# Location-Based Services Handbook

## Applications, Technologies, and Security


Edited by
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# Preface

Mobile devices today are boasting processing power and memory on par with that found in desktop computers. Wireless connectivity has become much more readily available. Many metropolitan areas feature large-scale wireless networks, and cellular or satellite connections are accessible in many remote areas. Furthermore, we are seeing a continuous decrease in the cost of hardware—the mobile devices themselves, as well as accessories, such as global positioning system (GPS) units. As people are increasingly mobile in terms of lifestyle and occupational behavior, and there is a demand for delivering information to them according to their geographical location, a new system known as location-based services (LBSs) was developed by integrating satellite navigation, mobile networking, and mobile computing to enable such services. Such a system combines the location information of the end user with intelligent application in order to provide related services. The LBS system has become popular since the beginning of this decade mainly due to the release of GPS signals for use in civilian applications.

With the continuous decrease in the cost of these devices, we see not only the use of the location-aware devices proliferating in an increasing number of civilian and military applications, but also a growing demand for continuously being informed while on the road, in addition to staying connected. Many of these applications require efficient and highly scalable system architecture and system services for supporting dissemination of location-dependent resources and information over a large and growing number of mobile users. Meanwhile, depending on wireless positioning, geographic information systems (GIS), application middleware, application software, and support, the LBS is in use in every aspect of our lives. In particular, the growth of mobile technology makes it possible to estimate the location of the mobile station in LBS. In the LBS, we tend to use positioning technology to register the movement of the mobile station and use the generated data to extract useful knowledge, so that it can define a new research area that has both technological and theoretical underpinnings.

The subject of wireless positioning in LBS has drawn considerable attention. In the wireless systems in LBS, transmitted signals are used for positioning. By using characteristics of the transmitted signal itself, the location estimation technology can estimate how far one terminal is from another or where that terminal is located. In addition, location information can help optimize resource allocation and improve cooperation in wireless networks. While wireless service systems aim at providing support to the tasks and interactions of humans in physical space, accurate location estimation facilitates a variety of applications, which include areas of personal safety, industrial monitoring and control, and a myriad of commercial applications, e.g., emergency localization, intelligent transport systems, inventory tracking, intruder detection, tracking of fire-fighters and miners, and home automation. Besides applications, the methods used for retrieving location information from a wireless link are also varied. However, although there may be a variety of different methods employed for the same type of application, factors including complexity, accuracy, and environment play an important role in determining the type of distance measurement system.

LBSs will have a dramatic impact in the future, as clearly indicated by market surveys. The demand for navigation services is predicted to rise by a combined annual growth rate of more than 104% between 2008 and 2012. This anticipated growth in LBSs will be supported by an explosion in the number of location-aware devices available to the public at reasonable prices. An in-Stat market survey estimated the number of GPS devices and IEEE 802.11 (Wi-Fi) devices in the United States in 2005 to be approximately 133 and 120 million, respectively. The report also estimated market penetration would increase to approximately 137 million by 2006 for GPS and 430 million by 2009 for Wi-Fi.

Many of today's handheld devices include both navigation and communication capabilities, e.g., GPS and Wi-Fi. This convergence of communication and navigation functions is driving a shift in the device market penetration from GPS-only navigation devices (90% in 2007) to GPS-enabled handsets (78% by 2012). These new, multifunction devices can use several sources for location information, including GPS and applications like Navizon (Navizon) and Place Lab (Place Lab), to calculate an estimate of the user's location. Navizon and Place Lab both use multiple inputs, including GPS and Wi-Fi, to generate estimates of the user's current location.

This book provides technical information on all aspects of LBS technology. The areas covered range from basic concepts to research grade material including future directions. This book captures the current state of LBS technology and serves as a source of comprehensive reference material on this subject. It has a total of 12 chapters authored by 50 experts from around the world. The targeted audience for the Handbook include professionals who are designers and/or planners of LBS systems, researchers (faculty members and graduate students), and those who would like to learn about this field.

The book is expected to have the following specific salient features:

- To serve as a single comprehensive source of information and as reference material on LBS technology
- To deal with an important and timely topic of emerging technology of today, tomorrow, and beyond
- To present accurate, up-to-date information on a broad range of topics related to LBS technology
- To present the material authored by the experts in the field

- To present the information in an organized and well-structured manner

Although the book is not precisely a textbook, it can certainly be used as a textbook for graduate courses and research-oriented courses that deal with LBS. Any comments from the readers will be highly appreciated.

Many people have contributed to this handbook in their unique ways. First and foremost, the group that deserves immense gratitude is the group of highly talented and skilled researchers who have contributed 13 chapters to this handbook. All of them have been extremely cooperative and professional. It has also been a pleasure to work with Nora Konopka, Amy Blalock, and Glen Butler at CRC Press, and we are extremely grateful for their support and professionalism. Our families have extended their unconditional love and strong support throughout this project and they all deserve very special thanks.

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Syed has published more than ten books on emerging technologies such as cloud computing, mobile web 2.0, and service delivery platforms. His recent books include *Cloud Computing and Software Services: Theory and Techniques* and *Mobile Web 2.0: Developing and Delivering Services to Mobile Phones*. Syed has authored several research papers and teaches computer engineering courses as adjunct faculty at Florida Atlantic University, Boca Raton, Florida, where he introduced a course on Smartphone technology and applications. Syed received his MS degree in computer engineering in July 1998 at Florida Atlantic University. Syed received his BSc degree in electrical engineering from Aligarh University, India, in 1995.

**Dr. Mohammad Ilyas** is associate dean for research and industry relations at the College of Engineering and Computer Science at Florida Atlantic University, Boca Raton, Florida. Previously, he has served as chair of the Department of Computer Science and Engineering and interim associate vice president for research and graduate studies. He received his PhD degree from Queen's University in Kingston, Canada. His doctoral research was about switching and flow control techniques in computer communication networks. He received his BSc degree in electrical engineering from the University of Engineering and Technology, Pakistan, and his MS degree in electrical and electronic engineering at Shiraz University, Iran.

Dr. Ilyas has conducted successful research in various areas, including traffic management and congestion control in broadband/high-speed communication networks, traffic characterization, wireless communication networks, performance modeling, and simulation. He has published over 25 books on emerging technologies, and over 150 research articles. His recent books include *Cloud Computing and Software Services: Theory and Techniques* (2010) and *Mobile Web 2.0: Developing and Delivering Services to Mobile Phones* (2010). He has supervised 11 PhD dissertations and more than 37 MS theses to completion. He has been a consultant to several national and international organizations. Dr. Ilyas is an active participant in several IEEE technical committees and activities. Dr. Ilyas is a senior member of IEEE and a member of ASEE.

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# Contents

# 1

# *Positioning Technologies in Location-Based Services*

**Eladio Martin, Ling Liu, Michael Covington, Peter Pesti, and Matthew Weber**

**CONTENTS**

## 1.1 Introduction

Mobile devices today boast processing power and memory on par with that found in desktop computers. Wireless connectivity has become much more readily available. Many metropolitan areas feature large-scale wireless networks and cellular or satellite connections are accessible in many remote areas. Furthermore, we are seeing a continuing decrease in the cost of hardware—the mobile devices themselves, as well as accessories, such as global positioning system (GPS) units. What was once a cost-prohibitive, underpowered, immature technology is now a reality.

With the continued decrease in the prices of these devices, we see not only the use of the location-aware devices escalating in an increasing number of civilian and military applications, but also a growing demand for continuously being informed while on the road, in addition to staying connected. Many of these applications require an efficient and highly scalable system architecture and system services to support dissemination of location-dependent resources and information over a large and growing number of mobile users.

Consider a metropolitan area with hundreds of thousands of vehicles. Drivers and passengers in these vehicles are interested in information relevant to their trips. For example, a driver would like her vehicle to display continuously on a map the list of Starbucks coffee shops within 10 miles around the current location of the vehicle. Another driver may be interested in the available parking spaces near the destination, say the Atlanta Fox Theater, in the next 30 min. Some driver may also want to monitor the traffic conditions five miles ahead (e.g., average speed). Such information or resources are important for drivers to optimize their travel and alleviate traffic congestion by better planning of their trip and avoiding wasteful driving. A key challenge is how to disseminate effectively the location-dependent information (traffic conditions) and resources (parking spaces, Starbucks coffee shops) in this highly mobile environment, with an acceptable delay, overhead, and accuracy.

One of the fundamental components common to all location-based services (LBSs) is the use of positioning technologies to track the movement of mobile clients and to deliver information services to the mobile clients on the move at the right time and right location. Therefore, the effective use of positioning technologies can have a significant impact on the performance, reliability, security, and privacy of LBSs, systems, and applications.

In this chapter, we will present an overview of the localization techniques in LBSs, aiming at understanding the key factors that impact the efficiency, accuracy, and usability of existing and emerging positioning technologies.

### 1.1.1 Overview of localization systems

A generic localization system based on an underlying communications network consists of two key components: the portable device or mobile terminal carried by the user, and the base stations or beacon nodes constituting the infrastructure of the communications network. Existing localization techniques rely on measurement methods to estimate ranges by means of which the user's location can be calculated. Consequently, two separate phases can be distinguished in the process: the initial range measurement phase to calculate some range (typically distance or angle) between the user's device and the beacon nodes, and the positioning estimation phase where a geometric principle is applied with the obtained ranges to estimate the user's location. The main geometric principles used to estimate locations are trilateration, multilateration, and triangulation, and these principles will be explained in detail in Section 1.2.

Figure 1.1 gives a sketch of a generic scenario with a user moving along the coverage area of a communications network, whose location has to be estimated by means of the information exchanged between the user's mobile terminal and the network infrastructure. In general, two types of scenarios can be distinguished considering the direction in which the signals exchanged between a user and the infrastructure will travel: (1) The user's mobile terminal may receive signals originating from the network infrastructure's beacons working as landmarks of known location. (2) The beacons may be receiving signals from the user's mobile terminal in an attempt to let the network estimate its location.

In the first scenario, the user's mobile terminal receives signals from the network infrastructure's beacon nodes; these beacons usually transmit identification signals containing technical parameters on a periodic basis, in order to let users know about their presence. Some measurable quality of these signals can be utilized by the user's device to estimate a range from the beacon nodes. For example, if the user's radio frequency (RF) device is capable of measuring the power from the received signal, a comparison of the power difference from transmitter to receiver can be leveraged to estimate

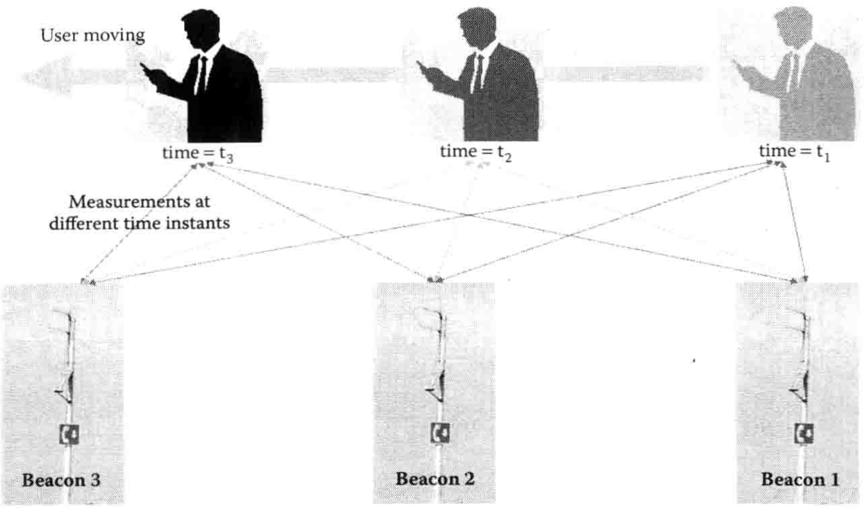


**FIGURE 1.1**
Basic representation of a generic infrastructure to allow the estimation of the user's location.

the distance between them, making use of a radio propagation model. In the same sense, if the user's device can precisely measure the time of arrival (ToA) of the signal, the time elapsed from transmission to reception can be employed to calculate distance by means of the space-time relationship with the speed of the signal. In general, the infrastructure provided by the underlying technology will allow the user's device to observe signals originating from multiple beacon nodes, which can be employed to estimate the user's location through the application of basic geometric principles, which will be explained in detail in Section 1.3.

The second scenario applies to the infrastructure's beacon nodes receiving signals from the user's mobile terminal. In this case, the user's device transmits signals for the network infrastructure to extract some measurable quality. These measurements can be employed by each of the beacon nodes receiving the signals from a user's mobile terminal to estimate the distance separating them from the user. Eventually, and in analogy with the previous case, multiple distances can be used to obtain locations through the application of geometric principles (see Section 1.3 for details).

Many positioning techniques have been proposed, developed, and deployed in production. The most widely accepted classification of localization techniques are "range based" and "range free" (Poovendran et al. 2006). The former obtains either distances or directions from reference points and estimates locations through trilateration or multilateration when distances are available, or triangulation when directions are the known data. Distances can be calculated through the study of the received signals (strength or ToA), while directions can be determined through the angle of arrival (AoA) of the signal. On the other hand, range-free techniques, also called by some authors "connectivity based" or "proximity based" (Poovendran et al. 2006), estimate locations making use of the proximity information to several reference points. Although this is a simple and widely accepted classification, there is a need to distinguish a group of techniques based on environmental features that can be sensed and leveraged to infer locations without the need to apply complicated and error-prone measurements or geometric principles (Hightower and Borriello 2001; Kaiser et al. 2009; Abielmona and Groza 2007). For example, simple detection of pressure or light events would constitute the environmental features that could be used for localization. We will refer to this group of techniques as "environment based" in this chapter.

In this chapter, we classify the existing and emerging localization techniques into two categories: geometric based and environment based, according to whether the location measurement techniques are geometric based or environment based. It is clear that range-based techniques, regardless of their use of distance or direction, are founded on geometry to estimate locations. On the other hand, proximity-based techniques, such as those that rely on node proximity or node connectivity instead of geometric distance, ultimately resort to geometric principles to estimate locations. Thus, we classify proximity-based techniques under the umbrella of "geometry-based" techniques (Anjum and Mouchtaris 2007). Consequently, throughout the rest of this chapter, the different localization methods that can be used to enable LBSs will be classified into two main categories: geometry-based techniques and environment-based techniques. The former is mainly measurement based while the latter is primarily observation based.

In the remainder of the chapter, we will first review the geometric principles for positioning in LBSs. Then, in Section 1.3, we describe the four most popular geometry-based localization techniques, including ToA, time difference of arrival (TDoA), received signal strength indication (RSSI), and AoA. In Section 1.4, we give a brief overview of other positioning techniques, including inertial navigation systems and proximity-based methods, environment-based techniques, and a multimode approach to localization. Section 1.5 concludes the chapter.

## 1.2 Geometric Principles for Location Estimation

Most of the popular positioning technologies used today in LBSs and applications are geometry-based methods, regardless of whether they are range based or proximity based. A common feature of all geometry-based localization techniques is their use of geometric principles, such as triangulation, trilateration, and multilateration, to estimate locations. It is important to note that although some researchers (Abielmona and Groza 2007; Hightower and Borriello 2001) make use of concepts such as angulation or lateration, these are generalizations of triangulation and trilateration/multilateration, respectively. In Section 1.3, we will provide a detailed discussion on geometry-based localization techniques with examples on the concrete localization technologies in terms of how each of these principles is used in practice. In general, different positioning technologies (e.g., Wimax, Wi-Fi, UWB, and RFID) will make use of certain geometric principles (e.g., triangulation, trilateration, multilateration) that best leverage their respective positioning techniques (e.g., ToA, TDoA, RSSI, AoA).

### 1.2.1 Trilateration

Trilateration is a method used to determine the intersection of three sphere surfaces given the centers and radii of the three spheres. The trilateration principle is used specially for ToA and RSSI. By trilateration, the location point of a mobile object is obtained through the intersection of three spheres, or so-called beacons, provided that the centers and the radii of the spheres are known. This technique usually relies on the use of the RSSI or ToA of a signal between two nodes in order to obtain the radius of each sphere. In the case of ToA, the clocks in both ends of the communication must be synchronized; otherwise, the method to use is multilateration. Mathematically, the estimated location in a three-dimensional (3D) space $(x, y, z)$ will be the solution of the following system of equations:

$$r_1^2 = (x - x_{c1})^2 + (y - y_{c1})^2 + (z - z_{c1})^2,$$

$$r_2^2 = (x - x_{c2})^2 + (y - y_{c2})^2 + (z - z_{c2})^2,$$

$$r_3^2 = (x - x_{c3})^2 + (y - y_{c3})^2 + (z - z_{c3})^2,$$

where $(x_{c1}, y_{c1}, z_{c1})$, $(x_{c2}, y_{c2}, z_{c2})$, and $(x_{c3}, y_{c3}, z_{c3})$ represent the locations of the three beacons to which a mobile object is referencing its location; these coordinates are the centers of the spheres whose intersection will represent the estimated location of the object. On the other hand, $r_1$, $r_2$, and $r_3$ denote the calculated distances from the object to each of the three beacons, representing the radii of the spheres.

### 1.2.2 Multilateration

Multilateration is a position estimation principle using measurements of TDoA at (or from) three or more sites. Multilateration is also known as hyperbolic positioning and it refers to the process of locating an object through the intersection of hyperboloids, which result either from accurately computing the TDoA of a signal sent from that object and arriving at three or more receivers, or by measuring the TDoA of a signal transmitted from three or