Unified Cooperative Location System

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Abstract. In recent years, several techniques based on location have been developed, allowing for services based on location with different degrees of precision. The possibility of using different techniques varies between devices and regions in space, according to the available hardware on the equipment and the infra-structure. This article presents the Unified Cooperative Location System, which allows the use of every available technology to a mobile device, providing a higher availability of location services. Additionally, the system implements an information exchange mechanism, allowing devices to gather location information from nearby users, like GPS or Wi-Fi, which would otherwise be unavailable for some. The possibility of exchanging GSM information provides a viable solution for the gathering of multiple GSM signals by one device, thus significantly increasing location accuracy with this technology.

Abstract. Nos últimos anos desenvolveram-se várias técnicas de localização que permitem fornecer serviços baseados na localização com diferente precisão. A possibilidade de utilizar as diferentes técnicas varia entre dispositivos e região do espaço, consoante o hardware disponível nos equipamentos e na infra-estrutura. Neste artigo apresenta-se o Unified Cooperative Location System, um sistema que permite utilizar todas as tecnologias dum dispositivo móvel para fornecer uma maior disponibilidade do serviço de localização. O sistema implementa ainda um mecanismo de troca de informação, que permite que dispositivos próximos partilhem entre si informação importante para o processo de localização que poderia não estar disponivel aos mesmos, tais como medidas Wi-Fi e GPS. A troca de informação GSM permite uma solução viável para a obtenção de múltiplos sinais GSM por um dispositivo, permitindo assim aumentar significativamente a precisão de localização usando esta tecnologia.

1 Introduction

Improvements in hardware and wireless technologies during the 90's have led to the development of multiple mobile devices, creating a new computer environment usually designated as mobile computing.

Recently, the widespread use of smaller, less expensive, and more capable devices, has opened the door for more complex applications, of which, location-aware applications are just an example [7]. Some location-based applications are already becoming an integral part of out lives, GPS probably being the most widely publicized and used of these systems, allowing for user location and navigation.

Handheld computers are now capable of running different types of applications. Additionally, manufacturers are increasingly equipping these handheld devices with different types of wireless connectivity, including Bluetooth, Wi-Fi and sensors, such as GPS.

Taking advantage of the new characteristics and availability of these devices, several research and implementations have already been presented, in an attempt to gather all the available information surrounding a user, using it to locate himself or other individuals [1, 2, 3, 4, 5, 6]. However, even though several location systems already exist, most of these systems focus on providing location for a given user using a particular technology, without trying to leverage the advantage of the existence of multiple co-located users with different available technologies.

This paper presents our Unified Cooperative Location System, which tries to rely on every technology available to a mobile device to provide an as accurate and ubiquitous location service as possible. Our system also uses the concept of sharing location information between nearby users, in order to obtain not only better accuracies, but also to gather enough information for establishing the location. Our results show that this approach provides a viable alternative for location estimation to the end user using GSM.

The UCLS provides privacy, as well as a low cost solution by establishing the location in the users' mobile phones. Additionally, much like Placelab [1], we identified the need to provide a location framework that a programmer can use. This approach simplifies the creation of location-based applications and can be used to develop social applications to search for a friend, gaming environments, children locators, or even offer services based on the users current location [7].

The remainder of this paper is organized as follows. The following section will present the main goals of the Unified Cooperative Location System and how we aimed to achieve them. We then introduce our System's Architecture and Implementation, followed by a presentation of the early results obtained from our system. Finally, we discuss some of the existing related work and a brief conclusion.

2 Unified Cooperative Location System Principles

The Unified Cooperative Location System (UCLS) intends to provide a location solution for the end user, that has low-cost, maintains privacy and provides good accuracy. To this end, our solution runs on commodity mobile phones. Thus, unlike other solutions that require additional hardware [6], it requires no configuration or deployment overhead, and no additional costs. To maintain privacy, we rely on a client-based solution, where location is determined in the end-user device, instead of relying on an external server to continuously calculate the user's location. For providing good accuracy, we rely on the use of all available technologies, as explained throughout this paper.

Our system uses fingerprinting [7] to build a database with readings, which is later used to determine users' location. This method requires a time-consuming process, that many people may not be willing to take on. To minimize the time required for building the needed databases, we used the same strategy as Placelab [1]. Data can be gathered automatically through wardriving (wireless information is gathered at regular intervals if a GPS device is available) and stored on the device. When an available connection to the Internet is available, the user can, if he wishes, share that information to a database, and obtain readings from every user using that database. This allows for a faster database construction.

Given the fact that mobile devices are not yet capable of heavy computations, our system allows for the construction of maps by another computer (it can be the user's own computer). The construction of the database map includes creating the data structures that allow for a fast search of the stored mappings. This is important, as it reduces the processing performed in the mobile phones when trying to determine the user's location.

Finally, our sharing mechanism allows users to anonymously share location information with other nearby users. This approach has two benefits. First, it allows to obtain better estimates by using more readings. Second, it allows users to access information their devices could not naturally obtain (e.g., a device with only a GSM connection can obtain GPS information via bluetooth from a nearby user).

Fingerprinting Fingerprinting is a simple method, where a user collects, for a set of locations, signal strength information of his surrounding wireless technologies, be it Wi-Fi APs, GSM Towers or even Bluetooth beacons. This allows for three types of locations. For Relative and Symbolic locations, there is a need for user input, where he states the location where the reading was made. For Absolute location, if GPS is available, one can automatically store the current coordinates together with the readings.

In order to locate himself later on, these readings are usually shared to other users, who do not possess either the knowledge or the technology (e.g.GPS) to locate themselves. With this information, the user locates himself as follows. First, he obtains a reading. Then, he searches the local information for the closest match, thus inferring the current position. This is possible thanks to the fact that wireless communications signal strengths do not vary significantly in a given location over time [2].

3 System Architecture and Implementation

The Unified Cooperative Location System (UCLS) consists of five Modules and a collection of Sniffers, as depicted in figure 1. The Sniffers are small and simple background services, whose purpose is to detect and gather the surrounding wireless signals and report that information to the Communications Module.

This Communications Module collects the information provided by these Sniffers and makes it available to the system. The Communications Module also contains a bluetooth service search primitive, which is mainly used by the Information Exchange Module to search for sharing-enabled devices.

The core of the system is represented by the Location Module, whose function is to control the mentioned modules, choose which information to store or retrieve from the Database Module, as well as access the available algorithms and configurations, in order to gather and provide location information. Finally, a Location API Module was conceived, so that the system can be used by a developer to integrate it easily on his developed location-aware application.

We detail the several modules in the remainder of this section, discussing not only the design but also implementation details of the UCLS prototype. Our current prototype was written mostly in Java 2 Micro Edition, with some notable exceptions that are discussed later.

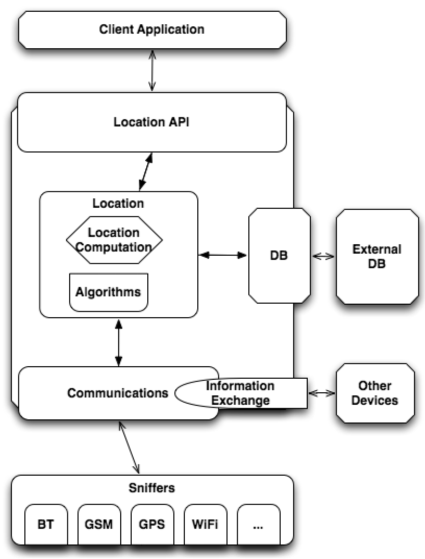

Fig. 1. Unified Cooperative Location System architecture.

3.1 Sniffers

The Sniffers basically access the Operating System's native APIs to obtain the signal strengths of the different available wireless technologies. Unlike the rest of the UCLS prototype, the sniffers were written in Python S60. This was necessary due to the limitations of the Java 2 ME system, which does not provide access to the necessary information about wireless signal strengths. As we want our system to be extensible and modular, we have implemented an independent Sniffer for each technology. This allows to use only the sniffers for which there is hardware.

Sniffers Communication Protocol For making Sniffers information available to the rest of UCLS, Sniffers must act as a simple TCP server, and execute a basic standard communication protocol. The protocol works as follows.

Each Sniffer needs to receive an activation message to start collecting information. This is necessary because, unlike GSM information which is always available to the device at no extra cost, some technologies, such as GPS, need to be active only when location information is required. A deactivation message is also used, since some sniffers (e.g.:GPS) waste high amounts of energy while working. This allows to deactivate them when not needed, conserving battery. Other than that, the server only receives reading requests and replies back with the gathered information.

The code itself is very simple to implement, and it should be fairly quick to implement a new module, be it a new technology, or an implementation for another Operating System. In the current prototype, the available Sniffers are implemented in PyS60 (Python for Symbian S60), since it provided the necessary tools to gather the required information, while providing a very simple programming environment.

3.2 Communications Module

The Communications Module is responsible for contacting the available Sniffers and grouping the acquired information. This Module controls the communications to the Sniffers, and reports the gathered readings as well as the available technologies for location to the system.

Additionally, a set of bluetooth primitives are also available when the package for bluetooth (JSR82) is available. These primitives are mainly used to search for devices running specified services. This is used primarily by the Information Exchange Module, which uses this functionality to search for sharing-enabled devices. This functionality can also be used by the Database Module to communicate with external services or servers to obtain or store data when a Wi-Fi connection is unavailable.

3.3 Information Exchange

The Information Exchange module is responsible for exchanging location information with nearby devices. This module exports a bluetooth service that allows other devices to obtain information gathered locally. We have decided to use only bluetooth communication because of its ubiquity and short-range. This guarantees that a device can only access devices that are close enough to provide useful information.

To obtain information from nearby devices, the Information Exchange Module continually searches for available devices by using the Communications Module service search functionality. When a device available for sharing is detected, they can exchange any kind of location information. For example, a device with less capabilities can obtain the GPS location information from a nearby device with such functionality. Additionally, a device can obtain the raw signal strength readings from the nearby devices, and use them in its local location computation. Depending on the technology and distance between the devices, this information can be used to average the error of individual readings. Additionally, by using every available reading from all devices it might also be possible to improve location accuracy. This is especially evident when devices share GSM signal information, where the presence of only two devices connected to two different GSM Towers immediately offers a more accurate result.

There are some points to take into account when implementing an information exchange service for location. The first is how useful the information can be to improve accuracy. Bluetooth can reach only a few meters at most of range, thus users must be very close to each other when sharing location information. Although this adds some error, one can still obtain improvements when the error of the location technique used is much higher than a couple of meters, like when using GSM. Unfortunately, the Symbian implementation for bluetooth does not provide the signal strength information of a bluetooth communication, which could eventually help to estimate the relative distances between users. This information could be used to lower the estimation error while sharing location information.

When sharing information, an important aspect is whether the users are moving or not. If users are moving, it is important to have the readings at the same time (or as close as possible). To this end, the service provides a reading timed request, which basically receives a time when the reading should be performed. In the current prototype, we assumed that the clock in the devices were sufficiently synchronized through the mobile operator, but some internal clock synchronization protocol could be implemented. If users are mainly stationary, the reading can be obtained immediately. To this end, the service also provides a primitive that immediately returns the value read.

3.4 Database Module

The Database Module allows other modules to store and retrieve readings information. This module stores readings and mapping information on the mobile phone by default, but it can be configured to communicate with an external server to gather or deploy new information.

Additionally, a simple mechanism was devised, to share the whole readings collection with an external server. This server can then aggregate readings from multiple users, and maps can be created based on all available information. Maps are basically data structures that are designed to make efficient the execution of the location algorithms in the mobile phones. This data structures can consist in simple listings of all readings or more complex data structures that allow for faster and more efficient searches.

Database Creation UCLS supports two approaches to add new readings to the system database: automatic and manual. The manual mapping is useful for symbolic locations, allowing to map areas such as buildings and, if the technologies are available and allow for such precision, floors, rooms or even smaller sections of rooms. The automatic location is used for wardriving-like fingerprinting, storing location information when a new GPS lock is acquired every few seconds.

Whenever the Location Module uses the Communication Module to gather location information, it then sends that information to this Database Module. Since some devices may be more limited than others, the Database Module can be set to either store the information locally or externally. Additionally, the Database has mechanisms to communicate with a server via Wi-Fi (or bluetooth if available) and upload the users' readings.

Information uploading provides two advantages: the first is the creation of an external shared database, that stores location information from several users. The second is the possibility of creating offline maps, more complex but allowing for faster searches when working with the mobile phone offline. The system currently has a very simple algorithm, where a device can communicate with an external server and download a map containing all the location information. This can be a complete map, or just a portion of it.

Map building The current implemented method to build a map for the mobile device is very simple, yet efficient. When the user requests a map from the server, the server gathers all the relevant location information stored and builds a map for the user.

The maps are nothing more than a collection of data structures that allow a quick search of a small grouping of possible current locations given a set of readings. A set of hash tables are created, each storing signal strength information ranging from a group of signal strength values. This information is accessed by the algorithm that determines user's location.

3.5 Location Module

At the core of the system, the Location Module is in charge of controlling each Module of the system, allowing for automatic location sensing capabilities, or more precise and controlled options. This module acts as the coordinator of the System, obtaining location information from the Sniffers, and contacting nearby devices, if available, to increase location accuracy. Furthermore, it uses the DB's information to read whatever maps are available, be it local or external to the device, and infer the current position using the available algorithms.

In our current prototype, we have only implemented a single location approach, based on fingerprinting. In this case, for inferring the user's location, the algorithm, based on the solution proposed in RADAR [2], gathers all the available wireless information at a given time, and it tries to find similar matches using the Database Module. Based on this information, the algorithm just guesses to be in the location of the closest match.

In the future, we expect to extend the location module to include additional algorithms, and allowing for a choice between different algorithms, based on the available information, energy remaining, etc.

3.6 Location API Module

The API Module serves the simple purpose of delivering an API for a developer to use a location system on his application. This API provides calls to enable or disable any available technology on the device (GPS, GSM, Wi-Fi), as well as a call to enable or disable the information sharing mechanism. The API also supplies the programmer with two distinct reading gathering mechanisms: manual and automatic. The manual gathering call is used mainly for symbolic gathering, although if no symbolic location information is supplied, as long as a GPS lock is acquired, it will still store the reading. The automatic is used only for absolute positioning, and can be enabled or disabled through this API.

The Location API Module also provides primitives to share the currently stored readings with an external server, as well as a primitive to request an updated map from the same server. This map can be a simple collection of signal readings, or a more complex map, as mentioned previously. Finally, the API supplies a single call for estimating the device's current location, which will automatically gather the surrounding wireless information, including nearby devices information (if that option is enabled), and infer the position with the available algorithms present in the Location Module.

4 Experiments

Although the evaluation of our system is still underway, we have already obtained interesting results regarding GSM localization, when sharing information among different users connected to different operators. We have gathered information over the course of two days for four different buildings in our campus. Three of those buildings are close together, while the fourth is no more than 100 meters distant from the other three. In order to obtain the readings, we used between three and six devices (N82 and E70 Nokia mobile phones) where we had installed our system. Each phone was connected to one of three providers, and each two connected to the same provider, were using a different type of connection (GSM and UMTS). This is important as we have observed that different connection types supply different cell ids and signal strengths.

For building the database, all the readings were collected in a single mobile phone by using our information exchange technique to obtain the reading from all devices. We then stored all the information on a database in a server. We managed to obtain a total of 450 shared readings, where each reading contained at least three identified cells. In total, there were 1958 readings from 21 distinct cell ids. The readings in some buildings include unique cell ids that make determining the location very simple. Thus, we concentrate our study in the subset

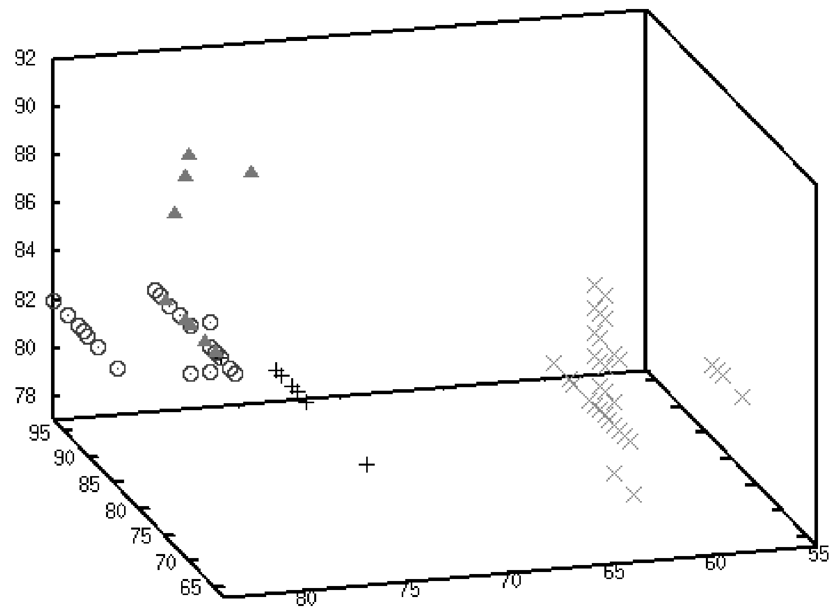

Fig. 2. 3D visualization of the three cells signal strengths. Legend: black plus signs building I, magenta crosses building II, blue circles building VII and the red triangles building X

of readings that include the same three cell ids. These readings include locations in all buildings. Figure 2 shows a graphical representation of the readings, with each axis representing the signal strength for each of the three cells. We represented the reading in each building with the same symbol and color.

A quick look at the figure allows us to clearly distinguish 2 buildings, the first relative to building II, and the second one relative to building I. The readings for the other two buildings (VII and X) are not so distant, as those buildings are located very close to each other.

After these initial observations, we used our algorithm to test the location accuracy offline. We executed the following process 10.000 times. From the complete database, we have randomly removed one reading. We applied the location algorithm to the removed reading, considering only a subset of the cell-ids obtained for the reading (e.g., if a reading includes the signal strengths for six cell-ids, we have randomly considered only n of those values). Then, we compared the estimated and actual location (considering the symbolic location consisting in the buildings). Table 1 summarizes the results obtained, representing the amount of cells used to calculate the symbolic location on the first column, and the percentage of times a location was correctly identified out of 10.000 at-

Table 1. Symbolic location accuracy using GSM

Number of Cells	Hit Rate
1	73.0
2	94.0
3	97.3
4	98.5
5	99.9
6	100.0

tempts at location. These results show that by considering a second cell, similar to sharing the information with just a single other mobile phone connected to a different cell, the accuracy improves from 73% to 93%. These results suggest that the use of our Cooperative System may allow important improvements in location estimation, even when using just GSM/UMTS technologies.

5 Related Work

There has been a lot of research on the area of location systems, and many different approaches to it. Some use specialized hardware to provide a solution [3, 6] while others use the available infrastructure [2, 4, 1] to provide users with a cost-free solution for location estimation. Amongst the available solutions, we find three main types of location: symbolic[4], relative[2] and absolute[1]. Besides using fingerprinting methods [2, 4] to locate a user, there has also been some research to use signal propagation modeling for both symbolic [5] and absolute [1] location estimation.

The cricket system [6] provides an automatic indoor mapping service, where a user needs only add a new device and set its location name, allowing for an easy to deploy symbolic location environment, though it also needs specialized equipment.

For automatic data gathering, Placelab's solution [1] introduced the concept of using wardriving to obtain location information, which also meant public wardriving databases could be used to gather maps quickly and provide absolute location. Additionally, some research has been done regarding self-mapping algorithms[9], though the map building phases have revealed to be very intensive and require an available computer with stronger computational power.

Calibree [8] uses relative location estimation to help determine users positions by sharing GPS coordinates.

GSM technology location-based solutions already have been subject of several studies [10, 11]. It has been shown that GSM can be used for symbolic location differentiating between floors and within-floor accuracy ranging from 2.5 to 5.5 meters [10] and absolute ranging from 100 to 200 meters [11]. However, this work is based upon special devices (either modified phones or special modems), which do not present a low-cost solution for GSM location. Our solution of sharing information provides a practical approach to use similar ideas.

6 Conclusions and Future Work

In this paper, we have presented a system that provides location based on any wireless technology available to a mobile device, effectively providing a unified solution that can take advantage of several algorithms. Unlike previous solutions, our approach allows a device to share its location information, both raw and processed, with nearby devices. This may allow a device to improve location results, both by using information from technologies that are not available in the device and by using additional readings. For example, this approach makes the Unified Cooperative Location System a practical solution for GSM based location, by recruiting the help of other nearby devices and obtaining multiple cell readings, thus improving accuracy compared to systems that can only obtain a single GSM reading, as is usual on most mobile phones.

We presented early evaluation results of our system, starting with the technology that takes the most advantage of these shared readings, GSM. We are planning to further extend our research of Wi-Fi and GSM location as well as attempt to determine how to best take advantage of simultaneous technologies for location inference.

In the future, we also plan to add Relative location estimation to our system, as well as try to use mobile devices or computers that can calculate a Bluetooth's connection signal strength, to determine relative distances between devices. Additionally, it would be interesting to add signal propagation modeling [12] to the system, and try to measure our distance to an AP or GSM Tower based on the signal strength.

If mobile operators would provide, besides cell information, the absolute coordinates of the tower the device is connected to, a user could use our information-exchange mechanism to share tower information between nearby users and triangulate his position based on the signal strengths of each tower.

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