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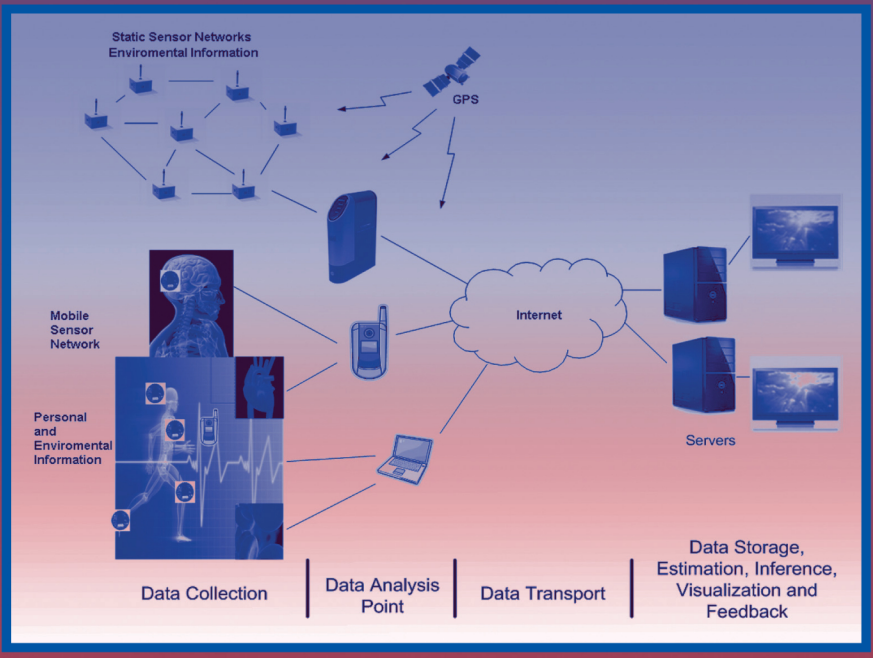
# Location-Based Information Systems

## Developing Real-Time Tracking Applications




Miguel A. Labrador, Alfredo J. Pérez,
and Pedro M. Wightman

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# *Preface*

Location-based services (LBS) are finally coming out of research labs and getting into the hands of final users. It is fairly common to see cellular carriers and private companies offering LBS to locate your children, friends, and sites of interest, track assets, enhance the security of key personnel, help people with disabilities use public transportation, guide tourists, and many others. Location-based advertisement is becoming a very big business. Very soon users will be receiving customized advertisements in their cellular phones according to their current location. Military-related LBS systems have also been implemented to provide real-time situational awareness. Soldiers are receiving alert messages with additional information according to their current location. The interesting aspect is that LBS applications are just starting to emerge and the potential for growth the next several year is tremendous.

One common aspect of all these LBS applications is that they are built on top of an infrastructure that includes not only the cellular phone and the application that runs in it but also a communication network, a back end application that runs in a server somewhere, and a series of supporting servers and databases that together provide useful information back to the user. This entire infrastructure on top of which many LBS applications can be efficiently supported and run is what we call Location-Based Information Systems (LBIS). LBIS are being developed to target problems in many, if not all, sectors of the economy. In this regard, the timing of this book could not be better.

Looking into the future, current research is bringing new refinements and improvements and is pushing the technology even further. We can see LBIS systems transforming into what is being called "Participatory Sensing" and "Human-Centric Sensing" systems. In addition to having the location of the user in real-time, the cellular phone could integrate and provide information coming from other sensors or devices. For example, the user could be wearing Bluetooth-based sensors to continuously measure his or her temperature, heart rate, and other vital signals. Accelerometers are already integrated in several cellular phones. They are very useful in determining the type of activity that the user is doing, which along with their vital signals could be used in many health care-related applications. Cellular phones could also integrate measurements from other types of sensors and be used to address large-scale societal problems. For example, if all cellulars phone were equipped with air-quality sensors, and all users participated in the application, we could have

information about the pollution level in an entire city very easily. Similarly, we should be able to easily determine the congestion level, travel times, etc., in most of our major roads. As you can see, the future of location-based information systems is very promising.

## Book Origin and Overview

This book is the result of more than six years of research and development in location-based information systems. This research involved the investigation of new architectures, middleware, algorithms, protocols, mechanisms, etc., to address particular problems related to the implementation of a variety of location-based applications, mostly for the transportation industry and the military. It is also the result of our active participation in the definition of the Java ME Location API 2.0 as part of the JSR 293 working group. After all these years, we thought it was time to include this topic into the mainstream of courses in our university, so we prepared a junior-/senior-level course and wrote this book to support it.

The book contains information and examples to implement a general real-time location-based information system. In fact, all chapters of the book target the implementation of a general real-time tracking system example. It is general in the sense that the system should be easily adapted to target any application domain. Further, the incorporation of other sensors's data to make the system "participatory" or "human-centric" should be a straight-forward extension.

The book consists of twelve chapters and one appendix. Chapter 1 introduces the definition and classification of location-based services and the types of LBS applications. It also describes the three most important location provider architectures. This chapter describes an entire real-time tracking system that will be used throughout the book as an example. Each subsequent chapter of the book shows how to implement a piece of the tracking system example. The chapter concludes with a description of the software architecture we used to implement the tracking system and a look into the future, including concepts such as participatory sensing and human-centric sensing. Chapter 2 describes the hardware and software architectures of a typical cellular phone. Chapter 3 describes the Java Platform Micro Edition, or Java ME, the Java platform for resource-constrained devices. The chapter includes the description of the entire software stack: the Connected Limited Device Configuration 1.1, the Mobile Information Device Profile 2.0, and the optional packages. Chapter 4 shows how to create MIDlets, those Java-based programs that comply with the Java ME platform. Some of the most important APIs used in the development of MIDlets are also described there. The chapter also touches on security and privacy issues and mechanisms. Chapter 5 is devoted to other important programming aspects such as memory management, concurrency, dynamic linking, and energy management, all especially important for resource-constrained devices. Chapter 6 is about obtaining the user's po-

sition, the different technologies, systems, and players. At the end, the Java Location API 2.0 is also described in detail. Chapter 7 is about relational and geographical databases, how to define them, and how to store and retrieve information from a cellular phone. Similarly, Chapter 8 covers the topic of communications, or how to exchange data between the cellular phone and the main application server. Chapter 9 explains how to create and use Web services from cellular phones. Chapter 10 introduces the reader to the Google Web Toolkit and how to use it to create system administration functions, such as creating and deleting users, modifying the user information, and the like. Chapter 11 shows how to display the location of the users in Google Maps or Google Earth in real-time using the browser of any computer connected to the Internet. Finally, Chapter 12 includes some examples of additional processing functions at the cellular phone and the server meant to improve the system's performance and provide enhanced services. The Appendix A tells the reader where to download all the software needed to implement the entire location-based information system and guides the reader through the installation procedure.

## Intended Audience

The book is intended for undergraduate students in their junior or senior years, professors, researchers, and industry professionals interested in the design and implementation of location-based information systems. The book can also be used as a reference book in a graduate class on the same topic.

## Resources

A companion Website has been set up to provide additional information and supporting material. The Website contains all software packages and applications utilized in the book as well as the PowerPoint slides and laboratory examples utilized to teach the course CIS 4930 Location-Based Information Systems at the University of South Florida (USF). All this material and more can be found at `http://www.csee.usf.edu/~labrador/LBIS`.

## Acknowledgments

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Tampa
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# *Dedication*

Dedicado a mi esposa Mariela, y a mis hijos Miguel Andrés y Daniel Ignacio.
Miguel A. Labrador

Dedicado a mis Padres, mis hermanas y a Rossana. Ad Maiorem Dei Gloriam.
Alfredo J. Pérez

Dedico este trabajo a mi familia por todo el apoyo que me han bridado desde que tengo memoria, en especial a los Arango y a los Chiriboga.
Pedro M. Wightman

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# *Contents*

# *Acronyms*

**A-GPS:** Assisted GPS
**AJAX:** Asynchronous JavaScript and XML
**AMS:** Application Management Software
**AOT:** Ahead of Time Compilation
**API:** Application Programming Interface
**ARM:** Advanced RISC Machines
**ASP:** Active Server Pages
**BSC:** Base Station Controller
**BTS:** Base Transceiver Station
**CA:** Certificate Authority
**CDC:** Connected Device Configuration
**CDMA:** Code Division Multiple Access
**CLDC:** Connected Limited Device Configuration
**CPA:** Critical Point Algorithm
**CUT:** Coordinated Universal Time
**CSS:** Cascade Style Sheet
**DAC:** Dynamic Adaptive Compilation
**DBMS:** Database Management System
**DDL:** Data Definition Language
**DML:** Data Manipulation Language
**DOP:** Dilution of Precision
**DRAM:** Dynamic RAM
**DSP:** Digital Signal Processor
**E-OTD:** Enhanced Observed Time Difference
**GCF:** Generic Connection Framework
**GGSN:** Gateway GPRS Support Node
**GIS:** Geographic Information System

**GMSC:** Gateway Mobile Services Switching Center
**GR:** GPRS Register
**GPRS:** General Packet Radio Service
**GPS:** Global Positioning System
**GSM:** Global System for Mobile Communications
**GWT:** Google Web Toolkit
**HLR:** Home Location Register
**HOW:** Hand-Over Word
**HTTP:** HyperText Transfer Protocol
**IDE:** Integrated Development Environment
**IETF:** Internet Engineering Task Force
**ISDN:** Integrated Services Digital Network
**JAD:** Java Application Descriptor
**JAM:** Java Application Manager
**JAR:** Java Archive Files
**JAXP:** Java API for XML Processing
**JAX-RPC:** Java API for XML-Based RPC
**JCP:** Java Community Process
**JDBC:** Java DataBase Connectivity
**JDK:** Java Development Kit
**JIT:** Just-in-Time Compilation
**JNDI:** Java Naming and Directory Interface
**JSP:** Java Servlet Pages
**JSR:** Java Specification Request
**J2ME:** Java 2 Micro Edition
**JVM:** Java Virtual Machine
**KML:** Keyhole Markup Language
**KVM:** Kilo Virtual Machine
**LBIS:** Location-Based Information Systems
**LBS:** Location-Based Services
**LMU:** Location Measurement Unit
**MIDP:** Mobile Information Device Profile
**MIME:** Multipurpose Internet Mail Extensions
**MLC:** Skyhook's Mobile Location Client

**MMAPI:** Mobile Media API
**MMS:** Multimedia Messaging Service
**MMU:** Memory Management Unit
**MS:** Mobile Station
**MSC:** Mobile Services Switching Center
**MSISDN:** Mobile Subscriber ISDN Number
**NSS:** Network and Switching Subsystem
**OGC:** Open Geospatial Consortium
**PDA:** Personal Digital Assistant
**PHP:** Hypertext Preprocessor
**RAM:** Random Access Memory
**RFC:** Request for Comments
**RISC:** Reduced Instruction Set Computer
**RMI:** Remote Method Invocation
**RMS:** Record Management System
**ROM:** Read-Only Memory
**RPC:** Remote Procedure Call
**SDK:** Software Development Kit
**RSS:** Radio Subsystem
**SDE:** Software Development Environment
**SEQUEL:** Structured English Query Language
**SGSN:** Serving GPRS Support Node
**SIM:** Subscriber Identity Module
**SMS:** Short Message Service
**SOAP:** Simple Object Access Protocol
**SPI:** Service Provider Interface
**SQL:** Structured Query Language
**SRAM:** Static RAM
**SSL:** Secure Socket Layer
**SWWT:** Sprint Wireless Web Toolkit
**TCP:** Transport Control Protocol
**TLM:** Telemetry Word
**TLS:** Transport Layer Security
**TTFF:** Time to First Fix

| | |
|---|---|
| **TTP:** | Trusted Third Party |
| **UDDI:** | Universal Description, Discovery, and Integration |
| **UDP:** | User Datagram Protocol |
| **URI:** | Uniform Resource Identifier |
| **URL:** | Uniform Resource Locator |
| **U-TDoA:** | Uplink-Time Difference of Arrival |
| **VLR:** | Visitor Location Register |
| **WKT:** | Well-Known Text |
| **WLAN:** | Wireless Local Area Network |
| **WMA:** | Wireless Messaging API |
| **WPS:** | Skyhook's Wi-Fi Positioning System |
| **WSA:** | J2ME Web Services API |
| **WSDL:** | Web Services Definition Language |
| **WSN:** | Wireless Sensor Network |
| **XML:** | eXtensible Markup Language |
| **XPS:** | Skyhook's Hybrid Positioning System |