The Jini architecture also provides other kinds of services, such as a message board to which every conference participant can subscribe. The message board can be used by the conference organization to publish changes in the conference schedule or information related to social events. Participants can use the message board to make announcements to the other participants, for instance to ask about lost objects or to chat. In addition, the Jini architecture provides users with an estimation of the current positioning accuracy. A screen dump of the user interface can be seen in Figure 3.

Figure 3. Screen dump of the FLAVOUR user interface.

The tests at SVG Open 2005 were reasonably successful. Most conference participants experimented with the localization features of the system, while the messaging and FriendFinder functions were used to a lesser extent. Various extensive interviews were held with persons participating in the experiments and written feedback was collected.

The localization functionality worked reliably, and its accuracy was somewhat better than that of the FriendFinder prototype (the highest was around 4.2 m) but this accuracy varied quite a bit at different conference locations. There is research currently underway on possible alternatives for, and improvements of, the localization strategy.

The mapping part of FLAVOUR is based on the RIMapper application developed at ITC and described in Köbben (2004). Using this application one can offer web maps that are generated on the fly by Java Server Technology middleware from a spatial database backend. The maps are generated in SVG and they incorporate all the functionality, scalability, and graphics quality that this standard offers. The original RIMapper outputs the whole map extent in one client-side SVG file, which simplifies setup. This feature constituted no problem for the small-risk indicator maps the application was originally designed for, but it makes the system not well scaleable. Because the Wireless Campus LBS requires a fairly large spatial database, RIMapper was modified so that it requests only those parts from the geodatabase that are needed for the requested map extent.

Derived Projects: CampusMapper and RIMapperWMS

The geodatabase built for the Wireless Campus LBS can serve more purposes then only WiFi localization. The university service departments (such as Public Relations and Facility Management) are especially interested in this database, as it can provide the basis for easily customizable maps of the campus or parts thereof. The ITC's Geo–Information Processing Department, which has considerable experience in developing such mapping services, has helped this idea move forward by building, in the spring of 2006, a prototype of an interactive, web-based application called *CampusMapper* (Köbben and Krane 2006). CampusMapper uses DHTML for the user interface of the client (i.e., choosing the layers, visualization type, zooming, panning, etc), instead of the XML configuration files of earlier projects. These configuration settings are communicated to the application tier as parameters of either the HTTP-GET QueryString or the HTTP-POST Form object. With these changes, the application tier had become very similar in functionality to an Open Geospatial Consortium Web Map Service (OGC-WMS). It therefore seemed logical to take a next step: making its behavior fully conform to the WMS specification.

The RIMapperWMS project is described in more detail in Köbben (2007). The WMS implementation of the RIMapper is somewhat different compared to the many existing WMS implementations. It stands out because it serves its maps in the SVG format. This allows it to offer high-quality vector cartography, especially suitable for mobile devices such as PDAs and smartphones. Furthermore, RIMapperWMS includes certain VendorSpecific capabilities that the OGC specification allows, which enables it to produce the SVG output with a built-in Graphical User Interface (GUI) and thus disseminate the data to any SVG-capable application without the need for a separate WMS client.

Conclusion and Outlook

The Wireless Campus LBS project described in this paper has been active for over a year now. Although it is an informal project, with hardly any funding, it builds on the solid foundations of the well established infrastructure of the Campuswide WLAN at the University of Twente, and it has had a successful pilot in the FLAVOUR tests at SVG Open 2005. The hope therefore is that the project will be put to use and expanded in the coming years.

Further, the project is expected to become an important platform for testing concepts and implementations that would facilitate further research into the idea of cartography aware database objects. For example, we may want to try out a system where the spatial distance of the objects to the focus of the map (the user's position) influences their representation, i.e., interior walls will only show themselves in buildings that the user is in, while room numbers will appear only if the user is within a "reading distance." Complex positioning systems are under consideration, which might lead to research on generalization techniques that are hard to achieve in traditional layer-based systems. It is our intention to further use the Wireless Campus LBS to test these concepts in practice and provide proof-of-concept applications.

Probably the most exciting aspect of the Wireless Campus LSB project at the University of Twente is the fact that it provides the opportunity for a very diverse group of people from different disciplines to contribute to a technical infrastructure that can serve as a test bed for their respective research work, while potentially becoming a useful everyday feature for mobile users.

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