Journal of Systems Engineering and Electronics
Vol. 19, No. 3, 2008, pp.405–418

Available online at www.sciencedirect.com
ScienceDirect
www.sciencedirect.com/science/journal/10044132

Distributed localization for anchor-free sensor networks*

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(Received August 30, 2006)

Abstract: Geographic location of nodes is very useful in a sensor network. Previous localization algorithms assume that there exist some anchor nodes in this kind of network, and then other nodes are estimated to create their coordinates. Once there are not anchors to be deployed, those localization algorithms will be invalidated. Many papers in this field focus on anchor-based solutions. The use of anchors introduces many limitations, since anchors require external equipments such as global position system, cause additional power consumption. A novel positioning algorithm is proposed to use a virtual coordinate system based on a new concept—virtual anchor. It is executed in a distributed fashion according to the connectivity of a node and the measured distances to its neighbors. Both the adjacent member information and the ranging distance result are combined to generate the estimated position of a network, one of which is independently adopted for localization previously. At the position refinement stage the intermediate estimation of a node begins to be evaluated on its reliability for position mutation; thus the positioning optimization process of the whole network is avoided falling into a local optimal solution. Simulation results prove that the algorithm can resolve the distributed localization problem for anchor-free sensor networks, and is superior to previous methods in terms of its positioning capability under a variety of circumstances.

Keywords: anchor-free localization, distributed algorithm, position estimation, sensor networks.

1. Introduction

Node localization is an important enabling technology for the deployment of sensor networks in a wide variety of applications. It refers to the process of determining the position of every sensor. Their locations are known in advance by some deployed nodes, which are called anchors. Other nodes compute their locations based on those anchors. The localization/positioning problem has been an active research area for the last few years, which can trace back to early node positioning for personal mobile computing[1]. For the sensor networks applied to monitoring and military applications, the capability for nodes to establish their positions is recognized as an essential competence. The position availability enables more efficient protocols and new applications[2−3].

Various objectives such as scalability, energy efficiency and accuracy will influence the design of a sensor localization system. A localization algorithm should achieve as low bias and variance as possible, and meanwhile they need to be scalable to very large networks without dramatically increasing energy and computational cost. Many localization algorithms in the field of sensor networks have been proposed to endow with a position for each node. Detailed reviews of localization have been presented[4−5].

Usually sensor network localization is 'cooperative' in the sense that nodes work locally with neighbors only using their local information, and then estimate a global map of the network. With regard to diverse mechanisms used for positioning, localization algorithms are divided into different categories. A recent work of Patwari et al[6] classifies them into central-

* This project was partially supported by the National Natural Science Foundation of China (60673054, 60773129); the Excellent Youth Science and Technology Foundation of Anhui Province of China.

ized and distributed algorithms. The former collect measurements at a central processor prior to calculation, but the latter requires sensors to share information only with their neighbors possibly in an iterative fashion. For some applications, no central processor or none with enough computational power is available to handle localization calculations. Furthermore, when a large sensor network adopted a centralized algorithm should forward all measurement data to a single central processor, there is a communication bottleneck and higher energy exhaust near the central processor. Distributed algorithms are often appreciated in sensor networks.

According to the number of nodes with known position, localization algorithms are divided into anchor-based and anchor-free algorithms. Anchor-based algorithms rely on the fact that a certain number or fraction of the nodes know their position, e.g., by manual configuration or using other location mechanisms in advance. The final position assignment of each node is valid with respect to a globally coordinate system. Anchor-based localization is intuitive; however it is not flexible due to its inherent need of pre-planned anchors. In contrast, anchor-free algorithms use local distance and angle information to determine coordinates when there are no any nodes with identified coordinates. Relative positions may be obtainable in anchor-free sensor networks where there are not enough anchors present to uniquely determine the absolute coordinates of the nodes. Some applications only require relative positions, such as in the direction-based routing algorithms[7,8]. Of course, such arbitrary coordinate system provides relative location and will not be unique.

Anchor-free localization is a new research direction to pursue[4,9]. Establishing anchors is a manual deployment task, and sometimes is unfeasible. Additionally, anchor-based approaches may not scale well when many anchors are desired to configure a large network area. The stability of anchor-based approaches is also questionable in some algorithms. If more weight is assigned to anchor coordinates, the small error of anchor position would effect on the global solution. Clearly, in absence of any anchors, nodes are clueless about their real coordinates. For many network applications, it is not necessary to have real positions of nodes; usually it is sufficient to have virtual coordinates, e.g. two nodes with approximative coordinates imply that they are physically close together. An exciting example of such a distance-based virtual coordinate problem is Internet mapping[10], the goal of which is to obtain topological information about the Internet graph.

In this paper, DAFL (distributed anchor-free localization) algorithm is proposed for anchor-free sensor networks without any prior geographic information, and it focuses on static networks where nodes do not move. The novelties of this algorithm contain four aspects:

(1) First, a new concept of virtual anchor is proposed. The fictitious anchors know their geographical positions after a relative coordinate system is constructed. Thus they are identical with actual anchors that can assist other nodes to accomplish a positioning.

(2) Another new concept called localization reliability is introduced, which represents the correctness level of an estimated position for a node during the localization process. By calculating the localization reliability of a node, determine whether its coordinates are regulated in a large scale. This notion will be used for coordinate mutation of the estimated points in the position refinement stage.

(3) The algorithm is completely distributed from the viewpoint of entire localization, neither partly distributed nor locally centralized like previous approaches. The actual geographical coordinates are replaced by a virtual coordinate system, which enables a better representation of the network graph and still provides network-wide coherence.

(4) The ranging information is fully used in the positioning process; especially both adjacent member and ranging distance are combined to generate the estimated positions of a network, one of which was independently adopted for localization previously. At the position refinement stage the intermediate estimation of a node begins to be evaluated on its reliability for position mutation; thus the positioning process of entire network is avoided falling into a local optimal solution.

The requirement of running the algorithm is that