



Eddie C. L. Chan  
George Baciú

# INTRODUCTION TO WIRELESS LOCALIZATION

With iPhone SDK Examples

[Companion Website](#)



# **INTRODUCTION TO WIRELESS LOCALIZATION**



# **INTRODUCTION TO WIRELESS LOCALIZATION**

## **WITH iPhone SDK EXAMPLES**

**Eddie C.L. Chan**

*The Hong Kong University of Science and Technology, Hong Kong*

**George Baci**

*The Hong Kong Polytechnic University, Hong Kong*



This edition first published 2012  
© 2012 John Wiley & Sons Singapore Pte. Ltd.

*Registered office*

John Wiley & Sons Singapore Pte. Ltd., 1 Fusionopolis Walk, #07-01 Solaris South Tower, Singapore 138628

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at [www.wiley.com](http://www.wiley.com).

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as expressly permitted by law, without either the prior written permission of the Publisher, or authorization through payment of the appropriate photocopy fee to the Copyright Clearance Center. Requests for permission should be addressed to the Publisher, John Wiley & Sons Singapore Pte. Ltd., 1 Fusionopolis Walk, #07-01 Solaris South Tower, Singapore 138628, tel: 65-66438000, fax: 65-66438008, email: [enquiry@wiley.com](mailto:enquiry@wiley.com).

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The Publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the Publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

All iPhone and IOS images in the book are produced by the authors. This book's use or discussion of iPhone and its applications does not constitute endorsement or sponsorship by Apple Inc. of a particular approach or use of its application software. iPhone is a trademark of Apple Inc., registered in the U.S. and other countries. IOS is a trademark or registered trademark of Cisco in the U.S. and other countries and is used under license by Apple Inc.

***Library of Congress Cataloging-in-Publication Data***

Chan, Eddie C. L.

Introduction to wireless localization : with iPhone SDK examples / Eddie C.L. Chan, George Baciu.  
p. cm.

Includes bibliographical references and index.

ISBN 978-1-118-29851-0 (cloth)

1. Location-based services. 2. iPhone (Smartphone)–Programming. I. Baciu, George, 1961- II. Title.  
TK5105.65.C48 2012  
005.3–dc23

2011052849

Set in 10/11.5pt NimbusRom9L by Thomson Digital, Noida, India.

# Contents

<b>Preface</b>	<b>xiii</b>
<b>About the Authors</b>	<b>xvii</b>
<b>1 Introduction to Wireless Localization</b>	<b>1</b>
1.1 Open Problems in Positioning Technologies	3
1.1.1 Inaccurate Positioning Algorithms	3
1.1.2 Unstable Wireless Signal Transmission	4
1.1.3 Unstructured WLAN Infrastructure	4
1.1.4 Lack of Signal Analytical Models	5
1.2 Factors Leading to Effective Positioning Systems	5
1.2.1 An Accurate Positioning Algorithm/Approach	6
1.2.2 A Stable WLAN Signal Transmission	6
1.2.3 A Structural WLAN Infrastructure	7
1.2.4 A Graphical Fuzzy Signal Visualization Model	7
1.2.5 A Location-aware Information Retrieval System	7
References	9
<b>Part I: Wi-Fi Positioning Systems</b>	
<b>2 Installation of Wi-Fi Infrastructure</b>	<b>13</b>
2.1 What is the IEEE 802.11 Family?	14
2.2 Properties of Wi-Fi Signal Strength	15
2.2.1 Distribution of Wi-Fi Signal Strength	15
2.2.2 Large Value of Path Loss	17
2.2.3 Small Value of Path Loss	17
2.2.4 Behavior Study on the Human's Presence	18
2.3 Optimal Channel Allocation for Wi-Fi Positioning	19
2.3.1 Overlapping Channel Interference	20
2.3.2 Distribution of Channel Interference	21
2.3.3 Channel Assignment Schemes	23
2.4 Determining Number of APs to be Installed	24
2.4.1 Square Tessellation Installation	24
	v

2.4.2	Z Factor	24
2.4.3	Environmental Factors	24
2.4.4	Number of Access Points Needed	25
2.5	Other Tessellation Installations	27
2.5.1	X and Y Factors	27
2.5.2	Environmental Factors	30
2.5.3	Determining Number of APs to be Installed	30
2.5.4	Summary of AP Deployment Approach	31
	Reference	33
<b>3</b>	<b>Algorithms Used in Wi-Fi Positioning Systems</b>	<b>35</b>
3.1	Taxonomy of Indoor Positioning Techniques	36
3.2	Propagation-based Algorithms	37
3.2.1	Angle of Arrival (AOA)	38
3.2.2	Time of Arrival (TOA)	40
3.2.3	Phase of Arrival (POA)	42
3.2.4	Time Difference of Arrival (TDOA)	43
3.2.5	Roundtrip Time of Flight (RTOF)	46
3.3	Location-fingerprinting-based Algorithms	47
3.3.1	K-Nearest Neighbor Algorithms	47
3.3.2	Smallest M-vertex Polygon (SMP)	50
3.3.3	Neural Network	50
3.3.4	Support Vector Machine (SVM)	53
3.3.5	Probabilistic Algorithms	57
3.4	Evaluation of Positioning Techniques	58
3.4.1	Mean Square Error (MSE)	58
3.4.2	Cumulative Distribution Function (CDF)	59
3.4.3	Cramèr-Rao Lower Bound (CRLB)	59
3.4.4	Circular Error of Probable (CEP)	63
3.4.5	Geometric Dilution of Precision (GDOP)	65
3.5	Comparison of Indoor Positioning System	66
	References	68
<b>4</b>	<b>Implementation of Wi-Fi Positioning in iPhone</b>	<b>71</b>
4.1	Site-surveying of Wi-Fi Signals Using iPhone	73
4.2	Implementing Location Fingerprinting Algorithm in iPhone	83

---

4.3	Orientation Filter	86
4.4	Newton Trust-Region Method	88
4.4.1	TR Subproblem	89
4.4.2	TR Fidelity	89
4.4.3	TR Radius	89
	References	95
<b>5</b>	<b>Positioning across Different Mobile Platform</b>	<b>97</b>
5.1	Signal Strength Value Ratio Approach	98
5.1.1	Signal Strength Ratio	98
5.1.2	Log-normalized Signal Strength Ratio	99
5.1.3	K-NN Hyperbolic Location Fingerprinting	99
5.1.4	Probabilistic Hyperbolic Location Fingerprinting	100
5.2	Signal Strength Value Difference Approach	100
5.2.1	Signal Strength Value Difference	100
5.2.2	K-NN DIFF Location Fingerprinting	100
5.2.3	Probabilistic DIFF Location Fingerprinting	100
5.3	Fourier Descriptors Approach	101
5.3.1	Fourier Location Fingerprint	101
5.3.2	Example of Fourier Location Fingerprint	103
5.3.3	K-NN Fourier Location Fingerprinting	103
5.3.4	Probabilistic Fourier Location Fingerprinting	104
	References	105
<b>6</b>	<b>Wi-Fi Signal Visualization</b>	<b>107</b>
6.1	Why Do We Need a Wi-Fi Visualization Tool?	107
6.2	Fuzzy Color Map	108
6.2.1	Fuzzy Membership Function	108
6.2.2	Fuzzy Spatio-temporal Cluster	109
6.3	Topographic Map	110
6.3.1	Topographic Node	110
6.3.2	Nelder-Mead Method	110
6.3.3	Topographic Model Generation	112
6.4	Signal Visualization Experiments and Results	113
6.4.1	Experimental Setup	113
6.4.2	Visualization Results	115

6.5 Refinement of Positioning Systems Based on Wi-Fi Visualization Result	118
References	120

## **Part II: Outdoor Positioning Systems**

<b>7 Introduction of Global Positioning System</b>	<b>123</b>
7.1 History of GPS	124
7.2 Functions of GPS	125
7.3 Components of GPS	125
7.3.1 Space Segment	125
7.3.2 Control Segment	126
7.3.3 User Segment	127
7.3.4 Ground Segment	127
7.4 Types of GPS Receivers	127
7.5 Sources of Errors in GPS	128
7.5.1 Ephemeris Errors	128
7.5.2 Satellite Clock Errors	129
7.5.3 Receiver Errors	129
7.5.4 Atmospheric Errors	129
7.5.5 Multipath Interference	130
7.6 Precision of the GPS	131
7.6.1 Geometric Dilution of Precision (GDOP)	131
7.6.2 User Equivalent Range Error (UERE)	133
7.7 Coordinate Systems on the Earth	133
<b>8 Study of GPS Signal and Algorithms</b>	<b>137</b>
8.1 GPS Signals	137
8.1.1 Coarse Acquisition Code	138
8.1.2 Precision Code	138
8.1.3 Navigation Message	138
8.1.4 Navigation Message Format	139
8.2 Modernized GPS Signals	141
8.2.1 L2 Civil Signal (L2C)	142
8.2.2 L5 Signal	142
8.2.3 M Code	143
8.2.4 L1 Civil Signal (L1C)	143
8.3 GPS Absolute Point Determination	143

---

8.3.1	Trilateration Algorithm	143
8.3.2	What is Pseudorange?	146
8.3.3	Determining the Location	147
8.3.4	Determining the Location Using Linearization	148
8.4	Calculating User Velocity	153
<b>9</b>	<b>Differential GPS and Assisted GPS</b>	<b>157</b>
9.1	Types of DGPS	158
9.2	How DGPS Works	158
9.2.1	Real-time DGPS	158
9.2.2	Post-process DGPS	161
9.3	DGPS Navigation Message Format	161
9.3.1	RTCM SC-104 Version 2.3	162
9.3.2	RTCM SC-104 Version 3.0	164
9.4	Assisted GPS	166
9.5	AGPS in iPhone	167
9.5.1	Core Location Framework	168
9.5.2	Core Location	171
9.5.3	GPS Program in iPhone	173
9.5.4	Core Location Heading	176
9.5.5	Compass in iPhone	179
9.5.6	MapKit framework	180
<b>10</b>	<b>Other Existing Positioning Systems</b>	<b>185</b>
10.1	Acoustic-based Positioning	186
10.1.1	Active Acoustic Positioning	187
10.1.2	Passive Acoustic Positioning	187
10.1.3	What is Beamforming?	187
10.1.4	Applications of Acoustic Positioning	188
10.2	Vision-based Positioning	188
10.2.1	Camera-based Positioning	188
10.2.2	Landmark-based Positioning	190
10.2.3	Applications of Vision-based Positioning	192
10.3	What is RFID Technology and Its Components?	192
10.3.1	RFID Reader	193
10.3.2	RFID Tag	193

10.3.3	RFID Positioning	195
10.3.4	Applications of RFID Positioning	196

### **Part III: Applications in Wireless Localization**

#### **11 AI for Location-aware Applications 201**

11.1	What is Location-aware Application?	202
11.2	What are AI Techniques?	204
11.2.1	Fuzzy Logic	205
11.2.2	Natural Language Processing	207
11.3	Example of the Tourist Guide Application	209
11.3.1	System Overview of the Tourist Guide Application	209
11.3.2	Applying Fuzzy Logic in the Tourist Guide Application	210
11.3.3	Building the Database Structure	211
11.3.4	Setting Up the Server Side in PHP	212
11.3.5	Setting Up the Client-side in iPhone	213

#### **12 Beyond Positioning: Video Streaming and Conferencing 223**

12.1	What is Video Streaming?	224
12.1.1	Point-to-point Video Streaming	224
12.1.2	Multicast Video Streaming	225
12.1.3	Broadcast Video Streaming	225
12.2	Networks and Formats in Video Streaming	225
12.3	How Does Video Streaming Work?	227
12.3.1	Traditional Video Streaming	228
12.3.2	Adaptive Video Streaming	228
12.4	Location-aware Video Streaming	229
12.4.1	Building the Location-Based Bandwidth Lookup Database	230
12.4.2	Location-based Bit-rate and Quality Monitoring	231
12.5	What is Video Conferencing?	231
12.6	Implementation of Video Streaming in iPhone	233
12.7	Implementation of Video Conferencing in iPhone	241

#### **Appendix A Starting the iOS SDK 245**

A.1	Getting the iOS SDK	246
A.2	What Can You Create Using iOS SDK?	248
A.2.1	What Tools Are in the iOS SDK?	248

---

A.2.2	Apple Developer Center	249
A.3	Limitations of iPhone Environment	250
A.4	Introduction to Xcode	251
A.4.1	Xcode Project Template	253
A.4.2	Xcode Project Summary	253
A.5	Xcode Project Interface	254
A.5.1	Toolbar	255
A.5.2	Navigation Area	256
A.5.3	Editor Area	257
A.5.4	Debug Area	257
A.5.5	Utility Area	258
<b>Appendix B</b>	<b>Introduction to Objective-C Programming in iPhone</b>	<b>261</b>
B.1	Objective-C Program, HelloWorld	262
B.1.1	Using Xcode to Code and Compile Programs	263
B.1.2	What is #import?	265
B.1.3	What is Main?	266
B.1.4	Automatic Reference Counting (ARC)	266
B.1.5	What is NSLog()?	266
B.2	Object-Oriented Programming (OOP)	266
B.2.1	Infix Notation	268
B.2.2	The @Interface Section	269
B.2.3	The @Implementation Section	270
B.2.4	The Program Section	271
B.2.5	@property, @synthesize and @dynamic	272
B.2.6	@property in the @interface Section	273
B.2.7	@synthesize in the @implementation Section	274
B.2.8	@dynamic in the @implementation Section	275
B.2.9	Dot Notation	275
B.2.10	Category	275
B.3	HelloWorld iPhone Application	278
B.3.1	Using Interface Builder	279
B.3.2	Creating User Interface by Click-dragging Processes	281
B.4	Creating Your Web Browser in iPhone	282
B.5	Creating a Simple Map Application	287
B.5.1	Map Function from MapKit Frameworks	289

B.5.2	Locate Yourself and Shift Center View in the Map	291
B.5.3	Translate and Zoom by MKCoordinateRegion Class	291
B.5.4	Switch from Satellite Map to Standard Street Map	292
B.5.5	UISlider Item Handles Zoom Events	294
B.5.6	Switches Web Browser and Simple Map Application	298
	Index	305

## Preface

**W**ireless 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 dining 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](http://www.wiley.com/go/chan/wireless)*

The reader is encouraged to send any corrections to

*[csclchan@gmail.com](mailto:csclchan@gmail.com)*

## Acknowledgements

I (Eddie C. L. Chan) am deeply indebted to Professor George Baciu for his support in writing this book. He is my mentor and my friend who always encourages me. I had my

knowledge enriched and gained greatly from his clarity of vision and his view of computer science.

I am obliged to Professor Mordecai J. Golin and Professor Brian Mak for providing me with a warm and friendly working environment in the Department of Computer Science and Engineering at The Hong Kong University of Science and Technology.

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.

I would like to express my gratitude to my friend, Mr. Tony Ao Ieong for providing me with a wealth of ideas about positioning techniques. He is an integral part of this book. Mr. Raymond Ho Man Chun gave me advice to design the layout of book. I would like to thank him for the excellent design skills he has applied to this book. I am also pleased to acknowledge the cooperation and technical support of Mr. Mak Sin Cheung.

My mother and father certainly merit mention for not only offering support when I quit my job in order to work on this book, but also throughout my entire life. They have worked very hard to raise me and give me love and support. They have shaped and molded me into the person that I am today, and my only wish is to see them happy and healthy.

I am also grateful for those whom I hold dear to my heart for the long hours that they sat and listened to the issues I had surrounding this book. I want to thank my uncle, Dr. Alfert Tsang, and his wife, Mrs. Michelle Tsang, are always good listeners and advisers. Special thanks goes to my girlfriend, Miss Kami Hui, for her encouragement and support while writing this book. I want to thank Mr. Martin Kyle for his patience, understanding, and valuable assistance with many aspects of this book, including proofreading and indexing. Lastly, special thanks must go to the publishing team, Mr. James Murphy and Miss Shelley Chow from John Wiley & Sons, Mr. Prakash Naorem and Mr. Martin Noble, for their help and support in the production process of this book.

## About the Authors

**E**ddie 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.

**G**eorge 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

**W**ireless 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

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).

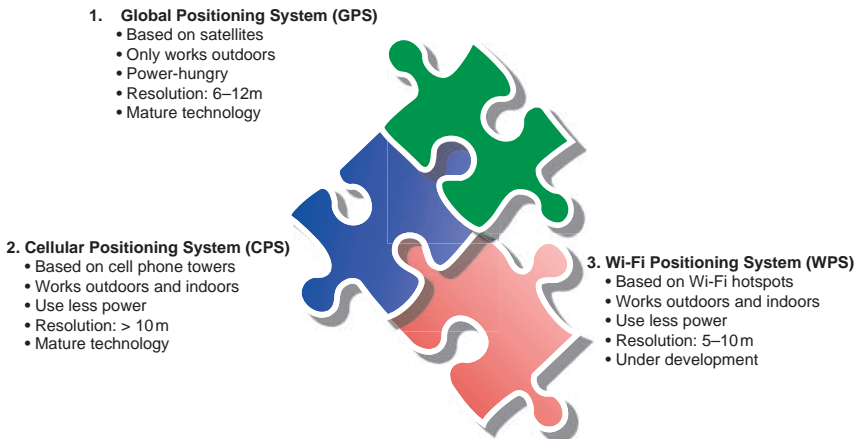


Figure 1.1 Overview of positioning systems.

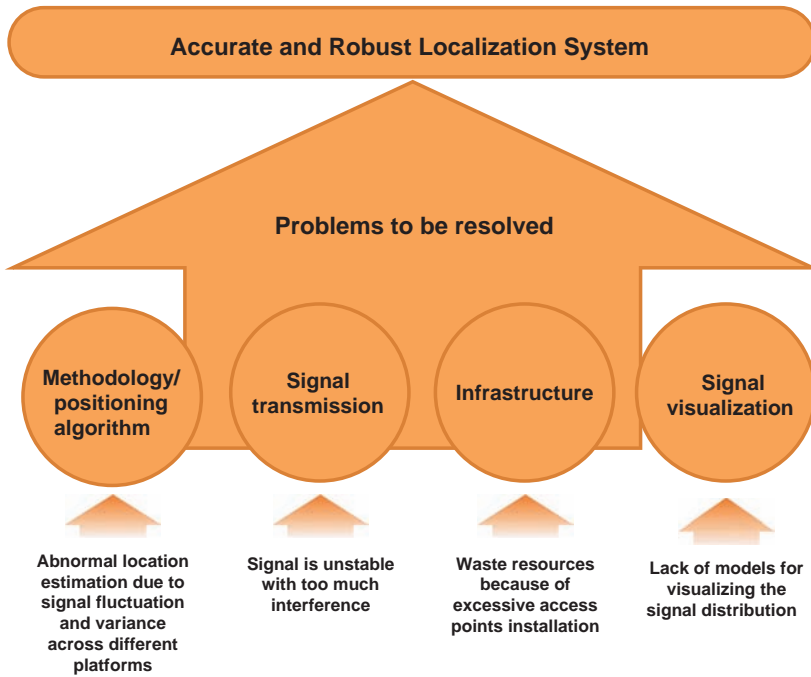


Figure 1.2 Four major problems of the localization system.

## 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.

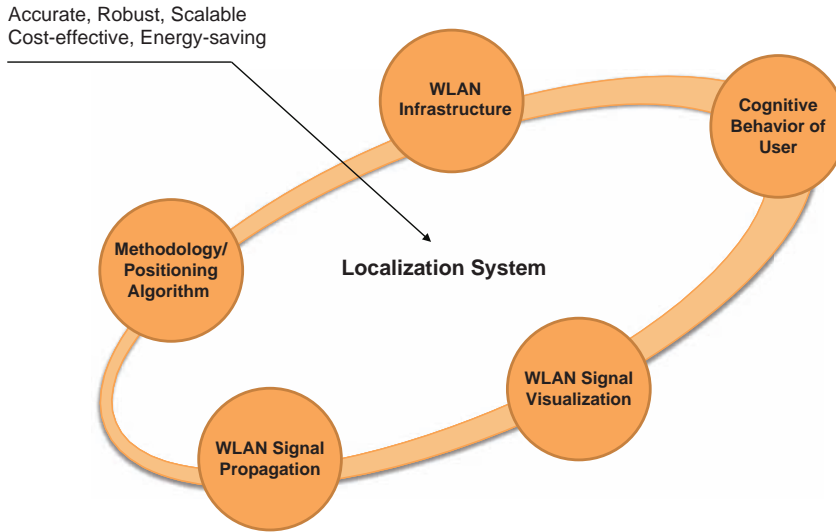


Figure 1.3 Five major factors of WLAN localization system.

### 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 TFIDE, 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.

## References

- Bahl, P. and Padmanabhan, V. (2000). RADAR: an in-building RF-based user location and tracking system. *The 19th IEEE International Conference on Computer Communications, INFOCOM*, pp. 775–784.
- Budianu, C., Ben-David, S., and Tong, L. (2006). Estimation of the number of operating sensors in large-scale sensor networks with mobile access. *IEEE Transactions on Signal Processing*, pp. 1703–1715.
- Chan, C. L., Baciuc, G., and Mak, S. (2009a). Cognitive location-aware information retrieval by agent-based semantic matching. *The 8th IEEE International Conference on Cognitive Informatics, ICCI*, pp. 435–440.
- Chan, C. L., Baciuc, G., and Mak, S. (2009b). Fuzzy topographic modeling in WLAN tracking analysis. *International Conference on Fuzzy Computation, ICFC*, pp. 17–24.
- Chan, C. L., Baciuc, G., and Mak, S. (2009c). Resource-effective and accurate WLAN infrastructure design and localization using a cell-structure framework. *The 5th International Conference on Wireless Communications, Network and Mobile Computing*, 6: 9–15.
- Chan, C. L., Baciuc, G., and Mak, S. (2009d). Using the Newton Trust-Region method to localize in WLAN environment. *The 5th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, WiMOB*, pp. 363–369.
- Chan, C. L., Baciuc, G., and Mak, S. (2010). Properties of channel interference for WLAN location fingerprinting. *Journal of Communications Software and Systems*, 6(2): 56–64.
- Chang, K., Hong, L., and Wan, H. (2007). Stochastic trust region gradient-free method (strong): a new response-surface-based algorithm in simulation optimization. *The 39th Conference on Winter Simulation*, pp. 346–354.
- Chen, W., Hou, J., and Sha, L. (2004). Dynamic clustering for acoustic target tracking in wireless sensor networks. *IEEE Transactions on Mobile Computing*, pp. 258–271.
- Chiu, H. S., Yeung, K., and Lui, K.-S. (2006). J-CAR: an efficient channel assignment and routing protocol for multi-channel multi-interface mobile ad hoc networks. *IEEE Global Telecommunications Conference*, pp. 1–5.
- Danesh, A., Moshiri, B., and Fatemi, O. (2007). Improve text classification accuracy based on classifier fusion methods. *The 10th International Conference on Information Fusion*, pp. 1–6.
- Dil, B., Dulman, S., and Havinga, P. (2006). Rangebased localization in mobile sensor networks. *European Conference on Wireless Sensor Networks*, pp. 164–179.
- Dutta, P., Jaiswal, S., and Rastogi, R. (2007). Routing and channel allocation in rural wireless mesh networks. *The 26th IEEE International Conference, INFOCOM*, pp. 598–606.
- Fang, S., Lin, T., and Lin, P. (2008). Location fingerprinting in a decorrelated space. *IEEE Transactions on Knowledge and Data Engineering*, 20(5): 685–691.
- Haidar, M., Ghimire, R., Al-Rizzo, H., Akl, R., and Chan, Y. (2008). Channel assignment in an IEEE 802.11 WLAN based on signal-to-interference ratio. *Electrical and Computer Engineering Canadian Conference, CCECE*, pp. 001169–001174.
- Hu, L. and Evans, D. (2004). Localization for mobile sensor networks. *The 10th International Conference on Mobile Computing and Networking*, pp. 45–57.
- Jan, R. and Lee, Y. (2003). An indoor geolocation system for wireless LANs. *International Conference on Parallel Processing Workshops*, pp. 29–34.
- Kaemarungsi, K. and Krishnamurthy, P. (2004). Modeling of indoor positioning systems based on location fingerprinting. *The 23th IEEE International Conference on Computer Communications, INFOCOM*, 2, pp. 1012–1022.

- Kjaergaard, M. B. and Munk, C. V. (2008). Hyperbolic location fingerprinting: a calibration-free solution for handling differences in signal strength. *The 6th IEEE International Conference on Pervasive Computing and Communications*, pp. 110–116.
- Kwon, J., Dundar, B., and Varaiya, P. (2004). Hybrid algorithm for indoor positioning using wireless LAN. *The IEEE 60th Vehicular Technology Conference, VTC*, 7, pp. 4625–4629.
- Li, B., Wang, Y., Lee, H., Dempster, A., and Rizos, C. (2005). Method for yielding a database of location fingerprints in WLAN. *IEEE Proceedings on Communications*, 152(5): 580–586.
- Liu, T. and Chen, H. (2004). Real-time tracking using Trust-Region methods. *IEEE Transactions on Pattern Analysis on Machine Intelligence*, pp. 397–402.
- Prasithsangaree, P., Krishnamurthy, P., and Chrysanthis, P. (2002). On indoor position location with wireless LANs. *The 13th IEEE International Symposium, Personal, Indoor and Mobile Radio Communications*, 2, pp. 720–724.
- Stoleru, R., He, T., Stankovic, J. A., and Luebke, D. (2005). A high-accuracy, low-cost localization system for wireless sensor networks. *The 3rd International Conference on Embedded Networked Sensor Systems*, pp. 13–26.
- Stoleru, R., Vicaire, P., He, T., and Stankovic, J. (2006). StarDust: a flexible architecture for passive localization in wireless sensor networks. *The 4th International Conference on Embedded Networked Sensor Systems*, pp. 57–70.
- Subramanian, A. P., Gupta, H., Das, S. R., and Cao, J. (2008). Minimum interference channel assignment in multiradio wireless mesh networks. *IEEE Transactions on Mobile Computing*, 2: 1459–1473.
- Swangmuang, N. and Krishnamurthy, P. (2008). Location fingerprint analyses toward efficient indoor positioning. *The 6th IEEE International Conference on Pervasive Computing and Communications*, pp. 101–109.
- Taheri, A., Singh, A., and Emmanuel, A. (2004). Location fingerprinting on infrastructure 802.11 wireless local area networks (WLANs) using Locus. *The 29th IEEE International Conference on Local Computer Networks*, pp. 676–683.
- Tiemann, C., Martin, S., Joseph, J., and Mobley, R. (2000). Aerial and acoustic marine mammal detection and localization on navy ranges. *U.S. Department of Commerce and Department of the Navy, Joint Interim Report: Bahamas Marine Mammal Stranding Event*.
- Wang, J., Zha, H., and Cipolla, R. (2006). Coarse-to-fine vision-based localization by indexing scale-invariant features. *IEEE Transactions on Systems, Man, and Cybernetics – Part B: Cybernetics*, 36(2): 413.
- Weiss, S., Kasif, S., and Brill, E. (1996). Text Classification in USENET newsgroup: A progress report. *AAAI Spring Symposium on Machine Learning in Information Access Technical Papers, Palo Alto*, pp. 125–127.
- Zeng, G., Wang, B., Ding, Y., Xiao, L., and Mutka, M. (2007). Multicast algorithms for multi-channel wireless mesh networks. *IEEE International Conference on Network Protocols, ICNP*, pp. 1–10.