Chapter 11
Map-Based LBSs for Hiking:
A Review of Requirements, Existing Solutions, and Future Trends

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ABSTRACT

In a map-based location-based service, a map on a mobile device is used to visualize and communicate spatial information to the user. The objective of this chapter is to provide a review of map-based LBSs that are especially directed to outdoor activities such as hiking. Hikers as users have special information needs and requirements, which, as in any development, should provide the starting point and the goal for the LBS. The authors list the requirements and solutions such a service must address and discuss the implications of using maps for the application development. They discuss the essential components, functionality, and architectural solutions of an LBS for hiking, and describe the functionality needed for wayfinding and navigation support. Finally, the authors portray the emerging trends, such as ubiquity, adaptivity, and personal cloud solutions, that will motivate future research.

INTRODUCTION

Since the beginning of civilization, the map has been an important tool for communication, guiding people from one place to another (Akerman & Karrow, 2007). Today, location-based services (LBS) have become commonplace tools which are constantly being adapted to new domains. In many countries, outdoor leisure activities such as hiking have become increasingly trendy during the past decades; for example, a growing number of hikers are visiting Finnish national parks every year. Maps have always played a dominant role, not only in navigating but also in planning the

DOI: 10.4018/978-1-4666-1827-5.ch011

hike. In spite of this, outdoor leisure activities still lack effective services for personal navigation, even though many users would need easy-to-use mobile guidance while hiking in the forest. An LBS is no longer used just for guiding the user in unfamiliar environment. People also want services that are fun and entertaining and have aesthetically pleasing user interfaces (Sarjakoski, Sarjakoski, Koskinen & Ylirisku, 2009).

The central feature of any LBS is its ability to connect a user with relevant services or places. This connection can be computed using only the coordinates of the user and the relevant places. The results can also be communicated to a user in non-graphical ways. Visual exploration of a map offers a powerful way for a person to link specific location information with its surroundings, and therefore most LBSs use a visual map on a mobile device as a part of human-computer communication and interaction. According to Sarjakoski and Sarjakoski (2007), the basic design principles for a map on a mobile device are the same as for any map: there should be a background map as a reference for the thematic or value-added information that is overlaid on top of the map.

The chapter starts with a brief review of the existing research on the topic and the development of maps in location-based services for hiking, followed by a discussion of the requirements for a hiking LBS. Map-related functionality, such as zooming, panning, and rotating, is described, followed by a discussion of navigation support (including wayfinding and routing), which is one of the most valuable services of map-based LBSs. Finally, we conclude by offering future perspectives on the further development of hiking applications.

BACKGROUND

Location-Based Services (LBSs) represent a logical follow-up to several enabling information technologies, the cornerstones being the Internet, mobile communication technology, positioning technology, and geospatial information technology. Several attempts have been made to define an LBS. The Open Geospatial Consortium Inc. (2008) defines an LBS as *"a wireless-IP service that uses geographic information to serve a mobile user or any application service that exploits the position of a mobile terminal"* (p. 4). According to Brimicombe and Li (2009), LBSs can be defined as the *"delivery of data and information services where the content of those services is customized to the current or some projected location and context of the user"* (p. 2). Wikipedia (2011) defines an LBS as *"an information or entertainment service, accessible with mobile devices through the mobile network and utilizing the ability to make use of the geographical position of the mobile device."* An LBS may be quite advanced (using complex information systems in the background) or relatively simple, but both would fit the definition of an LBS. Nevertheless, the ability to utilize the user's position should always be a central building block for any LBS. When an LBS also delivers network-based maps to the users' devices, it is called a map-based service (Sarjakoski & Sarjakoski 2007). In this chapter, we focus on map-based LBSs for hiking. In our approach, the role of a map is presumed to be an important part of the system, and the visual map is available for a user on a mobile device's display.

There are several commercial map-based LBSs on the market as well as several ongoing research projects on the topic. However, research on LBSs has so far mainly focused on personal navigation in the urban environment. Studies on presenting tourism-oriented multimedia information on mobile devices related to location and orientation at cultural sites or in urban settings have been carried out as a part of the LoVEUS project (Karagiozidis, Markoulidakis, Velentzas & Kauranne, 2003). The WebPark project (Krug, Mountain & Phan, 2003) aimed to develop an LBS for recreation in coastal, rural, and mountainous areas. This service offers adaptive information filtered according to the user's location, the time of year, and her or his user profile. The information may pertain to weather, flora, fauna, routes, tracks, restaurants, hotels, unexpected dangers, and so forth. For example, Edwardes, Burghardt and Weibel (2003) stated that weather is one of the most important safety aspects when hiking. The safety aspect has been taken into account in the commercial application that resulted from the research prototype of the WebPark project. In the iWebPark application (Camineo, 2011), warnings about dangerous areas appear in the form of clickable objects. Another example of an application that takes into account user safety is the Outdoor Navigation application (GPS Tuner Ltd., 2011), in which you can use OpenStreetMap maps as the background maps. From the application, you can also send an email indicating your location and information relevant to an emergency situation.

A prototype of mobile maps for hikers was also developed as a part of the PARAMOUNT project (Sayda 2005), where the objective was to provide hikers with information, navigation, and guidance tools as well as safety components. The final prototype provided such things as topographic maps, routing functions, tourist information on Points of Interest (PoIs), and local weather forecasts. Other studies on LBSs for hikers include the GiMoDig project, where a prototype for delivering real-time adaptive maps to mobile users in a national park setting was developed (Sarjakoski & Sarjakoski, 2007). As was shown in the GiMoDig mobile service, an adaptive context-aware map is able to adapt its presentation and contents to the user's context and needs (see Figure 1).

In a previous study, Vaittinen, Laakso and Itäranta (2008) discuss the design and prototype implementation of an LBS, named Kuukkeli, intended for hikers. In their design, they took advantage of the capabilities of touch screens, such as direct interaction through tapping the screen with a finger. In the application, the user can plan new routes and add PoIs by tapping the screen.

REQUIREMENTS FOR HIKING APPLICATIONS

A requirement is a property that must be exhibited in order to solve some real-world problem. As in any well-managed software development, one of the first steps in the development cycle of a map-based LBS is to define the requirements for

Figure 1. In the GiMoDig hiking LBS prototype, the visualization is adapted in real-time for the user group "Teenagers" and the map contents for the different seasons of the year (winter/summer) (Sarjakoski, Koivula & Sarjakoski, 2005).

the application. This step consists of collecting, analyzing, specifying, and, finally, validating the requirements. In the case of LBS applications, users are an especially challenging stakeholder class. LBS applications are used in particular by large and inhomogeneous user groups, and the starting point is to understand the users: who they are, what tasks they will conduct with the application, and what their usage context is. In an ideal case, if a developed application meets all the requirements, an application with a good usability is gained.

Usability is defined in the ISO 9241-1:1997 standard as the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments (International Organization for Standardization [ISO], 1997). The need to consider usability issues during product design and development is widely accepted, and the ISO 9241-210:2010 standard provides instructions for achieving user needs by utilizing a user-centered design (UCD) approach during the whole life cycle of a system (International Organization for Standardization [ISO], 2010).

In the following section we first give examples, based on our own research, of the kind of user requirements that have been identified from user studies on hiking. After that, we discuss the essence of information – what is the most important information the user needs for the specific tasks taking place in relation to hiking.

User Requirements Based on User Studies

When studying user needs for map-based mobile services while hiking, Nivala, Sarjakoski, Jakobsson and Kaasinen (2003) proposed methods for scenario-based design. They presented the compilation and results of a usability evaluation of topographic maps in mobile devices for the GiMoDig (Geospatial info-mobility service by real-time data-integration and generalization) project (Sarjakoski & Sarjakoski 2005). The evaluation was carried out as a field test, which is considered to be a controlled experimental method that provides the same conditions and tasks for all users. Usability studies should start early in the design process, they should be carried out without real devices and programs, and the studies should continue until the product development has been completed. A field test in the Nuuksio National Park, based on a mock-up mobile service with existing topographic maps, was conducted at an early stage of the project in order to gather user's requirements and ideas on what they would expect from such a system, and to identify the main benefits and obstacles evident when using topographic maps in mobile devices.

The study results indicated that the cartographic presentation and symbology of the present topographic maps are not well suited to mobile devices with small displays (Nivala, Sarjakoski, Jakobsson & Kaasinen, 2003). The identified usability problems included problems with the technical equipment, the functionality of the software, and the cartographic presentation. Clearly, the intuitivity of map symbols, the placement of the symbols, and other cartographic presentation need to be redesigned for small displays. One of the central outcomes of the results was that the main benefit of the mobile map services (besides positioning information) was seen to be the combined additional information from different databases, which was presented on top of the background map. Having the ability to adapt the map's presentation and content to the usage context would greatly improve the usability of mobile topographic maps. Users will require different maps for different purposes. The maps will need to be available at different scales, and the users will want the steps between the scales to be smooth enough so that they will not lose the overall idea of the area.

Nivala's (2007) study proposed a synergy model for UCD and the characteristics of mobile cartography which aimed to provide guidelines for putting the UCD approach into practice in the development of mobile map applications. Her study also identified the major usability requirements for interactive maps, which include mobile maps. The main aspects to pay attention to in the design of online map services were as follows:

- User interfaces (visualization, layout, and functionality),
- Maps (visualization and tools),
- Search operations (logics, default settings, results, route searches, and visualization of the results), and
- Help and guidance provided to the users.

In a later study related to user requirements for hiking carried out in co-operation with the Nokia Research Center and the Finnish Geodetic Institute (Nivala, Sarjakoski, Laakso, Itäranta & Kettunen, 2009), empirical usability-engineering methods, questionnaires, empathy probes, and focus-group discussions were used to gather qualitative information about potential users and their tasks. The objective was to use the collected information to compile a set of user requirements to further develop an LBS for hikers. Approximately 100 specific user requirements for the development of future location-based services were recognized, from which nine major categories were identified (see Figure 2).

In a survey presented by Sarjakoski, Ylirisku, Flink and Weckman (2009), user requirements for LBSs supporting hiking were further studied using the empirical user study approach of design probing. In the empathic design approach adopted for the study, the resulting output from the user studies is usually understood as design material rather than scientific data. It was not objective truths that the researchers were after, but, rather, useful content that would have the potential to foster the discovery and development of user requirements for navigational applications assisting hiking. The material in this case was formed by the stories in the diaries, the photographs, the drawings, the hand-made appliance mock-ups, and the explanations by the participants. The results from the probe study were further used to create so-called "Personas" describing the characteristic users of the LBS for hiking (Flink, 2009). Based on these results, the identified main user requirements had to do with new technical properties, adaptability, graphics, sound and vibration, physical properties, data content, and interaction.

Information Needs for Hiking

Based on the studies presented above, this section briefly summarizes what information the user needs before the hike, during the hike, and after the hike.

Before the Hike

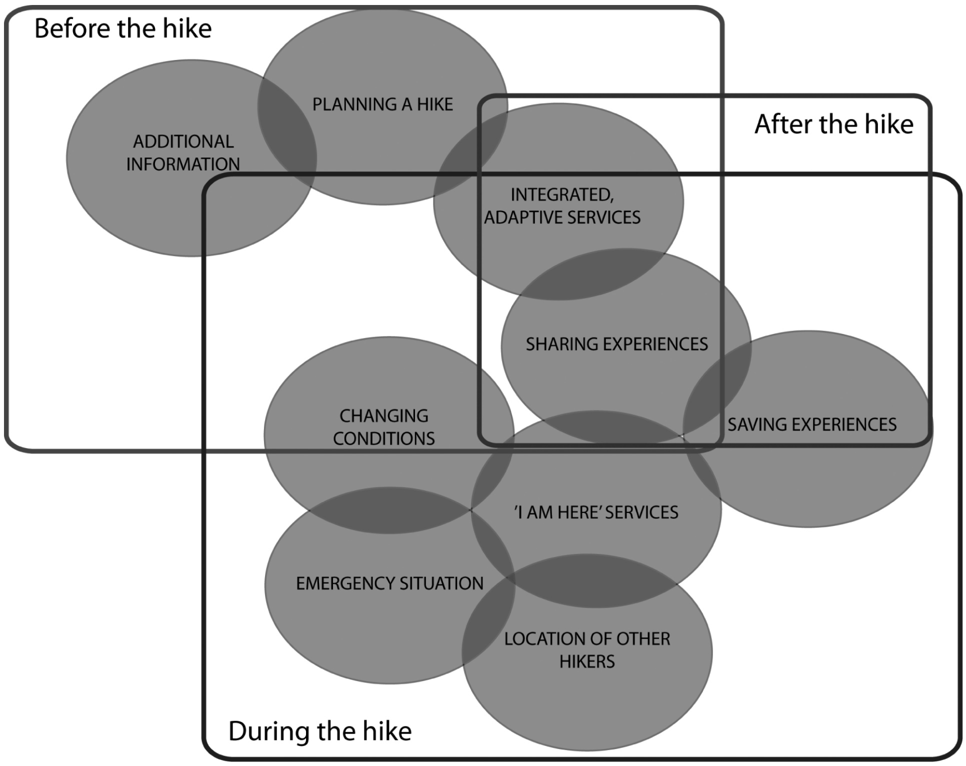
The most essential task before the hike is the planning of the hike. For this task, the user will need information about the hiking area and both general knowledge about the topography and detailed knowledge about the routes and existing facilities such as fireplaces. The user will also want to add his or her own PoIs on top of the background map. The user will need to have tools for planning the hiking route, for example some kind of drawing tool or the possibility to select among routes provided by the service.

During a Hike

The user's needs during the hike can be presented as a set of key questions:

- Where am I? This has to do with knowledge about the user's position and orientation on a map
- How can I get from place A to place B? What is the shortest/fastest route?
- Where is the nearest fireplace, camping area, or other interesting facility?

Figure 2. Identified user requirements grouped into 9 thematic categories and their relationship to different phases of the hike (before, during, and after) (Nivala, Sarjakoski, Laakso, Itäranta & Kettunen, 2009).



- What interesting things can I see along the route? (Nice views, historical places, etc.) The user will need to query information about some specific object.

The most essential feature for the hiking LBS is showing one's own location. During the hike, the need for interaction with the service is high. Most user studies show that hikers, especially the elderly, are worried most about their safety and would need a "help" button in case of an emergency. It is thus also crucial that the service be adaptable. Users would like to receive immediate help when they have gotten lost; similar to car navigators, they would like the service to suggest a new route to the original destination.

During the hike, integration with other services (such as weather forecasts and transportation services) is needed, since many changing situations may occur during the hike.

After the Hike

Users often want to save their routes, videos, and photographs and put their own markings on the map. They also want to share their experiences with other hikers.

Tasks for a Hiking LBS

The information needs of hikers can also be expressed by setting up the service tasks:

- Show my location
- Find the current user locations of other hikers
- Plan a route
- Guide through a route
- Query and retrieve information about points of interest, landmarks, or other specific objects

- Adapt to the changing situation
- Integration with other services to acquire additional information
- Save and share the hiking information.

Structuring of Essential Map Information

As the summary above shows, the most essential part of a map-based LBS is the map. The map can be composed of several layers that are used to organize the map data. A layer primarily includes features with a common theme or types of attributes. The way in which the different layers are overlaid constitutes the final map representation. On paper maps, the integration of the layers is always performed beforehand, preferably by a cartographer, but Web map applications have for years offered users the possibility to choose different representations.

On applications serving a multi-layer overlay, the lowest layer typically acts as a background map. The function of a background map is to orient the user to the real environment. To fulfill its function, the background map typically contains fundamental map features, such as roads, buildings, and bodies of water. For hiking, for which topographic maps are typically used, background maps differ from maps for urban areas. For example, contours lines, individual buildings, vegetation, and the type of forest become essential elements. In a hiking context, the level of detail on mobile applications should correspond to the level of detail of traditional topographic paper maps in scales ranging from 1:10000 to 1:50000.

Background maps in mobile applications do not contain frequently changing thematic information. Value-added thematic information is located on top of the background maps. It uses a presentation that enables the user to still correctly interpret the background map. Thematic data can include point-like features, such as resting places, wildlife observations, attractions, or even the location of friends. This type of data is generally presented using intuitive cartographic symbols. Geometrically complex features (such as hiking paths, bush fire areas, and nature protection sites) are an essential part of modern hiking applications.

Modern mobile applications can be built to automatically change the background maps and value-added information based on user preferences. For instance, a mobile application might take the spatio-temporal context into account, and, based on the time of year, provide a different background map for summer and winter scenery (Sarjakoski & Nivala, 2005). Context-based automation is not just restricted to background maps. It is usually simpler to take the context into account using vector data. For instance, a setting may be provided to define a user's level of presbyopia. The font sizes of name labels and the size of PoIs can be accommodated based on the value of the setting. Similarly, the preferences can affect all the data. For example, an application might contain a setting that determines whether the application automatically changes between night and day views. The switch could be based on the user's location and the time of year, or the output of a built-in ambient light sensor.

MAP-RELATED FUNCTIONALITY IN MOBILE APPLICATIONS

The basic operations for manipulating a map view on the display of a mobile device are as follows:

- Panning,
- Zooming, and
- Rotating.

The user can carry out these operations interactively, but they can also be automatic, controlled partly or fully by the software. Automation can be beneficial during a fast-paced tour or when driving a car. For instance, a map-based application could automatically zoom into a certain level of detail based on the speed of the user and center the map according to the location of the user.

The hardware puts strong constraints on the principles of interaction. Smartphones with multi-touch screens offer a good platform for direct interaction. Regardless of what functionality is realized, the interaction should be intuitive and quick to learn. Additionally, it can be claimed that no single ultimate function exists. Instead, a good application supports several effective methods and the success of a map-based application depends on both its interface and the map data (Harrower & Sheesley, 2005).

Panning Methods

Panning is one of the most important functionalities for maps on small-screen devices. Panning is used to reposition the center of a map view. Classic methods of panning include scrollbars and buttons. The problem with scrollbars is that they only support narrow geographical areas, they take up display space, and other methods are easier to use (MacKay, Dearman, Inkpen & Watters, 2005). Similarly, keyboard buttons and arrow buttons on the map border restrict panning to certain directions, and a joystick can only be used as additional hardware.

Simple methods that allow freedom of movement include tapping twice to center oneself on the map and touching the map edge (Johnson, 1995). More sophisticated panning methods include "grab and drag," and "inertial scrolling." With "grab and drag" (or "tap and drag") methods, a map location should stay under the gesturing finger as long as the finger presses on the screen, even if the finger is moved. In derived methods, several fingers may be required to perform the action. In "inertial scrolling" (or "kinetic scrolling"), map panning is initiated by some gesture such as swiping or flicking the map in some direction. After this has been done, the map moves swiftly in the direction of the movement. In some versions, the speed of movement decelerates the closer the original map center gets to the border of the map view, whereas in other versions the map movement continues until another gesture is made. A method similar to "inertial scrolling" is "touch-n-go" (e.g., Dearman, MacKay, Inkpen & Watters, 2005), where the speed of movement is based on the distance between the gesture and the map center. The further from the center the gesture is made, the quicker the speed of movement. The movement continues until the finger is lifted off the screen or until another gesture is made.

Zooming Methods

Zooming changes a map's scale, which is the ratio between the size of a geographic feature on the map and its corresponding size in the real world. Zooming must be performed in a way that keeps the visual representation between maps with different scales consistent and ensures that the transition between scale levels is smooth enough for users to preserve their orientation on the map (Nivala, Sarjakoski, Jakobsson & Kaasinen, 2003).

Zooming is basically performed in two ways:

- Continuously within a suitable scale range, and
- Between pre-defined static scale levels.

Continuous scaling gives the user a greater feeling of freedom to interact with the map, and it should be used especially with vector data if both the client and the server support progressive data streaming (Meijers, 2011) or if the application makes use of visually smooth cartographic generalization (e.g., van Kreveld, 2001; Nöllenburg, Merrick, Wolff & Benkert, 2008). The latter type of zooming has traditionally been used in a simple (thin) mobile client. Its benefit is that maps can be designed and generalized separately for each scale before publishing. The transition between the pre-defined scale levels can be smoothened by applying an animation.

A zooming action between predefined levels can be initiated by ordinary keypad buttons, a scale bar, or by selecting a scale level from a list where the scale levels are presented as a ratio or a descriptive phrase. On touch screens, tapping is the most typical method, but even keypad-related methods might be applied, such as ZoneZoom (Robbins, Cutrell, Sarin & Horvitz, 2004). Touch-screen users mostly prefer to use the relative distance change between two fingers. This is similar to the way a user zooms pictures in and out.

Map Orientation in Mobile Applications

A map is traditionally set to have true north at the upper top of a display. On city maps, the street names and real directions occur often enough for the user to understand how the map is orientated in comparison to the real world. During outdoor navigation or orienteering, it can be hard for the user to interpret a north-on-top map correctly without having a magnetic needle compass or being able to visualize the current path being taken. Thus, the application should in general show the orientation. The application has to recognize the orientation of the device; in other words, the application requires sensor input.

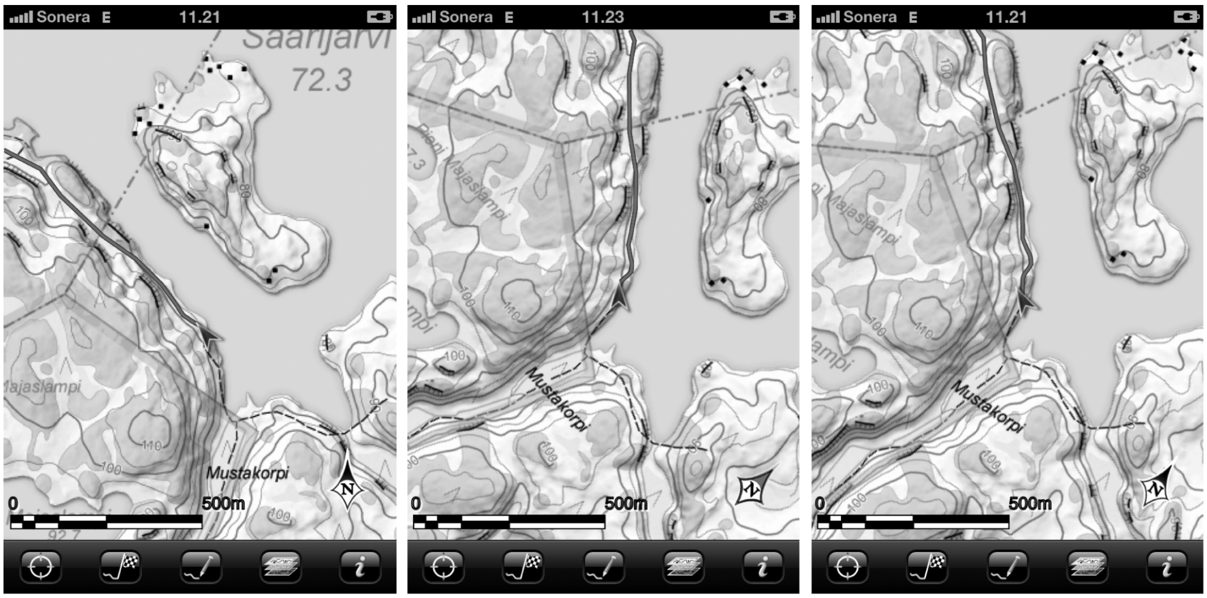
At moderate speeds with gradual turns (as with car or bicycle navigation), the orientation can be done through GNSS-based positioning. During GNSS signal loss, slow speeds, stops at traffic lights, or fast turns, a three-axis microelectromechanical system (*MEMS)* gyroscope can be used to maintain the correct orientation for a while. The most suitable single sensor for low-speed cases, such as hiking, is a two- or three-axis electronic compass (i.e., a digital compass). The sensor accuracy requirement is not strict because often enough the user obtains a rough estimate (like ± 45 degrees) to orient himself or herself with the environment.

Visualizing orientation changes can be performed basically in two ways: in a user-centered way or in a map-centered way (Frank, Caduff & Wuersch, 2004). In map-centered orienting, the map northing is kept towards the top of the screen while the symbol of the user is rotated (on the left side of Figure 3). User-centered (egocentric) orienting means that the orientation symbol of the user always points to the top of the screen, that is, in the direction of the user's movement, and the map objects around the user symbol are rotated (in the middle of Figure 3). Users prefer user-centered orienting; for instance, 86% percent of participants in a study by Radoczky (2003, as cited in Gartner, 2004) favored user-centered orienting. In both cases, the symbol of the user might not be in the center of the map. For instance, the symbol might be placed one-third of the way from the lower edge of the screen to represent more of the terrain ahead of the user.

Interacting with Map Features

Background maps do not typically include additional non-visual information. Thematic map layers in turn may well incorporate relevant information besides their geometry. Efficient and user-friendly tools for user-made queries are tricky to implement. So the tools are typically only made for specific tasks. In the case of hiking, a user could make a query about the closest camping area or the best sight along the current route. It is more common to use gestures. A gesture on a touch screen can, for example, stretch a bounding box around the feature geometries, or directly tap close enough on a single geometry. Hence, in the case of tapping the size of the map symbols is important because a symbol that is too large will hide information and one that is too small will be difficult to select. A study of one-handed thumb-based tapping performed by Perry and Hourcade (2008) revealed that the study participants were quicker and more accurate when tapping large targets. The same applies with feature selection as with the other functionalities; there is no ulti-

Figure 3. Orienting a map. The image on the left side shows a map-centered orientation. The image in the middle shows a user-centered orientation. In the image on the right side, the map is oriented according to the direction in which the target is located, in this case the next waypoint.



mate method and a variety of methods should be provided for the user.

An application must give immediate feedback to the user after she or he selects a feature. One method is to apply an effect that links the object to the action, in other words, one which highlights the geometry of the feature. The most common visual method of highlighting is color-based, in which the selected element is outlined with an outstanding color. Other visual methods presented by Robinson (2009) include depth of field, leader lines, transparency, contouring, color desaturation, and style reduction. Additionally, an application can present the name or description of a feature, and at the same time read it aloud using a text-to-speech synthesis. Applications supporting the Keyhole Markup Language (KML) format can use the "name" and "description" values as selectable feature properties. A creative combination of a variety of visual methods is possible, too, with auditory and tactile emphasis. Implicitly, this also increases the accessibility of the application for people with presbyopia.

Features can be associated with multimedia, such as digital images, audio, or video clips, at which point a second selection or another selection gesture could start or end playback of the multimedia. The additional data, such as multimedia, does not need to be stored in the client-application. Instead, the multimedia could be embedded, even in XML documents, by first encoding the data in a safe character set using an algorithm, such as base64. Nonetheless, multimedia is preferably delivered as a reference from which the client application can download or stream the actual data on demand, even if linking problems might occur later on.

NAVIGATION SUPPORT

As user tests have shown, navigation support is one of the most valuable services of map-based

LBSs. Currently, the term navigation is frequently used to refer to in-car navigation, but in a hiking context the activity may be expressed as personal navigation, during which time the guiding is taking place with the aid of a mobile device.

It is important for a navigation application developer to understand some spatial cognition principles, such as how humans acquire spatial knowledge, in order to develop usable applications. The developer should take into account, for example, the fact that people build up spatial knowledge with different effectiveness. In the following section we discuss the basic principles related to personal navigation.

Wayfinding

Montello (2005) describes navigation as a coordinated and goal-oriented movement through the environment, which involves both planning and the execution of movements. He considers navigation to consist of two components: locomotion and wayfinding. Locomotion is the movement of one's body around an environment. According to Montello, in contrast to locomotion, wayfinding is goal-oriented and involves decision-making and the planned movement of one's body around an environment in an efficient way. Furthermore, Golledge (1999) defines wayfinding as "*the process of determining and following the path or a route between an origin and a destination. It is a purposive, directed, and motivated activity*" (p. 6). Wayfinding is a process that is performed both consciously and unconsciously.

From the cognitive mapping perspective (Downs & Stea, 1973), the dominant framework describes how a new large-scale environment can be perceived. It is composed of three different types or levels of knowledge (Siegel & White, 1975; Golledge, 1992): landmark knowledge, route knowledge, and survey knowledge. Landmark knowledge is gained by acquiring information about landmarks. A landmark is an easily recognizable, concrete, outstanding object that typically is unique to its surroundings (e.g., a statue, a sign, or an unusual building). A landmark may also be a discrete scene (Montello, 1998). Because landmarks stand out, they are easier to perceive, to remember, to recall, and to use. Recognizing landmarks in nature is especially demanding, since, in contrast to landmarks in urban environments, natural landmarks often tend to be ambiguous. Sarjakoski, Kettunen, Flink, Laakso, Rönneberg and Sarjakoski (2011) have studied verbal route descriptions and landmarks for hiking during summer and winter seasons and they found that the same landmarks were included in most of the propositions subjects used (70% in the winter and 79% in the summer). This reinforces the importance of using landmarks to provide navigational support for such activities as hiking.

The route-like organization of spatial knowledge has been identified as part of the human spatial mental model and often as an alternative for the survey-like model (Thorndyke & Hayes-Roth, 1982). Route knowledge is composed by acquiring knowledge about a fixed sequence of travel paths connecting locations such as landmarks. A connection can be concrete and seen as geometrically linear, like a street or hiking path, or it can be areal, like a market square. A connection is unidirectional, that is, passable in only one direction. Werner, Krieg-Brückner, Mallot, Schweizer and Freksa (1997) explain that route knowledge can be acquired in five ways. First, the information about travel paths can be formed without any knowledge of their context or surroundings. The second method is to apply knowledge of the general properties of the surroundings. For example, in some cities the road network is built in the form of a division of blocks, that is, all major roads lead to a single center or only right turns from the main street are allowed. A third way is to familiarize oneself with the context, for example by making observations while following another path. The last two methods involve connecting other travel paths and reading a map.

Survey knowledge uses the travel path sequences from route knowledge in addition to other experiences. Survey knowledge can be seen as knowledge on how to cut parts of the sequences and glue the parts back together to form new sequences. Gluing can even switch the direction of a connection. In order to go in the opposite direction, a new route is required, which may sometimes be achieved by inverting the original route. Thus, survey knowledge is about integrating and flexibly making it possible to create new routes.

It is also important to understand spatial knowledge to create applications suitable for specific, unexpected situations. For instance, a navigation device may lose its positioning for some reason, or the device's batteries may go dead. In such a situation, the user should not only be aware of route segments, but should also be able to create new routes without the application pointing to his or her current location. This is necessary during hikes where external help might not be available. Consequently, in addition to guiding users, applications should help them to recognize environmental elements, acquire survey knowledge, and be ready to work out new routes on their own. However, current map-based navigation systems do not extend survey knowledge, even if they efficiently build up route knowledge (Aslan, Schwalm, Baus, Krüger & Schwartz, 2006).

Routing

Routing, as performed by computers, differs from the wayfinding process of humans. Human navigation is suboptimal. In contrast, computers calculate an optimal route based on some minimizing or maximizing criteria and some source data. The source data for routing can be a route network, that is, a graph where nodes (vertices) have properties that are taken into account when calculating weights (costs). The total cost of a path is typically the sum of the costs of its vertices, but it can also be implemented in such a way that the calculation is performed from edge to edge while allowing for restrictions on turning.

The most common criteria include calculating the fastest or shortest route. Additionally, the criteria can be the route's suitability for some specific transport modality (mode of locomotion), such as walking, roller skating, biking, or using a car. Transportation may also be multimodal. Multimodal routing has its own problems, for example, integrating the networks and cost models of different modalities (Barnhart & Ratliff, 1993). And even if the networks of different modalities have the same coordinate reference system, the same object may have divergent co-ordinate values (Rehrl, Bruntsch & Mentz, 2007). For urban conditions, Hochmair (2004) created a set of four of the most important criteria based on an empirical study: fast, safe, simple, and attractive. Each criteria class was affiliated with a set of the most essential member attributes. For example, the five most important members for an "attractive" criteria included "sights," "parks," "lakes and rivers," "a nice view," and "nice bridges." For recreational hiking, an important criterion is maximizing the amount of beautiful scenery along a route. Scenic routes can be made by buffering attractive locations, followed by an optimal (shortest) path calculation where a multiplication factor and the number of buffering rings define how much longer a route needs to become in order to be more scenic (Hochmair & Navratil, 2008). The growing amount and quality of data has even made it possible to use demanding criteria, such as accessibility (Yang & Mackworth, 2007; Kasemsuppakorn & Karimi, 2009).

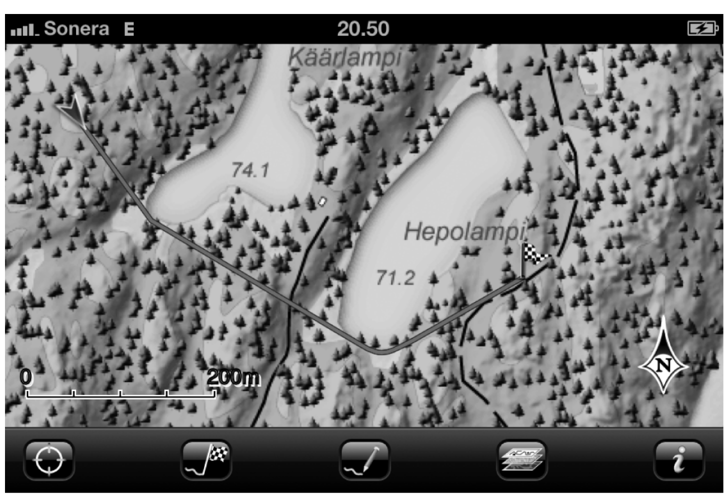
Routing is always performed based on some algorithm. In the case of routing, the most important algorithms solve a single-pair shortest path problem, that is, they find the optimal route from a given location to a particular destination. The problem is one of the most studied problems in algorithmic graph theory and is usually solved with an algorithm based on the A*-algorithm (Hart, Nilsson & Raphael, 1968). A* is an extension of the famous Dijkstra's algorithm (Dijkstra, 1959). A* is a best-first type of algorithm where the cost function of a node is composed of the sum of two other functions. The first of the functions is the cost of getting to the node from the root. The second function is a heuristic estimate of the cost of the path remaining between the node and the goal node. The use of heuristics speeds up the performance of A* in comparison to Dijkstra's algorithm. But A* can only be used for a single target, whereas Dijkstra's algorithm can be used to calculate the cost of getting to multiple targets from one location.

Another important set of algorithms is based on D* (Stentz & Mellon, 1993), which behaves like A*, except that it is incremental. The cost parameters of D* are allowed to change during processing.

In that sense D* is similar to Lifelong Planning A* (Koenig, Likhachev & Furcy, 2004) and suitable for real-time routing, especially in an unfamiliar environment where the application obtains new sensor data to recalculate the shortest route. In the case of hiking, when a path network is not available one option is to use line-of-sight-based visibility graphs as routing input. In line-of-sight navigation, the user is routed to the goal around visible obstacles. Krisp and Liu (2009) compared the algorithm results with the results from other routing services and found that the results from line-of-sight navigation were more natural (Figure 4).

In addition to vector data, the input for routing can also be raster data, or it can involve both. With raster data, routing may be seen as one application field of cost surface analysis, in which the aim is to calculate least-cost paths from the accumulated cost surfaces (de Smith, Goodchild & Longley, 2009; Eastman, 1989). The cost is, in general, defined as the friction per unit cell that occurs when passing through the cell (Douglas, 1994). Typical input data for creating the cost surface is a gridded digital elevation model, but, depending on the complexity of the defined cost, the input data may address a number of attributes, such as land use, soil, and vegetation (Balstrøm, 2002; Arnett, 2009; Theobald, Norman & Newman, 2010). The least-cost path can then be found from the accumulated cost surface by constructing the path with slope-tracing lines or by using a back-link mechanism (Yu, Lee & Munro-Stasiuk, 2003).

Figure 4. Line-of-sight navigation. The lakes constitute obstacles when the route is being calculated.



Geocoding as the Basis for Searching Functionality

Geocoding is most usable in urban areas, where streets and other objects have addresses and other references. In nature, such references are scarce. Nevertheless, geocoding is important for planning and executing a hike. It is used to obtain the locations of particular places, like locally well-known cabins or lakes, which are used as source, target, and intermediate nodes for the routing process.

Geocoding generally refers to the process of converting a postal address, the well-known name of a building (such as the Empire State Building), or some other spatially referenced textual data into point co-ordinates. However, as Goldberg, Wilson and Knoblock (2007) state, geocoding can also return a geographic object, and the co-ordinates of the particular object do not need to be point co-ordinates. An object is generally a better alternative to point co-ordinates because with objects the geocoding process does not need to select and return a certain point from a non-point geometry. In addition, geocoding is mostly imprecise because of the typically ambiguous nature of both the input and referenced data and several objects may match the input data with varying accuracy in relation to their true ground location. Hence, the result can be a set of best candidate locations or geographic objects rather than a single value. If no optimal candidate is found, the process might not return anything, or it can specify the spatio-temporal accuracy for each returned candidate, use secondary reference data sources, or request more specific details about the target object as input. The geocoding process in the other direction, that is, when converting co-ordinates into spatially referenced data, is called *reverse geocoding*.

A geocoding process can be built into a mobile application, but a more flexible and lighter method involves using online Web services. Many of these services are free to use, even for commercial applications, and service interfaces are provided using a multitude of techniques (such as SOAP and REST), and a variety of encodings (such as XML and JSON). The downside of Web services is the potential network delay and availability. An evaluation of five widely used commercial online Web services has been performed by Roongpiboonsopit and Karimi (2010).

Route Guidance

After a routing algorithm has calculated an optimal route, a navigator is tasked to guide the user along the route. Guiding the user in the wild is a more complex task than the turn-by-turn guidance applied in car or urban pedestrian navigation systems. New paths are easily created and remain unmapped for a long time, existing paths meander, and the degree of freedom to move in any direction is only restricted by a couple features, such as bodies of water or steep cliffs.

The simplest method is simply to visually render the route on the map and point to the direction of travel. The route and direction are constantly updated to respond to changes in location and orientation. Images of crossings or landmarks, textual descriptions, and statistics (such as distance or the amount of time to the next crossing) can further extend visual guidance. The disadvantage of visual methods is that the user needs look at the device's screen (and normally stop walking), and elderly people with presbyopia might need to put on reading glasses to read the instructions. In addition, visual instructions take up valuable map space. The solution is to apply multimodal instructions. A study by Kovanen, Sarjakoski and Sarjakoski (2010) contains a review of different types of auditory cues that can even be used in a hiking context. Tactile feedback can be given with a variety of methods, such as the Tactile Compass of Pielot, Poppinga, Heuten and Boll (2011), which encodes directions in rhythmic vibration patterns. Auditory and tactile guidance can be used alongside visual instructions, because none of the modalities is better than the other in every situation. For example, spoken instructions require less attention from the user and can be used to explain rare landmarks without map symbols, but they are unsuitable for complex scenarios or objects such as landmarks with associated pictures.

ARCHITECTURAL SOLUTIONS FOR A MAP-BASED LBS

System Architecture

In the following section on system architecture for a map-based LBS, we describe software components, their functionalities, and how they interact with each other. We also must specify the hardware platforms on which the software components run. There are a number of issues that are especially crucial and should be solved when designing the system architecture for a map-based LBS:

- What geospatial information is stored permanently on the user's mobile device, and what is stored and maintained on the server and sent to the mobile device for temporary storage only?
- Can data be obtained from a server on demand, or is some kind of pre-loading and caching used?
- Are maps rendered from vector data to visual map images on the server, or is the rendering performed on the mobile device?
- Is the routing algorithm run on a server or on the mobile device?

The *Google Maps* application on smartphones is an example of an application that is strongly dependent on the server. Rasterized map tiles are loaded onto the mobile application on demand and stored in cache memory for future use. The routing calculation is also done solely on the server. *Google Maps* on the iPhone (Google Inc., 2011a) noticeably does not provide real-time recalculation of routes when moving. The *TomTom* navigation application (TomTom International BV, 2011) represents the other end of the spectrum. The routing database and the map databases are downloaded to the mobile device as part of the purchase and download of the application. The routing calculations are made on the mobile device. The basic functionality of the *TomTom* therefore does not need a mobile communication connection. Regarding the hiking applications, for example with *Trail Maps*, you can explicitly download the map tiles for selected areas (National Geographic Society, 2011). You also have some options to control these downloads, such as the map scaling and maximum cache size. The Trail Maps application has a locally stored overview map covering the continental United States. Detailed maps can be downloaded for selected map sheets. Noticeably, the detailed maps still originate from scanned paper maps.

It is evident that for server-side solutions, there are many options regarding the system architecture. To take one example, if map tiles are provided to the client, those tiles may be rendered on demand as a part of request processing. Alternatively, they may be rendered in advance as a batch process and stored in a database on the server. On-demand processing is especially favorable if the background map is updated frequently.

Cloud Computing for a Map-Based LBS

Cloud computing is one of the big trends or paradigm shifts in information and communication technology, and it also has had an impact in terms of system architectures for mobile map-based LBSs. With cloud computing, we denote shared computing resources that are available and can be used as a service on the Internet. Companies and other organizations may run the applications or services on remote cloud servers, allowing them to concentrate on their core business. Cloud computing resources are also typically very scalable, such that the allocation of resources can be dynamically adapted to their actual need.

The notion of cloud computing has also entered consumer services. Google Docs (Google Inc., 2011b) serves as a good example of a service that allows a single user or group of users to edit and share documents of various kinds using Web browser-based tools. More recently, Google Docs has started offering a service that allows Microsoft Office documents to be stored on a local computer and automatically synchronized after editing. The Google mail service, Gmail, is a prominent example of a service that allows users to access their e-mail using either a Web browser or a specific e-mail client, whether on a mobile device or at a stationary platform. The core of consumer-oriented cloud services includes storing personal data, accessing it through multiple channels, and sharing it with others.

What do the cloud services have to offer for a map-based LBS, especially in a hiking context? A few examples exist, even though the area is still being developed and there are questions as to what essential features of a service are actually part of a cloud service. Sports Tracker (2011) is a service that lets you to track your workouts using a mobile application. It currently runs on Google Android, Apple iOS, and Nokia Symbian platforms. You can upload the information onto the Sports Tracker service and study it afterwards, using either your mobile client or a Web browser. You may also let the Sports Tracker user community see your tracks on a map and share your experiences.

To summarize, the following features characterize a cloud-enabled map-based LBS:

- You can create your personal work space in the cloud and store your own location-related information, whether it is PoIs, personal tracks, or settings for your applications.
- You can access this information using mobile or stationary devices: whatever is available at the moment and whichever is more suitable for the task you are doing. For example, a Web browser on your laptop or an application on a tablet computer would be better for exploring and planning a hike, whereas a mobile device would be more useful during a hike.
- You basically have a super-computer at your fingertips, even when you are mobile. This feature could even be used to offer advanced geographic analysis services to a mobile user.

Mobile networks typically have rather poor coverage in hiking environments such as national parks. This sets a specific precondition for making mobile hiking applications heavily dependent on cloud services. The application should offer basic services even when the communication connection is totally broken. For example, for downloading users should have the option to preload the map for a selected area. And for uploading, the application should be able to store the data locally on the mobile client, and upload it to the server when the communication connection is available again.

USABILITY OF MOBILE MAP-BASED SERVICES

Finally, the developed map-based LBSs need to be evaluated for how well the application meets the requirements that were identified for the application. In the following section we give some examples of such evaluations.

Usability testing can be done either in a laboratory environment or in an authentic environment. Field evaluations are not normally used in the early stages of product development, mainly due to technical and practical problems in organizing the evaluation. However, when the usage environment is essential for performing typical tasks with the system, field evaluations should be organized as early as possible in the design process. In a hiking context, many of the user studies are based on field studies (Figure 5) and often aim to gather qualitative data. This is because users often have difficulty imagining something that does not yet exist, while developers and research are aware of emerging technologies. Van Elzakker, Delikostidis and van Oosterom (2008) recommend a combination of laboratory tests and field tests in order to obtain a deeper knowledge of different usability issues.

In a recent study, Flink, Oksanen, Pyysalo, Rönneberg and Sarjakoski (2011) presented the usability evaluation of a map-based multi-publishing service for outdoor leisure activities. The multi-publishing service allows users to access the same spatial information contents through different channels, such as printed maps, map applications for the Web or mobile phones, and other interactive media. The evaluation was conducted for the channels of a Web map application, a mobile map application on an iPhone, and printed maps. The study illustrated how the usability evaluation methods of thinking aloud and questionnaires can be exploited to achieve results for concrete input for the iterative user-centered design process of a map service.

Schobesberger (2009) lists in his study a set of usability evaluation methods for online mapping applications. He states that combining remote evaluation methods with observation and survey methods seems to be successful. As part of the HaptiMap project, Magnusson et al. (2009) give user study guidelines for UCD in which haptic, audio, and visual interfaces for maps and location-based services are being developed. Burghardt and Wirth (2011) present a comparison of evaluation methods for field-based usability studies of mobile map applications. They provide an overview of the advantages and disadvantages of the applied field-based evaluation methods. A comparison of laboratory tests and field tests for the usability evaluation of mobile applications has also been provided by Kaikkonen, Kekäläinen, Cankar, Kallio and Kankainen (2005).

Figure 5. In a hiking context, many of the user studies are based on field studies.

FUTURE RESEARCH DIRECTIONS

Mobile map applications received a big boost when smartphones with GPS receivers, electronic compasses, and high-resolution color screens became available. The easy purchase, download, and installation of applications from the application stores have also had a radical impact on the spread of mobile map applications. All this has happened within a short period of time: for Apple iPhone the software development kit and application store were first released in 2008 and for Google Android about a year later. Since then, many applications related to personal navigation have become available. In particular, many of them use global routing databases and background maps originally targeted for in-car navigation. However, these are only marginally suitable for hiking because the level of detail and the richness of the maps are not compatible. On the other hand, there are also hiking-specific applications that use national topographic maps as background maps. Although their maps are better suited for hiking, they usually do not include any routing functionality. It is also likely that in the future the hiking applications will be specific for each country, because the conditions and the availability of topographic data are often specific to each country.

The availability of mobile communication networks in hiking areas is likely to remain a challenge. In remote rural environments the available bandwidth may be sufficient for phone calls and SMSs, but it is not possible to communicate spatial data at a reasonable speed. Therefore, strategies and technologies for preloading and caching the data must be developed. For static background maps, preloading the data for a certain area remains a viable approach, especially because the memory capacity of the smartphones is increasing steadily. For dynamic data that should be obtained on-demand, research on intelligent caching techniques is needed. The same applies for the user-generated content to be uploaded to servers.

A traditional paper map and an old-fashion analog compass are still a must for serious hikers. They are more reliable than any electronic solution in outdoor usage, especially in difficult weather conditions. A paper map also has the benefit of a very large display compared to the relatively small area of the mobile device displays. A paper map can easily be used to explore large areas around the actual hiking trail, whereas using the small display on a mobile device easily produces a certain kind of pinhole effect. Having the ability to zoom and pan smoothly can reduce this problem, but it still appears to be difficult to solve in the context of hiking. Hiking is seldom purely a task of getting from point A to point B, as is often the case in car navigation or even personal navigation in an urban environment. As regards functionality and user interface issues, the search for good terrain navigator solutions will remain a research and development topic for some time.

CONCLUSION

In this chapter we have studied the requirements, the level of development, and the technologies of a map-based LBS for hiking. Smartphones with good color displays, GPS receivers, and digital compasses have clearly played an important role in the emergence of mobile map applications, and many of them are available in the application stores. Their basic functionalities follow similar patterns in the sense that a user can zoom in or out on visual maps, the GPS-based location of the user on the map is available, and orientation information from a digital compass is utilized. There is much variation in other functionalities. Our user studies indicate that some of the requirements are also common, whereas some other requirements depend a great deal on the user group; and therefore, the ability to personalize and adapt the services seems to be an important requirement for the future. There is a recognizable need for sharing information about places, tracks, experiences, and other hiking-related personal matters. We have just experienced the very first examples of ubiquitous services, which are mainly available in smart urban environments. Building ubiquitous LBS services for hikers seems to be especially challenging because wireless telecommunication technology is much less robust in remote areas. Many innovations, such as intelligent caching solutions, are therefore needed in order to provide hikers with good map-based LBSs. Likewise, having an updated paper map and a compass as backup will definitely remain good advice for a hiker for the foreseeable future.

ACKNOWLEDGMENT

This survey is a part of two research projects. The European Commission-supported HaptiMap project (FPT-ICT-224675) is coordinated by the Rehabilitation Engineering Research Group of Lund University's Department of Design Sciences (www.haptimap.org). The UbiMap project is funded by the Academy of Finland's Motive programme and is carried out in co-operation with the Finnish Geodetic Institute (FGI), the Department of Geoinformatics and Cartography, and the University of Helsinki, Department of Cognitive Science.

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KEY TERMS AND DEFINITIONS

Landmark: Landmarks are prominent objects that act as marks for places and that can be used as reference points.

Map Orientation: The relationship between the directions presented on the map and the corresponding directions of the (co-ordinate) reference frame.

Map-Based LBS: A location-based service (LBS) in which the map on a mobile device is used to communicate spatial information to the user.

Navigation: Navigation is coordinated and goal-oriented movement through the environment, which involves both planning and execution of movements. Navigation consists of two components: locomotion and wayfinding.

Routing: Routing is the process of determining a path from a point of origin to a destination based on certain criteria.

Usability: The effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments.

User Requirement: A requirement is a property that must be exhibited in order to solve some real-world problem. A user requirement for an LBS specifies what a user wants or desires from the service.

Wayfinding: Wayfinding is a purposive, directed, and motivated activity for determining and following a path or route between a point of origin and a destination.