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AN OPEN SOURCE APPROACH TO WIRELESS POSITIONING TECHNIQUES

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ABSTRACT:

There are several problems encountered when trying to determine the location of a mobile phone, including whether you are in an urban or rural environment. Also, it is well known that some positioning technologies work better than others depending on the environment they are in. For example, GPS works well in rural areas but not as well in urban areas, GSM positioning accuracy can be acceptable in urban areas with the right triangulation technology, but is less accurate in rural areas. Positioning with other technologies such as WiFi, Bluetooth, and Semacode all have their own advantages and disadvantages as well, depending on the overall environment in which they are used. One research task of the ICiNG project is to address these issues and introduce the next logical step for freely available mobile positioning, advancing the pioneering work done by Place Lab at Intel. The EU-FP6 ICiNG project component that initiates this advance is called the *ILC (ICiNG Location Client)*. The ILC integrates all the above location finding technologies into one positioning module. This paper outlines the technique we developed to combine these technologies and the architecture used to deploy them on a mobile phone. With all these technologies finally available on one device, it is now possible to employ a personal positioning system that can work effectively in any environment. Another important advantage of the ILC is its ability to do this without any direct communication with outside sources, so users need not worry about “big brother” tracking their every movement. The ILC only “listens” for, and makes use of, radio signals that are freely available in the current environment, and does not actively connect to any external network or other services to triangulate its position.

1. INTRODUCTION

The ICiNG project is about researching a multi-modal, multi-access concept of e-Government (DIT, 2006). It develops the notion of a 'Thin-Skinned City' that is sensitive to both the citizen and the environment through the use of mobile devices, universal access gateways, social software and environmental sensors. Intelligent infrastructure enables a Public Administration Services layer and a Communities Layer.

Communities interact with the infrastructure to avail of services created by the administration, and can also create their own information-based services. The ICiNG project will set up test-beds in high-profile European locations such as Dublin, Barcelona and Helsinki to act as ‘City Laboratories’ for researching, evaluating and demonstrating technologies and services using intelligence in the environment.

In the ICiNG project, the fundamental requirement for this type of service interaction is location. For example: in Dublin, one service to be provided is an *issue tracker* that enables citizens to report accessibility issues (e.g. lack of wheelchair access) to Dublin City Council. This requires location as part of the report and the module that will provide this location is the ILC (ICiNG Location Client). The ILC is by design an open source, network independent, location determination mobile application that can utilise GPS, WiFi, GSM, Bluetooth and Semacode information or any combination of them, to calculate location. (Kilfeather et al., 2007)

The paper is organised as follows: Section 2 gives a brief summary of currently available location determination techniques. Section 3 focuses on the ICiNG Location Client and Section 4 covers the conclusions for the project so far and comments on the expectations for the ILC location determination methodology implemented.

2. LOCATION DETERMINATION TECHNIQUES

2.1 Radio Signal Strength: Signal Strength is the measure of how strongly a transmitted signal is being received or measured at a reference point that is a particular distance from the transmitting antenna. By using the signal strength of a particular radio wave and the position of the transmitting antenna, it is possible to calculate the location of the receiving device. The degree of accuracy for this location can vary greatly using this method depending on the environment that the signals have to travel through. (Cheng et al., 2005) For example, in an urban environment, the signals may have buildings and even traffic (e.g. double-decker bus) to travel through before reaching the receiving antenna. In such a dynamic environment, it is found that estimating a position based on signal strength alone can be prone to significant error in accuracy.

2.2 Radio Time-of-Flight: Radio Time-of-Flight is measuring the time needed for a radio wave to travel from a transmitter to the receiving antenna. However, since radio waves travel at different speeds depending on the atmospheric conditions they travel through, this also needs to be taken into account. For example, sound waves have a velocity of approximately 344 meters per second in 21°C air. Therefore, an ultrasound pulse sent by an object and arriving at a point 14.5 milliseconds later calculates out to the object being 5 meters away from the point. (Hightower and Borriello, 2001) Using this method to determine location can be very useful but it does require that certain extra hardware be installed in the transmitting tower and therefore rules out the possibility of calculating the position of a mobile device independently of such infrastructure.

2.3 Proximity: Proximity location determination is a technique whereby a location is determined when an object is near a known location. Of the different proximity techniques such as: physical contact (e.g. pressure sensors); monitoring radio access points (e.g. determine where a device is connected to a physical network) or; automatic ID systems (e.g. last login on a computer terminal), only monitoring radio access points would offer a benefit to the ILC as it is designed to listen for radio signals, check its own database of beacon locations and then triangulate a position.

2.4 GPS: The Global Positioning System (GPS) is a constellation of satellites of known position operated by the U.S. military and is made accurate to use for all, providing its *selective availability* (SA) feature is set to introduce zero error. It uses the Time-Of-Flight positioning technique and is currently the oldest fully functional satellite navigation system in operation, followed by GLONASS and two additional systems, Galileo and Beidou, which are proposed to come on-line over the next few years.

2.5 GLONASS: The Russian GLONASS system is a counterpart to the U.S. GPS and is managed by the Russian Space Forces. Both systems share the same principles in the data transmission and positioning methods. However, due to the recent economic situation in Russia the system became almost obsolete, but following a joint venture with the Indian Government it is hoped to have the system fully operational again by 2008 with 18 satellites, and by 2010 with 24 satellites.

2.6 Galileo: Galileo is an E.U. led project to make GPS style positioning available to its civilian population with higher accuracy than current GPS and GLONASS, and without intentional error added to the signal in times of political strife. It is expected to be operational by 2011-2012, three or four years later than was originally expected.

The accuracy of the three systems above varies. GPS and GLONASS have similar accuracy of ~20-100 meters unassisted and with SA switched off, but both systems can increase their accuracy to sub-meter using a technique called differential positioning (El-Rabbany, 2006). Although Galileo is not complete, it is expected to provide greater accuracy (down to ~1m) than the previous two systems with greater penetration in urban canyon type environments and a faster fix. Additionally, it will not suffer from one disadvantage of the current GPS system in that it is still possible that the U.S. could at any time reintroduce a selective availability error to intentionally reduce the accuracy of the positioning signal.

2.7 Beidou: Even though China has a €200M stake in Galileo, Beidou is their contribution to the choice of Satellite Positioning System. The main difference between this system and the others is that Beidou will use a circular geostationary orbit where each satellite appears to remain at a fixed point in the sky over a fixed point on the earth. Although this means that the system does not require a large constellation of satellites, it will have limited use in the higher latitudes as the coverage area is reduced.

Overall, these are the four main satellite systems that will be used in the near future for location determination and although newer technology will increase the accuracy, such systems also suffer from varying degrees of similar signal fix problems in urban environments. Also, even though GPS chips are getting cheaper, in mobile phones they will continue to suffer more in urban environments than bulkier, albeit more robust, professional survey standard receivers.

2.4 Semacode: Semacode is a relatively new technology that uses print tags to provide location to mobile devices with a camera and Semacode software installed. The location of the tag is encoded on a 2D barcode and when imaged, is decoded and made available to LBS applications on the device. This is a very accurate positioning technique (+/- 1m) and can be used to correct the position estimates of less accurate techniques like stand-alone GPS readings.

2.5 Place Lab: Place Lab was an Intel research project from 2003 to 2006. The goal of Place Lab was to try and use available radio signals (GSM, WiFi, and Bluetooth) by building a database of their locations, and then use these radio beacon locations to triangulate for the users location. However, at the time, certain technologies were not yet advanced enough to take Place Lab fully mobile as some of the signal spotters worked on mobile phones (i.e. Bluetooth) while others needed a laptop (i.e. WiFi). Like the ICiNG Location Client, Place Lab also wanted to determine position using passive monitoring and gives the user control over when their location is disclosed, laying the foundation for privacy-observant location-based applications. (LaMarca et al., 2005)

2.6 Privacy: One of the main concerns during the ILC design phase was that of user privacy. We did not want to design a system that would or could be used to track a citizen's location without their knowledge or prior consent. Instead, we wanted to develop a system where all the location determination could be done on the mobile device itself and then, only if the user wanted, it would be possible to inform the rest of the ICiNG system of their location. In this way, the user will have full control over their location and would not have any concerns about their movements being tracked without their knowledge.

For users that allow the ILC to disclose their location to ICiNG services, we also wanted a system that would address any other privacy concerns they might have. Of these issues, we identified the following to be particularly important; location information retention, location information use, and location information disclosure.

For ICiNG, it was decided at an early stage that location information retention, if it needed to happen at all, would be only for a short task-specific time frame depending on whether the user was partaking in specific studies or if they had signed up to a service that required their movements to be tracked. For example, a parent could register their child's mobile phone to such a service to monitor their child's whereabouts. Another issue that needed to be addressed was that of disclosing movements of users to 3rd parties, which the ILC never directly does.

So far we have discussed some of the different positioning techniques available, and some of their advantages and disadvantages. We identified concerns that most people would have about their privacy being infringed upon and what the possible solutions to these issues are. We also noted, due to technology limitations of the day, what Place Lab was not able to do in bringing a fully mobile location based system to fruition, and how ICiNG would take the next step and extend their work by designing and developing such a system. The next part of this paper gives a more detailed overview of the ICiNG system, focusing on the ICiNG Location Client.

3. ICiNG

3.1 ICiNG Test Bed

The ICiNG system is designed to help bring communities closer to information about their environment with the use of mobile phones, universal access gateways, social software and environmental sensors. It will be deployed in three cities namely, Dublin, Barcelona and Helsinki. As illustrated in Figure 1, the proposed system architecture can be seen as a layered structure of services, technologies, and networks that allow ICiNG services to reach the citizens and vice versa. The bottom layer is composed of the two main sources of data for the ICiNG project: the city and its citizens. In ICiNG we generalize the concept of "Citizen Sensor" in its objective of creating an 'always on' channel of available and context rich bi-directional communications between the city and its citizens across a broad range of technologies, content formats and interaction schemes.

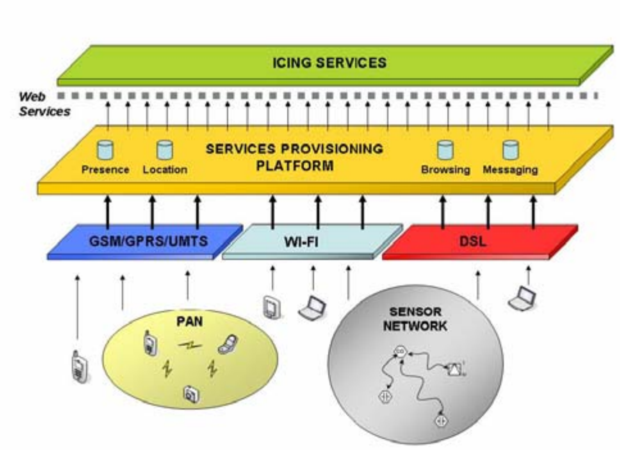

Figure 1: Test bed Layered Architecture (Telefonica, 2007)

Thus, in ICiNG we see citizens not only as consumers of the provided services but also as an active part in the creation of them. Furthermore, if we consider the capillarity of citizens, and more concretely of their personal devices, we can see them as a source of passive information of paramount importance for the construction of the 'Thin-Skinned City' model.

The general approach of the Dublin test bed specifically is to bring existing wireless and wired infrastructure belonging to the Dublin Institute of Technology and Dublin City Council together within an experimental on-street wireless network (Figure 2). Access to the new wireless network will, in the first instance, be open, free and supported by the Dublin ICiNG project team.

The ICiNG street signs will be the WiFi/Bluetooth Access points and the ILC will use its internal logic to determine a best guess location from the known positions of the street signs and other radio signals in the area.

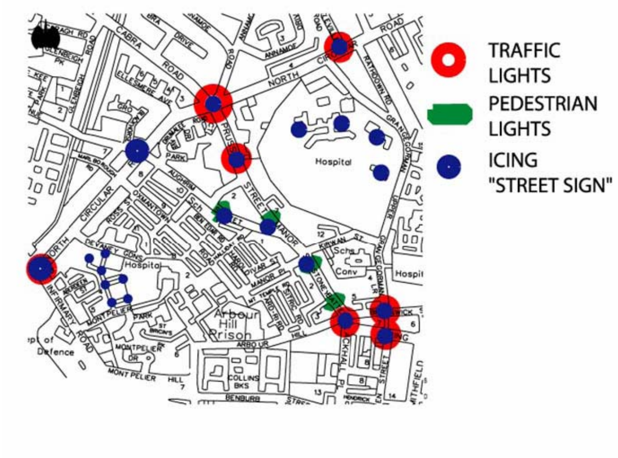

Figure 2: Dublin Test Bed

3.2 Specific Terminology

The *Icing Mobile Client (IMC)* refers to the complete set of application components on the mobile device. The IMC is comprised of:

- The *ICING Location Client (ILC)* whose purpose is to calculate and make available the device location to the MDA based on GPS, Semacode, and Wireless Beacon information.
- A number of *Mobile Device Applications (MDA)*. An example of an MDA is an accessibility application that enables users of the ICiNG system to report accessibility issues to the City Council using a Jabber client[1] extension.

3.3 Location Considerations

There are many Location Based Services (LBS) identified in the ICiNG project. These range from providing a location tracking sensor network to retrieving metadata based on a mobile device's location. While these services are heterogeneous in nature they all require a method of determining the location of a particular device or sensor. There are many existing systems available to provide this location information, some using cell services provided by mobile telecoms providers or others using satellite technology such as GPS.

However, as discussed previously each of these technologies and services have inherent advantages and disadvantages. Some services operate well in urban areas and in areas of high cellular radio density while others perform well where line of sight to satellites in the GPS system is established. Also, beyond the purely technical or technological considerations to be taken into account in location determination are issues of privacy and safety which location technologies raise. (Vossiek et al., 2003)

Fortunately, the issue of deciding which of these technologies to use is being somewhat mooted by the increasing trend of mobile devices to incorporate multiple access technologies in

[1] An open, secure, ad-free alternative to consumer IM services like AIM, ICQ, MSN, and Yahoo. Jabber is a set of streaming XML protocols and technologies that enable any two entities on a network to exchange messages, presence, and other structured information in close to real time.

the same platform. The availability of GSM, WiFi, Bluetooth and GPS on the same device offers the possibility of intelligently using all these technologies in combination to improve location availability and accuracy.

3.4 ILC – ICiNG Location Client

For the ILC, we use a combination of technologies to develop a location determination system that integrates the best features of all technologies available. By using all these technologies together, any disadvantage that each individual technology has diminishes. The ILC is designed as provider-network independent, privacy sensitive and zero cost (in terms of network resource usage) software component that allows mobile devices to determine location by a “best guess” methodology. The prototype ILC is designed to run on a Series 60 (3rd Edition) mobile phone running the Symbian operating system (version 9.x), although other platforms and operating systems could be accommodated with relatively minor changes. Figure 3 shows how this architecture works together.

There is a set of rules that the ILC will follow when searching for beacons in its RMS Database. It will be dictated by the degree of accuracy that should be expected depending on the beacon. Although all beacons in the RMS Database will be read, it will first look for Bluetooth beacons and if any are found it will discard the other beacons for determining its location; hence the degree of accuracy should be <10 meters. Next, if there are no Bluetooth beacons, it will look for a GPS reading, if there is no GPS reading then it will look for WiFi beacons and if there are no WiFi beacons, it will look for GSM beacons. As the technologies used changes, so will the degree of accuracy the tracker is providing. Even though beacons with a lesser weight for accuracy are disregarded in the location determination returned to the MDA, this beacon data does not get totally discarded. If the more accurate beacons become unavailable and the ILC switches to the less accurate beacons in its Database for triangulating position, then the lesser accurate location get a correction applied based on its proximity to the last known more accurate beacons.

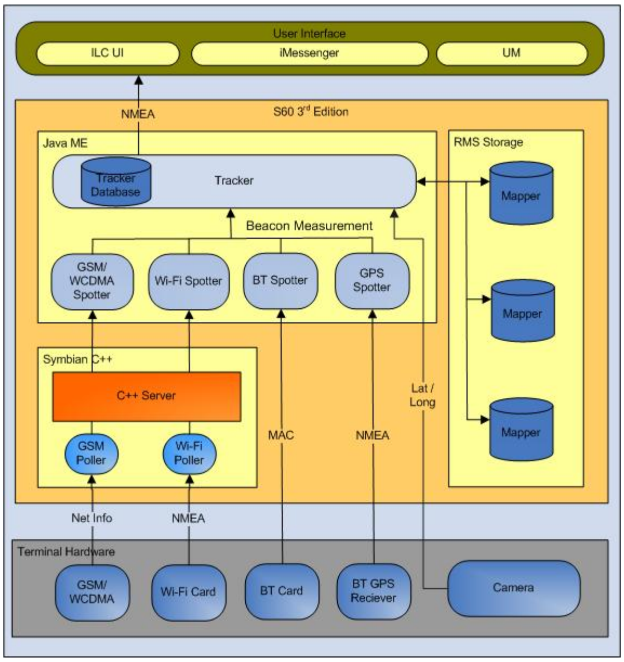

Figure 3: ILC Architecture

3.4.1 Java Bluetooth Spotter:

The Bluetooth spotter will poll the Bluetooth Terminal hardware to scan for any Bluetooth devices in range, and any devices found in range will be returned to the tracker module.

3.4.2 Java GPS Spotter:

The GPS Spotter communicates with the external GPS receiver to get Lat/Long coordinates and returns these coordinates to the tracker module.

3.4.3 Java GSM Spotter:

The Java GSM spotter sends requests to the C++ GSM spotter to retrieve the current GSM tower information and returns it to the tracker module.

3.4.4 Java WiFi Spotter:

The Java WiFi spotter sends requests to the C++ WiFi spotter to retrieve information about the WiFi access points present in the area and returns it to the Tracker module.

3.4.5 Semacode Spotter:

The Semacode module is responsible for taking photos of 2D barcodes and translating them into Lat/Long coordinates. The spotter then returns these accurate coordinates to the tracker module.

3.4.6 Tracker Database:

This is a list of the beacons that are currently in range of the mobile device. This list is compared against the known beacon database to get the beacon locations.

3.4.7 RMS Database:

This is a database of known beacons and their locations. This list is used by the tracker to get beacon locations which are used to triangulate the current position of the mobile device. Initially this database has only data we inputted into it manually, but future versions of the ILC will use databases created directly from Wardriving and that can be downloaded from websites like [**www.wigle.net**].

3.4.8 C++ GSM Spotter:

The C++ GSM spotter polls the GSM terminal hardware to determine the cell information about the currently active cell tower and returns this data back to the GSM spotter.

3.4.9 C++ WiFi Spotter:

The C++ WiFi Spotter polls the WiFi terminal hardware to determine the MAC addresses of any WiFi access points in range and returns this data to the WiFi spotter.

3.4.10 Tracker Module:

The Tracker module is responsible for collecting beacon information from the four Java Spotters, organizing the beacon information into local databases, triangulating the current position of the mobile device based on the data it has and responding to location requests from Mobile Device Applications. The tracker works as follows,

1. The tracker module waits for location requests from Mobile Device Applications.
2. Upon receiving these requests, the tracker module polls four Java spotters for any beacons in range of the phone.
3. The Java spotters return information about any beacons in range.
4. The tracker module then stores this information in the tracker database.

5. The tracker module then checks to see what beacons are in the tracker database.
6. Depending on the beacons available, the tracker chooses which beacons to use and then compares them against known beacons in the RMS database.
7. If the current beacons are unknown, then the tracker module will revisit the tracker database to select the next viable beacons to check against the RMS database.
8. Once the tracker module's beacons have been checked against the RMS Database, it then attempts to triangulate the best possible position based on the current beacon information.
9. When the position has been determined, it is returned to the Mobile Device Application that sent the request, along with a degree of accuracy.

3.5 Location Calculation

The ILC will implement and test several different location triangulation algorithms to determine the best possible location. After initial testing we will look at improving upon one or more of these algorithms as there might be a performance price that needs to be paid on a mobile device to achieve increased accuracy. Only after careful testing will we make these determinations. Of the algorithms we have decided to implement and initially test, a brief description of each one follows.

3.5.1 Centroid Location Determination: This is one of the simplest algorithms that can be implemented. It involves taking into account the locations of all known beacons in the area and then positioning the user mathematically at the centre of them. This approach ignores many things that could improve the location determination including beacon signal strength, confidence in the beacons location and environmental issues (tall buildings, hills, buses). (Hightower et al., 2006)

3.5.2 Weighted Centroid Location Determination: This is very similar to the Centroid algorithm above but it takes into account other values in the RMS database when calculating a location. For example the signal strength of each beacon can be taken into account to further determine if the ILC is nearer one beacon or another. In our test bed, we have fixed beacons with exact known positions. Initially we will only be using these beacons but during later testing, it is possible to do Wardriving in and around the test bed area and add unknown beacons to the RMS database that might have only an estimated location. In this case, we give our known beacons a greater weight when calculating location than beacons that are found through Wardriving.

3.5.3 Assisted ILC: Much like assisted GPS, assisted ILC will use an Assistance Server but on the phone. For example, if a mobile device was within signal distance of a known Bluetooth beacon but then moves out of range of that Bluetooth beacon. This information would not be discarded straight away. Assisted ILC will use this information to help correct the location determination for a period of time/distance after the user has moved away from the more accurate beacons. As the time/distance passes so the weight of the correction will decrease. Also depending on the type of beacon being used for the correction, there will be an error attached to the expected accuracy it can correct for.

Initially we have decided to implement and test these three algorithms in our test bed environment. There are other techniques that were considered, e.g., Particle Filters (Hightower and Borriello, 2004) and Fingerprinting like what is used in RADAR (Bahl and Padmanabhan, 2000) but initially it was decided that these might be too costly in terms of performance on a mobile device. Another possible technique is Gaussian Processes for Signal Strength-Based Location Estimation (Ferris et al., 2006) which appears more optimal for mobile devices. After thoroughly testing our first three Location Algorithms we will then decide if a different approach is required.

4. CONCLUSIONS

The ICiNG system is designed to allow citizens of the city to interact with Government Departments and City Councils in a context sensitive way using 3rd generation mobile phone technology. In this paper, the initial attempts at designing and developing an open source location determination approach has been described. This approach has been taken to provide the next step for context sensitive interaction through the ILC. The ILC is developed as fully open source and is aimed at providing a location determination component to provide a quick to market solution for LBS applications. The ILC is a zero cost, privacy sensitive location determination application.

The development of the ILC is ongoing. The next step in the development will involve investigating increasing the accuracy of the calculated location, based on integrating a number of triangulation algorithms mentioned and testing them in environments that have a sectorized and structured infrastructure and in environments that do not have a structured infrastructure. We will also test how each of the triangulation algorithms performs on a mobile device to verify any performance issues and what alterations are needed.

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