Indooria - A Platform for Proactive Indoor Location-based Services

Peter Ruppel
Mobile and Distributed Systems Group
Ludwig-Maximilians-Universität
Munich, Germany
Email: peter.ruppel@ifi.lmu.de

Cornel Klein
Corporate Research and Technologies
Siemens AG
Munich, Germany
Email: cornel.klein@siemens.com

Claudia Linnhoff-Popien
Mobile and Distributed Systems Group
Ludwig-Maximilians-Universität
Munich, Germany
Email: linnhoff@ifi.lmu.de

***Abstract*—Positioning mobile terminals, persons and assets inside buildings opens several new possibilities for service providers and their users. Many different indoor positioning systems have been developed in the past, which differ e.g. in the underlying infrastructure, accuracy, energy consumption, or frequencies used. But sophisticated indoor location-based services (I-LBS) require not only knowledge about the targets' positions but also detailed information about the topology of a building. A building topology comprises shapes of rooms together with their interconnections and other meta data like escape routes or entrance restrictions. That allows e.g. to calculate walking distances, to determine the accessibility for a certain room or to define topological zones in the building. However, bringing together indoor positioning systems and building topology information raises a couple of problems. In this paper we present an approach that combines real time position data with building topologies. Requirements and a classification for future indoor LBS are given and an approach for modeling the appropriate topologies as well as integrating position data from several positioning systems is presented. An open platform has been developed which offers interfaces for indoor LBS developers and providers e.g. to automatically detect proximity between mobile assets, or to calculate routes between locations in the building, which can be used by indoor navigation applications.**

I. Introduction

In the past years much research was done in the field of Location-based Services (LBS) [1] on how to locate, track and monitor mobile entities inside buildings. Several positioning systems have been developed, and there are many products already available on the market. These products often come together with several graphical user interfaces and other interfaces that also allow e.g. the integration into existing asset management, staff administration, or security applications. The measurements that are used by these systems to calculate a position of a mobile entity include WiFi signals, the sensing of nearby RFID tags, ultrasonics, infrared light, or ultra wideband signals. There are many possible scenarios for an indoor positioning system (IPS), which is sometimes also called *Real Time Location System* or *Real Time Tracking System*. In general, IPSs can measure and compute the current positions of mobile targets, i.e. Euclidean coordinates, string representations for room identifiers, or graphical representations like maps. One main advantage is that the disposition of assets can be planned much more efficiently and thus monetary costs can be saved. At an airport or inside a hospital many movable resources are provided redundantly because in case of need a staff member should not have to search for an available resource for too long. Especially if these resources are very expensive (like. e.g. a defibrillator or a prime mover), the costs for deploying an IPS can easily pay off the costs for redundancy.

At the same time proactive LBS are emerging. They constantly monitor and observe the positions of mobile targets and automatically trigger events based on the movement of the targets. Such events include entering or leaving a certain geographical area or approaching another person. Aside from the problem that constant network connectivity may be required, also energy and privacy issues need to be taken into account.

However, a comprehension of proactive *Indoor Location-based Services (I-LBS)* is missing so far. Looking at the available I-LBS and solutions, they all have in common that until now there is no standardized way in which the topology of a building can be described or services could access information not only with respect to the positions of entities in the building, but also spatial and contextual relations between the entities. Representations for the topology of a building may vary depending on the requirements of the service. Especially the accuracy requirements for calculated walking distances affect the resolution (and thus the complexity) of the building topology. Looking at current outdoor location-based services there are many existing service providers that offer e.g. maps, route calculations, search for nearby points of interests (POIs), or even the possibility to be alerted if a mobile entity approaches.

A scenario for future I-LBS could might look as follows: As a user enters a building, her mobile device automatically downloads a map of the building and shows the position of the user on the map. As the user moves through the building, nearby entities of interest (EOIs) like a colleague that she works together with, or a device that needs maintenance are shown on the map. If the user has an appointment at a certain time in a certain room, her device automatically reminds her in time and takes into account the time she will need to walk from her current position to the room.

From a technical perspective such a scenario raises many questions, including how the service discovery is done, which indoor positioning system should be used, how the building topology can be described, which privacy aspects are important and how the overall architecture should look like.

In this paper we present an approach to model building topologies in a way that an IPS can be easily integrated and walking distances between arbitrary locations in the building can be computed. An open platform called *Indooria* is shown that offers several interfaces for proactive indoor location-based services.

In the next section, requirements for I-LBS are identified, a role model is presented and the building topology is described. In section III an open platform for proactive I-LBS is presented and discussed. Section IV covers related work and section V concludes the paper.

II. Proactive Indoor LBS

Location-aware services for indoor environments belong to the class of context-aware services. They utilize position and location information from different sources and offer a specific functionality to the user or to another service. Examples for I-LBS include asset management, staff tracking, patient support, security and safety applications, gaming, tourist guides, facility management and others. Position and location data can be derived from different kinds of sources like WiFi positioning systems, RFID signals, measurement systems based on ultrasonics or infrared light, or ultra wide band positioning systems [2]. Like in outdoor environments the positioning systems can be either terminal-based, network-based, or terminal-assisted; depending on whether the position is calculated on the device, by the network, or in a hybrid fashion. The calculated position itself is expressed either through a coordinate in an Euclidean or spherical coordinate system, or through symbolic identifiers, e.g. a room number or floor identifier (cf. II-C).

Proactive I-LBS observe the positions of targets inside buildings and automatically trigger an event e.g. when different targets approach the same room or part of the building, or when the topological distance between a target and a room falls below a certain threshold. Constantly measuring positions often results in a high energy consumption on the devices especially when a high spatial-temporal resolution for positions is required by the application. See [3] for an approach to reduce the amount of transmitted messages in a WiFi positioning system.

Following the classification for LBS in [1], I-LBS can be classified among the following features:

- The interaction between user and service is either reactive or proactive. The former handles queries in a synchronous request-response manner, whereas the latter is asynchronous and events are generated once a predefined condition comes true.
- Relationship between user and target: for self-referencing services the roles of the user and the target that is being tracked refer to the same entity, whereas in cross-referencing services the position of the target is revealed to a third party.
- Mapping of position data: many services only present a visual map to the user (e.g. a floor plan with positions marked on it) and they only map position data onto a 2D space. More advanced services also take into account the building topology (e.g. to calculate a route) and map position data onto a topology.

In this paper we focus on both reactive and proactive, cross-referencing services which utilize a topology as well as a 2D space. In the following, requirements for I-LBS are described, a role model is presented and fundamentals for a building topology and a topology graph are described.

A. Requirements

Both reactive and proactive I-LBS require a way to locate a target. For reactive requests the current location of a target can simply be polled once it is needed whereas proactive services require interfaces which inform the service about changed positions. Many I-LBS need to calculate distances between entities in a building, which will normally be the walking distance. Thereto a topology of the building is needed that stores the physical shape and connectivity of rooms in the building [4]. The walking distance between two positions p_1 and p_2 in a building is defined as the shortest possible path from p_1 to p_2 in the building topology. Depending on the application, the positions have to be expressible by coordinates as well as by human readable designators. As users can enter a building in different roles like e.g. a staff member, a visitor, or a technician, such properties have also to be taken into account when computing walking distances.

Another requirement is the representation of zones that describe certain areas in the building. Zones are used by many I-LBS to observe certain parts of a building or to dynamically configure devices with zone-based trigger conditions. A zone may be expressed e.g. by a set of room identifiers, by a polygon, or by a position P and a distance d. In the latter case the resulting zone contains all locations in the building that are accessible from P within a distance $\leq d$, whereas the distance can be either an Euclidean or a walking distance (i.e. topological distance).

B. Role model

Figure 1 shows a role model for I-LBS, which extends the existing role model of [5]. The model provider and the model

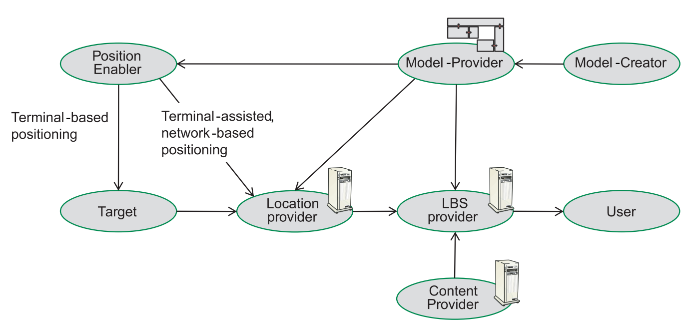

Fig. 1. Role model for indoor LBS

creator are the two roles that are specific for I-LBS and which enable the usage of building topologies.

- Position enabler: maintains the component that is responsible for measuring and calculating positions of the target. If terminal-based positioning is applied, the position enabler resides in the target.
- Target: the entity being tracked. The target may be a vehicle, a person, a bag, or an instrument or else.
- Location provider: collects and holds the positions of the targets. It offers interfaces for the LBS provider to request the position of a target or to be notified about spatial events.
- LBS provider: the service provider which executes the location-based service.
- User: the user of the service.
- Model provider: offers an interface to access building-specific data like floor plans or topological distances. The model provider can be accessed by both the Location Provider and by the LBS provider, whereas the former can run e.g. distance calculations and the latter accesses map data.
- Model creator: responsible for generating the building topology.
- Content provider: can be any other party that offers additional information, e.g. a POI database.

In the following we discuss fundamentals for building topologies that are generated by a model creator.

C. Building topology

Permanent information about the physical structure of a building resides in the *building topology*. Building topologies can be derived from different kinds of sources. A common way is to use blueprints or other maps and convert them manually into digitalized polygons as in [6]. It is also possible to parse existing digital maps e.g. from CAD files that are commonly used by architects. However, in such files the shape of a room is often represented through many different polygons on different layers and as there is no standard that requires a single polygon for each room it normally requires a great deal of labor to achieve the conversion.

To store a building topology and to calculate e.g. the walking distance between two rooms, several representations can be used. A geometrical representation contains the exact shape of each room within an Euclidean coordinate system, whereas symbolic representations use abstract identifiers to express relationships between areas in the building [4]. For example sets, simple hierarchies, graphs and subgraphs are utilized for symbolic representations.

A hybrid approach is necessary that combines geometrical and symbolic representations in order to compute walking distances not only between whole rooms but also between arbitrary positions in the building.

We propose to describe a building topology by a set of *rooms* and *transits*. Each room is connected to one or more other rooms by transits. A transit associates two rooms (which may also be located on different floors) and indicates a direct connection between them. The shape of a room is described by a two- or three-dimensional polygon, which represents the physical borders of the room. If a room is of concave shape it is necessary to further divide the room into convex sub-polygons (see below). Different kinds of transits are possible: a starting point and an end point can be used to indicate a simple transit like a door or a narrow passage, but when it comes to more wider interconnections between rooms it may also be necessary to describe the transit by a two- or three-dimensional polygon (see figures 2 - 5). Each transit has also certain attributes that indicate e.g. whether the transit is directed or whether it belongs to an emergency route and normally must not be passed. The properties of rooms and transits together define the building topology.

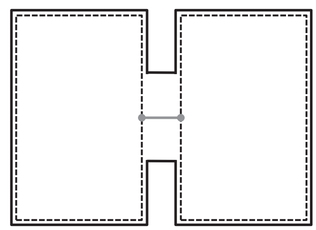

Fig. 2. Two-point transit between room A and B. Solid lines: physical walls. Dotted lines: room polygons.

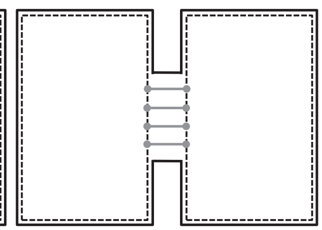

Fig. 3. Four two-point transits. Each pair of points indicates a connection between A and B.

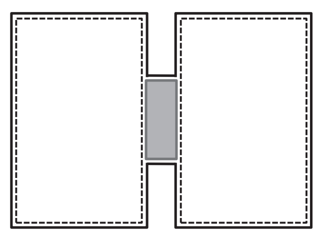

Fig. 4. 2D transit polygon

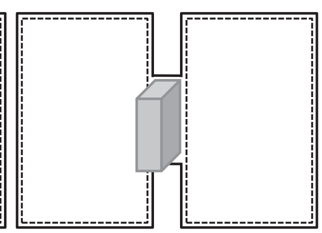

Fig. 5. 3D transit polygon

Within such a topology, a coordinate together with an associated floor can easily be mapped to the corresponding room and vice versa as the polygon for each room is known. Based on the rooms and transits, a directed weighted graph is generated that allows the computation of walking distances between arbitrary points in the building. This topology graph $G(R, E)$ consists of the set R of room nodes (vertices) and the set E of weighted edges. For each transit $t_k(i, j)$ between room i and room j (where $i \neq j; k =$ # transits between i and j) one or several pairs of room nodes rn_i, rn_j are created, which represent the connection point(s) between the two rooms. An edge $e_{(i,j)_k}(rn_i, rn_j) \in E$ is created with a weight $d[t_k(i, j)]$ that denotes the distance between rn_i and rn_j. Multiple transits between a pair of rooms are necessary when the two rooms are connected by two different ways like an elevator and an adjacent escalator. Each edge is also flagged with the properties of the corresponding transit such as staff, visitor, stairs, elevator, etc.

Two major questions arise during the generation of the topology graph and computation of walking distances:

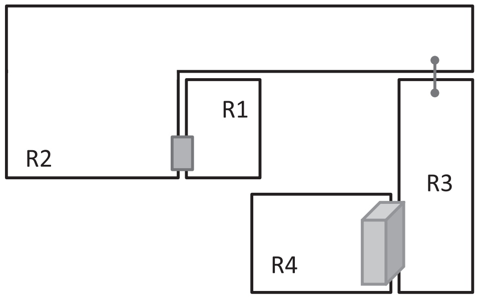

Fig. 6. Four rooms $R1 - R4$. $R1$ and $R2$ are connected by a 2D transit, $R3$ to $R2$ by a two-point and to $R4$ by a 3D transit. $R2$ has a concave shape, the other rooms are convex.

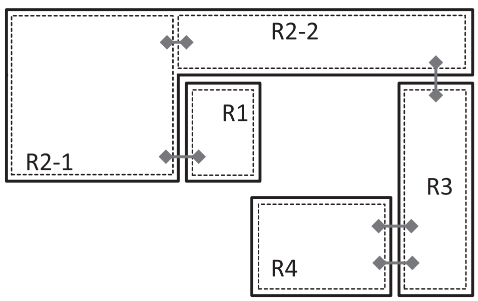

Fig. 7. Generated topology graph. $R2$ has been split up into two convex sub-polygons $R2$-1 and $R2$-2. Due to its width the 3D transit between $R3$ and $R4$ has been converted into two pairs of room nodes (square nodes in the figure) and two edges have been created.

1) How to compute $d[t_k(i,j)]$?
2) How to calculate walking distances within rooms which are of concave shape?

When the model creator generates the topology she has to make sure that all room polygons are convex. Rooms with a concave shape need to be split up into convex sub-rooms. Several algorithms for converting concave to convex polygons exist, see e.g. [7].

The distance between two room nodes that are located in the same room is the Euclidean distance between the coordinates of the two room nodes. The distance between two connected room nodes in different rooms is defined by the properties of the corresponding transit. For transits that reflect simple doors or passages the Euclidean distance can be applied, too. Wider hallways or stairs need to be converted to several room nodes.

Figures 6, 7 and 8 show a simple example for the generation of a topology and the computation of walking distances. The rooms $R1 - R4$ in figure 6 are connected by three transits. $R2$ is a concave room and has to be split up into two sub-rooms (figure 7). The exact set-up of the sub-rooms depends on the specific segmentation algorithm and its parameter values. Then the topology graph is created and due to the width of the transit between $R3$ and $R4$ two edges have been generated. In figure 8, the walking distance between two entities a and b is illustrated.

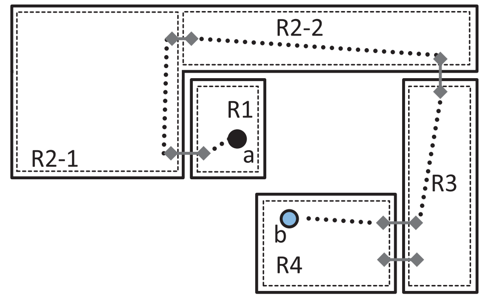

Fig. 8. Walking distance between entity a and b.

D. Joining position data to the topology

According to the role model described above the Location Provider needs to join the position data from the Position Enabler to the topology, which is maintained by the model provider. If the positioning system delivers symbolic identifiers like room or floor numbers, these identifiers can easily be mapped. However, if the positioning system provides coordinates to the location provider, several parameters need to be taken into account. Many IPSs use an internal coordinate system, which corresponds e.g. to a bitmap image where the position of an object is given by the (x,y) coordinate in the image. At the same time such bitmap images are often used e.g. by WiFi positioning systems for internal calibration purposes. Different map scales may be used for different floors, which also need to be considered while mapping a coordinate to the topology.

The positions that are calculated by the IPS can suddenly vary e.g. because of temporary radio interferences. But a small change in the Euclidean space can cause a huge change in terms of topological distance. Imagine e.g. that entity b in figure 8 moves a little bit up and to the left so that its new position is now in room $R1$. With respect to the Euclidean distance it may only be a slight change but the change in walking distance space is more than five times longer. In future work such effects could be used to further increase the accuracy of the positioning system.

III. A PLATFORM FOR PROACTIVE INDOOR LBS

The open platform *Indooria* has been developed, which allows to create topologies for buildings, integrates position data from indoor positioning systems, and provides interfaces for external services. That way I-LBS developers can easily access locations of targets, obtain walking distance calculations, and subscribe for different location-based events. Maps and floor plans with different scales can be used and topologies may be drawn by hand or may be loaded from an external file. The topology graphs are generated as described above and the properties of each transit can be configured individually. Multiple floor maps can be aligned in the buildings' coordinate system.

For example the platform provides geocoding and reverse geocoding functions, current locations of mobile targets can be polled, and zone-based triggers can be set. Routes between arbitrary locations in the building can be calculated and the paths are chosen according to the properties of the transits and the query, i.e. for example wheelchair accessible paths or staff-only routes are taken into account. Proximity as well as separation between mobile and stationary targets can be detected. The platform has been successfully tested with Ekahau, which is a commercial WiFi-based terminal-assisted positioning system. Each target periodically measures the received signal strengths from access points within range and transmits them to the positioning engine where the position estimation is done.

IV. Related Work

This section gives an overview of existing location models [4], symbolic and geometric coordinate systems [8], and existing platforms and positioning systems for I-LBS. In [9] a layered architecture following the Location Provider specified by the Open Geospatial Consortium is described, which uses a hybrid location model. Hohl et al [10] focus on modeling the environment, but not on connecting to positioning systems. Another model uses an exit hierarchy to capture spatial connectivity between rooms [11], [12]. The framework in [13] is based on a hierarchical location model and examines the distribution of location data among distributed servers. In [8] also symbolic and geometric coordinate systems are used, but an interface for positioning systems is missing.

Indoor positioning systems are available already for a couple of years. Many successful approaches utilize WiFi radio signals [2], [14], [15], [16], [17], as WiFi networks are available on a large scale and in the meantime commercial solutions are offered by several companies. Also very accurate ultra wide band positioning systems have been introduced [18].

V. Conclusion

In this paper we have presented an approach to model the topology of a building for indoor location-based services and for combining position data from indoor positioning systems with building topologies. Requirements and a role model have been discussed and we presented an open platform that can be utilized by different indoor LBS.

Future work includes the automatic generation of topologies from different digital sources and the augmentation of indoor positioning systems by observing changes in the topological distance. As many architects use standardized representations for their blueprints, a promising approach would be to develop a parser which generates building topologies automatically from construction plans. Secondly, erratic jumps in the positions that are caused e.g. by radio interferences could be avoided when filters are used that also take into account the corresponding change in the topological space and which eliminate jumps that are too far.

References

[1] A. Küpper, *Location-based Services - Fundamentals and Operation*. John Wiley and Sons, 2005.

[2] J. Hightower and G. Borriello, "Location systems for ubiquitous computing," *IEEE Computer*, vol. 34, pp. 57–66, 2001.

[3] M. B. Kjrgaard, G. Treu, P. Ruppel, and A. Küpper, "Efficient indoor proximity and separation detection for location fingerprinting," in *Mobilware 2008, First International Conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications*, Innsbruck, Austria, 2008.

[4] C. Becker and F. Dürr, "On location models for ubiquitous computing," *Personal Ubiquitous Comput.*, vol. 9, no. 1, pp. 20–31, 2005.

[5] A. Küpper, G. Treu, and C. Linnhoff-Popien, "Trax: A device-centric middleware framework for location-based services," *IEEE Communications Magazine*, vol. 44, no. 9, pp. 114–120, 2006.

[6] C. Stahl and J. Haupert, "Taking location modeling to new levels: A map modeling toolkit for intlligent environments," Saarland University, Tech. Rep., 2006.

[7] S. B. Tor and A. E. Middleditch, "Convex decomposition of simple polygons," *ACM Trans. Graph.*, vol. 3, no. 4, pp. 244–265, 1984.

[8] C. Jiang and P. Steenkiste, "A hybrid location model with a computable location identifier for ubiquitous computing," in *UbiComp '02: Proceedings of the 4th international conference on Ubiquitous Computing*. London, UK: Springer-Verlag, 2002, pp. 246–263.

[9] A. Ranganathan, J. Al-Muhtadi, S. Chetan, R. Campbell, and M. D. Mickunas, "Middlewhere: a middleware for location awareness in ubiquitous computing applications," in *Middleware '04: Proceedings of the 5th ACM/IFIP/USENIX international conference on Middleware*. New York, NY, USA: Springer-Verlag New York, Inc., 2004, pp. 397–416.

[10] F. Hohl, U. Kubach, A. Leonhardi, K. Rothermel, and M. Schwehm, "Next century challenges: Nexus—an open global infrastructure for spatial-aware applications," in *MobiCom '99: Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking*. New York, NY, USA: ACM, 1999, pp. 249–255.

[11] H. Hu and D.-L. Lee, "Semantic location modeling for location navigation in mobile environment," *mdm*, vol. 0, p. 52, 2004.

[12] D. Li and D. L. Lee, "A lattice-based semantic location model for indoor navigation," in *The Ninth International Conference on Mobile Data Management (mdm 2008)*.

[13] J. Roth, "Detecting identifiable areas in mobile environments," in *SAC '06: Proceedings of the 2006 ACM symposium on Applied computing*. New York, NY, USA: ACM, 2006, pp. 986–991.

[14] P. Castro, P. Chiu, T. Kremenek, and R. R. Muntz, "A probabilistic room location service for wireless networked environments," in *UbiComp '01: Proceedings of the 3rd international conference on Ubiquitous Computing*. London, UK: Springer-Verlag, 2001, pp. 18–34.

[15] T. Kitasuka, T. Nakanishi, and A. Fukuda, "Wireless lan based indoor positioning system wips and its simulation," in *Nara Institute of Science*, 2003, pp. 272–275.

[16] M. Youssef and A. Agrawala, "The horus wlan location determination system," in *MobiSys '05: Proceedings of the 3rd international conference on Mobile systems, applications, and services*. New York, NY, USA: ACM, 2005, pp. 205–218.

[17] P. Bahl and V. N. Padmanabhan, "RADAR: an in-building RF-based user location and tracking system," 2000.

[18] S. Gezici, Z. Tian, G. B. Giannakis, H. Kobayashi, and A. F. Molisch, "Localization via ultra-wideband radios," *IEEE Signal Processing Magazine*, vol. 22, pp. 70–84, 2005.