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

I would like to thank Professor Thomas Kunz for his guidance and encouragement that made this research possible. Further, I would like to thank Li Li whom, along with Professor Kunz, performed the initial CCA research and wrote the basis for the Matlab simulations used in this thesis. Finally, my colleagues Shafagh Alikhani and Ben Gardiner who provided a tireless ear to listen to ideas throughout the process.

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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 propopsed [TODO refs] 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 by using GPS or some other source. This can be achieved by operators recording the global coordinates during network deployment or by the device having GPS embedded in a subset of the nodes. 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.

1.1 Motivation

During previous work designing localization protocols[TODO ref Li Li, etc], 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 detemine the best location. In fact, this would defeat the purpose of the localalization 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 propability 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 straigh line, the propability of high errors decreases, leaving network designers a relatively simple chore when choosing anchor nodes locations.

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 [TODO] as the algorithm to provide simulation results. A Matlab©simulation of this algorithm already existed [TODO], and was modified to provide the necessary output statistics presented here. CCA is described in more detail in [TODO reference Background - CCA].

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

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 wirelessly 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 specifici, but unknown apriori, locations, as in placing them in bird nests [1]. Or, they may be rolled into a transportation tunnel to give firefighters and emergecny crews a current information about heat and oxygen levents [2]. 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 localalization protocols: ranging and range-free.

2.2.1 Ranging Protocols

A 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 [3], Time-Differential-of-Arrial (TDOA) [4], Angle-of-Arrival (AOA) [5], or Received-Signal-Strength-Indicator (RSSI) [6].

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

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. Other papers have shown that getting even further neighbor information as drastically diminishing returns.

DV-HOP

[7]

MDS-MAP

[8]

CCA-MAP

[9]

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Appendix A

Derivation of Some Nasty Equation

Here is the derivation.