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Synchronization and Localization in Wireless Networks

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Contents

Synchronization and Localization in Wireless Networks

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ABSTRACT

This review addresses the role of synchronization in the radio localization problem, and provides a comprehensive overview of recent developments suitable for current and future practical implementations. The material is intended for both, theoreticians and practitioners, and is written to be accessible to novices, while covering state-of-the-art topics, of interest to advanced researchers of localization and synchronization systems.

Several widely-used radio localization systems, such as GPS and cellular localization, rely on time-of-flight measurements of data-bearing signals to determine inter-radio distances. For such measurements to be meaningful, accurate synchronization is required. While existing systems use a highly synchronous infrastructure, such as GPS where satellites are equipped with atomic clocks or cellular localization where base stations are GPS synchronized, most other wireless networks do not have an sufficiently accurate common notion of time across the nodes. Synchronization, either at link or network level, thus has a principal role in localization systems. This role is expected to become more important in view of recent trends in high-precision and distributed localization, as well as future communication standards, such

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as 5G indoor localization when access points can not be externally synchronized. Since synchronization is generally treated separately from localization, there is a need to harmonize these two fundamental problems, especially in the decentralized network context. In this monograph, we revisit the role of synchronization in radio localization and provide an exposition of its relation to the general network localization problem. After an introduction of basic concepts, models, and network inference methods, we contrast two-step approaches with single-step (simultaneous) synchronization and localization. These approaches are discussed in terms of their methodology and fundamental limitations. Our focus is on techniques that consider practical relevant clock, delay, and measurement models in order to guide the reader from physical observations to statistical estimation techniques. The presented methods apply to networks with asynchronous localization infrastructure and/or to cooperative ad-hoc networks.

1

Introduction

Synchronization is of utmost importance in all localization systems that use the signal time-of-flight. While early systems and satellite navigation imposed such synchronization by physical effects, as for example by the use of atomic clocks, recent wireless network developments have multiple asynchronous nodes either among their anchor nodes or among collaborating network nodes. For such networks, a large variety of methods have been recently presented, where either localization and synchronization are considered as disjoint problems, or as simultaneous localization and synchronization (SLAS). This monograph introduces the reader into this field in a structured way. Chapters 2–4 comprise introductory material, covering motivation, applications, basic models and methods related to network synchronization and localization. Chapters 5–6 deal with separate and joint synchronization and localization, respectively. Chapter 7 closes this review.

In Chapter 2, the role of synchronization in localization is discussed and how it is considered in current localization systems and its wider impact on future localization systems [16, 54, 61, 97]. Furthermore, a discussion on other applications that depend on synchronization is included.

In Chapter 3 we introduce the most widely used models involved in

synchronization for localization. These models include clock models (phase and frequency errors) [77], models for measurement errors of time-based measurements [32, 44, 67, 85], and models for the communication between nodes [134]. Chapter 4 provides a background on two classes of signal processing methods for network inference: optimization-based methods using semidefinite programming relaxation [14, 81] and message passing methods [128, 136]. This background is required to understand network synchronization and localization algorithms, as well as fundamental performance bounds [63].

In Chapter 5, we revisit the synchronization (and ranging) [33, 45, 52, 57, 82, 85, 110, 117, 134, 142] and localization [11, 98, 107, 115, 135] problem, dealing specifically with separate approaches, whereby localization is based on distance measurements and distance differences, obtained after synchronization is completed. Practical implementations and the combination of recently proposed methods from both fields are analyzed. In Chapter 6, an overview of simultaneous approaches is presented, with a distinction in centralized and distributed computation [1, 19, 26, 35, 36, 37, 75, 89, 124, 129, 137, 138, 139, 141, 143, 144]. In this review we provide a comprehensive orientation in this novel topic. Chapter 7 summarizes the key-insights obtained in this monograph, and discusses extensions of simultaneous synchronization and localization methods with respect to mobility, security, and requirements for practical implementations.

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