

Anchor Node Placement for Localization in Wireless Sensor Networks

by

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Abstract

Applications of wireless sensor network (WSN) often expect knowledge of the precise location of the nodes. One class of localization protocols patches together relative-coordinate, local maps into a global-coordinate map. These protocols require nodes that know their absolute coordinates, called anchor nodes. While many factors influence the calculated position errors, in this class of protocols, the placement of these anchor nodes significantly impacts the error. Through simulation, using the Curvilinear Component Analysis (CCA-MAP) protocol, we show the impact of anchor node placement and a set of rules to ensure the best possible outcome. Scientists are thus enabled to focus on the sensed data, and rely on a maximum node position error.

Dedicated to my wife and children who supported me through the long process of
this research.

Acknowledgments

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Chapter 1

Introduction

Scientists, engineers, and researchers use wireless sensor networks (WSN) for a wide array of applications. Many of these applications rely on knowledge on the precise position of each node. While some may only require relative coordinates within the network, most biological, geophysical, and other scientific applications require coordinates on a global coordinate system. Perhaps the obvious solution is for each node in the network to be equipped with GPS or other location positioning service. However, constraints on cost, power consumption, as well as visibility of satellites forbids this.

Many protocols have been proposed [?,2,3] to calculate relative positions amongst the nodes of a network. They vary in the required network functionality in terms of radio ranging or range-free. However, in all cases, in order to convert from relative to global coordinates, some of the nodes do require a local source of global coordinates. This can be achieved by operators recording the global coordinates during network deployment, by the device having GPS embedded in a subset of the nodes, or some other source. We call these enhanced nodes anchors. Here, we explore the effect of anchor node placement within the network on the overall localization errors, on a network-wide basis. This provides network planners with a set of general rules to minimize the number of anchor nodes required while avoiding poor node localization,

allowing scientists to assume a maximum position error during their own research. Further, based on application requirements of location accuracy, planners can minimize the cost of the network associated with anchor nodes by using the minimum number and best position.

1.1 Motivation

During previous work designing localization protocols [4, p. 11], authors often choose anchors at random within the network. Frequently, their simulations are run multiple times with different anchors in order to statistically exclude anchor node placement from their results. Figure [TODO] demonstrates this using a CCA simulation. This phenomenon led to this quest to determine the best anchor node placement.

//TODO Include result plot showing varying errors for same network with different anchors

In practical applications, scientists and engineers do not have the luxury of running their localization protocols multiple times to determine the best location. In fact, this would defeat the purpose of the localization protocol in the first place. Therefore, it is critical to be able to assign a maximum location error to all the nodes in a network so that data processing that relies on location can effectively take the location error into account.

1.2 Thesis Contribution

We demonstrate that by avoiding certain poor anchor node placements, extremely poor location errors can be avoided. Further, we demonstrate that other than these edge cases, the location error falls within a statistically insignificant range, where the range can be determined based on network connectivity and topology. Specifically, we

show that the probability of extremely high location error result from anchor nodes being roughly in a geographically straight line. As the anchor nodes are spread out from a straight line, the probability of high errors decreases, leaving network designers a relatively simple chore when choosing anchor nodes locations.

While some papers have touched upon anchor node placement, we have yet to come across a comprehensive study of the optimal anchor node placement. This paper provides a comprehensive study of possible anchor node placements and their differing effects on overall network localization accuracy.

1.3 Methodology

Many localization protocols and algorithms provide a set of relative coordinates that are then transformed into global coordinates. For the purpose of this research, we chose CCA-MAP [3, 4] as the algorithm to provide simulation results. A Matlab©simulation of this algorithm already existed from Li Li [3], and was modified to provide the necessary output statistics presented here. CCA-MAP is described in more detail in 2.2.3 on page 6.

1.4 Thesis Organization

A brief background of Wireless Sensor Networks and localization protocols in general are presented in Chapter 2. Chapter 3 presents the limited related work in anchor node placement, in particular. Chapter 4 contains the various anchor node placements and summaries of how they perform. The cause of the extreme edge cases comes to light in Chapter 5, along with a discussion of the Procrustes algorithm. Chapter 6 presents conclusions and future work.

Chapter 2

Overview of Wireless Sensor Networks and Localization

2.1 Wireless Sensor Networks

A wireless sensor network (WSN) consists of a set of nodes tasked with sensing environmental phenomenon at or near each node. Nodes communicate via radios to send their data back to a central acquisition system. Nodes are typically small, cheap devices and are designed with power efficiency in mind to prolong the lifetime of the network's ability to collect data. Nodes are often distributed in the field of interest randomly, sometimes even by dropping them from the air, as on a military battlefield. Other times, they are placed in specific, but unknown a priori, locations, as in placing them in bird nests [5]. Or, they may be rolled into a transportation tunnel to give firefighters and emergency crews a current information about heat and oxygen levels [6]. The list of applications goes on and on.

A number of issues arise when designing a WSN. Each node must be able to communicate with each other and send data to a central collection site. Each node must know what time it is, for purposes of data sampling, and often for routing protocols as well. Further, each node must know where it is so spatial data can be

properly correlated. Location can also be useful for geographic routing protocols. This thesis focuses on determining location of each node.

2.2 Localization Protocols

There are two general classes of localization protocols: ranging and range-free.

Ranging protocols rely on information from the radio. With this information, a fairly accurate network topology can be built. Ranging techniques can use a variety of metrics to build the network topology. These include Time-of-Arrival (TOA), like GPS [7], Time-Differential-of-Arrival (TDOA) [8], Angle-of-Arrival (AOA) [9], or Received-Signal-Strength-Indicator (RSSI) [10].

However, the special hardware and power requirement to perform these ranging techniques is counter to the goal of low-cost, low-power nodes, and thus we exclude ranging protocols from our study. Regardless, if a ranging protocol does build a relative map, and then does a post processing step by mapping this relative map to a global map based on a subset of anchor nodes, the results of this thesis apply to ranging as well as range-free protocols.

Range-Free protocols do not rely on any specialized hardware for additional information. Rather, they rely solely on network connectivity, specifically knowledge of their direct neighbors. Often, a node will collect information about their direct neighbors' neighbors as well, known as one-hop information.

2.2.1 Ad Hoc Positioning System

Nicelsu, et al. propose a distributed localization algorithm known as Ad Hoc Positioning System (APS) [?]. It is similar to GPS in that it uses triangulation to determine node position. In APS, each node maintains a table of distances to each anchor. The distance can be represented as a hop count, estimated distance using RSSI, or

Euclidean distance in cooperation with its neighbors, using propagation methods DV-HOP, DV-Distance or Euclidean, respectively. As a distributed algorithm, each node determines its own position based on the distances to the anchor nodes. Thus, APS does not perform well in anisotropic network, that is networks with wholes or "C" shapes in the topology.

2.2.2 MDS-MAP

Shang, et al. attempt to correct the errors introduced by APS and other distributed algorithms through a centralized localization algorithm called MDS-MAP [2]. MDS-MAP is divided into three phases. In phase one, shortest path distances or hop counts are exchanged via distance vector exchange. This provides a rough estimate of the distance between each pair of sensors. In phase two, multi-dimensional scaling (MDS) is applied, resulting in a relative map. MDS is a general data analysis tool originating from psychophysics to transform data from many to few dimensions. In this case, the relative map conforms closely to the pair-wise distances provided. In phase three of MDS-MAP, the relative map is transformed into the global coordinate system using at least three anchors.

The authors provided a modified, distributed version, MDS-MAP(P) [?]. This variation simply divides the network into smaller, more manageable sections so the algorithm can be performed locally, with the limited node resources available. Each local map is then merged together, although this part of the algorithm is not distributed.

2.2.3 CCA-MAP

Li, et al, propose a similar style algorithm to MDS-MAP called CCA-MAP [3,4]. It is similar in that it generates relative, local maps of sections of the network and then

patches them together into a global coordinate system.

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Appendix A

Derivation of Some Nasty Equation

Here is the derivation.