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Power Efficient Indoor/Outdoor Positioning Handover

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Abstract— **This paper presents a novel technique to switch automatically between indoor and outdoor modes in an on-campus positioning system. This system uses Wi-Fi fingerprinting for indoor positioning, and GPS for outdoor positioning, and provides useful information to students about their location, and what surrounds them. The technique described in this paper detects when the user comes in or out of a building and switches the positioning technology automatically. It is also battery conservative, as it switches off the unused radio depending on the users environment. We show that the algorithm performs well by investigating the transition detection probabilities.**

Keywords — **Fingerprinting; Indoor/Outdoor Switch; Wi-Fi/GPS Switch; Environment Transition**

I. INTRODUCTION

The Location Based Services (LBS) market has grown exponentially since the first mobile device capable of delivering LBS was released in 1999 by Palm [1]. At that time, the device was able to deliver weather and traffic information using ZIP code-level position information. The growth of LBS has been fuelled by the technological advance in consumer electronics (smart phones), wireless networking, and cloud-based location enabled databases and mapping software. Examples of LBS are Google Maps [2], which can deliver a huge range of information such as real-time traffic information, nearby public transport options, places of interest, itineraries, etc. Point Inside is a relatively new service running on mobile devices, providing maps of the inside of malls and airports, and user-location using Wi-Fi in a few of them [3]. Foursquare is a location-enabled social network which allows you to check-in into places, and share that information with your friends and family [4].

Although the sector is experiencing tremendous growth, there are still barriers against it, the main one being that the positioning technology is not truly ubiquitous. GPS, for instance, has difficulties providing a position with reasonable accuracy in urban canyons, and plainly doesn't work in most indoor environments as the walls block the satellite signal. Many technologies have been investigated to bridge the gap and bring positioning indoors. Reference [5] presents a system using a combination of Assisted-GPS (A-GPS), accelerometer, and magnetometer. Other alternative technologies have been investigated, such as Bluetooth [6], Ultra-wideband [7] [8], ZigBee [9], GSM [10], or even high sensitivity GPS [11]. Wi-Fi fingerprinting, pioneered in [12], and refined in [13] and [14] among others, takes advantage of the extremely complex propagation model of Wi-Fi signals indoors to provide location with accuracies which can range up to 1 meter. Among all these technologies, Wi-Fi has attracted the most interest as more and more Wi-Fi access points (APs) are installed, and no additional hardware is required for the user (Wi-Fi chips are now in most recent mobile phones).

In this paper, we present work made on a Wi-Fi positioning system developed at the University of New South Wales in Sydney. The system uses GPS for outdoor positioning, and Wi-Fi fingerprinting indoors. This paper focuses on the handover between indoor and outdoor modes. Automatic handover is of great interest for several reasons. First, as this work is part of a greater project aimed at developing a navigation and information system for blind and visually impaired people [16], it is obvious that automatic handover is of great interest to these people. Second, the handover can be used to detect which building the user is coming in, and to automate map and radio map download. Finally, it makes it possible to build a standalone device capable to track goods or people indoors and outdoors without any human intervention. To our knowledge, only [15] presents a similar system, but it needs GPS and Wi-Fi to be constantly on and tracking, draining the battery of the device very quickly. We present here a power-efficient algorithm to perform the switch, and test it in terms of global accuracy, and switching detection probabilities.

The remainder of this paper is organized as follows. First, we present briefly the positioning system used as a platform for our tests. In section 3, we detail the switching algorithm and the choices that were made. Finally, we present the result of our tests on the algorithm.

II. UNIWIDE POSITIONING SYSTEM

A. System overview

The positioning application aims to provide students and staff of the university with software able to guide them through the complex campus, and provide them with information about the location of useful services such as location of theatres, ATMs, bus stops, etc. It is built on a client-server type of architecture, the server hosting all the positioning algorithms, Wi-Fi database, and all information administrators want to add about on-campus facilities. The system uses Wi-Fi fingerprinting for indoor positioning, and GPS outdoors. The switch is made automatically when the user moves from one environment to the other; the algorithm used to perform this switch will be detailed further on in this paper.

The client application allows users to find their location anywhere on campus indoors or outdoors and search for specific places on campus. An experimental feature has also been included, allowing users to see their friends' location on campus. At the moment, this feature is not fully implemented for privacy reasons. The application also allows users to provide feedback about the indoor positioning, to increase the accuracy of the system, and provide information about change in the wireless environment to the system administrators, as described in [17].

B. Server and database design

The indoor positioning part of the software uses a room-based radio map initially built by a surveyor. Instead of recording signal strength at a unique set of coordinates across the area, so called "reference points", the surveyor just enters the room he is in, and walks around it carrying the phone which records all the signal strength information. That makes the task of building the fingerprint database a lot easier and shorter. With this method, surveying the five storey building in which our lab is located only took a little more than an hour. The main disadvantage is that the algorithm will not locate a user within a room, but with reasonably sized rooms, this is not an issue for the applications of our software.

The indoor positioning algorithm implemented on the server is a variation of "classic" Wi-Fi fingerprinting, and is fully described in [18].

In the positioning phase of fingerprinting, the database is first reduced to a smaller set of fingerprints before computing the signal distance between the scan sent by the user and the scans recorded in the database. The simplest way to reduce the database is to search for all fingerprints that contain the strongest AP present in the user scan. A more elaborate way is to match a larger number of APs and also match their signal strengths. As reported in [18], matching half of the APs, and their signal strength in a range of +/- 15dBm gives the best result in terms of accuracy.

C. Applications

The applications of our system can be grouped into three categories:

- Navigation: to navigate students and staff through the campus.
- Location-Based Information: deliver information to the user, such as location of ATMs, shops, toilets, bus stops, etc.
- Tracking: tracking of assets on the campus, lone workers such as security guards, or even friends.

III. SWITCHING POLICIES

A. Indoor to outdoor

There are two conditions that can trigger the switch from indoor to outdoor mode.

First, if the server hasn't reported any indoor position for a certain amount of time, one can assume that either the user is outdoors, or in a building where the radio map has not been built yet. In both cases, it makes sense to switch to GPS, even if its accuracy is greatly degraded indoors. In our software, the phone will switch if the server hasn't reported an indoor position five times in a row.

The second condition can be triggered as follows. In a given building, a certain number of rooms are marked as "indoor transition zones". They are linked with a specific entrance to the building. For a given entrance, there can be several rooms associated, to take into account the uncertainty of the users' indoor position, inherent to Wi-Fi positioning. Figure 1 shows the indoor transition zones for the level 2 entry to the Electrical Engineering building at the University of New South Wales. These transition zones have to be manually marked as such and entered in the database. When the user enters these zones, there is a strong probability that he or she is heading outside. However, as can be seen in Fig. 1, there is also a probability that the user is just "walking by" the entry. So, only after the server locates the user in a transition zone for a given number of times, it will tell the phone to switch on GPS, and start looking for a fix. This threshold is set by default to 3, but can be modified by the administrator to reflect the size of the transition zone; the bigger it is, the bigger the threshold should be. It is important to note that the server is able to deliver a position in usually less than 500 ms; hence the "positioning rate" of the user is almost entirely dependent on network times, and on the rate at which his device is able to scan for Wi-Fi APs. With all our devices, this usually results in the device receiving a position every 1-3 seconds.

Once the GPS system acquires a fix, the software switches to outdoor mode. If no GPS fix is acquired, and the server keeps reporting indoor locations, then it means the algorithm did a false detection, i.e. the user probably just walked by the building entrance. The GPS is then switched off and the software remains in indoor mode. If no GPS fix is acquired, and the server stops reporting indoor locations, the outdoor environment is probably too "difficult" for the GPS chipset, and the software then displays the outdoor map and keeps trying to acquire the GPS signal.

B. Outdoor to indoor

The policy to switch from outdoor to indoor mode is a lot simpler. As soon as the user moves indoor, it is reasonable to assume that the GPS signal will be lost quite rapidly, especially using the lower end GPS chips that can be found on smartphones. Moreover, when the GPS signal is lost, Wi-Fi is turned on and starts scanning for APs. The result of this scan is then sent to the server. If the server reports a position, GPS is then switched off and the software switches to indoor mode. If no position is returned,

Figure 1. Indoor transition zone at level 2 of our building. It contains rooms 2Q2_3, 2Q2_4, and 2Q2_5.

the software remains in outdoor mode where the GPS tries to obtain a fix.

IV. PRELEMINARY TESTS

We here present the result of preliminary tests conducted in our building. The building was first surveyed in order to build the Wi-Fi radio map. Depending on the size of the room, between 10 and 30 fingerprints were recorded in all public parts of the five storey building. We then entered indoor transition zone information into the database.

Figures 3 and 4 show the results in terms of accuracy of two tests performed at two different entrances of the building. In both cases, we can notice that the algorithm successfully switched the positioning source, and relatively close to where the user actually moved from one environment to the other. When moving from indoors to outdoors (Fig. 4), the switch will always be delayed as the GPS needs some time to calculate the first fix, especially as the building is blocking GPS signals when the user just steps out of the building. It can also be noticed that in both cases, the accuracy of the first fix is degraded, but still acceptable.

We also started work to obtain quantitative results. We performed statistical tests to evaluate the probabilities of detection of the switch. In order to do so, 3 walking paths at Level 2 of our building were surveyed, as shown on Fig. 2. Two of these paths lead outside, through the exit door of the building. The last one just passed by the entrance. On each of these paths, 100 scans were performed every meter, for a distance of roughly 50-60 meters, depending on the path. This way, we simulate a person walking outside holding his phone in front of him a hundred times. Moreover, we have measured that our software is able to deliver an indoor position roughly every second. Sampling scans every meter allows us to also simulate the walking speed of the person. Indeed, taking every scan into account simulates a walking speed of 1 m/s. Taking one out of two scans simulates a walking speed of 2 m/s, etc… Table 1 summarizes the results for three different walking speeds for each path. As expected the results degrade as the walking speed increases. This follows intuition as it seems natural that the faster the user

Figure 2. The three paths surveyed for the statistical test.

TABLE I.
PROBABILITY OF SWITCHING FOR DIFFERENT PATHS AND SPEEDS

Path / Speed	1 m/s	2 m/s	3 m/s
Path 1	97 %	79 %	49 %
Path 2	97 %	78 %	58 %
Path 3	19 %	7 %	1 %

goes, the harder it will be for the system to detect the switch. The probabilities are also a lot lower for path 3 which is the desired behaviour; the system should not switch when the user is only passing by an entrance. More tests of this nature will be conducted in different environments and with different parameters.

V. CONCLUSION

A novel algorithm to automatically switch between Wi-Fi and GPS for indoor and outdoor positioning has been presented. It uses transition zones to detect when a user is approaching the borders of a coverage zone, Wi-Fi radio map availability in indoor environments, GPS availability in outdoor environments. It is battery-efficient as it only turns on the adequate positioning source when needed. Preliminary tests have been conducted that have shown satisfactory results in terms of accuracy. More tests are needed to check the performance of the system in terms of detection probabilities.

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Figure 3. Transition from outdoor to indoor. The green line is the true path followed. The star symbol represents the position of the user when the software switched. Yellow dots with an "o" represent locations obtained with GPS, dots with an "i", with Wi-Fi.

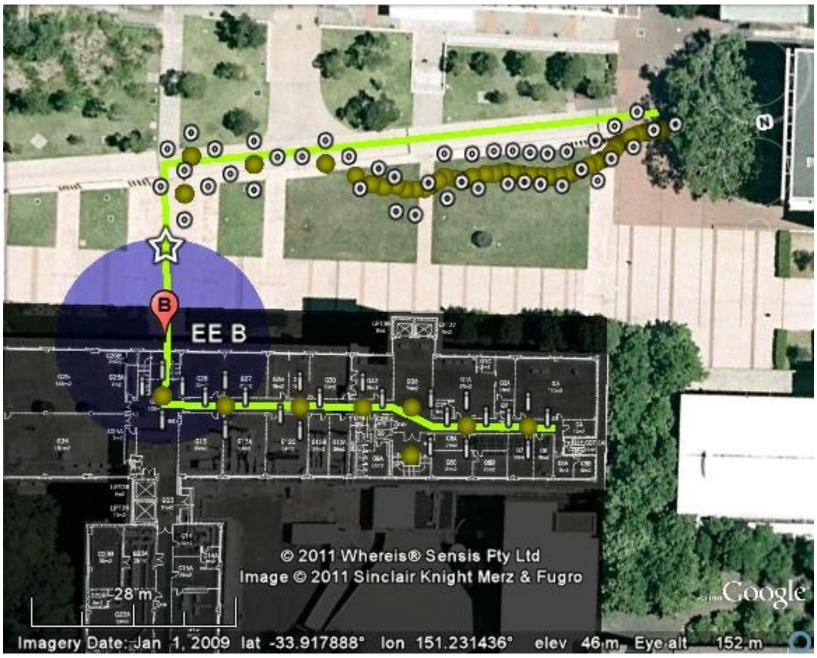

Figure 4. Transition from indoor to outdoor. The green line is the true path followed. The star symbol represents the position of the user when the software switched. Yellow dots with an "o" represent locations obtained with GPS, dots with an "i", with Wi-Fi.

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