Towards Ubiquitous Indoor Location Based Services and Indoor Navigation

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Abstract—**Outdoor navigation services have become ubiquitously available due to small handheld devices such as GPS enabled mobile phones or dedicated mobile navigation systems. Two main drivers were necessary in order to provide widespread location based services: Acquiring positioning information with a certain degree of precision and widespread (mobile) access to computer networks to use the position information with a large information basis such as the Internet. Envisioned is a future, where indoor navigation and location based services are used as naturally as outdoor location based services are now. To achieve this long term vision where users seamlessly navigate for example from work desk to departure gate at the airport and use location based services on the way, various challenges have to be solved.**

In this paper, these challenges and open issues are discussed. The paper proposes an architecture which abstracts from different mobile devices and localization technologies. Additionally, it sketches the use of indoor topology information to increase the accuracy of indoor localization. These two presented concepts form a basis for a transition period until standards for ubiquitous indoor location based services have emerged.

Index Terms—**Indoor navigation, location based service, localization, positioning.**

I. Introduction

Location based services (LBS) integrate geographic location into services to provide added value for the user [1]. LBS and navigation have ubiquitously spread driven by evolution in mobile devices, the availability of GPS and lately of mobile Internet. Nowadays, these services are extensively used in outdoor navigation systems and mobile web applications. The success of outdoor navigation systems shows the need of users for navigation and location based information.

Navigation handhelds provide vehicle or pedestrian navigation and are able to incorporate information about traffic jams, close points of interest (POI) such as gas stations or parking spaces, and others. This additional information is either provided with the device, via system update or loaded from the Internet while in use.

Many promising applications of navigation technologies in buildings are conceivable. In large buildings like companies, factories, train stations, stores, airports, universities, stadiums and others different groups of users would use different kinds of services: rescue forces are looking for the fastest path to an injured person or maintenance personnel is looking for access to service tunnels which are hidden from other users. Customers, for example, could look up clerks, shops or offices and could navigate there using only publicly accessible paths.

These scenarios gain more importance if a standard technology emerges and people use the same device for accessing the services of any buildings. This creates the opportunity for new and more flexible resource allocation concepts, such as dynamic conference room allocation. Depending on the number of participants at the time of the conference, a system could allocate a suitable room automatically. This process would be transparent for the participants, they just arrive at the conference center and will be guided to the right room. Together with the ability to switch between indoor and outdoor positioning, a seamless navigation becomes feasible.

However, up to now, a standard technology for indoor localization is missing. Different technologies and products are available, which usually do not work together. Outdoor LBS benefit from a large amount of content available on the Internet. Map data and content are available by providers like Google, OpenStreepMap[1] or yellow page services.

Data for indoor navigation / location based services (INLBS) is characterized by a much more local and temporal context. The internal structures of buildings, such as topologies, are not always publicly known and are probably subject to more frequent changes than for example road topologies. Employees move to other offices or quit their jobs, meeting rooms are booked so rooms have to be looked up and the position of important shared devices changes, too. As this information is only locally available and possibly subject to access restrictions, it is not desirable to share this information publicly on the Internet.

Instead, the content has to be provided and managed by an operator or an organization that maintains the information contemporary. Due to a lack of standards, any INLBS is an isolated system. Up to now the integration between different INLBS providers or between indoor and outdoor systems is realized in an individual way - if it is done at all.

Indoor localization standards are expected to exist in the future. An accurate and precise localization technology for the localization of users inside buildings is the precondition for a successful adaption of outdoor LBS towards INLBS. Until this technologies exists, an abstraction of the different technologies is necessary, in order to be able to start building software on

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[1] www.openstreetmap.org

top of these technologies. By abstracting from the hardware technologies, one achieves the benefit of software reuse when the hardware is replaced.

The remainder of the paper is organized as follows: Section II describes the challenges and open issues towards an ubiquitous indoor navigation. An architecture which abstracts from the mobile device and the localization technology is proposed in Section III. Section IV sketches the use of topology information to increase the robustness and accuracy of localization. Related work is presented in Section V. The paper closes with a summary of the results and gives an outlook of future research and goals in Section VI.

II. Open Issues

In general, two preconditions are expected to be essential factors for INLBS, these are:

- An indoor positioning technology which is capable of providing position estimates with a certain degree of precision and accuracy.
- Wireless communication in order to transfer data between the infrastructure and the mobile devices.

There are additional factors, which apply for almost all handheld devices such as price, dimensions and battery lifetime. These are considered non-essential since other devices such as mobile phones or Digital Personal Assistants (PDA) are subject to the same factors.

As mentioned earlier in this paper, currently there is no common technology stack for indoor localization. To cope with this heterogeneous set of hardware it is necessary to hide as much as possible from the differences and provide a common interface for applications and services on the upper layers.

Two scenarios for positioning are conceivable:

- *Self Positioning (Figure 1):* The mobile device is able to determine its location by consuming data which is broadcasted by different base-stations. This scenario is similar to GPS, where satellites send data and the GPS device computes its positions. The location information is held inside the device and is not known by anyone else. In order to use location based services, the device has to send its position.
- *Distributed Positioning (Figure 2):* The mobile device itself is not capable of determining its own position. This could be the case for low cost, low power devices which lack the computational power or capable positioning hardware. However, it may still be possible to estimate the position at the back-end side by incorporating data from different base stations placed inside the building. The position information is held inside the back-end system. Thus, it can be used by different services and does not have to be submitted by the mobile device.

The first solution seems more likely in the long term as positioning hardware becomes cheaper due to effects of economies of scale and scope. Hardware components for indoor positioning could find their way into Personal Digital Assistants (PDA) and mobile phones making them, together with GPS, a personal, universal location aware tool. The later solution provides the possibility for low cost devices which could be given away. This scenario is also in reach, as hardware prices are dropping. Consequently, both scenarios should be supported by the back-end software.

Besides a precise indoor localization, many other requirements for a ubiquitous INLBS exist. Those requirements rise scientific challenges that have to be solved in the future in order to make the huge potential of INLBS accessible. The diversity of wireless transmission technologies and their varying bandwidths have to be considered, as existing mobile devices use ZigBee, WIFI, Bluetooth, GPRS, UMTS or others.

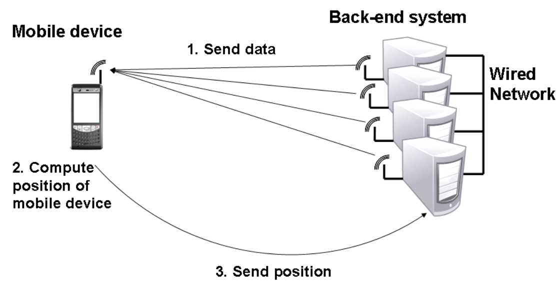

Fig. 1. Self Positioning: The mobile device estimates its position based on data transmitted from the back-end system.

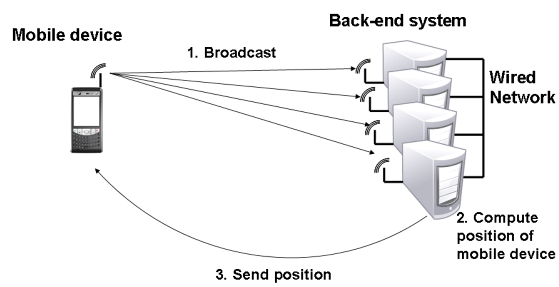

Fig. 2. Distributed Positioning: The back-end systems distributively estimates the position of the mobile device based on data transmitted from the device.

Even if neither GPS nor WIFI are part of a future standard for INLBS, the handover issue between indoor and outdoor systems is an important one. Choosing a technology for indoor or outdoor service may be difficult, GPS for outdoor use may not always be the best choice. If, for example, in urban canyons GPS reception is insufficient and WIFI predominant, it may be worth using WIFI positioning instead.

A seamless transition between outdoor and indoor navigation using the same device is a basic requirement for INLBS. For example, a user in a metropolitan area is navigated outdoor to the nearest metro station and navigated indoor to the desired track as he enters the station. A driver for the use of INLBS in different buildings is a standard position format and a standard conversion of indoor coordinates into the de-facto outdoor standard of NMEA-coordinates used by GPS.

INLBS have to be integrated between different buildings and institutions. Users who enter a building have to discover services provided by the infrastructure. A standard service discovery protocol and standard data formats and communication protocols have to be developed which enable users to use their own device in different buildings regardless of the infrastructure systems' vendor.

An intuitive graphical representation for indoor navigation has to be developed. The presentation of indoor topologies has to be a trade-off between abstraction and temporal actuality. An abstract representation like a bird's eye view 2D-map has a longer life-time but might be too abstract. A highly precise 3D-model, on the other hand, which also features landmarks inside a building, may be difficult to keep up to date as landmarks (for example wallpapers, water dispensers, picture frames with certain pictures) are subject to reordering. Other representations which could be used for indoor navigation are based on natural language or verbal guidance [2]. A sophisticated navigation mechanism using augmented reality is also conceivable. As there are many possible representations, the data format for storage and transfer of indoor topologies has to be chosen carefully, in order to support many different navigation devices.

Standardized software services (navigation, yellow-pages, ...) could help to reduce the overall costs if devices can be used in any building and feature the software clients needed. Different vendors implement those client devices, competition between them fosters device evolution. This is especially important for the user interface for the software clients, as the user interface is highly dependent on the device (graphical processing power) and is thus provided by the vendor.

Business models have to be found which on one hand amortize the installation costs of the providers but on the other hand are accepted by the users. Besides the installation costs the operation of the INLBS and the administration of the system and the content costs money and time.

Software tools have to be developed that allow for user friendly administration of INLBS and content provision. Administration includes access rights management and maintenance of the infrastructure hardware. Content provision needs integration into other facility management systems to receive up-to-date information. Additionally, the reverse direction is conceivable: Building facilities like light or heating installation might be regulated according to the number of people that are within the relevant rooms. Conversion of building schematics of different formats into topology data has to be automated by providing software tools.

The information provided by INLBS has to be protected against malicious users and security concerns have to be considered, too. That also applies for users who are concerned about data protection and privacy. Encryption and authentication standards have to be defined which can be implemented on the different mobile devices. In INLBS, not only users, but also service providers have to be authenticated. The topology system of an institution has to ensure that a person really is an employee before sending topology or navigation information. On the other hand the infrastructure has to be authenticated as well, to make sure a person gets trustworthy data from the provided services.

III. Architecture

In this section an abstract layered architecture (Figure 3) is introduced. It aims at providing a stack which is able to cope with different hardware and mechanisms for positioning. It bases on distributed transceiver stations, with possibly different localization hardware such as Bluetooth, 802.15.4(a), or others. Additionally, it abstracts from the infrastructure of the INLBS.

Ts the goal of this layer is to provide support for different positioning technologies and different mobile devices. This is important until convergence to a standard technology is achieved. Besides localization the architecture is able to provide communication with different hardware devices to the application.

A positioning stack (2-4, in Figure 3), a LBS stack (5-6) and a communication stack (7-8) are part of the architecture. Different hardware and localization methods are labeled with Greek letters and depend on each other. Their differences are hidden from the layers on top of them.

When implementing the stack, one has to consider the technical capabilities of the hardware components and the mobile device that compose the INLBS. In general, the decision which layers of the architecture are implemented on the mobile devices and which are realized in a back-end system is based on memory use, computation power, energy budget and the characteristics of the localization. Whether the localization is performed in a distributed fashion in the back-end system or on the mobile device itself is an important criteria when implementing the architecture.

The format of positions could either be logical positions like for example *city, street, house number, floor, room* or coordinates like in the NMEA data format. The data format of topologies also has to be defined. The implementation of the interfaces between the layers and the data formats is in the focus of future work.

In Figure 3 the different layers of the proposed architecture are depicted, they are explained in the following.

A. Hardware (4)

Devices like Bluetooth, ZigBee or WIFI transceivers are possible hardware of which the hardware layer is composed. The devices provide different hardware dependent measurements used for positioning. Depending on the capabilities of the hardware these values might be link qualities, received signal strengths, Time-Of-Arrival or Angle-Of-Arrival measurements. This layer is inherently distributed, as it measures at various locations. The upper layer acquires these measurements to perform positioning of a mobile device.

B. Positioning (3)

The positioning layer provides the position of the mobile device in a hardware dependent manner. If the distributed positioning scenario described in Section II is envisioned, the data samples of different transceiver stations have to be

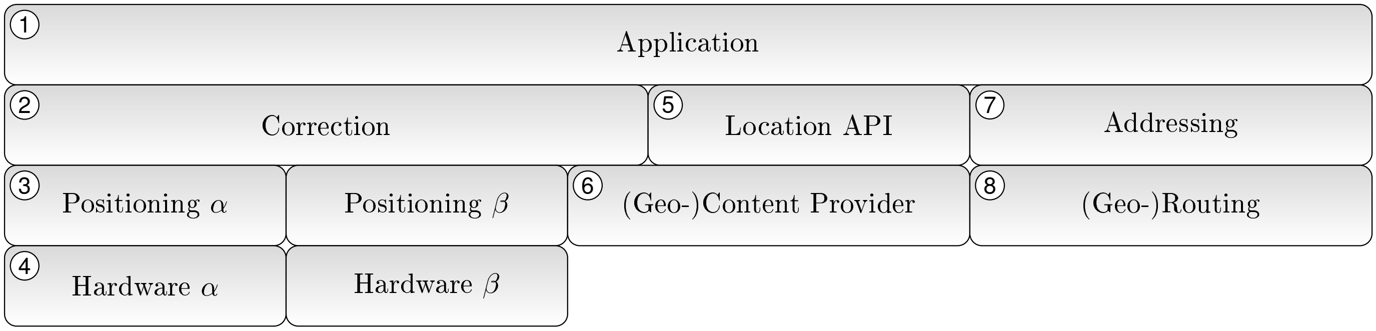

Fig. 3. Layered architecture for indoor location based services.

grouped for an entity and for a certain time in order to estimate a position. To group the different measurements for an entity, the measurements have to be identified using for example an entity ID. The samples are collected from different spatially distributed transceiver stations, thus network latency is expected due to switching delays along the route. Consequently, different samples of one entity have to be grouped by the time they were sampled. The requirement that different transceiver stations have to be synchronized to a necessary degree of accuracy arises. Once a set of samples is identified and grouped, positioning is performed. Depending on the supported positioning algorithms in this layer, coordinates of the calculated position, 2-dimensional or 3-dimensional, or the cell id are returned.

C. Correction (2)

Position estimates provided by the positioning layer (3) is expected to deliver faulty, imprecise positions resulting from imperfect localization technologies, physical limitations and boundary-effects. The general goal of this layer is to limit the error from the hardware and positioning mechanisms and to increase the confidence in the location estimation by correcting, filtering and enriching the collected data.

Possible mechanisms implemented in this layer are recursive estimation or a history of position estimates which is used to calculate the mean positions or to filter outliers. A promising approach is map matching (see Section IV which utilizes topology information provided by layer 6 and the expected behavior of the users like walking speed or access restrictions. Finally, this layer produces a position which is hardware and localization mechanism independent.

D. (Geo-)Content Provider (6)

This layer provides topology content and further meta data and provides the functionality to access this data. Typical functionality would be to look up rooms within a geographic region or return the room number for a position. Additional properties like access restrictions, information for disabled people, heights and widths for doors in a factory, weight limits for elevators and inventory information like printers, security access are stored or referenced.

E. Location API (5)

This layer provides the basic functionality which location based applications use in order to enable location awareness.

The functionality provided covers functions like reverse-resolving the name of a room given a coordinate (and a radius), resolving the coordinates for a room given a name, determining whether an entity is inside a geographic region given coordinates and a diameter and, most basic, returning the position for an entity. It uses the topology information of the (Geo-)Content provider to access the required information.

F. (Geo-)Routing (8)

In general, the technologies for position estimation and communication do not have to be the same. It is possible to support many different communication and position estimation hardware types during the transition time towards a standard. For communicating with a mobile device the information which technology to use has to be managed.

A users' mobile device resides in a specific area and has connections to the transceiver stations in that particular area. It is desirable to submit messages selectively to those transceiver stations and not all possible ones. Finally, at the transceiver stations, the communication technology for sending to the mobile device is selected and the data is sent.

G. Addressing (7)

Apart from positioning, communication with mobile entities is of importance in order to send messages, transfer navigation routes or for other purposes. Four basic communication schemes are considered in the addressing layer:

- *Unicast:* Messages are intended for exactly one mobile entity.
- *Multicast:* Messages are sent to a group of mobile entities.
- *Broadcast:* Messages are directed to all mobile entities.
- *Geocast:* Messages are directed to all mobile entities in a certain area.

The first scheme is thought for individual communication with one entity, for example for transmitting navigation information. Multicast traffic is used for example for messages that affect many people, for example the change of a gate at the airport. Broadcast messages could be used for emergency or evacuation messages. Finally, geocast messages are for example for customers of a shop that remain in the geographic region of the shop to inform them about the shop being closed soon.

H. Application (1)

The top layer is where location-aware applications reside in. These applications use the functions defined in the Location API (5), the position of the mobile device provided by the Correction layer (2) and communication APIs provided by the communication stack in order to provide their services.

Possible examples for such applications are:

- Navigation
- Selective Information Dissemination
- Yellow / White Pages
- Friend Finder
- Congestion detection

IV. Using topology information

Layer 2 of the proposed architecture in Section III performs correction of the estimated position of the mobile device provided by layer 3. A possible approach is map matching (MM) supported by topology information. To perform this task, the correction layer needs access to the building structure provided by the content provider (layer 6).

In vehicle navigation topology information is used to increase the precision of the localization. Outdoor MM algorithms are based on the discretization of the road map into a geometric representation consisting of nodes and lines (node / line representation). The raw GPS position readings are mapped to a position on a road segment to reduce the impact of GPS inaccuracies.

Using the experience gained in outdoor LBS, MM can be used for INLBS. Building topologies restrict the possible whereabouts of people and allow to increase the precision of the localization. For example, people can not reside in walls, pedestrians can not exceed a given speed or will not have access to admission restricted areas. Several topology patterns occur in buildings like corridors, stairways, elevators or walls that can be utilized to map a position acquired by a localization technology to an estimated position. MM in INLBS could be used to provide sufficient precision and robustness of the localization until a more precise localization technology exists.

A basic requirement to utilize the topology information of the building is a standard representation format of indoor topologies. To use existing outdoor MM algorithms, a transformation of indoor topologies and frequent indoor topology patterns into a node / line representation is a necessity. On the other hand, Glanzer et al. [3] argue that streets and rooms have completely different dimensions and thus existing MM algorithms can not be applied to indoor scenarios. While roads are represented by lines, structures in buildings like rooms are represented by polygons and the position of a person within a room can not be determined precisely.

An automatic transformation of a map stored in an image format into a suitable representation for indoor MM is desirable. The INLBS system must have an understanding of the restrictions that emerge from such a topology in order to perform MM.

With respect to the issue concerning topology data in Section II, it is important to identify the topology properties which can be used in MM and have to be provided by the topology data, for example access properties or meta information. Future research focuses on these topics and on the question whether additional information like moving patterns can be utilized in MM algorithms.

V. Related Work

Several other platforms and architectures have been proposed. Nexus [4] can be used for indoor and outdoor services, it generally bases on a shared global model. This is achieved by integrating federated partial models from various providers. The system consists of various Context Servers, which are registered with an Area Service Register. These Context Servers answer spatial queries and return the results to the requester. The Area Service Register is comparable to a spatially enhanced DNS where Context Servers for a region are looked up. Nexus supports additional value-added services like an event service, navigation service, geocast and hoarding. Georouters are proposed to distribute the workload of large geocasts over many servers.

MobIS [5] concentrates on a framework for mobile devices. Their design criteria are platform independence, low demands on technical expertise, rich media content and low demands on infrastructure, content deployment and reusability. It provides a JavaScript engine and content storage based on an embedded SQL server, image and video rendering as well as abstractions for using maps and position data. This system does not require a device to be connected to some network, all information could be stored in local storage space.

In [6] modeling of the building topology and features are discussed. An open platform for INLBS, called Indooria, is presented. It provides geocoding and reverse geocoding, zone based triggers, route calculation and choosing paths according to properties of the transits.

Nexus provides an interesting approach of federated models which are combined into one global context model. However, no details on navigation or specific indoor issues are given. MobIS focuses on the handheld device, a connected back-end system is not necessary. Indooria has a strong focus on indoor navigation and the modeling of topologies.

[7] discusses the handover issue between indoor and outdoor positioning mechanisms for WIFI and GPS based systems. For four different scenarios the position accuracy and battery consumption were investigated. The scenarios were: always prefer GPS, always prefer WIFI, prefer GPS until lost signal then prefer WIFI until lost signal and prefer GPS upon continuous readings.

Several geometric MM algorithms with respect to vehicle navigation, like Point-to-Point, Point-to-Curve or Curve-to-

Curve [8], have been proposed over the past years. More complex algorithms use mathematic models like Kalman-filters, Fuzzy-logic or Hidden-Markov-models. In [9] MM is modeled as a stochastic classification task considering position history, road map topology and driving restrictions. In [10] topology information is used in the following way: if a previous measure had a high confidence, only adjacent road segments are considered for the following position estimate. If the confidence is too low, a range query is performed.

Several approaches utilizing MM in INLBS to increase localization accuracy have been proposed. In [11], [12] a particle filter is used: Each particle represents a possible position of the user. Topology information is used to discard particles that cross walls or other obstacles. In [13] MM is applied to a dead reckoning pedestrian indoor navigation system. The MM algorithm considers floor changes by elevators or staircases based on a link / node representation of the building. A point-to-curve matching with a weighted sum of azimuth, horizontal distance and elevation error as error measure is used.

VI. Conclusion

This paper presents the vision of ubiquitous indoor navigation and indoor location based services. To accomplish this goal many open issues have to be solved, some of them have been addressed in this paper.

Important drivers towards ubiquitous INLBS are standardized indoor positioning technologies. Software standards provide interoperability across different vendors. Until positioning standards have emerged, a transition and convergence phase has to be supported by enabling different technologies with the same software system. To allow for seamless navigation, the issue of indoor / outdoor handover has to be solved. While outdoor navigation benefits from a relatively static road topology which is exploited by many map matching algorithms, this subject has to be readdressed for indoor navigation. As mobile devices roam through different buildings of large institutions, addressing for communication of these devices becomes an issue. Geographic addressing schemes for indoor services have to found and standardized, too. A great diversity of handheld devices is expected to use INLBS, these devices differ in size, battery power, computational power and screen resolutions, thus the representation of the INLBS services has to be adapted. Realizing INLBS, however, will cost money, consequently business models have to be found which help amortizing these investments. Other very important issues are security and privacy concerns of the institutions and users.

Solutions for these challenges will be the key factors towards widely-adopted INLBS and make novel applications possible.

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