Chapter X

Theory and Practice of Signal Strength–Based Localization in Indoor Environments

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ABSTRACT

In this chapter, the authors concentrate on signal strength-based localization in indoor wireless networks, with emphasis on 802.11 networks. The authors briefly summarize some architectures and approaches researchers have taken to address this problem. They then present some insight into theoretical limits to location accuracy, and identify that the issues driving research work in this area will not only be location accuracy but other factors like deployment ease, management simplicity, adaptability, and cost of ownership and maintenance. With this insight, they present the LEASE architecture for localization that allows easy adaptability of localization models. The chapter discusses the use of Bayesian networks for localization and presents a zero-configuration Bayesian localization algorithm that simplifies the maintenance of the model. Although presented in the context of signal strength-based localization in indoor environments, the concepts are general enough to be applicable to sensor, ad hoc, mesh, and infrastructure-based deployments. They conclude with some open issues.

INTRODUCTION

Indoor wireless networks, especially 802.11-based wireless systems, are increasingly being deployed. Looking beyond simple untethered network access, services based on end-user location information
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provide compelling benefits, and in some cases satisfy regulatory concerns. Examples of such services include location-aware content delivery, emergency location, presence-enabled applications, services using location-based resource management, and location-based access control.

The techniques used for localization will depend on the constraints imposed on the problem, and the underlying technology being used. For example, base stations in outdoor wireless (e.g., cellular) networks are controlled by the service provider and have specialized hardware and software. The endpoints may have service provider-specific software as well. In contrast, indoor wireless networks are built using off-the-shelf components (e.g., access points) and endpoints that are more open (e.g., laptops). Clearly, these two environments present different constraints for localization, and hence the architecture and techniques needed for localization in these environments would differ. Sensor networks usually consist of low-power, low-bandwidth components and these impose additional constraints on the techniques employed.

Localization is of value in both wired and wireless environments. In this chapter, we concentrate on wireless localization, and more specifically on indoor wireless environments. A commercially attractive option for localization in some scenarios is the Global Positioning System (GPS). Usually, GPS technology works well outdoors but has problems in indoor environments. Furthermore, GPS receivers form a closed platform and are co-resident with the device being located. In typical indoor environments, the devices used are general-purpose and do not necessarily have GPS receivers. Therefore, we look at localization aided by the wireless technology itself, namely the classes of techniques that can be used in radio networks. We then concentrate on localization in indoor wireless networks, specifically networks based on IEEE 802.11.

In radio networks, four classes of techniques have generally been used for localization, as depicted in Figure 1. These techniques are based on different features of the radio signal: angle of arrival, time of arrival, time difference of arrival, and received signal strength. The first is a technique using angles or an angulation technique. The other three are based on distances and thus are lateration techniques. With each technique, the location may be obtained directly by employing geometry, by using scene analysis techniques, or by probabilistic methods. These techniques have been used in many application contexts, e.g., navigation, radar, cellular communication systems, and robotics. An overview of the application of these techniques and others for indoor localization can be found in Hightower and Borriello (2001) and Pahlavan et al. (2002). An overview of localization in CDMA cellular systems is available in Caffrey and Stuber (1998).

Some of the techniques mentioned above require capabilities not typically found in off-the-shelf components used in indoor wireless communications. In general, time-of-arrival and time-difference-of-arrival techniques require an accurate time reference. This is usually available in systems such as cellular communications since an accurate time reference is needed for proper communication as well. Special equipment – such as multiple directional antennas or an antenna with a steerable beam – is needed to measure the angle of arrival. Other systems such as Cricket described in Priyantha et al. (2000) require special co-located radio and ultrasound transceivers.

Our emphasis in this chapter is on localization in indoor wireless networks, and specifically, techniques for localization in 802.11-based wireless networks. As mentioned earlier, the capabilities mentioned above are not available in typical off-the-shelf components used for indoor wireless networks. For example, with 802.11 systems the typical time reference available is of the order of 100ns, which is insufficient for accurate location based on time of arrival or time difference of arrival. The special requirements for localization via angle of arrival, time of arrival, and time difference of arrival methods make signal