Always Best Located, a pervasive positioning system

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***Abstract*- A new concept called Always Best Located (ABL) is introduced to achieve an indoor-outdoor pervasive positioning system. Based upon currently deployed technologies, this positioning system is shown to meet the requirements of both coverage and radio localization accuracy. Results issued of an intensive measurements campaign are used to assess the value of the predicted results.**

I. Introduction

New positioning technologies are enabling an innumerable set of new applications and services. Wireless positioning can be used to track products on assembly lines, expensive equipments in hospitals, and fleets of vehicles. *Social applications* are another set of applications targeting people in their daily activities. Location-aware reminders, instant messaging, children finder, gaming, personal security, peer to peer, navigation and local web search are just a few examples.

Each of these applications has numerous requirements on the positioning system, such as coverage, accuracy, location sample rate, etc. When it comes to social applications, the main simultaneous requirements are:

1. Ubiquitous Coverage.
2. Outdoors accuracy (~30 m)
3. Indoor accuracy (~Room level)

Coverage can be seen as the most important requirement. Location-aware applications should work at least 99% of the time in order to be adopted by a significant proportion of the cell phone users. Indoor positioning should also not be limited to small, controlled, indoor environments; it has to be available in any place users may travel to.

In addition to providing good coverage, these positioning systems have to be reasonably accurate. People are also expecting accurate positioning similar to eyesight recognition a distance, typically 20 to 30 meters outdoors, and within a distance of one room indoors.

This paper introduces the concept named ''always best located'' (ABL), aimed at building a positioning system meeting both requirements of coverage and accuracy from a combination of existing technologies.

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II. Current Technologies

So far, none of the currently deployed technologies are able to simultaneously meet both coverage and accuracy requirements. GPS, the most widely used technology, is offering global coverage and excellent accuracy but exclusively outdoors, receivers requiring direct line of sight to at least three satellites, something that cannot be achieved indoors. It is indeed in this environment that users are spending 90% of their time [1]. GPS therefore falls short on the ubiquitous coverage requirement. Also, in high rise areas where scattering and multiple bouncing are common features of GPS signals, significant positioning errors can occur.

Cellular telephony has enabled a new set of positioning technologies relying on radio base stations locations. Various algorithms have been developed using a single base station (Cell-ID) or numerous (trilateration). These technologies offer near pervasive coverage as they are available anywhere cellular networks can be reached, outdoors as well as indoors. The drawback is the poor accuracy, ranging from 100 to 800 meters. Positioning systems based on cellular telephony do meet coverage requirements but are not accurate enough, especially indoors, to meet the accuracy requirement.

Other location systems rely on IEEE 802.11 Wireless LAN (WLAN) networks. These systems are mostly used indoors, where advanced fingerprinting algorithms yield accuracy up to 1 meter [2]. However, these positioning systems only operate in controlled environments. They require knowledge of the access points' location, and an expensive training phase to obtain samples on every squared meter of the office space. These positioning systems may be suitable for an office, but cannot be scaled at the size of a city. Therefore WLAN based positioning system meets accuracy but not coverage requirements.

None of these existing positioning systems is suitable by itself to achieve the concept of ''Always Best Located (ABL)'' required to implement fully ubiquitous services. However, it seems they are complementary. For instance GPS provides good coverage and accuracy outdoors, whereas WLAN offers the best coverage indoors. Coverage and accuracy characterizing each technology has to be precisely known so that one can exploit their complementarities to build a ubiquitous positioning service. This is what we have done by conducting an extensive measurements campaign for GPS, GSM, WLAN, and Bluetooth networks both indoors and outdoors.

A. Experimental Set-up

Measurements are taken using a laptop computer equipped with GPS, WLAN, and Bluetooth adapters. An I-mate SP3i cell phone is used to take GSM measurements which are sent to the laptop computer.

Outdoor measurements were collected in five different environments of Montréal, Québec, Canada, namely downtown, residential, suburban, countryside, and highways. The equipment was place in a car, moving at approximately 20 km/h except on highways. Two series of measurements were taken in for each area – first one is used to calculate coverage, second to calculate accuracy as detailed hereafter.

Indoor measurements were taken in different buildings such as university buildings, libraries, shopping malls, offices, and train stations. The equipment placed on a moving chariot was moved at slow walking speed. Only coverage has been measured, as GPS estimates were not available indoors.

The experimental set-up is illustrated in fig. 1.

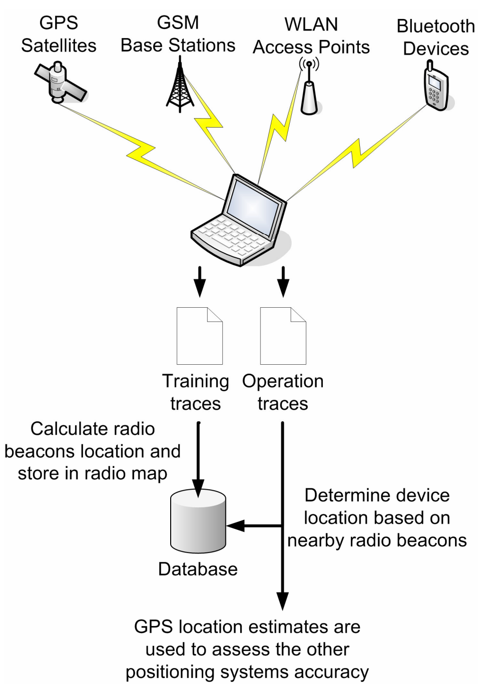

Figure 1. Experimental set-up for field measurements.

B. Algorithms

Coverage is calculated as the percentage of the measurements for which a location estimate could be obtained. In the case of WLAN, a sliding buffer has been used. Coverage is said to exist if at least one access point has been detected during the 10 last measurements.

GPS location estimates are calculated by the device, therefore no further processing is required. In order to measure GPS accuracy, ground truth would have been necessary. Unfortunately, this could not be achieved due to the large areas explored, so the fidelity of the GPS measurements has been calculated instead. This corresponds to the average distance between the two series of GPS measurements. These two series of measurements have been taken on the same road, in the same direction, between 1 and 2 hours apart. These results are not as precise as real accuracy measurements using ground truth, but it gives an idea of which outdoors environments suffer the most from GPS signal distortion.

WLAN location estimates are calculated using a typical radio beacon approach consisting of two phases. First, an offline training phase is used to calculate the location of each access point. This location is calculated as the average of the access point measurements location (obtained by GPS) weighted by their received signal strength. The resulting location is stored in a database (*radio map*) along with the number of measurements and the access point coverage – computed as the maximum distance between the access point location and all of its measurements. Then, during the online phase, location estimates are calculated using the radio map and the detected access points. For each scan, the location of the detected access points is retrieved from the radio map. The mobile device location is calculated as the average of the detected access point locations weighted by their received signal strength, number of detection, and coverage. The number of detection is used to reduce the impact of access points whose location is based on a few measurements only – their estimated location is more erroneous. Similarly, a higher weight is given to access points with small coverage as they convey more information on the mobile device location than access points with large coverage.

Two different algorithms are considered for GSM positioning. The first one, Cell-ID, uses only a single cell. The user location is considered to be the location of the cell to which he is currently connected. The second algorithm, Trilateration, takes into account multiple cells in the user's vicinity. It implements the same algorithm as detailed for WLAN.

C. Results

The results obtained for the various technologies, both indoor and outdoor are summarized in Table I .Coverage is displayed in bold and accuracy in italic. As it appears in Table I, ABL requirements are not met by one technology alone. However, they can be addressed using a combination of them, as follows.

Requirement 1: ubiquitous coverage

GSM alone meets this requirement, as at least one cell has been detected at all times throughout the experiment. GPS has shown a full coverage outdoors, but falls flat indoors. Indoors, GPS satellite signals have been detected 7% of the time, but have never been sufficient to obtain a position fix. WLAN could also be part of the solution as it offers a full coverage indoors and in dense urban areas. Bluetooth however, cannot be considered, as its coverage is insufficient in all environments. Indoors, Bluetooth devices have been detected in 31% of the measurements, but 94% of them are mobile (cell phones, laptops, headsets, etc), and therefore cannot be used as a reference point for positioning.

TABLE I
COVERAGE AND ACCURACY.
COVERAGE IS DISPLAYED IN REGULAR FONT, ACCURACY IN ITALIC

	Indoors	Outdoors				
		Downtown	Residential	Suburban	Countryside	Highways
GPS	0% -	100% *27m*	100% *3m*	100% *2m*	100% *5m*	100% *5m*
GSM: Single cell	100% *same as outdoors*	100% *219m*	100% *384m*	100% *438m*	100% *941m*	100% *704m*
GSM: Multiple Cell	100% *~5m*[a]	100% *177m*	100% *301m*	100% *318m*	100% *680m*	100% *572m*
WLAN	98% *~5m*[a]	100% *26m*	100% *27m*	92% *45m*	46% *77m*	73% *155m*
Bluetooth	31% *~2m*[a]	0% -	0% -	0% -	0% -	0% -

[a] accuracy has not been determined indoors. These values are given as examples of what has been obtained by previous research projects [3], [4].

Requirement 2: outdoor accuracy (~30m)

GPS provides the best accuracy, and therefore it is the solution of choice to meet this requirement. WLAN could be considered as a solution, since its accuracy almost reaches the upper bound of our interval. However, its coverage is not sufficient in rural areas. In addition, WLAN requires a fastidious training phase to get knowledge of all access points' location, whereas GPS can operate off the shelf.

Requirement 3: indoor accuracy (~room level)

Indoors, accuracy has not been measured in our survey. However, past research projects have shown that accuracy less than 10 meters can be met using GSM, WLAN or Bluetooth, which is enough to distinguish rooms [3], [4]. GSM and WLAN could be part of a solution, but not Bluetooth since its coverage is insufficient.

The obtained results call for an ABL positioning system built from a combination of GPS and WLAN that will meet the above requirements. In addition, two different approaches in positioning systems are also introduced: *absolute* and *place* positioning. Absolute positioning characterizes a location as a global coordinate (i.e. 45.56N 73.45W), while place positioning identifies it as a label (i.e. "at home"). Absolute coordinates are particularly useful outdoors. They can be mapped, enabling users to understand their location. Place labels are useful indoors, where people have already identified every location by room names or numbers. For instance, the labels "board room" and "cafeteria" are more meaningful than two pairs of numbers. The absolute positioning approach will be used to achieve ubiquitous coverage and outdoors accuracy requirements, while the place positioning approach will be used to accurately locate users indoors.

These two components of our positioning system are reviewed in details in the following sections.

III. ABSOLUTE POSITIONING

Absolute positioning is the first component of our ABL positioning system. It aims at providing absolute coordinates (namely latitude and longitude), continuously as users are traveling outdoors, indoors, and in between these two environments. In addition to ubiquity, the absolute positioning component has to meet the outdoor accuracy requirement. Indoor accuracy is not a primary concern; it will be handled by the place detection component.

This component is built by a combination of GPS and WLAN. GPS is used outdoors, where its excellent accuracy meets the outdoors accuracy requirement. As soon as GPS satellites signals are lost (i.e. the user is entering into a building) the system automatically switches to WLAN positioning, providing a continuous service, outdoors and indoors.

A. WLAN indoor mapping

In order to use WLAN positioning indoors, the location of the detected WLAN access points has to be known. Traditional ways to map WLAN access points – using GPS location estimates – cannot be used indoors since GPS is not available. A new and automatic algorithm inspired by previous research achievement [5] has been developed to map WLAN access points indoors.

First an outdoor map is created, placing WLAN access points (AP) at the GPS location where the maximum received signal strength has been observed. Indoors, links between detected AP are recorded. For instance, if 3 AP are measured, a link between each pair is created, and a weight is given to this link. The weight is function of the received signal strength of each AP and the time difference between their measurements. From this meshed networks of AP links, our algorithm calculates the location of the new AP which do not yet exist in the map. For each new AP, the algorithm determines the shortest path through the link network to the AP existing in the radio map. Then, the new AP location is calculated as the average of the kwon AP location weighted by the links' weight. Once these new AP locations are calculated, they are added to the radio map, and are used to calculate the user location estimates. The process of creating links and updating the radio map is operating continuously and transparently as users are traveling. This way, AP locations are constantly added and refined without requiring user interaction, yielding to a robust radio map covering both outdoors and indoors environments.

Field trials have been conducted in different buildings of the city of Montreal, and have shown that after a few visits, the indoor map is sufficiently dense and precise to maintain a continuous positioning service as users are walking through the building.

To assess the accuracy of our automatic indoor-mapping algorithm it was compared to GPS and *traditional WLAN* positioning – where access points are located using GPS location estimates. A residential district of approximately 200x200 meters has been used as test area. Our mapping algorithm has been developed for indoors environment but it is used here outside, so that it can be compared to the other techniques. Our algorithm relies on an existing radio map of the building surroundings in order to interpolate the indoor access points. So the WLAN access points on the test area borders have been mapped using GPS, and provided to the algorithm. GPS and traditional WLAN positioning are used as described in section II. Ground truth is used by taking coordinates from commercial maps. Results are presented Table II and illustrated in fig. 2. Of course, results based on our automatic mapping algorithm are less accurate, since it does not make use of GPS estimates within the test area. However its accuracy is still in the same range as traditional WLAN and meets our accuracy requirements.

By combining GPS outdoors and WLAN indoors, using our automatic mapping algorithms, a continuous positioning service can be achieved with only slight decrease in accuracy indoors.

TABLE II
ACCURACY COMPARISON OF GPS AND WLAN, BASED ON DIFFERENT RADIO MAP ACQUISITION TECHNIQUE

Positioning technique	Accuracy
GPS	3.7 m
WLAN: radio map based on GPS	8.5 m
WLAN: radio map based on our automatic indoor mapping algorithm	14.1 m

B. *Transitions*

Outdoor-indoor transitions are fast and transparent. Switching from GPS to WLAN requires less than a second. However, the first location estimates produced using WLAN may be largely erroneous. Indeed, when users are just entering a building, WLAN access points are still detected from nearby buildings. It may yields location estimates in the middle of the street, as shown in yellow on fig. 2. The solution used consists in repeating the last GPS location estimate for a short delay, to give the user time to enter more deeply into the building before the switch from GPS to WLAN positioning occur.

Indoor-outdoor transitions are simpler; WLAN is used until a GPS fix is obtained, which requires less than 10 seconds. This delay can be reduced to 1 second by sending an initialization command to the GPS receiver (NMEA $PSRF101) specifying the current time and location.

In conclusion, this combination of GPS and WLAN enables our ABL positioning system to provide a continuous positioning service, which meets our ubiquitous coverage requirement.

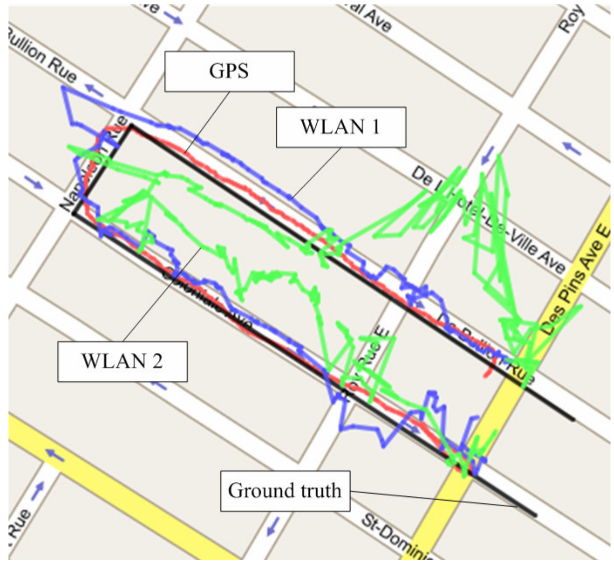

Figure 2. Location estimates obtained by GPS, and WLAN. WLAN 1 refers to the algorithm using a radio map based on GPS, while WLAN 2 refers to the same algorithm based on a radio map based on our automatic indoor mapping algorithm.

IV. PLACE POSITIONING

Place positioning is the second component of our ABL positioning system. While the absolute positioning component met ubiquitous coverage and outdoors accuracy requirements, place positioning has for objective to refine indoors accuracy by recognizing the room in which users are currently located.

First, users are asked to complete a training phase in each room to be recognized. During this training phase, WLAN samples are recorded while the user is asked to complete a form to specify a room name, a building address, a link to a floor map, and an absolute coordinate (automatically obtained from the absolute positioning component). Once this training phase is complete, the room information is placed in a directory and the room is ready to be recognized during the operation phase.

The developed algorithms are based on a probabilistic approach which has already been the subject of numerous publications [6], [7]. During the training phase, WLAN samples are recorded, and for each detected access point, the distribution of the received signal strength is modeled. According to [6], different models were implemented and the histogram model has been found yielding the best results. It consists in modeling the distribution of received signal strength into a histogram of k different non overlapping intervals of width w. The received signal strength is a one-dimensional variable bounded by min and max. The interval width can be written as

$$w=(max-min)/k. \tag{1}$$

Then each measurement M, fall into the interval

$$I=floor(M/w). \tag{2}$$

Empty intervals are set to the value 1, in order to void null probabilities later on. Finally, the histogram is normalized so that the sum of all intervals equals to 1. The resulting model is illustrated in Fig 3.

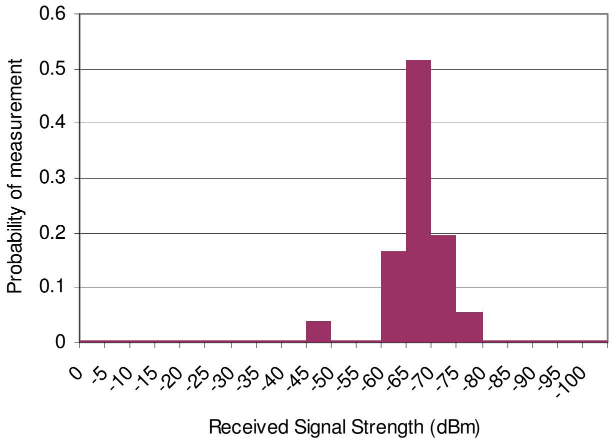

Figure 3. Histogram model, for k=20 intervals

During the operation phase, WLAN measurements are taken and compared to each room models in order to determine in which room the user is most likely to be located. Assuming the WLAN observations <o_1, o_2,..,o_i>, where o_i is the received signal strength of access point *i*, the probability $P_{Place\ j}$ the user is located at *Place j* is given by

$$P_{\text{Place j}} = \prod_{i=1} h_{\text{Place j}}(o_i), \qquad (3)$$

where $h_{Place\ j}(o_i)$ equals the value of the interval in which falls o_i for the model of access point *i* at *place j*. If *Place j* has no model defined for the access point *i*, then a small constant value is used as a penalty.

These algorithms have been tested in the research facilities of the International Institute of Telecommunications. The histogram model described above has shown the best results, recognizing the correct room 88% of the time.

V. In Situ Experimentation

In situ experimentation is currently conducted to assess whether the ABL positioning system truly meet the three coverage-accuracy requirements. A prototype has been developed, and three participants will be asked to carry it for 2 weeks. The results will be presented at the conference.

The prototype has been developed as an application for Pocket PC, and is shown in fig. 4. It includes both absolute and relative positioning components, enabling participants to define their own places. Location estimates are calculated every seconds and logs are recorded to know whether this estimate has been calculated using GPS, WLAN, or if it has been deducted from the current place.

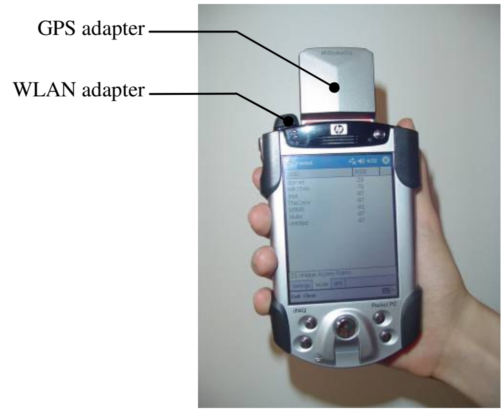

Figure 4. The prototype unit consists of a Pocket PC Ipaq h5550 integrating in one block both WLAN and GPS adapters.

VI. Conclusion

Derived from an extensive survey of existing positioning technologies, the ABL approach makes use of the best location technique available in every situation. Ensuring outdoors accuracy using GPS, indoors accuracy using WLAN, and a ubiquitous coverage by automatically switching from one to another, the ABL positioning system is a step toward real pervasive location-aware services.

References

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