Chapter IV

RF Ranging Methods and Performance Limits for Sensor Localization

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ABSTRACT

Localization or geolocation of wireless sensors usually requires accurate estimates of the distance between nodes in the network. RF ranging techniques can provide these estimates through a variety of methods some of which are well suited to wireless sensor networks. Noise and multipath channels fundamentally limit the accuracy of range estimation, and a number of other implementation related phenomena further impact accuracy. This chapter explores these effects and selected mitigation techniques in the context of low power wireless systems.

INTRODUCTION

In this chapter we will discuss techniques for estimating the range between wireless sensor nodes using radio frequency (RF) measurements. Localization is a two part process that can roughly be divided into a phase where the relationships between nodes are estimated (range or angle) and a phase where these relationships are used to estimate locations of the devices. RF ranging, one of the options for the first phase, will be the topic of this chapter. In particular, RF time of flight methods where RF propagation time is estimated will be considered in depth. Other ranging methods (ultrasonic, sonic, light) have been proposed and tested but they are all limited from widespread adoption. Ultrasonic and sonic signals have
limited range and do not pass through obstacles well when compared to RF signals. Acoustic systems also require the addition of speakers and microphones that are cumbersome for most applications. Light based systems require line of sight and are typically directional. Radios are pervasive in WSNs, and adding an accurate ranging feature would enable location aware networks in ways that are not possible using other technologies (Pahlavan, 2002).

Ranging accuracy is limited by noise, multipath channel effects, clock synchronization, clock frequency accuracy, and sampling artifacts. Fundamental performance limits exist due to these error sources, and these limits will be discussed qualitatively and mathematically. Signal bandwidth is an important factor when considering performance limits, and the impact of varying bandwidth will be shown.

Ranging methods will be discussed in the context of how well they meet application requirements for accuracy, energy consumption, latency, and useful range, and these requirements will be based on sample wireless sensor network applications. The major commercial application is asset tracking and management in factories, hospitals and other large spaces, and some commercial systems are available for these applications. Other applications including network configuration will be considered.

A number of RF based ranging systems have been proposed and implemented. The most common is the Global Positioning System (GPS), but others including cellular phone based systems are also widespread. Currently, ultra-wideband techniques are starting to be demonstrated along with more advanced narrowband techniques. The methods used and performance capabilities and limitations in selected systems will be discussed.

APPLICATION REQUIREMENTS

The requirements of a localization system are dependent on the application. This section will discuss a few applications to determine requirements on accuracy, latency, useful range, and infrastructure complexity of a ranging system. The accuracy requirement is defined to be the maximum error between true and estimated position that is acceptable for some percent of all estimates. For example, if 80% of estimates must be accurate to within 2 m, then 20% of measurements can have larger error. It is important to understand that localization is probabilistic in that the environment among other factors randomly degrades the accuracy of a measurement. Latency is the time it takes from when a request for a location update is made to when the update is presented to the user for a single device in the network. The range requirement is roughly how large of a sphere must one make around any node to find at least 4 other nodes or infrastructure points in 3D and 3 infrastructure points in 2D. Infrastructure requirements impact the cost of a network, and this impact can be considered qualitatively.

Relationship between Range Accuracy and Location Accuracy

Location accuracy requirements are in terms of difference from estimated location to true location as opposed to range accuracy. Localization algorithms and network geometries differ in how ranging accuracy translates to location accuracy, and many range based localization methods are presented in this book. In order to address the link between location and range accuracy, we apply a common method of range based location estimation: the maximum likelihood estimate (MLE) of the location based on a set of range estimates. The MLE of the location is found by calculating probability density function (PDF) of the location based on each range estimate, multiplying the
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