Preface

Distributed sensor networks have been discussed for more than 30 years, but the vision of wireless sensor networks has been brought into reality only by the recent advances in wireless communications and electronics, which have enabled the development of low-cost, low-power and multi-functional sensors that are small in size and communicate over short distances. Today, cheap, smart sensors, networked through wireless links and deployed in large numbers, provide unprecedented opportunities for monitoring and controlling homes, cities, and the environment. In addition, networked sensors have a broad spectrum of applications in the defence area, generating new capabilities for reconnaissance and surveillance as well as other tactical applications.

Localization (location estimation) capability is essential in most wireless sensor network applications. In environmental monitoring applications such as animal habitat monitoring, bush fire surveillance, water quality monitoring and precision agriculture, the measurement data are meaningless without an accurate knowledge of the location from where the data are obtained. Moreover, the availability of location information may enable a myriad of applications such as inventory management, intrusion detection, road traffic monitoring, health monitoring, reconnaissance and surveillance.

Wireless sensor network localization techniques are used to estimate the locations of the sensors with unknown positions in a network using the available *a priori* knowledge of positions of, typically, a few specific sensors in the network and inter-sensor measurements such as distance, time difference of arrival, angle of arrival and connectivity. Sensor network localization techniques are not just trivial extensions of the traditional localization techniques like GPS or radar-based geolocation techniques. They involve further challenges in several aspects: (1) a variety of measurements may be used in sensor network localization; (2) the environments in which sensor networks are deployed are often complicated, involving urban environments, indoor environments and non-line-of-sight conditions; (3) wireless sensors are often small and low-cost sensors with limited computational capabilities; (4) sensor network localization techniques are often required to be implemented using available measurements and with minimal hardware investment; (5) sensor network localization techniques are often required to be suitable for deployment in large scale multi-hop networks; and (6) the choice of sensor network localization techniques to be used often involves consideration of the trade-off among cost, size and localization accuracy to suit the requirements of a variety of applications. It is these challenges that make localization in wireless sensor networks unique and intriguing.

This book is intended to cover the major techniques that have been widely used for wireless sensor network localization and capture the most recent developments in the area. It is based on a number of stand-alone chapters that together cover the subject matter in a fully comprehensive manner. However, despite its focus on localization in wireless sensor networks, many localization techniques introduced in the book can be applied in a variety of wireless networks beyond sensor networks.

The targeted audience for the book includes professionals who are designers and/or planners for wireless localization systems, researchers (academics and graduate students), and those who would like to learn about the field. Although the book is not exactly a textbook, the format and flow of information have been organized such that it can be used as a textbook for graduate courses and research-oriented courses that deal with wireless sensor networks and wireless localization techniques.

ORGANIZATION

This book consists of 18 chapters. It begins with an introductory chapter that covers the basic principles of techniques involved in the design and implementation of wireless sensor network localization systems. A focus of the chapter is on explaining how the other chapters are related to each other and how topics covered in each chapter fit into the architecture of this book and the big picture of wireless sensor network localization. The other chapters are organized into three parts: measurement techniques, localization theory, and algorithms, experimental study and applications.

Measurement techniques are of fundamental importance in sensor network localization. It is the type of measurements employed and the corresponding precision that fundamentally determine the estimation accuracy of a localization system and the localization algorithm being implemented by this system. Measurements also determine the type of algorithm that can be used by a particular localization system. The part on *Measurement Techniques* includes Chapters II-V, which discuss various aspects of measurement techniques used in sensor network localization. Chapter II introduces a common framework for analysing the information content of various measurements, which can be used to derive localization bounds for integration of any combination of measurements in the network. Chapter III discusses challenges in time-of-arrival measurement techniques and methods to overcome these challenges. A focus of the chapter is on the identification of non-line-of-sight conditions in time-of-arrival measurements and the corresponding mitigation techniques. Chapter IV gives a detailed discussion on the impact of various factors, that is, noise, clock synchronization, signal bandwidth and multipath, on the accuracy of signal propagation time measurements. Chapter V features a thorough discussion on a number of practical issues involved in the use of received signal strength (RSS) measurements. In particular, it focuses on the device calibration problem and its impact on localization.

Chapters VI-XV give an in-depth discussion of the fundamental theory underpinning sensor network localization and various localization approaches. Chapter VI gives a detailed overview of various tools in graph theory and combinatorial rigidity, many of which are just recently developed, to characterize uniquely localizable networks. A network is said to be uniquely localizable if there is a unique set of locations consistent with the given data, that is, location information of a few specific sensors and inter-sensor measurements. Chapter VII presents a class of computationally efficient sequential algorithms based on graph theory for estimating sensor locations using inaccurate distance measurements. Chapter VIII presents several centralized and distributed localization algorithms based on multidimensional scaling techniques for implementation in regular and irregular networks. Chapters IX-XI feature a thorough discussion on theoretical and practical issues involved in the design and implementation of RSS-based localization algorithms. Chapter IX focuses on localization in indoor wireless local area network (WLAN) environments and presents a RSS-based localization system for indoor WLAN environments. The localization problem is formulated as a multi-hypothesis testing problem and an algorithm is developed using this algorithm to identify in which region the sensor resides. A solid theoretical discussion of the problem is provided, backed by experimental validations. Chapter X first presents an analytical framework for ascertaining the attainable accuracy of RSS-based localization techniques. It then summarizes the issues that may affect the design and deployment of RSS-based localization systems, including deployment ease, management simplicity, adaptability and cost of ownership and maintenance. With this insight, the authors present the "LEASE" architecture for localization that allows easy adaptability of localization models. Chapter XI surveys and compares several RSS-based localization techniques from two broad categories: point-based and area-based. It is demonstrated that there are fundamental limitations for indoor localization performance that cannot be transcended without using qualitatively more complex models of the indoor environment, for example, modelling every wall, desk or shelf, or without adding extra hardware in the sensor node other than those required for communication, e.g., very high frequency clocks to measure the time of arrival. Chapter XII presents a machine learning approach to localization. The applicability of two learning methods, the classification method and the regression model, to RSS-based localization is discussed. Chapter XIII presents another paradigm for robust localization based on the use of identifying codes, a concept borrowed from the information theory literature with links to covering and superimposed codes. The approach is reported to be robust and suitable for implementation in harsh environments. Chapters XIV and XV consider the evaluation of localization algorithms. Chapter XIV introduces a methodological approach to the evaluation of localization algorithms. The authors argue that algorithms should be simulated, emulated (on test beds or with empirical data sets) and subsequently implemented in hardware, in a realistic WSN deployment environment, as a complete test of their performance. Chapter XV looks at evaluation of localization algorithms from a different perspective and takes an analytical approach to performance evaluation. In particular, the authors advocate the use of the Weinstein-Weiss and extended Ziv-Zakai lower bounds for evaluating localization error, which overcome the problem in the widely used Cramer-Rao bound that the Cramer-Rao bound relies on some idealizing assumptions not necessarily satisfied in real systems.

Chapters XVI, XVII, and XVIII discuss the applications of localization techniques in tracking and sensor network routing. Chapter XVI discusses algorithms and solutions for signal processing and filtering for localization and tracking applications. The authors explain some practical issues for engineers interested in implementing tracking solutions and their experiences gained from implementation and deployment of several such systems. Chapter XVII presents an experimental study on the integration of Wi-Fi based wireless mesh networks and Bluetooth technologies for detecting and tracking travelling cars and measuring their speeds for road traffic monitoring in intelligent transportation systems. Chapter XVIII discusses an interesting aspect of the geographic routing problem. The authors propose the use of virtual coordinates, instead of physical coordinates, of sensors for improved geographic routing performance. This chapter motivates us to think beyond the horizon of localization and invent smarter ways to label sensors and measurement data from sensors to facilitate applications that do not rely on the knowledge of physical locations of sensors.

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