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INTRODUCTION TO WIRELESS LOCALIZATION

With iPhone SDK Examples

Companion Website

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Contents

Preface

Wireless localization is a fascinating field at the intersection of wireless communication, signal processing, physics, mathematics and human behavior, which strives to harness different mobile platforms to navigate and broaden our horizon. This book is exclusively dedicated to the positioning system, which is the killer application of the 21st century, riding on the success of Global Positioning Systems and mobile technologies. Many commercial and government organizations as well as university campuses have deployed wireless broadband such as IEEE 802.11b. This has fostered a growing interest in location-based services and applications. This book provides a comprehensive overview of the entire landscape in both outdoor and indoor wireless positioning systems with practical iPhone application examples.

Who This Book Is For

The text you hold in your hands has a different flavor from most of the other currently available books on wireless positioning. First and foremost, this book should be readable by anyone who is in or beyond their second year in a computer science program. We assume a bare minimum of mathematical sophistication and C programming skill (or some familiarity with object-oriented programming skill).

This book is primarily intended for anyone who wants to study wireless localization. It offers an insight into the maze of mobile, positioning and AI technologies. This book covers basic formulae, algorithms and mathematical calculations involved in location-aware applications. It has been planned in a manner to benefit all those developing positioning systems, such as professionals, engineers and researchers.

This book is intended for students taking a course in wireless localization that emphasizes positioning technologies and mobile application developments. The content can be treated as the material in a course structure with many explanations of fundamental positioning techniques throughout the text, and we have added many programming examples. All programming examples are updated and developed on the iOS 5.0 platform. These are an independent, practical, fun way of learning the material presented and getting a real feel for the subject.

Features

Each chapter in this book is almost self-contained. We do not demand that the reader come armed with a thorough understanding of positioning technologies. This book guides you through understanding the signal propagation, positioning and interference concepts and algorithms. We have incorporated iPhone programming examples that help readers to understand the concepts, theories and algorithms. Readers will come away from this book with an ability to develop and implement real location-aware applications.

Themes featured in *Introduction to Wireless Localization* include:

- An accessible introduction to positioning technologies such as Global Positioning System and Location Fingerprinting
- A thorough grounding in signal propagation, line-of-sight and interference effects to the positioning accuracy
- Hands-on skill to iPhone programming for location-aware application
- An in-depth solution to some open problems in wireless positioning

Organization

There are three main parts in this book. Part I covers the Wi-Fi positioning systems (Chapter 2 to 6); Part II covers the outdoor positioning systems (Chapter 7 to 10) and finally Part III introduces the applications of wireless localization (Chapter 11 to 12). Two appendix chapters are included at the end of the book for those not familiar with the iOS Software Development Kit (SDK) and Objective-C programming environments.

- Chapter 1 – Introduction to Wireless Localization
  This chapter is an introduction and overview of the material.
- Chapter 2 – Installation of Wi-Fi Infrastructure
  Localization systems for indoor areas that make use of existing wireless local area network (WLAN) infrastructure and location fingerprinting approach have been suggested recently. Chapter 2 covers how to set up a Wi-Fi infrastructure specifically for the positioning system. It gives an overview of the pre-installation criteria, standard of the Wi-Fi positioning infrastructure.
- Chapter 3 – Algorithms in the Wi-Fi Positioning System
  This chapter covers the positioning algorithms of location fingerprinting and propagation based methods. It also includes the evaluation methods and comparisons of each WLAN positioning system.
- Chapter 4 – Implementation of Wi-Fi Positioning in iPhone
  The chapter introduces how to build a customized Wi-Fi positioning system. It includes the implementation of the algorithms in iPhone.
- Chapter 5 – Positioning across Different Platforms
  This chapter presents the signal variance issue of different mobile platform. It also solves the problem due to the signal variance from different platforms.
- Chapter 6 – Wi-Fi Signal Modeling
  This chapter introduces Wi-Fi signal modeling methods that visualize and analyze the intensity of the Wi-Fi zone for post-installation.
- Chapter 7 – Introduction of Global Positioning System
  This chapter describes the history, algorithms and components of GPS.

- Chapter 8 – Study of GPS Signal and Algorithms
  This chapter provides an in-depth study on GPS signal and algorithms.
- Chapter 9 – Differential GPS and Assisted GPS
  This chapter presents the methodologies of AGPS using the GSM and 3G cell phone networks. It also covers algorithms used in DGPS and includes the implementation of GPS system in iPhone.
- Chapter 10 – Other Existing Positioning Technologies
  This chapter introduces other existing positioning technologies such as acoustic-based, vision-based and RFID-based.
- Chapter 11 – AI for Location-aware application
  Location-aware application is not only to solve the problem 'Where am I?' but also solve more complex questions such as 'Any good burger joints around here?'. It should assist the user to make the best choice using artificial intelligence (AI). This chapter includes the implementation of an iPhone application which finds the favorable dinning place according to user preference.
- Chapter 12 – Beyond Positioning: Video Streaming and Conferencing
  While reaching the meeting place, users may need to download some location-aware information or communicating with other persons. In Chapter 12, we look at data streaming technology and communication applications in iPhone. It includes the implementation of multimedia data transmission, such as data streaming and video conferencing.
- Appendix A – Starting the iOS SDK
  This is the first appendix chapter that helps readers to get ready for the iOS SDK environment.
- Appendix B – Introduction of Objective-C Programming in iPhone
  This is the second appendix chapter that introduces basic programming techniques in the Objective-C language. Objective-C is slightly different from C language in syntax, pre-defined methods and naming of files. After you read through this chapter, you will have become familiar with the Objective-C language.

Supplemental Material and Technology Support

This book includes lecture outlines in PowerPoint for the text and program codes which are free to adopters. Periodic updates and slides to this book can also be downloaded in the web page below at

www.wiley.com/go/chan/wireless

The reader is encouraged to send any corrections to

csclchan@gmail.com

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I obtained my Ph.D. in Computer Science at The Hong Kong Polytechnic University (PolyU). Studying at the PolyU was not only a turning point in my life, but also a wonderful experience.

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About the Authors

Eddie C. L. Chan received his BSc, MSc and PhD degrees, all in computer science, from The Hong Kong Polytechnic University (PolyU) in 2005, 2007, and 2010, respectively. During his postgraduate study, he was the recipient of the Best Student Paper Award in the International Conference on Fuzzy Computation, Madeira, Portugal in 2009. He received the Best Presentation Award of Research Project and Alan Turing scholarship from PolyU in 2007 and 2008. He was awarded the 2nd-Class Group Award from the 9th Philip Challenge Cup in China in 2005. His work in wireless localization has been published in around 30 refereed papers. He has also participated in academic conference events. He was the local chair in IEEE WiMob 2011, session co-chair in IEEE CMC 2010 and publicity chair in IEEE ICCI 2009. He was a system consultant in Itapoia Group Limited (2007) and PTec Limited (2005). His research interests include wireless localization, communication, fuzzy logic, 3D visualization of tracking system, agent technology and data mining.

George Baciu holds a PhD and a MSc degree in Systems Engineering and a B.Math degree in Computer Science and Applied Mathematics from the University of Waterloo. He has been a member of the Computer Graphics Laboratory and the Pattern Analysis and Machine Intelligence Laboratory at the University of Waterloo and subsequently Director of the Graphics and Music Experimentation Laboratory at The Hong Kong University of Science and Technology in Hong Kong. Currently, Prof. Baciu is a full Professor and Associate Head in the Department of Computing, and the founding director of the Graphics and Multimedia Applications (GAMA) Laboratory at The Hong Kong Polytechnic University. His research interests are primarily in mobile augmented reality systems, user interfaces, physically-based illumination, rendering, image processing, motion tracking and synthesis for both outdoor and indoor location aware systems.

Chapter 1

Introduction to Wireless Localization

Don't let the noise of others' opinions drown out your own inner voice. And most important, have the courage to follow your heart and intuition. They somehow already know what you truly want to become. Everything else is secondary.

Steve Jobs
2005

Chapter Contents

- Introducing the background of positioning technologies
- Defining the open problems for positioning technologies
- Understanding factors leading to a successful wireless positioning system

Wireless localization in this book means 'determining the position of a user/object by wireless signal.' Determining the position of a user requires tracking techniques from indoors to outdoors. Global Positioning System (GPS) is a fully functional Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. In the early days it was used as a tool for map-making, land surveying, and scientific uses. Nowadays it is more widely used. Some individuals may own a pocket PC or palm phone with GPS functions. However, GPS is limited in that it requires dedicated hardware. It is also very expensive in terms of labor, spectrum and capital costs to implement a specialized infrastructure in indoor areas solely for position location. GPS and other positioning approaches like acoustic-based and light-based are most effective in relatively open and flat outdoor environments but are much less effective in non-line-of-sight (NLOS) environments such as hilly, mountainous, or built-up areas. These localization applications have two particular disadvantages: first, they require the source to have a high intensity and

Introduction to Wireless Localization: With iPhone SDK Examples, First Edition. Eddie C.L. Chan and George Baciu.

to be continuously propagated and, second, they can localize only within the area covered by the sound, light or FM wave signals.

Cellular Positioning System (CPS) makes use of radio waves broadcast in the cell phone towers to determine the position. It works in outdoors and indoors environments, but it can only get a rough positioning. Therefore, it usually works together with GPS. Assisted GPS (AGPS) uses the cellular network tower which installed the GPS receiver to assist users to get the satellite information.

Recently, many public places and campuses have deployed the wireless local area networks (WLANs) such as Wi-Fi – IEEE 802.11b. Wi-Fi is a wireless technology brand owned by the Wi-Fi Alliance intended to improve the interoperability of wireless local area network products based on the IEEE 802.11 standards. Wi-Fi networks have become widely deployed and are fueling a wide range of location-aware computing applications. Accurate user location information enables a wide range of location-dependent applications. A software-only solution can be integrated as a location-sensing module of a larger context-aware application on infrastructure wireless LANs. Wi-Fi positioning may be a useful supplement to any of these localization approaches.

The most widely used techniques that Wi-Fi positioning uses to locate Wi-Fi enabled devices are the propagation-based and location-fingerprinting-based (LF-based). Propagation-based techniques measure a Wi-Fi transmission's received signal strength (RSS), angle of arrival (AOA), or time difference of arrival (TDOA). Propagation-based techniques use mathematical geometry models to determine the location of the device. LF-based techniques locate devices by accessing a database containing the fingerprint (i.e., the RSSs and coordinates) of other Wi-Fi devices within the Wi-Fi footprint. These devices then calculate their own coordinates by comparing with those contained in the relevant LF database.

Figure 1.1 summarizes the equipment, working environment, power usage and resolution of these three positioning systems (GPS, CPS and WPS).

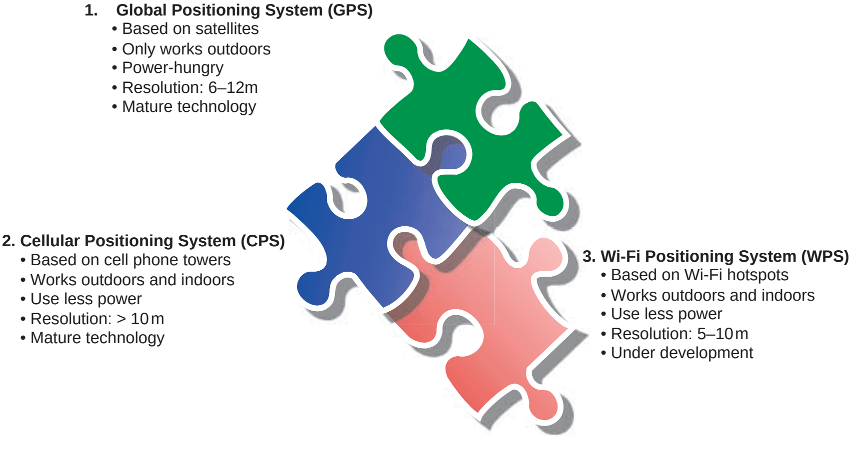

Figure 1.1 Overview of positioning systems.

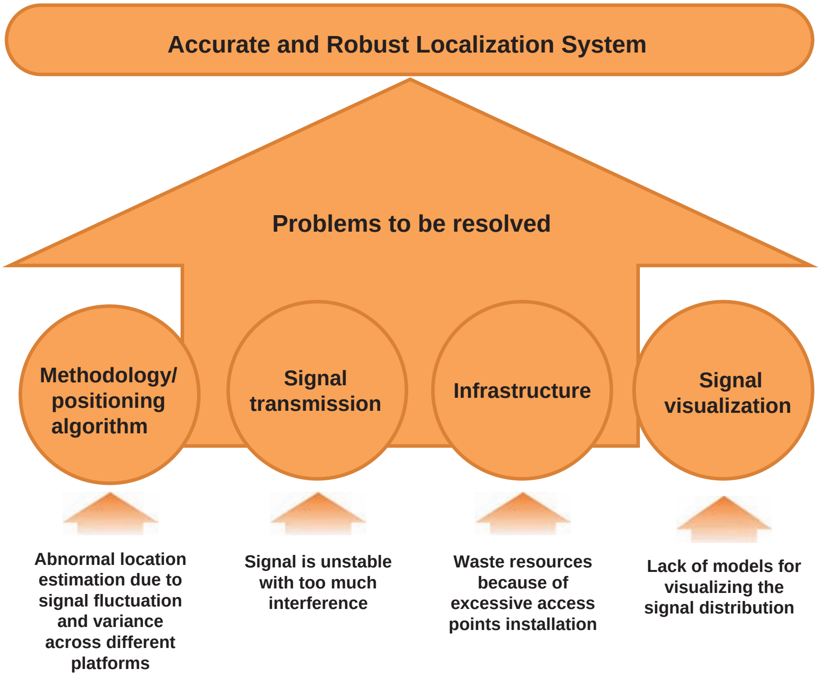

Figure 1.2 Four major problems of the localization system.

1.1 Open Problems in Positioning Technologies

Although there has been a large amount of research on positioning systems, the accuracy and robustness of these systems are still not entirely satisfactory and many open problems have not yet been solved. There are four major problems: (1) computational-intensive and inaccurate positioning algorithms, (2) unstable wireless signal transmission, (3) interference caused by unstructured WLAN infrastructure and (4) lack of models for visualizing the signal distribution. Figure 1.2 depicts the four major localization problems.

1.1.1 Inaccurate Positioning Algorithms

Existing Wi-Fi positioning algorithms (Kaemarungsi and Krishnamurthy, 2004; Kwon *et al.*, 2004; Taheri *et al.*, 2004; Li *et al.*, 2005) suffer from the high computational complexity of location estimation. These algorithms perform signal sampling, weighting, and filtering. Some algorithms (Tiemann *et al.*, 2000; Chen *et al.*, 2004; Wang *et al.*, 2006) make assumptions, such as assuming that WLAN signals obey a Gaussian distribution, even while it has been shown that WLAN signals very often obey a left-skewed distribution (Bahl and Padmanabhan, 2000). Another unsatisfactory assumption is that no loss of energy arises from signals being reflected by obstacles.

Common positioning approaches such as GPS (Taheri *et al.*, 2004), acoustic-based (Chen *et al.*, 2004; Stoleru *et al.*, 2005, 2006), and light-based approaches are the most effective in relatively open and flat outdoor environments but are much less effective in non-line-of-sight (NLOS) environments such as hilly, mountainous, or built-up areas. Some filter signal algorithms (Liu and Chen, 2004; Chang *et al.*, 2007) use a convergence factor of a trajectory to eliminate the noise from signal strength.

Sequential Monte Carlo (SMC) approaches (Hu and Evans, 2004; Dil *et al.*, 2006) estimate locations by calculating the weighted average of all signal samples. However, these are not effective and have high computational costs in sensor networks. An optimization or filtering algorithms may help to improve the dependency problem of wireless signal transmission.

1.1.2 Unstable Wireless Signal Transmission

Unstable wireless signal transmissions are usually caused by interference and by wave propagation problems. Signal overlaps and interferences can seriously worsen the performance of localization systems. A stable and accurate localization depends on a stable wireless signal transmission yet neither the propagation techniques nor the LF-based techniques can guarantee that.

LF-based localization techniques (Kaemarungsi and Krishnamurthy, 2004; Taheri *et al.*, 2004; Li *et al.*, 2005; Fang *et al.*, 2008; Kjaergaard and Munk, 2008; Swangmuang and Krishnamurthy, 2008) require an initial survey with a very large training dataset and each signal sampling is very sensitive to signal fluctuation.

Propagation-based localization techniques (Prasithsangaree *et al.*, 2002; Jan and Lee, 2003; Kwon *et al.*, 2004) must compute every condition that can cause a wave signal to blend.

Both techniques are strongly dependent on stable wireless signal transmissions. At the same time, the common unsystematic approach is to place more APs to improve coverage. However, this may still leave blind spots where there are too many access points packed too closely together. This can lead to signal fluctuation and overlap, which is both wasteful and can cause interference (Budianu *et al.*, 2006)

1.1.3 Unstructured WLAN Infrastructure

An unstructured approach to WLAN infrastructure design implies poor resource utilization (Budianu *et al.*, 2006) WLANs are typically made up of many access points (APs) or nodes. These access points (APs) are manually placed and positioned on the basis of measurements of RSS (received signal strength) taken by engineers empirically. For example, if wireless access points are placed too close together, their signals can overlap.

Not only can this cause interference, but it also poses a potential security risk and it increases the cost of the installation as in certain cases fewer access points could be used to achieve optimal coverage. If, on the other hand, the access points are placed too far apart, there will be a potential increase in the number or extent of flat spots or weak signal areas, which can cause connections to become unusable.

WLAN infrastructures are installed and operated in two configurations. The first configuration is in the absence of wireless access points, communicating directly with each other in a peer-to-peer style. The second configuration makes use of wireless access points where all devices on the wireless network communicate with each other and services provided by the network operate through these access points. This configuration is dominant and used by all network providers in a structured environment. However, peer-to-peer connections constantly change as nodes are removed and thus coverage cannot be guaranteed.

To provide wireless coverage in a particular area, several wireless access points are placed in strategic positions and emit a signal that the clients use to communicate. One of the main issues concerning this second configuration is the placement of the base stations so as to ensure that optimal coverage is provided, meaning that the number or extent of 'flat spots' (where no signal is present) is minimal.

1.1.4 Lack of Signal Analytical Models

The task of localization is not limited to location estimation but is also carried out using analytical models. For example, WLAN signal analytical models can be used to visualize the distribution of signals and help to improve the design of positioning systems by eliminating WLAN access points (APs), shortening the sampling time of WLAN received signal strength (RSS) in location estimation, and ensuring that all vital areas of a building have wireless coverage.

Currently there are very few support tools available for planning the installation of APs, or to visualize and monitor signal coverage of the installed network. The available tools are designed only for outside installations, where the wireless signal strength and Global Positioning Service information can be combined to provide feedback.

There is a lack of visualization models that can be used as a framework for designing and deploying positioning systems. These models should have spatial elements for visualizing the RSS distribution, evaluating and predicting the precise performance of indoor positioning systems based on location fingerprinting. Such an analytical model would support the placement of Wi-Fi APs so as to achieve the maximum throughput.

Most existing methods for modeling location fingerprinting (Kaemarungsi and Krishnamurthy, 2004; Swangmuang and Krishnamurthy, 2008) depend on the accurate performance of positioning systems and proximity graphs, such as Voronoi diagrams and clustering graphs. They usually make use of the Euclidean distance to determine positions. Some researchers (Fang *et al.*, 2008; Kjaergaard and Munk, 2008; Swangmuang and Krishnamurthy, 2008) have ignored radio signal properties and others have assumed the distribution of the RSS is Gaussian and pair wise. Yet Bahl and Padmanabhan (2000) have shown that the distribution of the RSS is not usually Gaussian but rather left-skewed and the standard deviation varies according to the signal level.

1.2 Factors Leading to Effective Positioning Systems

There are five major factors (Figure 1.3) that must be considered in the design of an efficient and effective localization system: (1) an accurate positioning algorithm, (2) a stable WLAN signal transmission, (3) a structural WLAN infrastructure that could support intensive tracking, (4) a model that can visualize the WLAN signal distribution to prevent signal black spots and interference and, finally (5) a retrieval system that can provide location-aware information that matches or responds to user needs. The following briefly describes each of these factors in greater detail.

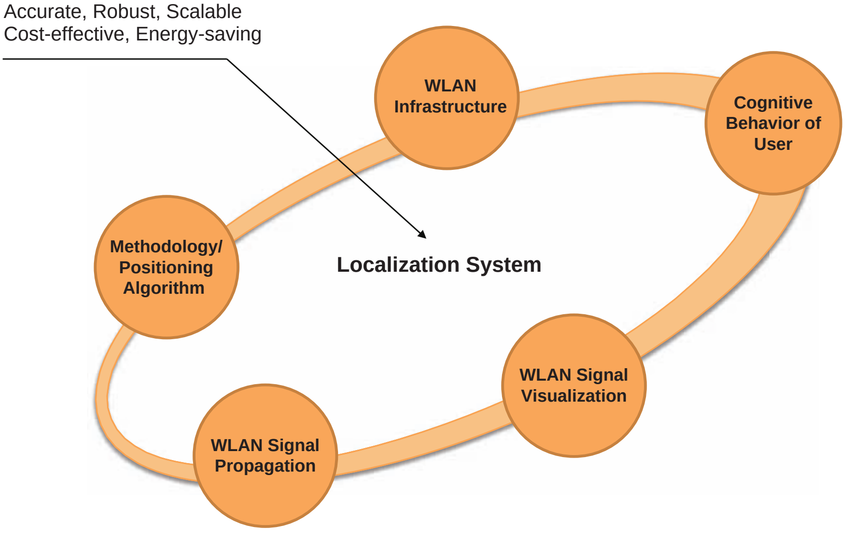

Figure 1.3 Five major factors of WLAN localization system.

1.2.1 An Accurate Positioning Algorithm/Approach

An accurate positioning approach is crucial for effective indoor localization. Chan *et al.* (2009d) discuss applications of the Newton Trust-Region method and the use of the convergence of a trajectory to remove the noise from the received signal strength. Chan *et al.* (2010) apply a Newton Trust-Region (TR) algorithm to trajectory estimation based on the traditional Location Fingerprinting/Localization approach. The Newton Trust-Region method optimizes Location Fingerprinting iteratively because each point in a trajectory normally falls into a region and converges in the same direction. More details will be discussed in chapter 3 and 4.

1.2.2 A Stable WLAN Signal Transmission

A stable WLAN signal transmission is usually obtained by reducing the signal interference. Interference is a major source of signal fluctuation so it is necessary to reduce channel interference between access points. Channel interference can occur because adjacent channels overlap in the frequency spectrum in IEEE 802.11b/g WLAN. Recent research has focused on either creating a new channel assignment scheme (Chiu *et al.*, 2006; Haidar *et al.*, 2008; Subramanian *et al.*, 2008) or enhancing existing MAC protocols (Dutta *et al.*, 2007; Zeng *et al.*, 2007) to reduce channel interference. The objective of this recent work has been to improve the data transmission through wireless networks. However, none of the existing work on channel interference has addressed accurate performance and the improvement of location estimation algorithms. In some cases it has even been wrongly suggested that interference might increase the accuracy of positioning.

Chan *et al.* (2010) investigate the influence of channel interference in a location fingerprinting approach and describe localization experiments and simulations on the IEEE 802.11 test-bed. Chan *et al.* (2010) also investigate AP channel assignment, the distribution of received signal strength (RSS) values, and variations in covered areas and the distances between APs. This analysis will provide guidance as to (1) how to assign channels, (2) space APs to reduce interference, and (3) calculate how many access points are required to uniquely identify a location at a given accuracy and precision. The relevant findings should be of assistance to engineers in designing and better understanding a WLAN channel assignment specifically for positioning. More details will be discussed in Chapter 2.

1.2.3 A Structural WLAN Infrastructure

A structural WLAN infrastructure deployment aims to achieve high localization accuracy and optimal coverage. As alternatives, Chan *et al.* (2009c) propose three structured approaches (triangular, square and hexagonal AP distributions) to achieve this aim. Overall, the hexagonal approach is the most effective for localization operations. A surprising result of this work is the discovery that the center of a square distribution produces a localization accuracy that is 30% higher than either of the other two structured approaches. The worst performer is the ad-hoc distribution, which requires 50% more APs than the hexagonal distribution to achieve effective localization. More details will be also covered in Chapter 2.

1.2.4 A Graphical Fuzzy Signal Visualization Model

Fuzzy logic modeling can be applied to evaluate the behavior of the received signal strength (RSS) in Wireless Local Area Networks (WLANs), which is a central part of WLAN tracking analysis. Previous analytical models have considered in depth how the WLAN infrastructure affects the accuracy of tracking. Chan *et al.* (2009b) propose a novel fuzzy spatio-temporal topographic model implemented in a large (9.34 hectare), physical university campus where the WLAN received signal strength (RSS) was surveyed from more than 2000 access points. The Nelder-Mead (NM) method was applied to simplify this authors' previous work on fuzzy color maps into a topographic (line-based) map. The new model provides a detailed, quantitative representation of WLAN RSS. More details will be discussed in Chapter 6.

1.2.5 A Location-aware Information Retrieval System

One of the most challenging problems in retrieving location-aware information is to understand user queries in such a way that it is optimally suitable to the user's current location. The speed and accuracy of retrieval and the usefulness of the retrieved data depends on a number of factors including constant or frequent changes in its content or status, the effects of environmental factors such as the weather and traffic and the techniques that are used to categorize the relevance of the retrieved data.

Chan *et al.* (2009a) preliminarily attempt to deal with this task that makes use of artificial intelligent (AI) technologies operating in both wired and wireless networks to find and retrieve location-aware information. AI computer programs are endowed with a wide range of human-like abilities, including perception, the use of natural language, learning, and the ability to understand user queries. More specifically, this work proposes semantic TFIDF, an agent-based system for retrieving location-aware information that improves the speed of retrieval while maintaining or even improving the accuracy by making use of semantic information in the data to develop smaller training sets. The method assigns intelligent computer programs to first gather location-aware data and then, using semantic graphs from the WordNet English dictionary, the agents classify, match and organize the information to find a best match for a user query. Experiments show it to be significantly faster and more accurate. More details will be discussed in Chapters 11 and 12.

Chapter Summary

This chapter has introduced the background, open problems and five factors that affect the effectiveness of positioning systems. The next chapter focuses on how to build a cost-effective and resource-efficient Wi-Fi infrastructure for positioning.

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