Smartphone-based information and navigation aids for public transport travellers

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Abstract

Digital navigation assistance on Smartphones has recently gained high attention due to capable mobile devices, off-board based navigation software and advancements in wireless network technologies. Mobile information and navigation aids can assist travellers in non-trivial navigation and orientation tasks in unknown geographical regions or transport systems. Whereas car navigation has reached a certain level of maturity, assistance for multimodal travellers especially in public transport networks is still in its infancies. Integration of mobile multimodal journey planning and navigation and guidance in complex public interchange facilities is not adequately addressed by existing systems. Thus, in this paper we propose a personal travel companion on Smartphones for assisting multimodal travellers. We focus on the topics mobile journey planning, pedestrian route calculation, navigation and guidance in public interchange buildings and seamless transition between indoor and outdoor positioning. Moreover the paper describes the prototypical implementation on Off-the-shelf Smartphones and evaluation results.

1 Introduction

One of the most important needs of society today and tomorrow is mobility. Mobility is always closely related to travelling, describing a person's task of moving from place A to place B. Travelling can be done using different transport means, including individual motorised transport or public transport. Travelling to foreign places is considered as non-trivial navigation task [26]. Wayfinding in unknown geographical regions demands spatial knowledge which can be provided by navigation aids [5],[23]. Recent technological advancements in the field of Location-based Services and Telecartography build the basis for digital navigation assistance.

While more and more car drivers are used to relatively mature guidance and navigation systems, providing trip information, guidance and orientation for public transport travellers is still an open issue. Investigations have shown that public transport systems are complex [16] and often provide obstacles for travellers which are not used to public transport systems. Digital information and navigation aids can provide continuous on-trip assistance and thus overcome existing barriers.

When we take a closer look at travelling in the public transport system we can distinguish between two typical travel situations: travelling with public transport means where travel routes are fixed in time and space and wayfinding situations in interchange facilities or in the surrounding areas of public transport stops. Digital information and navigation aids for public transport systems have to cope with both travel situations. Providing overall trip information containing information on timetables, transport means, interchanges and final stops requires trip management on mobile devices. Finding the way from an address to the nearest transport stop or from the final transport stop to an address requires outdoor pedestrian navigation. Finding the way in public transport interchange facilities requires indoor navigation. A combination of both is needed if the pedestrian route starts in an interchange building (e.g. an underground station) and leads to an address or public transport stop over ground.

Due to the constantly increasing technical advantages of Smartphones, pedestrian navigation recently has gained high interest as one of the potential mobile killer-applications in the near future. However, pedestrian navigation on Smartphones is still in its infancies. Most of the commercially available systems were originally designed as car navigation systems and are now sold as pedestrian navigation systems with only minor modifications (e.g. Wayfinder Navigator [36]). An integration of public transport trip management and indoor as well as outdoor guidance is not yet achieved by existing systems. The missing link is a mobile traveller assistance system for palm use providing on-trip information and guidance according to specific travel situations on multimodal journeys[1].

Having this vision in mind, a consortium of Austrian and German transport associations, research organisations and companies, led by the biggest Austrian public transport association, the Verkehrsverbund Ost-Region (VOR)[2] has worked over the last three years to integrate and extend existing travel information systems in order to achieve continuous personal on-trip assistant for public transport travellers. The goal was to overcome the deficiencies of heterogeneous, not integrated systems for multimodal journey planning and pedestrian navigation in order to provide new approaches to passenger guidance and information, which should increase the attractiveness of public transport.

Our approach to a multimodal travel assistance application on Smartphones combines two modules. The first module is a browser-based mobile access to a server-based multimodal journey planner which allows users to calculate multimodal routes between given start and end points. The result is composed of individual trip segments tagged with information about type of transport and estimated travel time. The second module provides an off-board navigation service that guides the user on outdoor as well as indoor pedestrian routes. Both components are integrated in a mobile application called the personal travel companion that can be accessed by public transport travellers whenever and wherever they want or need to.

The main questions answered in this paper are how to bring multimodal journey planning and trip management to mobile devices, how to enable location-based journey planning on the Smartphone, how to provide guidance and orientation to passengers in interchange situations and how to assist travellers in finding their ways to and from addresses or public transport stops.

The paper is structured as follows: First we describe requirements for providing information and navigation aids for public transport travellers. Building on these requirements we describe related work as well as the design and prototypical implementation of a personal travel companion for Smartphones. We focus on the topics mobile journey planning, route calculation, navigation and guidance in and in the surrounding of interchange buildings and positioning. We finish with concluding thoughts.

[1] Using different transport means on a single journey

[2] http://www.vor.at/

2 Requirements

Examining typical travel situations of public transport passengers we have identified four requirements which are crucial to the design of a personal travel companion:

- Mobile trip planning and management
- Detailed modelling of pedestrian networks
- Navigation and guidance for public transport travellers
- Continuous positioning

These requirements were considered as the key research questions.

2.1 Mobile trip planning and management

Regarding this requirement we mainly focus on extensions of existing multimodal journey planners concerning mobile trip management and planning. Mobile trip management means that a personal travel companion on a mobile device allows to access personal trips planned in the pre-trip phase, e.g. by the use of a web-based multimodal journey planner[25], to store personal trips locally on the mobile device or on a server and to keep a personal history of planned routes or preferred travel locations. Mobile trip planning includes location-aware journey planning via mobile access to a server-based journey planner. Results from the journey planner should provide optimised route suggestions from the current location to a destination address under consideration of connections in the public transport network and pedestrian routes for interchanges. If available, personal travel preferences as well as real-time data from operational control systems should be considered.

2.2 Detailed modelling of pedestrian networks

Multimodal web-based journey planners have recently come to maturity and thus gained considerable attention [33],[31]. Whereas typical multimodal routes consist of at least car, public transport and pedestrian parts, detailed data of pedestrian networks is often poor or missing. Especially when it comes to complex interchange buildings, interchanges are calculated on the basis of an interchange matrix, connecting different transport means logically. However, in order to provide navigation and orientation aids in these situations, detailed modelling of interchange facilities and pedestrian routes is necessary.

Concerning the surroundings of interchange facilities, a fine-grained geographical modelling of pedestrian routes and the surrounding environment is necessary. The typical scales used for modelling the road network for car navigation are to coarse-grained in order to cope with the requirements of pedestrian navigation [6].

2.3 Navigation and guidance for public transport travellers

Increased complexity [16], information overload and unknown situations often make people feel uncomfortable while travelling with public transport. Especially when public transport means are left for interchanges people are confronted with complex wayfinding tasks. A key requirement for a personal travel companion is to provide orientation and guidance in complex interchange situations. Experiences with car navigation systems have shown that navigation tasks can be successfully assisted by electronic navigation devices. Until now navigation systems for public transport passengers are missing, in spite the fact that orientation with unknown public transport systems is not easier as it is with road networks. From a technical point of view, providing navigation and guidance in complex interchange facilities as well as from public transport stops to addresses is a challenging task. Pedestrian navigation in combined indoor/outdoor environments is still an open question of research. The key questions address positioning, description of buildings, transition from indoor to outdoor and vice versa and the generation of route descriptions considering the surrounding environment. Integrating the combined indoor/outdoor pedestrian navigation into the mobile journey planner on Smartphones was one of the most challenging tasks during the development phase of the personal travel companion.

2.4 Continuous positioning

As mentioned in the section above, the means of obtaining the user's position is a key question of every location-based services. The task of positioning is also particularly difficult for public transport travellers. Looking at typical interchange buildings in urban areas we face the problem that most of the pedestrian routes are indoors. Although considerable advancements to the use of GPS in buildings have been made [8],[32], GPS technology is still not capable of replacing indoor positioning technologies. Finding suitable indoor positioning technologies for public interchange buildings, allowing a seamless transition from indoor to outdoor and vice versa was considered a main requirement for our approach to a personal travel companion.

3 Related Work

According to the key research questions described in the requirements section we classify related work into the following categories: multimodal journey planning, theory of wayfinding in public transport buildings, pedestrian navigation pilot systems as well as outdoor and indoor positioning technologies.

Multimodal journey planning is a relatively well researched area and some of the research prototypes are already in commercial stage. EU-Spirit [10] is a European travel information system offering calculation of door to door travel itineraries between European cities or regional areas. Besides the operational system results include open interface definitions and harmonised metadata. The main goal of the ISCOM [18] project was to model the ways to and from public transport stops in a geographic reference system in order to integrate these paths in the multimodal routing network. Results from the ISCOM project are the basis for the intermodal journey planner (IJP) provided by Mentz Datenverarbeitung GmbH[3] which was used for our prototype applications. However, none of the projects focuses on the combination of mobile multimodal trip management and pedestrian guidance along public transport routes.

The human navigation and wayfinding process is based on concepts of human cognition [7],[15]. Rüetschi and Timpf [29],[30] developed a conceptual model for describing the wayfinding process in public transport stations. They differentiate between the network space (the public transport network itself) and the scene space (the nodes of the public transport network, e.g. interchange facilities). The scene space is modelled by the schematic geometry, which is based on image schemes [19] and affordances [13]. In another study Fontaine und Denis [11] analyse spatial human cognition in subway stations. One of the results of the study with several users is that direction signs are particularly important elements for the navigation and wayfinding in public transport stations. Signposts are significant elements for the orientation at decision points. This result is also confirmed by May et al. [23] in a requirement study of pedestrian navigation. Our approach builds on theoretical concepts of wayfinding, focusing on the design and implementation of navigation aids. Especially the incorporation of path segment types and signs in the generation of

[3] http://www.mentzdv.de/

maps and guidance instructions addresses the peculiarity of human spatial cognition.

There are many pilot projects which tackle different topics of pedestrian navigation, like user interaction, positioning, cartographic visualisation and data transfer. REAL [1] and M3I [20] are developed for indoor and outdoor environments. REAL describes a hybrid navigation system that adapts the presentation of route directions to different output devices and modalities. M3I presents an approach that connects a variety of specialised user interfaces to achieve a personal navigation service spanning different situations. The NAVIO project [13] analyses major aspects being important when designing a pedestrian navigation system for indoor and outdoor environments. The main parts of the project are integrated positioning technologies, multi-criteria route planning and multimedia route communication. LoL@ [4] is a pedestrian navigation system for tourists which operates on Smartphones. LoL@ concentrates on cartographic visualisation of multimedia content. As far as we know, there is no existing pilot system which focuses on mobile multimodal route planning in combination with navigation and guidance of public transport passengers in interchange facilities.

Addressing the field of positioning Retscher and Thienelt [28] discuss suitable location technologies for pedestrians. In their study they test and demonstrate different positioning technologies like satellite-positioning, cellular phone positioning, dead reckoning sensors for measurement of heading and travelled distance as well as barometric pressure sensors for height determination. For indoor positioning most of the prototypes or commercial systems are based on Infrared, WLAN or Bluetooth [11], [17], [20], [35]. Whereas Infrared needs line of sight, WLAN positioning needs costly calibration and can not be accessed by typical Smartphones. Bluetooth positioning systems are mainly server-based and thus require a costly installation procedure. In our approach the main requirements were defined by an easy and cheap installation procedure and the use of Off-the-Shelf Smartphones.

4 Design of the personal travel companion

Starting from the requirements outlined above the design of a personal travel companion for mobile use focuses on detailed pedestrian route calculation as extension to coarse-grained multimodal route calculation, navigation and orientation in complex interchange buildings as well as positioning techniques.

4.1 Pedestrian route calculation and modelling of interchange facilities

Multimodal route calculation is done between two points. These points may be addresses, entrances of a POI (point of interest) or public transport stops. The route is calculated on integrated public transport, road and pedestrian networks. The networks are connected at defined transition points and are based on a common geographic reference system.

An important topic of research within the project was the very detailed calculation of pedestrian routes in public transport interchange buildings. A pre-requisite for this task is a model for interchange buildings including a routing-enabled pedestrian network.

For modelling interchange buildings we have adapted and extended a conceptual model originally proposed by Ruetschi and Timpf [29], [30]. The model differentiates between the network space (the public transport network itself) and the scene space (the nodes of the public transport network, e.g. interchange facilities). The scene space describes the space where wayfinding in public transport interchange facilities takes place. The model is based on a hierarchical, logical representation of the real world which is capable of modelling the complex spatial relationships of structural elements in interchange buildings.

Our adapted model uses the following main data categories: building, floors, regions, gateways and items. This logical representation of buildings is necessary in order to model the pedestrian routing network in detail, position pedestrians along interchange routes, show floor plans and give meaningful routing instructions. Interchange buildings are divided into different floors with a hierarchical order. Floors are logically structured in non-overlapping walkable regions. For the connection of floors and regions gateways are used. Typical representations of gateways are stairs, elevators, escalators or ramps. For better orientation it can be useful to collect data of certain items. These may be signs, ticket machines, shops etc. Items can either afford a user interaction like ticket machines, or they can be used as orientation marks like signs. They are linked to regions and are used to provide a better interaction between wayfinders and the surrounding environment.

The logical model of buildings is augmented with a geographical model based on a coordinate system. The resulting model is called a hybrid location model [21]. All regions are modelled as non-overlapping polygons, so-called zones. Gateways have gateway areas (polygons) in the origin region and target coordinates in the destination region. The coordinate system was extended with a third parameter called level, which indicates the floor of the building.

In order to enable the calculation of pedestrian routes, a pedestrian routing network is added to the model. This graph-based network consists of nodes and segments and has to be linked to the logical model of buildings and to road and public transport networks. To each node or segment we are able to assign certain attributes which are used for route computation and generation of routing instructions. Nodes are marked with a floor number. When a path is computed, the order of floor numbers provides details whether the segment between two nodes leads up or down.

Segments have type attributes, which indicate the type of a segment like an ordinary path (even level), stairs, escalators, elevators or ramps. With this information we are able to realise a selective route computation based on personal demands in order to optimise interchange time, route complexity or walking effort [16]. Additionally, each segment has to be tagged with a direction because of the possibility that escalators are only available in one direction or the direction can be changed. For wheel chair users it is important to acquire details in the building structure like single steps or the grade of ramps as well.

Another important attribute is the time needed to walk along a certain segment. The overall interchange time has to be considered for continuous route calculation. In order to provide personalised interchange times we use time factors for each path segment. During the route calculation these time factors are multiplied by the default velocity settings in the traveller's personal profile.

In order to give travellers detailed route instructions for orientation inside the building, data about existing signs are collected and linked to the directed path segments. After computation of an interchange route relevant signs are selected and the corresponding text of the sign is included in the route description. Selection of relevant signs from all available signs is only possible if they are linked to exits and public transport transfer points of the building. This technique lays the ground for personalised guidance as an interaction between digital and physical guidance systems. Moreover, the model is the foundation for automatic positioning along the route and indoor/outdoor transitions.

4.2 Navigation and orientation in complex public transport interchange buildings

Starting from the conceptual model of buildings in this section we describe our approach to navigation and guidance in interchange buildings. We define guidance as an information technology based tool assisting pedestrians in the process of wayfinding, which means a purposeful interaction with an environment where the purpose is to reach a certain place or goal [29], [30]. Our guidance system provides the following services:

- select the optimised pedestrian route according to the user's profile in interchange buildings (e.g. from the car to the platform or from one platform to another)
- give instructions for pedestrians in order to optimise their interchange and to improve their orientation
- select the most relevant information out of the scene space based on the calculated footpath in order to improve the interaction between wayfinders and the environment [12]
- reduce complexity of the pedestrian's navigation task by providing detailed timetable information of public transport connections, detailed floor plans of interchange buildings, automatic positioning and thus filtering of information from an egocentric view [24]

The process of guidance in interchange buildings can be described as follows: Upon request travellers in interchange situations get a detailed description of the interchange building, the logical model of the building, floor plans, the calculated interchange route, route instructions and positioning information. After the user's current position has been determined, the location within the model is calculated and the according floor plan together with the relevant route instructions are displayed (Fig. 1). Floor plans are simplified representations of the scene space, including floor numbers, walkable regions, calculated route segments, gateways, signs and optional orientation marks. Beside general information on the building, they typically only show data relevant for the calculated path. Thus floor plans have to be generated dynamically from the model.

Regarding the route instructions it was important for us to avoid simple turn-by-turn instructions that are solely based on geometric information that result in guidance texts like "Walk nine meters straight and turn left." Instead of that instructions should refer to observable physical objects in the scene space in order to improve the interaction of pedestrians and the environment [12]. Referenced objects can be gateways, signs or orientation marks. The generation of route instructions is based on a set of standardised text building blocks which allow us to create appropriate path descriptions for most cases. For complex scenes it is possible to link manual route directions to specific path segments. This basic path description is combined with information from nearby landmarks and signs that are stored in the database. In doing so it is possible to reference signs that do not explicitly refer to the traveller's destination but point at the right direction. In this fashion we are able to automatically generate instructions like “Walk to the lower end of the stairs marked with the sign ‘Neubaugasse’. Walk up the stairs.”

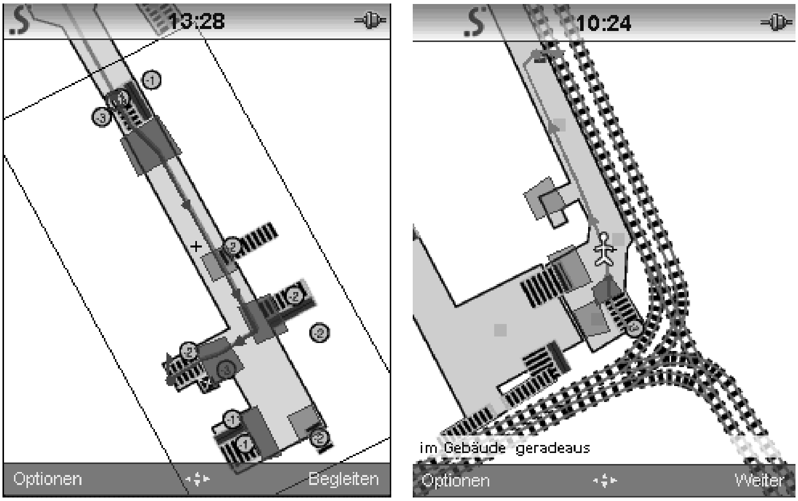

Fig. 1. Screenshots showing the map-based guidance in interchange buildings (manual and automatic navigation mode)

In addition to indoor guidance we address outdoor guidance as well. Outdoor pedestrian guidance is necessary for interchange facilities having bus or tram stations over ground or for finding the way to the destination address from the final public transport stop. For pedestrian routing and navigation the road network as well as separately modelled pedestrian networks can be used. Pedestrian networks can either be extensions to road networks (e.g. sidewalks, pedestrian crossings or pedestrian underpasses) or road independent networks (e.g. interchange buildings, parks, or pedestrian zones). The important difference between road and pedestrian networks is, that the routing network and the surrounding environment have to be modelled with different granularities. Whereas for car navigation it is sufficient to model roads in large scale (e.g. coarse-grained road segments with attributes), for pedestrian navigation paths and the surrounding environment have to be modelled in detail in order to be of use for navigation and orientation purposes [6]. Because of the slow movement of pedestrians the perception of the environment is significantly increased and thus local landmarks and detailed walkable regions in scales of 1:500 and below should be shown on maps and referenced in route instructions. E.g. modelling of over ground interchange facilities has to include public transport platforms, public transport infrastructure like tracks or bus stops, walkable pedestrian regions, non-walkable regions, prominent buildings or other objects, connections to sidewalks of nearby streets and pedestrian crossings. Maps or instructions generated on the basis of road network data can not meet these requirements, thus it was a challenging task to adapt the models and to generate fine-grained maps and routing instructions. Whereas a granularity of one meter is sufficient for car navigation systems, a pedestrian navigation aid for indoor use sometimes requires the model to be precise up to the range of centimeters, especially when it comes to the generation of fine-grained digital floor plans.

4.3 Positioning

Positioning is an integral part of navigation systems in outdoor as well as indoor environments. Although our guidance system provides manually navigable maps and a list of step-by-step route instructions which can be manually acknowledged, the maximum convenience for travellers can only be achieved with automatic positioning. In order to cope with the requirements for continuous positioning we had to find solutions to positioning for indoor as well as outdoor use. Whereas outdoor positioning in variable, yet sufficient quality is available by the use of global positioning systems (e.g. GPS), indoor positioning has not yet reached the same level of maturity. For indoor positioning numerous different approaches that vary greatly in terms of accuracy, cost and used technology [17],[23] exist. In order to be applicable for our scenario we determined the following criteria:

- to provide high enough accuracy to determine the region where the user is currently in
- to have broad support of end user devices
- to work without cellular network connection
- to be cost effective
  to require little installation effort

We opted for a Bluetooth based solution because it met our requirements most closely. First of all a great share of Smartphones sold today incorporates this technology and thus will support automatic positioning without additional hardware on the client side. Furthermore we felt confident to reach a high enough accuracy for providing orientation and useful instructions for the wayfinding process.

Most of the commercially available location systems based on Bluetooth (e.g. [2],[3],[22]) use an infrastructure of interconnected Bluetooth access points. These access points permanently execute inquiries in order to detect nearby Bluetooth devices. Once discovered, their location is determined on the server side and appropriate information is pushed onto the detected device. In large public transport stations, however, it would be very resource consuming or even impossible to install a LAN interconnecting the access points.

Our approach to a cell-based positioning system makes use of a client-side inquiry and a set of passive Bluetooth beacons. The Smartphone clients are constantly looking for beacons in the proximity that broadcast their unique ID. After receiving a beacon ID, the client looks up the associated position information in a list that is part of the building description. If all the relevant data for an interchange building is cached on the device, navigation will work without any network connection. This is a crucial requirement for underground stations suffering from low cellular network coverage.

Fig. 2: Bluelon BodyTag

The beacons utilised for the pilot system (BlueLon Bodytags [3], figure 2) have an adjustable transmit power which allows for adjusting cell sizes. This way we are able to adapt it to the needed accuracy or to the room topology at hand (i.e. hall, room or corridor). Ideally cell sizes should be selected in a way that the covered area is not overlapping with other beacons, otherwise this would result in an ambiguous position.

Due to the signals' spherical propagation behaviour it is not always possible to completely separate individual cells (i.e. signals crossing floor bounds). To overcome this problem we exploit the data model's hierarchical nature and use knowledge from the calculated path as well as information known from history. In a first step we sort out detected beacons that are outside the current region. Furthermore we can determine a sequence of beacons that will be passed when walking along the calculated route.

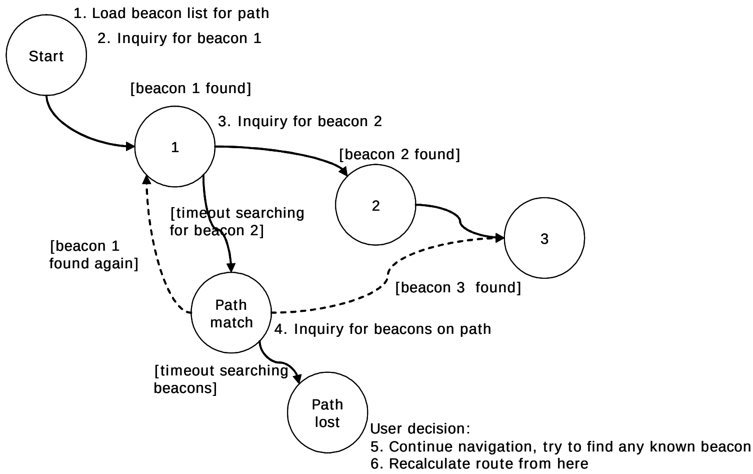

Fig. 3. State transitions of indoor navigation algorithm

If still more than one beacon is recognised and one of them is the next expected beacon, it is assumed that the user most probably moved one step further along the way. Likewise, if the next logical beacon is not found but the one following thereafter, we consider one beacon has been skipped. This procedure is illustrated in Figure 3.

Another challenging characteristic of the Bluetooth technology is the rather long delay from entering a device's transmit range until its actual detection. This can take up to 13 seconds and imposes a lower bound to the usable cell sizes, because a user may have passed the beacon without detecting it. However, tests have shown that most of the time beacons are found within the first five seconds. This observation is also confirmed by other studies [27]0. Experiments have further shown that restarting the inquiry after this duration yields higher detection probability. Together with the fault tolerance mechanism outlined above we achieved a usable cell size of down to 4 meters which is sufficient for providing useful route instructions. Improved inquiry performance is expected from Bluetooth 2.0. First tests have shown that inquiry time was reduced significantly and often successfully completed in one second or below. This would allow for smaller cell sizes and higher detection probability.

As described in the requirements section above, a crucial requirement for the personal travel companion is continuous positioning. Continuity in positioning means that transition from indoor to outdoor or vice versa is done automatically.

In our approach automatic transition is achieved through tagging regions with the positioning mode. Outdoor regions are mostly tagged with GPS whereas indoor regions are tagged with Bluetooth. This approach works well for outdoor to indoor transitions, where the navigation application simply disconnects from the GPS receiver and starts searching for Bluetooth beacons. Having found the first beacon the personal travel companion knows the indoor position and continues to give route instructions for the indoor route.

Transitions from indoor to outdoor are done in a similar way. When the last beacon before an exit is found the Smartphone client stops inquiry and connects to the GPS receiver. However, we are also facing the problem that currently available GPS receivers need an initialisation time of about 30 sec. up to several min. to deliver a reliable position. We try to address the problem by pretending to the user he is constantly moving along the calculated path until we are able to determine the exact location. In most of the cases this behaviour will lead to better results, because there is the chance of leaving the shadowed area during walk. We expect improved results with the broad availability of A-GPS [9].

5 Prototypical implementation

In this section we give some implementation specific details on the prototype application called the personal travel companion. The application is split up in server side and client side modules. For the multimodal trip planning on the server-side we use the Intermodal Journey Planner [25]. This service was adapted for calculating pedestrian routes and providing automatically generated pedestrian maps, path descriptions and data of interchange buildings. Communication between server and client is done via XML.

The Smartphone client was implemented with the mobile Java platform J2ME. The reference device is the Off-the-Shelf Smartphone Nokia N70. The architectural building blocks on the client are (Fig. 4):

- a micro browser for interaction with the multimodal journey planner and presenting server-calculated trip information
- a plugin mechanism for the micro browser to start specific extension modules (Smartlets and Services)
- a navigation plugin (Navigation-Smartlet) for handling all navigation specific user interactions
- a location service and two different location providers for automatic location acquisition
- a local data cache for caching trip and navigation relevant data

The main interaction concerning trip planning and browsing trip information on the client is done via a micro browser. This micro browser allows rendering of server generated pages similar to xHTML pages. However, advanced functionality on the client can not be handled appropriately by a standard xHTML browser. Thus, the browser is enabled for handling small functional extension modules called Smartlets. Smartlets are referenced in the markup language by proprietary tags. Upon activating a Smartlet link, the micro browser starts the corresponding Smartlet and hands over the control to this module. This mechanism guarantees a trade-off between server-generated user interfaces, where the design is easily exchangeable and additional functionality, which allows using local resources like positioning infrastructure on the Smartphone.

One of these Smartlets is the Navigation Smartlet. The Navigation Smartlet asks the local data cache for the journey data of the current trip including route descriptions, building descriptions and maps. Maps are delivered as geo-referenced bitmaps or vector graphics and can be split up in single tiles in order to improve loading times. The local data cache either uses locally stored data or fetches data from the server. This mechanism allows for preloading all the data for a whole journey or at least for one interchange building. Different strategies for preloading of data are possible.

The Navigation Smartlet performs the entire map rendering itself and communicates with locally available positioning providers like GPS and/or Bluetooth providers. Communication with Bluetooth is implemented using the Java Bluetooth API (JSR-82), which is available on recent Smartphones. Communication with the GPS receiver is done via the NMEA protocol over a serial Bluetooth connection.

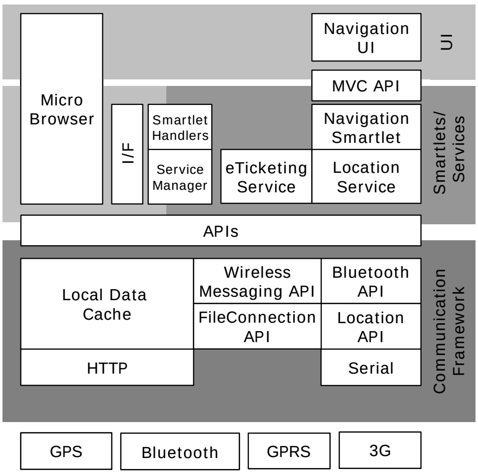

Fig. 4. Overview of the J2ME Client Architecture

A typical execution of the Navigation Smartlet is:

1. Determine the active journey part from the parameters passed via the Smartlet call
2. Load a list of instructions for the pedestrian route from the local data cache
3. Try to determine the current position automatically via the active location provider (Bluetooth or GPS)
4. Try to match the current position with the calculated footpath corridor
5. Get a map for the determined location from the local data cache
6. Render the map on the display and draw the current position on the map
7. Display the wayfinding instruction for the current position of the user
8. Repeat steps 3 to 8 until the user reaches the destination or exits navigation

Without automatic positioning the user has the possibility to scroll maps manually and to switch to other floors by interactively selecting gateways on the map. Moreover, users can also jump step-by-step through the instruction list and match the instructions with their actual position manually.

6 Conclusion

In this paper we described an approach to Smartphone-based information and navigation aids for public transport travellers. Surveys [34] have shown that disorientation on complex public transport routes is a typical barrier for travellers and thus will lead to a reduced use of multimodal transport. The assumption is that the share of multimodal transport can be significantly increased by providing digital mobile information and navigation aids. Studies on pedestrian navigation pilot systems and tests with commercially available pedestrian navigation services on Smartphones have shown that key requirements like mobile multimodal trip planning or navigation in interchange buildings are not addressed adequately.

Our approach identified basic requirements for a personal travel companion and addressed key research questions concerning mobile trip management, detailed pedestrian route calculation for interchange situations in public transport interchange buildings, navigation and guidance along pedestrian routes and continuous positioning. In the implementation section we described some implementation details.

For the evaluation of the prototype we conducted a user test setting in the Vienna underground tram station Matzleinsdorfer Platz in autumn

2005. Travellers were guided by the prototype application along 6 predefined test routes. 20 test persons participated in the test setting and completed the user survey. The average assessment of the prototype application was 2.43 on a scale from 1 (best) to 6 (worst). 4 persons found the travel companion very good, 9 persons good, 2 persons satisfying and 5 persons not useful. Criticised issues were the rather difficult input of addresses for route planning and orientation problems with the provided maps. One important result was that orientation of people can be improved by turning the digital floor plan on the mobile phone in an egocentric perspective [24]. Besides, we realised shortcomings regarding the accuracy and reliability of the Bluetooth positioning system. After extensive tests we are still convinced that Bluetooth-based indoor positioning meets our requirements. However, in the future we have to continue with fine tuning of the Bluetooth Beacon adjustments and additional research improving positioning accuracy, reliability and usability.

Acknowledgements

The work described in this paper is mainly based on results of the Austrian research projects Vienna-SPIRIT and Open-SPIRIT. The projects were partly funded by the Austrian Federal Ministry for Transport, Innovation and Technology in the research agenda I2 – Intelligent Infrastructure.

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