LOCALIZATION IN WIRELESS SENSOR NETWORKS

MA.MOHAMMED ANSAR ALI, R.RAJASEKAR, J.VIJAYARAJ
ASSISTANT PROFESSOR DEPT OF INFORMATION TECHNOLOGY
SKP ENGINEERING COLLEGE

ABSTRACT

With the proliferation of wireless sensor networks, providing location-aware technology and services to new applications has become important for developers. Localization is the problem of determining the positions of nodes in an ad hoc network. With the constrained resources of network sensors, providing robust localization services remains a fundamental research challenge facing the entire sensor network development community.

The initial localization problem that we addressed was to design and develop a working system that could locate equipment, such as a laptop or video projector. Ferret, the localization system developed, uses two different ranging techniques to help locate an object to within one meter.

Our next goal was to identify the locations of *all* nodes in a sensor network given the locations of a small subset of nodes. The system we developed, LESS or Localization using Evolution Strategies in Sensornets, provides substantial energy savings over existing techniques while providing comparable accuracy.

INTRODUCTION

Advancements in low-power electronic devices integrated with wireless communication capabilities and sensors have opened up an exciting new field in computer science. **Wireless sensor networks (WSN)** can be developed at a relatively low-cost and can be deployed in a variety of different settings.

A WSN is typically formed by deploying many sensor nodes in an ad hoc manner. These nodes sense physical characteristics of the world. The sensors could be measuring a variety of properties, including temperature, acoustics, light, and pollution. Base stations are responsible for sending queries to and collecting data from the sensor nodes.

Some of the main characteristics of a networked sensor include: (1) small physical size, (2) low power consumption, (3) limited processing power, (4) short-range communications, and (5) a small amount of storage. The typical size of today's networked sensor is a couple square inches, but the ultimate goal of the SmartDust project is to incorporate sensing, communication, processing, and power source all into the space of a few cubic millimeters [Ka99].

Individually, these resource-constrained devices appear to be of little value. Deploying these sensors in large scale across an area of interest, however, is when they can be most effective. Placing sensors in hostile or inaccessible regions may allow for data collection which was previously impossible. Spatial and temporal processing as well as dense monitoring is now feasible. The sensors must be able to form an ad hoc network and use collaborative techniques to monitor an environment and respond to users when appropriate.

Wireless sensor networks provide the means to link the physical world to the digital world. The mass production of integrated, low-cost sensor nodes will allow the technology to cross over into a myriad of domains. In the future, applications of wireless sensor networks will appear in areas we never dreamed. Listed below are just a few places where sensor networks can and will be deployed.

- Earthquake monitoring
- Environmental monitoring
- Factory automation
- Home and office controls
- Inventory monitoring
- Medicine
- Security

Although still in its infancy, wireless sensor network applications are beginning to emerge. A recent study on Great Duck Island in Maine used sensor networks to perform monitoring tasks without the intrusive presence of humans [Ma02]. When monitoring plants and animals in the field, researchers have become more concerned about the effects of human presence. In the Smart Kindergarten project [Sr01], using pre-school and kindergarten classrooms as the setting, the plan is to embed networked sensor devices unobtrusively into familiar physical objects, such as toys. The environment will be able to monitor the interactions of children and teachers in order to promote the development of skills. Researchers at Wayne State University believe implanted biomedical devices called **smart sensors** have the potential to revolutionize medicine. Proposed applications include an artificial retina, glucose level monitors, organ monitors, cancer detectors, and general health monitors.

Localization Problems

This dissertation addresses the challenge of localization in wireless sensor networks. There are a couple of localization problems that are of importance to ad hoc and wireless sensor networks. The first one is trying to locate a person or locate an object, such as a remote control, a set of keys, or even an enemy vehicle. There are many systems that address this problem, some of which are discussed in Chapter II.

Another localization problem is trying to find the positions of every node in an ad hoc or wireless sensor network. This standard problem can be defined as the following:

"Reconstruct the positions of all the nodes in a sensor network given the relative pairwise distances among all the nodes that are within some radius *r* of each other." While we are given 1-dimensional measures of the relative distances, we are required to compute the positions either in a 2-dimensional or a 3-dimensional space, which makes the problem interesting and challenging. Throughout this chapter, without loss in generality, we target our algorithms for the resource constrained and energy-critical WSNs, however, our solutions are applicable to more general wireless ad-hoc networks.

Existing Localization Systems

A variety of strategies and technologies are applied by existing location sensing systems. In this section, several existing localization systems will be described. This will include GPS, Active Badge, Active Bat, Cricket, and RADAR. In the following section, we will discuss localization techniques that are implemented with networked sensors.

GPS

The **Global Positioning System**, or **GPS** [En99], consists of 24 MEO (medium-earth orbit) satellites orbiting the earth at about 12,000 miles above the surface. Deployed in 1993, the satellites, equipped with atomic clocks accurate within a billionth of a second, make two complete orbits of the earth every 24 hours. Developed and operated by the United States Department of Defense, GPS is most commonly known for its navigation and tracking applications. To find the latitude and longitude of an earth-bound receiver, the signal delay from three GPS satellites is used. In order to calculate the receiver's altitude as well, a fourth GPS satellite is needed. The system is accurate within 1-3 meters 90-95% of the time. Receivers cost about $100. The system cannot be used indoors and it suffers outdoors when there are obstacles or heavy foliage.

Locating All Nodes

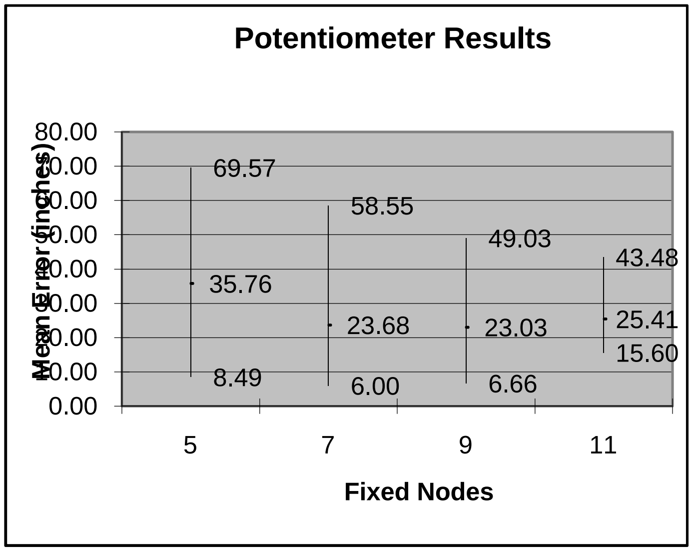
The problem of finding the location of *all* nodes in a wireless sensor network given the location of a subset of nodes has been approached by many researchers. A system called **AHLoS** (Ad-Hoc Localization System) [Sa01a] assumed that *beacon* nodes are aware of their positions. The rest of the nodes in the system are referred to as *unknown*, as these nodes will try to discover their location. The beacon nodes broadcast their location. An unknown node within range of three or more beacons estimates its position to minimize the mean square error. A technique called *iterative multilateration* is then used to handle the localization of all the nodes in the system. The accuracy of ranging in AHLoS was very precise, but it comes with a substantial cost in CPU power, energy consumption, and hardware circuitry. The percentage of beacons necessary to perform collaborative multilateration is still relatively high. For example, for 90% of the network to localize in a network of 300 nodes, it is necessary for 45 of these nodes to be designated as beacons.

Many of the other existing localization algorithms, such as ABC [SA01B], TERRAIN [Sa02], and the work proposed by Meguerdichian et al [Me01], consist of two phases: 1) Estimate Position, and 2) Iterative Refinement

Performance Results

An experiment was set up in the Western Michigan University Wireless Sensor Network Laboratory (WiSe Lab). The dimensions of the room are 22 by 9 feet, which is 198 square feet. The initial test used five infrastructure nodes (as illustrated in Figure 8). Fifteen uniformly distributed points (3 x 5 mesh) were used for objects to be located.

The results are minimum, maximum and mean errors are plotted for the potentiometer technique. A comparable graph is shown in Figure 11 for the RSSI technique. expresses the



CONCLUSIONS

The initial localization problem that we set out to solve in our research was one in an office environment. Given a building with many offices, hallways, closets, etc., the system's goal was to locate some piece of equipment, such as a laptop or video projector. More precise accuracy is always ideal, but if our system could pinpoint the object to the correct room, we considered this a success. Ferret, the localization system that we developed, uses two different ranging techniques to help locate an object. The system was successful in its goal of locating an object, as the mean localization error was approximately one meter. The details of the Ferret system were discussed in Chapter III.

We presented a novel power efficient approach aimed at identifying the locations of *all* the nodes in a sensor network given the location of a small subset of nodes in Chapter IV. Our system, LESS or Localization using Evolution Strategies in Sensornets, is independent of the ranging method used to estimate distances between nodes and involves sink nodes in the computation. The LESS system provides substantial energy savings over existing techniques while providing comparable accuracy, and requires the presence of at least one neighbor for each sensor node compared to at least 3 neighbors for most of the existing techniques.

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