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Distributed Localization in Wireless Sensor Networks

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ABSTRACT *: Due to the success of the emerging wireless sensor network (WSN) technology, localization has newly received research interest. This interest is expected to grow further with the proliferation of wireless sensor network applications such as medicine, military, transport. In this context routing, protocols and technologies of communication on those wireless area are enormously applied to sensor networks in order to improve the quality of service and communication. Related to this work, we present a distributed algorithm for localization of nodes in a discrete model of a random ad hoc communication network.*

KEYWORDS*: Distributed Algorithm, Localization, WSN*

I. INTRODUCTION

Recent advances in micro-electro-mechanical system(MEMS), computing, and communication technology have fomented the emergence of massively distributed, wireless sensor networks consisting of hundreds or thousands of nodes. Each node is able to sense the environment, perform simple computations, and communicate with its peers or to an external observer. The challenges these networks present are far beyond the reach of the current theory and algorithms[1]. One way of deploying a sensor network is to scatter the nodes throughout some region of interest. This makes the network topology random. Since there is no a priori communication protocol, the network is ad hoc. The first task that has to be solved is to localize the nodes i.e., to compute their positions in some fixed coordinate system. Since most applications (such as tracking an object moving through the network, environmental monitoring, etc.) depend on a successful localization, it is of great importance to design scalable localization algorithms and provide error estimates that will enable us to choose optimal network parameters before deployment.

1.1. COMPARISON CENTRALIZED AND DISTRIBUTED ALGORITHMS

Centralized and distributed distance-based localization algorithms can be compared from perspectives of location estimation accuracy, implementation and computation issues, and energy consumption. It is worth noting that decentralized localization is strictly harder than centralized, i.e., any algorithm for decentralized localization can always be applied to centralized problems, but not the reverse. From the perspective of location estimation accuracy, centralized algorithms are likely to provide more accurate location estimates than distributed algorithms. However centralized algorithms suffer from the scalability problem and generally are not feasible to be implemented for large scale sensor networks. Other disadvantages of centralized algorithms, as compared to distributed algorithms, are their requirement of higher computational complexity and lower reliability due to accumulated information inaccuracies/losses caused by multi-hop transmission over a wireless network[2].On the other hand, distributed algorithms are more difficult to design because of the potentially complicated relationship between local behavior and global behavior, e.g., algorithms that are locally optimal may not perform well in a global sense. Optimal distribution of the computation of a centralized algorithm in a distributed implementation in general is an unsolved research problem. Error propagation is another potential problem in distributed algorithms. Moreover, distributed algorithms generally require multiple iterations to arrive a stable solution which may cause the localization process to take longer time than the acceptable in some cases. To compare the centralized and distributed distance-based localization algorithms from the communication energy consumption perspective, one needs to consider the individual amounts of energy required for each type of operation in the localization algorithm in the specific hardware and the transmission range setting. Depending on the setting, the energy required for transmitting a single bit could be used to execute 1,000 to 2,000 instructions [3]. Centralized algorithms in large networks require each sensor's measurements to be sent over multiple hops to a central processor, while distributed algorithms require only local information exchange between neighboring nodes but many such local exchanges may be required, depending on the number of iterations needed to arrive at a stable solution.

1.2. BENEFITS OF DISTRIBUTED ALGORITHMS

Due to high long range communication costs and low battery power, it is natural to seek decentralized, distributed algorithms for sensor networks. This means that instead of relaying data to a central location which does all the computing, the nodes process information in a collaborative, distributed way. For instance, they can form computational clusters, based on their distance from each other. The outcome of these distributed, local computations is stored in local memory and can then be, when necessary, relayed to a centralized computing unit. Robustness to node failures is another reason to seek distributed rather than centralized algorithms. This paper is organized as follows. In Section 2, we establish the setting and introduce the basic terminology and notation. In Section 3, we discuss the basic localization algorithm which described in Section 4, and provide error estimates and simulation results.

II. PRIMARY WORKS

In this section we introduce the basic framework, terminology, and notation.We assume that in a square region Q = [0, s] × [0, s], called the region of operations, we randomly scatter N nodes, $S_1, \ldots, S_N$, each of which is equipped with an RF transceiver with communication range r > 0. In other words, a node Si can communicate with every node which lies in its communication region, which is the disk with radius r centered at Si. Each node has a unique ID which is a number between 1 and N. The nodes form an ad hoc network N in which there is an edge between S_i and S_j ,when their distance is less than r. We will call this the continuous model. Even though it is a rather simplified model of how the network is formed, we adopt it because it leads to an easier analytical treatment. However, instead of a disk of radius r, the communication range of a node could instead be an annulus (in case a node is able to decide when a nearby node is at a distance greater than some threshold, based, e.g., on signal strength), an angular sector (if a node is equipped, say, with laser transmitters and receivers that can scan through some angle) or an intersection of an annulus and an angular sector. More information on these types of constraints is available in [4].We assume that a certain positive number K of nodes know their location in Q, i.e., they are able to compute their position relative to some fixed coordinate system in Q.In practice this can be achieved by equipping K motes with GPS or a priori (meaning before deploying the ad hoc network) placing in Q .A certain number of beacons which can serve to compute the position of the nodes which are within certain distance from them. We call nodes that know their position as known nodes or beacon nodes and all other ones, unknown nodes. Furthermore, each node has communication as well as sensing capabilities [5].

The problems we address in this paper are:

- Design a distributed algorithm for localization of nodes in.N.
- Estimate the complexity and error of the above algorithm.
- Find an optimal number of known nodes depending on Q, N and r, which minimizes the error of the algorithm.

Centralized algorithms for localization were studied in [1, 2]. The reason we are interested in a distributed rather than a centralized solution is that we envision a massively distributed network in which communication with a centralized computer is expensive both because the power supply of each node is very limited and long-range multi-hop data transmission is costly and often inefficient. However, one quickly discovers that obtaining analytical estimates even in this simple setting can be rather challenging. Furthermore, in the design of a decentralized algorithm relying on node-based data processing, one must take into account that nodes have very limited computational power. This motivates the following discrete approach to the above problems. Let n > 0 be an integer. Partition Q into n^2 congruent squares called cells of area $\left(\frac{s}{n}\right)^2$ and suppose that for every known node S, we are only interested in finding the cell which contains S. To make this problem tractable, we make a simplifying assumption that the communication range is ρ cells in the max metric, distance denoted by $dist_\infty$. It is defined by

$$dist_\infty((i, j), (i`, j`)) = \max(|i-i`|, |j-j`|)$$

Where (i, j) is initial distance vector, (i`, j`) is final distance vector. It is possible for several nodes to lie inthe same cell. We call this the discretemodel of the network. For example, we can take $\rho = \left\lceil \frac{nr}{s\sqrt{2}} \right\rceil$

Each node S can communicate with every node lying in the square centered at S and containing $(2\rho + 1)^2$ cells. Since all our results are independent of the choice of ρ as a function of r and n, we can clearly select a different value for it. The situation where r is fixed and s, n → ∞ corresponds to increasing the size of the region of operations, while the situation where r/n and s stay constant while n → ∞ corresponds to refining the position estimate. We usually think of n as large and r as much smaller than n. In particular, 2ρ + 1 < n.

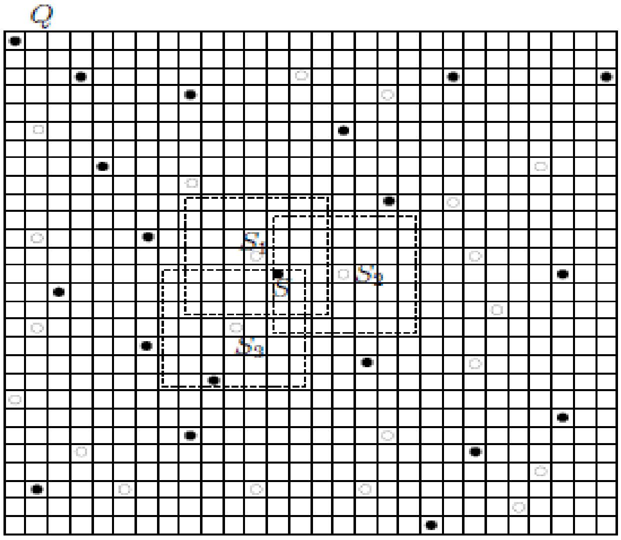

Figure 1: Discrete model. Filled circles denote unknown nodes. The dashed line bounds thecommunication range of the node at its center, with ρ = 3.

III. DISTRIBUTED ALGORITHM FOR LOCALIZATION

In this section we present a simple distributed algorithm for localization, based on the ideas in the previous section.Let S be an arbitrary unknown node in N. The localization algorithm LOCS at S then goes as follows –

Step 1. INITIALIZE the estimate:$L_S = Q$.

Step 2.SEND "Hello, can you hear me?"

Each known neighbor sends back (1, a, b), where (a, b) is its grid position, while each unknown neighbor sends (0, 0, 0).

Step 3.For each response (1, a, b), UPDATE the estimate by

$$L_S := L_S \cap [a - \rho, a + \rho] \times [b - \rho, b + \rho]$$

Step 4.STOP when all responses have been received. The position estimate is L_S

IV. SIMULATION RESULTS

To analyze performance of algorithm, we have taken three scenarios by varying number of nodes, n and number of beacon nodes, K in the network, where –

n = Unknown nodes + K;

Scenario 1: Chose No. of beacon nodes, K= 5.

Case 1: Chose unknown nodes=45 and calculated their positions.

Case 2: Chose unknown nodes=95 and calculated their positions.

Case 3: Chose unknown nodes=145 and calculated their positions.

Then we have calculated the performance of algorithm as shown in Fig. 2.

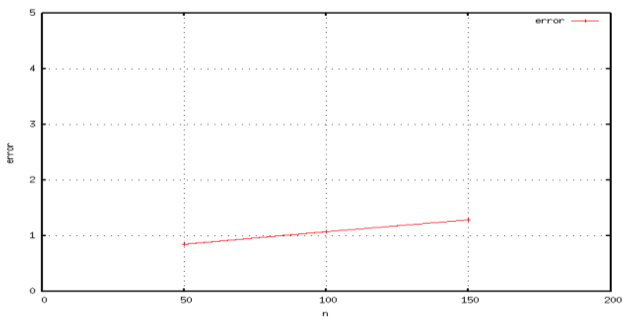

Figure 2: Performance of Network for K=5 and n=50,100 and 150.

Scenario 2: Chose No. of beacon nodes, K= 10.
Case 1: Chose unknown nodes=40 and calculated their positions.
Case 2: Chose unknown nodes=90 and calculated their positions.
Case 3: Chose unknown nodes=140 and calculated their positions.Then we have calculated the performance of algorithm as shown in Fig. 3.

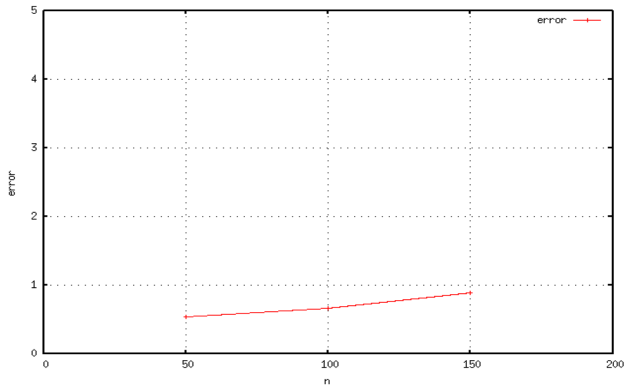

Figure 3: Performance of Network for K=10 and n=50,100 and 150.

Scenario 3: Chose No. of beacon nodes, K= 15.
Case 1: Chose unknown nodes=35 and calculated their positions.
Case 2: Chose unknown nodes=85 and calculated their positions.
Case 3: Chose unknown nodes=135 and calculated their positions.
Then we have calculated the performance of algorithm as shown in Fig. 4

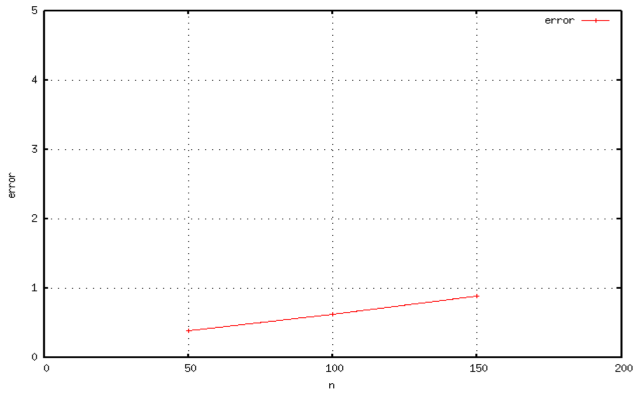

Figure 4: Performance of Network for K=15 and n=50,100 and 150.

Observe that the error of the algorithm steadily increases as total no. of nodes (n) increases. However, the error does not change considerably for K>=10.

V. CONCLUSION

The main contributions of this paper are a distributed algorithm for localization of nodes in a wireless ad hoc communication network and estimates of its error. There are many possible improvements of the algorithm.

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