Overview of Positioning Technologies from Fitness-to-Purpose Point of View

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Abstract— **Even though Location Based Services (LBSs) are being more and more widely-used and this shows a promising future, there are still many challenges to deal with, such as privacy, reliability, accuracy, cost of service, power consumption and availability. There is still no single low-cost positioning technology which provides position of its users seamlessly indoors and outdoors with an acceptable level of accuracy and low power consumption. For this reason, fitness of positioning service to the purpose of LBS application is an important parameter to be considered when choosing the most suitable positioning technology for an LBS. This should be done for any LBS application, since each application may need different requirements. Some location-based applications, such as location-based advertisements or Location-Based Social Networking (LBSN), do not need very accurate positioning input data, while for some others, e.g. navigation and tracking services, highly-accurate positioning is essential. This paper evaluates different positioning technologies from fitness-to-purpose point of view for two different applications, public transport information and family/friend tracking.**

Keywords- Location Based Service (LBS); Positioning Technologies; Fitness-To-Purpose;

I. Introduction

Location Based Services (LBS), such as navigation and tracking, location-based social networking and location-based marketing and advertising, are being widely used by many people around the world [1]. About three quarters (74%) of smartphone device owners are active users of LBS.

Global Positioning System (GPS) has been until now one of the most popular Global Navigation Satellite Systems (GNSS) in use for positioning information in mobile devices. In fact, it still remains as the main source of location information due to its low cost and high availability in outdoor environments [2]. A simple GNSS receiver commonly embedded in most mobile phones costs less than one euro. However, GNSS signals are mainly available in outdoor environments. This restricts GNSS applications to certain scenarios or imposes constrains in scenarios where GNSS are not available. Indoor scenarios are one of the best examples where GNSS are unavailable due to strong multipath, fading and shadowing and absence of line of sight. Consequently, for some LBS, e.g. pedestrian navigation in urban canyons on in indoor environments, these systems do not offer a high level of quality of positioning service.

From other important LBSs requirements' points of view GPS preserves privacy, being a downlink-only connection. On the other hand, GPS has got a high level of power consumption while working.

It is difficult (if not impossible) to find a positioning technology which can provide real-time position of users for almost free, seamlessly in indoors and outdoors, with a high level of accuracy, with very low power consumption and preserving users' privacy. Sometimes it is completely unnecessary to look for such positioning technology as the application does not need to have it. Some applications, such as location based advertisement, marketing and LBSN, might not need highly accurate position information, whilst preferring a lower power consumption and low-cost positioning technology to encourage more people to subscribe.

Fitness-to-purpose is one of the most important criteria to decide which positioning technology should be applied for an LBS. 'Fitness-to-purpose' terminology has first been published in [3] and refers to level of suitability of an item or system, for specific purpose of a system, service, etc. Fitness of a positioning technology for an LBS' purpose refers to the level of suitableness of a particular positioning technology for a particular application. This may be evaluated by considering quality of positioning service and requirement or quality of LBS that users wish to get [3]. Users' requirements, desires and characteristics have a great impact on the level of fitness to purpose. The LBS provider needs to consider all these aspects before service deployment.

This paper is structured as follows; section two explains LBS's definition and related concepts and then it categorises different applications of LBSs and enumerates general requirements of each category. Section three reviews some of most widely used positioning technologies, such as GNSS, Time Of Arrival (TOA), Angle of Arrival (AOA), Time Difference Of Arrival (TDOA), Wi-Fi positioning, Bluetooth and Radio Frequency Identification (RFID) positioning from different aspects, in order to have a better understanding of each positioning technology limitations and advantages. Section four evaluates different positioning technologies from fitness-to-purpose aspects of two applications of LBS. This is done on order to find out what would be the best positioning solution for public transportation information retrieval and for family/friend tracking applications. Finally, results of a survey which supports this paper's findings are discussed and the conclusions and further works are emphasized.

II. Location Based Services

LBS refers to the delivery of information services where the content of services is tailored to location of the user [4]. Use of LBS applications such as navigation and path finding, proximity search (location based query) for facilities such as gas stations and restaurants, emergency and security, location-based social networking, location-based marketing, etc is increasing rapidly [1]. It has forecasted that LBS will have more than double revenue in 2014 in comparison with 2011 [2] and this shows the LBS promising future.

Location data is a vital part of an LBS, which is used as an essential contextual data to exclude irrelevant responses. However, the purpose of the service might require different levels of positioning accuracy, availability, cost, etc. Thus, different services have different requirements from a positioning point of view.

As shown in Table 1, different LBS applications are categorized into five categories: 1) navigation and tracking, 2) marketing, 3) entertainment, 4) location-based information retrieval and 5) safety and security. For each category, some widely-used applications of each category are named. For each category there are some general requirements, which can vary slightly depending on different applications, explained briefly in the third column.

This paper evaluates positioning technologies from fitness-to-purpose point of view of two applications, namely the public transport information retrieval which falls into the category of location-based information retrieval, and the family/friend tracking which falls into category of navigation and tracking as two of the most appreciated LBS applications according to a survey conducted by authors. The survey's results are explained in detail in the next chapter.

TABLE I. LBS APPLICATION CATEGORIES AND REQUIREMENTS

LBS category	Application Domain	Positioning Component's Requirement
Navigation and Tracking	• Navigation • Positioning • Path Finding • Tracking • Asset Finding	- Very high availability (seamless indoors, outdoors) - Response in real-time or few seconds (in general applications) - accuracy of few meters or less - Very high reliability and continuity - Medium to low power consumption - Reasonable or cheap price - High privacy preserving
Marketing	• LB (social) Marketing • LB Advertisement • Proximity-based voucher/ Offers/ Rewards • LB Social Reward Sharing • LB Dealing	- Medium availability - Response in few minutes - Accuracy in the order of hundreds of meters - Medium reliability and continuity - Very low power consumption - Almost free or very cheap - Medium privacy preserving
Entertainment	• LB Social Networking • LB Gaming • LB Fun Sharing • Find Your Friend • LB Chatting • LB Dating	- Medium to high availability (seamless indoors and outdoors) - Response in real-time or few seconds - Accuracy in the order of tens of meter - High reliability and continuity - Low power consumption - Reasonable or cheap price - Medium privacy preserving
Location-Based Information Retrieval	• LB NEWS • Location-Based Q&A (Query) • Proximity Searching • Tourist Guide • City Sightseeing • Traffic, Weather and Transportation Info.	- Medium availability - Response in real-time or few seconds - Accuracy from a few meters (for Tourist Guide and proximity search) to hundreds of meters (for NEWS and weather) - High reliability and continuity - Low power consumption - Reasonable or cheap price - Medium Privacy preserving (depending on the application)

Safety and Security	• Emergency Services • Emergency Units Allocation • Emergency Alert Services • Ambient Assisted Living • Security Surveillance	-Very high availability (seamless indoors and outdoors) - Response in real-time or few seconds - Accuracy of tens of meters or lower -Very high reliability and continuity - Low power consumption - Reasonable or cheap price - Medium or low privacy preserving

III. Positioning Technologies

Although GPS, which is the most widely-used positioning technology, works well in open outdoor environment, it cannot provide the position of its users with an acceptable level of accuracy indoors. Microwaves are attenuated by roofs, walls and trees or experience shadowing and multipath. Alternative technologies are being researched [5, 6]. This paper categorise localisation techniques into four main categories; Radio-Frequency (RF) based positioning systems, Dead-Reckoning (DR) positioning systems, Multisensory positioning and finally Surveillance positioning systems. Subsections A to D review available technologies of each four categories in more detailed from different point of views including availability, cost, privacy and accuracy.

A. Radio-Frequency (RF)- Based Positioning Technologies

In this part some of the most widely-used positioning technologies which use radio frequency signals to find receiver's position are explained.

- *GNSS/ Pseudolite*

GNSS based positioning can achieve centimetre to few meters accuracy. Accuracy of position depends on the geometry of satellites from which signals are achievable, weather, environment of the GNSS receiver, applied positioning technique, etc. Finding position using GNSS is for free and also having a downlink-only connection, GNSS preserve privacy of its users, On the other hand, GNSS do not provide position in indoors. It takes hundreds of seconds to acquire a solution even in outdoor environments and using GNSS has got a high level of power consumption [7].

Pseudolites (PL) are ground based replacements for the satellites. Users' positions can be acquired from pseudolite systems with the same receivers as the GNSS, depending on national policy. In some countries, e.g. the UK, pseudolite systems must operate at different frequencies since it is not permitted to broadcast at GNSS frequencies. Nevertheless, pseudolite infrastructure is not available in all places, thus PL is not a low-cost solution. The accuracy and power consumption of PL positioning are same as GNSS [8, 9, 10, 11, 12].

- *Digital Video Broadcasting — Terrestrial (DVB-T)*

DVB-T has also been considered as a positioning technology due to its signal characteristics. It relies on OFDM signals, which can provide fine information regarding the channel state. Besides that, the emitters' locations are usually known, which also offers a great advantage over the other technologies. However, one of the main challenges is the low number of emitters. Besides that, the receiver has to identify and match the incoming signal to a specific emitter. This poses question on how accurate and reliable this can be done, increasing the risk of errors in the position estimation, [13].

- *WLAN*

IEEE 802.11 is certainly one of the most popular standards for wireless local area networks (WLAN). This protocol has made its way to almost every electronic device. Due to this, it has become ubiquitous in urban environments, residential and commercial. IEEE 802.11 currently operates in two frequency bands, the 2.4 GHz unlicensed industrial, scientific and medical (ISM) band and 5 GHz unlicensed National Information Infrastructure (U-NII) band.

In a positioning context, these networks have been used mostly under fingerprinting solutions, offering a relatively good performance, 5 to 10 meters, in densely covered areas [14, 15].

Since most recent IEEE 802.11 protocols rely on OFDM signals, these signals pose a new opportunity for positioning. These signals report the fine information regarding the channel state, which can be exploited in a positioning context to obtain range measurements. This metric is more reliable than Received Signal Strength Indicator (RSSI) but it also requires accurate environment models. So the accuracy and reliability are under question due to dynamic changes of environment including moving people since RF propagation changes in different situation due to absorption or reflection. Also these models are difficult to build, since most channel effects are difficult to model or understand how to properly model them. Therefore a training phase could also be necessary [16, 17].

- *Bluetooth*

Bluetooth is a wireless technology standard for exchanging data over short distances [18]. Several physical layer parameters are suitable to be considered in a positioning context, such as RSSI, Link Quality Indicator (LQ), and Transmit Power Level (TPL). However, most of these parameters are manufacturer dependent and some initial studies have reported a bad positioning performance [19]. Although, interest has been increasing with the release 4.0, since the LE protocol offers a direct relationship between the RSSI and the absolute received signal power. Having an absolute received power level indicator is seen as promising for Bluetooth positioning [19]. However it is still a short range positioning solution.

Hardware influence might be reduced by doing fingerprinting at the network nodes, instead of the mobile devices, but also raises further privacy concerns. Besides fingerprint, through the signal's angle of arrival is possible to design systems based with high precision. However, these require dedicated hardware, raising the costs in an initial phase.

B. Dead Reckoning Technologies

- *Inertial Navigation*

In [20], Inertial Navigation is categorised into two clusters; the plain Inertial Navigation Systems and Step and Heading Systems (SHS). Tactical grade Inertial Measurement Units have a drift of few meters in a minute [21], but they are quite expensive and bulky for pedestrian dead reckoning. Low cost MEMS inertial measurement units have to be constrained with an additional external feature to achieve similar accuracy as the tactical grade IMUs. Zero Velocity Updates, Map matching and external sensor aid are few possible constraints that are used [20, 21, 22, 23].

In [24], Zero Velocity detectors are evaluated for foot-mounted INS. The gait style, step size estimation and attitude determination are the key parameters in Step and Heading Systems. Furthermore, the positioning of the INS is important. Mounted on a shoe the IMU signal is more easily analysed than from a mobile device located in a pocket [24, 25].

Attitude initialisation can be aided with a magnetometer [22, 26], although usually in indoor environments magnetic perturbances are large. Map matching techniques like the cardinal heading aided inertial navigation that was used in [11]; bring the low cost MEMS INS accuracy closer to the pedestrian navigation requirements [25, 22, 27].

- *Camera Navigation*

Extracting features from successive images is one of the ways to acquire visual positioning information. A powerful processors or costly camera network are needed to find and track objects and people. Camera-based positioning consumes a lot of electricity power and battery on the device while the camera is on. In addition, large sets of data in the database are needed to store prior data such as to matching features [21, 28, 29, 30,31]. The quality of results depends on quality of input data, images, which might be affected by reflection, shadow or lightning.

C. *Multisensor*

Multisensor fusion and integration can be approached from different point of views. In [32], the main architectures are listed for sensor data fusion. The overall goal is to maximize the accuracy and minimize the complexity of the navigation system. The level of integration can be defined by the variables used in the integration. Deeper levels of integration operate in range and tracking domains while more loose integration on the position domain [26, 27, 32, 33, 34, 35, 36].

D. *Surveillance*

Surveillance positioning refers to smart environments providing the position of the user using ambient embedded sensors. The user, wearing no tags and carrying no receivers or transmitters, is tracked by the system using different alternative technologies [8], including floor pressure, capacitance sensors, thermal infrared sensors or sound source localisation techniques. Implementation cost and availability depend on the technology solution to be applied. Passive environment communicating with a mobile device decreases the computation load on the device and saves battery [37].

Table 2 summarises above mentioned positioning technologies' features from different point of views, including availability, cost, response time, accuracy, power consumption and privacy preserving.

TABLE II. POSITIONING TECHNOLOGIES'S FEATURES

Positioning Technology	Availability	cost	Accuracy	Power	Privacy
INS only (low cost MEMS)	Very high	Cheap	Hundreds of meters in seconds	Low	Very high
INS only (tactical grade)	Very high	Expensive	Few meters in seconds	High	Very high
Map aided SHS (Step heading system/ low cost MEMS)	Very high	Moderate	Few meters per hour	Medium	Very high
User Camera aided SHS	High	Moderate	Few meters in a minute	High	Medium
User Camera	Medium to Low	Moderate	10 -100s meters	High	Low
Passive environment	Medium	Expensive	Depending on technology	On network	Low
Bluetooth LE (Beacons)	Medium to low	Cheap	Few centimeters to meters	very low	medium/low
Bluetooth	Medium to low	Cheap	meters	low	medium
IEEE 802.11	High	Cheap	10s of meters	high	medium
DVB-T	high	Cheap	Couple of meters	medium	high
WLAN	Medium to high	Cheap	Couple of meters	Medium	Medium to low

IV. LBS USERS' REQUIREMENTS AND DESIRES

Friend tracking services and public transportation information retrieval are examined in this chapter. These have different application requirements, which makes it easier to show how fitness-to-purpose analysis can help in finding the best alternative positioning technology. Secondly, these two are the most appreciated applications according to the conducted survey. In the following we explain the details of the survey and the results. Furthermore we will discuss solutions by considering user's point of view and needs with the demands and advantages of different positioning technologies.

This section finds the best positioning solution for two different LBS applications, namely family/friend tracking services and public transportation information retrieval. These two applications are considered in this paper for two reasons. First, both have different application requirements, making it easy to show how fitness to analysis can help finding the most suitable positioning technology for a given application. Second, these two applications are two of the most appreciated applications of LBS according to a survey conducted during 2012-2014.

This section describes the survey and discusses its results, focusing on users' requirements and desires. Afterwards, the best positioning solution for two (most popular) applications types is obtained by performing fitness-to-purpose analysis.

A. Survey

An electronic survey using Webropol 2.0 survey software was conducted by the authors during 2012-2014 with focus on users' perception on LBS, and its requirements and trends from users' point of view. There were 119 answers from 14% female respondents and 86% male respondents. The answers were given anonymously and on a volunteer basis. 50% of the respondents were full-time workers at the time of the survey, while the rest were either part-time working (15%), unemployed (25%) or un-specified.

When asked about their expectations about positioning technologies to be available on a smart mobile device in 2017, more than 70% of the users answered that some satellite navigation technology (GNSS) is to be expected, as seen in Figure 11, while only about 60% of them answered that they would expect Assisted GNSS and indoor 3D navigation available. This also has been forecasted by European Space Agency GNSS market report [2] that GNSS will remain the most widely-used positioning technology in mobile applications. Somehow surprisingly, there was no unanimity in users' expectances about positioning technologies available on the future smartphone.

In terms of the top desired location features, the answers are summarized in Figure 2. Predictably, a good availability outdoors is desired by the majority (the answers were on a Likert scale from 1(= not at all important) to 5 (= Very important)). A little bit more unexpected was the fact that the user friendliness in reporting the location solution was preferred to accuracy and short delays in starting the location engine. The indoor accuracy seemed the least valued feature among the 8 considered features, motivated perhaps by the users' knowledge that indoor high positioning accuracy is still hard to obtain.

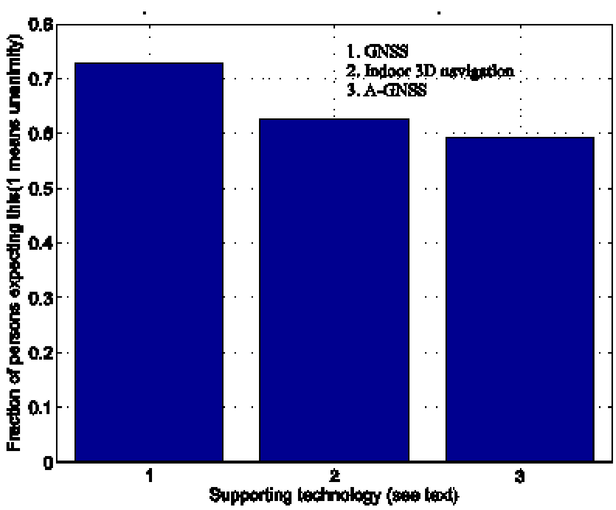

Figure 1. Expected positioning technologies (from users' point of view) on a smartphone in 2017.

In terms of most appealing LBS among a set of 10 possible LBS (see figure 3), the top three were: 1) the public transport routing service (e.g., showing several routes to reach a destination and showing the traffic status and information). 2) The automatic payments, referring to automatic checking or automatic payments to various attractions such as cinema, museums, trains and 3) family/friend tracking. The scale in here was as follows: 0 = users not interested in this application; 1 = users willing to pay up to 1 EUR/month for such an LBS, 2= users willing to pay between 1 and 2 EUR/month; 3 = users willing to pay between 2 and 5 EUR/month; 4 = users willing to pay between 5 and 10 EUR/month, and 5 = users willing to pay between 10 and 20 EUR/month. Not surprisingly, the amount of EUR that users are willing to pay for an LBS lies within the range of 1-2 EURs or below.

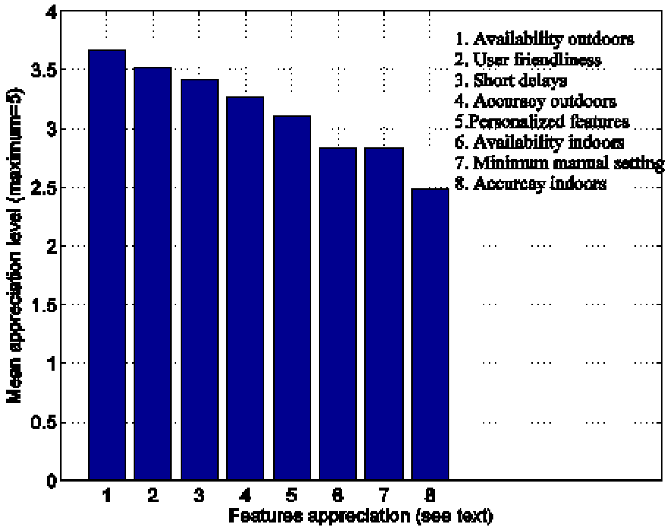

Figure 2. Top location engine features expected by the users.

B. Fitness-To-Purpose Analysis

The best positioning service for each LBS application can be found by taking into account applications' requirements, summarized in Table1, current positioning technologies limitations and advantages, summarized in Table 2 and results of conducted survey.

Considering public transportation information retrieval and family/friend tracking application, as two of most appreciated LBS applications according to the survey's results, their positioning requirements can be explained as following:

Family/friend tracking application needs a positioning engine which can provide position of the person to be tracked with accuracy of hundreds/tens of meters (all need to know is where the person is). However the position needs to be acquired both indoors and outdoors. It should have very low power consumption and be so cheap.

Bearing in mind each positioning technology's limitation and advantages, it can be understood that GPS is not a good solution for family/friend tracking since it has got a high power consumption, and it cannot provide position of user inside buildings. INS, Camera-based, passive and Bluetooth positioning need infrastructure development which might not be available in all places and also in some cases are not cheap. It seems that mobile network position such as TDOA is one of the best alternatives [38].

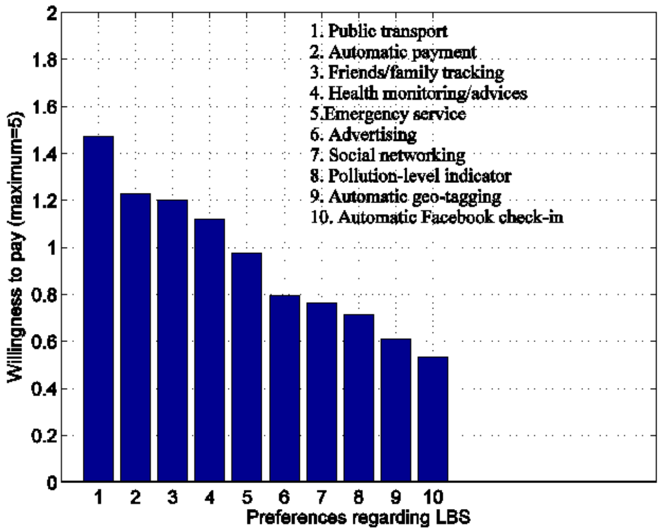

Figure 3. Preferred location based services

In regards of public transportation information retrieval, it needs a positioning service with accuracy of few meters with acceptable availability. The information need to be updated every few seconds or ideally real-time. It should have acceptable power consumption and medium privacy preserving features. Considering table 2 and above-mentioned requirement, it seems that it is quite difficult to find one positioning technology providing such a service. So it is recommended to have GNSS as outdoor positioning technology and for partially denied or indoors, a back up technology should be available. Again choosing between backup solutions depends on availability of infrastructure. Since many indoor places are now equipped with WLAN it is likely to have WLAN positioning technology almost ubiquitously. In both areas, indoors and outdoors, it is better to have network positioning services as the last option since it is providing location almost everywhere but with different degree of accuracy.

V. CONCLUSIONS AND FURTHER WORK

LBS has become a part and parcel of modern life. LBS use location data to exclude irrelevant information and services and provide contextual services to users. However finding the user location is a big challenge, due to environment characteristics and technology limitations. This paper reviewed two LBS applications from a positioning technology requirements point of view. It also evaluated positioning technologies from different aspect such as power consumption, cost, availability, accuracy to find out for each application what would be the best positioning solution. The fitness of positioning systems to LBS applications was explained in more detail with application into public transportation information retrieval and family/friend tracking. It has been found that for family/friend tracking mobile network positioning technologies such as TDOA gives a good response to most of application's requirement such as seamless indoor and outdoor availability, accuracy of tens of meters and low cost and power consumption. On the other hand for public transportation information retrieval, there is not only one positioning technology satisfying almost every requirement of the application. So the paper suggests having GPS as outdoor positioning technology and WLAN and mobile network for indoors and partially GPS denied areas. There is also a survey conducted which supports the outcome of this research. In this survey the important positioning technology features and most appreciated applications are ranked by users.

This work is the first step towards offering a glimpse into the tasks of fitting-to-purpose the design of future LBS applications and supporting technology. A link between the positioning technologies and the target applications is clearly needed and this kind of link has been so far discarded or little addressed. In addition, this paper only focused on users' requirements and points of view; however it is needed to look into the service requirement from service providers' point of view as well.

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