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Localization in Wireless Sensor Networks by Mobile Anchor Positioning with a Voting Heuristic

José Ignacio Cruz 1 , Ricardo Navarro 2 , Rafael Falcon 3 ,

Chyon Hae Kim 4 , Rafel Bello 5

1- José Ignacio Cruz. Department of Informatics, Universidad de Cienfuegos, Cienfuegos, Cuba, jcruz@ucf.edu.cu

2- Ricardo Navarro. Faculty of Science and Engineering, Iwate University, Morioka, Japan, ricardonrcu@gmail.com

3- Rafael Falcon. School of Electrical Engineering & Computer Science, University of Ottawa, Ottawa, Canada, rfalcon@uottawa.ca

4- Chyon Hae Kim, Faculty of Science and Engineering, Iwate University, Morioka, Japan, tenkai@iwate-u.ac.jp

5- Rafael Bello. Department of Computer Science, Universidad Central de Las Villas, Santa Clara, Cuba, rbellop@uclv.edu.cu

Abstract: In wireless sensor networks (WSNs), many problems call for the network nodes to be aware of their positions. This makes localization a key and challenging task in WSNs. The scientific literature on this topic distinguishes two major types of solution approaches: *range-based* versus *range-free* methods, depending on whether the sensor nodes make use of the range –signal features– of the messages between nodes to estimate their own location. In this work, we propose a heuristic mechanism to improve an existing range-free localization technique termed *mobile anchor positioning* (MAP). Our heuristic improves MAP's ability to decide between any two potential position

estimates, by performing a voting process with the beacons received by the sensor nodes. Our simulation analysis confirms that our approach reduces MAP's localization error.

Keywords: Wireless Sensor Network, Localization, Heuristic Method, Mobile Anchor Positioning

1. Introduction

A *wireless sensor network* (WSN) consists of physical devices –nodes– with the capability to monitor a certain field where they are deployed and transmit the collected data in a wireless manner [1]. Nodes are limited in resources, i.e. their power, computational capacities and memory are finite [2]. However, given the wide range of applications they have successfully tackled, an increasing interest from both industrial and academic viewpoints has emerged around WSNs [1]. As a result, they assist a plethora of applications in precision agriculture, environmental monitoring, vehicle tracking, health care monitoring, smart buildings, security and surveillance, animal tracking, and so forth [3].

Localization is a crucial problem for WSNs because many of these real-world applications assume that each sensor node knows its physical location [4]. Using a *global positioning system* (GPS) on every node would be the simplest manner to locate them. However, such a solution increases their cost, power consumption and size. What is more, even if available, GPS devices are not always reliable, e.g. in urban areas and indoor environments. Hence, an obvious need for better solutions still exists. Any potential solution will require that at least a few nodes, commonly referred to as anchor nodes [5], know their precise location within a frame of reference. In case such a requirement is not satisfied, it is not possible to locate the network nodes.

Beyond GPS-reliant methods, the available literature [4-8] typically categorizes localization mechanisms into two major groups, namely *range-based* versus *range-free* approaches [5]. Methods belonging to the former group use the range of the messages

between nodes; that is, some meta-information consisting of signal features, such as the received signal strength indicator [9], the time of arrival [10], the time difference of arrival [11], and the angle of arrival [12]. Those methods estimate the position of the nodes according to geometrical techniques, e.g. triangulation, trilateration and multilateration. The selection of the specific mathematical schema to apply depends on the signal feature being used.

While range-based algorithms ensure fine-grained accuracy using expensive hardware [13], range-free techniques achieve coarse-grained accuracy but without the need for any additional hardware. Among the range-free localization methods for WSNs, it is possible to distinguish two sorts of approaches, i.e. local versus hop-based techniques. Local methods employ a large number of anchor nodes so that each sensor node can connect to many of them. On the other hand, in hop-based methods, nodes spread all over the network broadcast the location of the anchor nodes [4].

Mobile anchor positioning (MAP) is an effective local range-free localization strategy. It was introduced in [8], together with two methods that implement such a mechanism, namely the MAP *with mobile anchor* (MAP-M) and the MAP *with mobile anchor and neighbor* (MAP-M&N) algorithms. In further works [13-15], MAP has been used for a preliminary estimation of sensor locations, which is then optimized by other mechanisms.

In this study, we propose a heuristic voting procedure to improve the localization accuracy by taking advantage of some aspects not considered in the original MAP approach. Our method takes beacons received by the sensor nodes from the mobile anchors and uses them as votes to determine which of the two possible locations of the sensor must be selected. Accordingly, we also extend those two MAP-based techniques by applying our voting heuristic to them. Simulation results confirm that our proposed extensions outperform the original baseline algorithms.

The remaining of this paper goes into details about MAP, in Section 2. The voting heuristic is depicted in Section 3, together with the extended versions of MAP-M and MAP-M&N. Section 4 explains the simulation setup and discusses the empirical results, while Section 5 states conclusions and future work remarks.

2. Revolving around Mobile Anchor Positioning

In this section we elaborate on MAP's two generalizations. Arguments for and against this method suggest that there is still room for decreasing its localization error.

2.1. MAP with Mobile Anchor

In MAP, mobile anchors move all throughout the monitored area and very so often, they broadcast beacons, i.e. packages containing their coordinates. Sensors keep a list of beacons received and use them to estimate their positions. The idea is to find two beacons as close as possible to a circle centered at the sensor position, using the communication range of the mobile anchor as radius; these beacons are called beacon points. Figure 1 (left) shows an example where the visitor list of sensor S is $\{T_1, T_2, T_3, T_4\}$ and points T_1 and T_4 are the beacon points. In this case, the two possible locations of S are S_1 and S_2, which are calculated by intercepting the circles centered at T_1 and T_4, respectively.

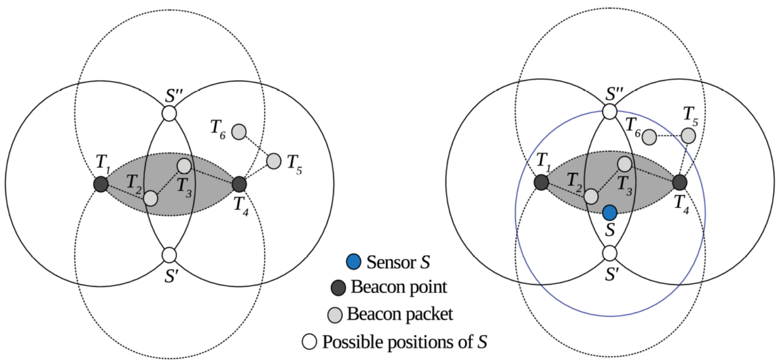

Fig. 1. MAP position estimation [8] (left) and wrong position selection issue (right).

Once the beacon points have been selected and the intersection points have been found, it is necessary to decide between the two possible positions. This problem is called the *flip ambiguity phenomenon*; it is discussed by many researchers, and different methods to solve it have been proposed [6]. MAP solves it as follows: assume that the visitor list of a sensor node S is $\{T_1, T_2,\ldots,T_n\}$, the beacon points are T_1 and Tn, the communication range is R and the candidate positions of the sensor are S′ and S′′. If there is any T_i $(2 \leq i \leq n - 1)$, such that the distance between T_i and S′ is less than R and

the distance between T_i and S″ is greater than R, then S′ is selected as the node position. This is because the sensor should be inside of the mobile anchor communication range. There are situations where it is not possible to decide between two candidate positions using the visitor list. When this happens, the sensor node must wait until it receives a beacon that is outside of the interception area as happens on Figure 1 (left) with beacon T_6. If the sensor node does not receive such a beacon, the sensor's location cannot be determined.

2.2. MAP with Mobile Anchor and Neighbor

Even though some sensor nodes can determine their locations using only the beacons received from mobile anchors, some others may not because they did not receive enough information to decide between multiple candidate locations. In order to help these non-localized sensors calculate their positions, the other sensors that were already localized can broadcast their estimated positions. Using the beacons received from their one-hop neighbors, sensors can finally determine their location. By doing this, the cost of movement of the mobile anchor can be reduced. This method allows locating more nodes but it also comes with an extra cost in energy because of the additional broadcasts.

2.3. A Few Observations about MAP

In this section, we analyze some aspects on the MAP approach, which are relevant for suggesting possible improvements of this method.

Beacons Received by Located Sensors. One of MAP's main advantages is that sensors may not need many beacons to estimate their positions. Locating a sensor only requires a minimum of three beacons: two as beacon points and one to decide between its two candidate locations. This allows to quickly locate sensors but once a sensor is located, received beacons are discarded. These apparently unnecessary beacons could be used to improve the already estimated positions.

Choosing among Two Candidate Locations. As mentioned, if the distance from a beacon B to one of the two candidate positions S′ of a sensor S is greater than the mobile anchor's communication range R, and the distance from B to the other candidate location S″ is less than R, then S″ is selected as the position of S. The problem is that even under these conditions, it is still possible that S′ is closer to S than S″. Figure 1 (right) illustrates this situation. This could lead to selecting the wrong estimated position (the one that is farther from the actual position of the sensor), thus increasing the localization error. This issue can have an even bigger impact in the MAP-M&N schema, since errors are propagated to the non-localized neighbors, hence making them also select the wrong position.

3. Proposed Voting Heuristic for Position Selection in MAP

The voting heuristic we propose in this paper is motivated by the observations made in Section 2.3. With this heuristic, we intend to mitigate the effect of the wrong position selection issue.

In MAP, only one beacon is used to decide between two candidate positions of a sensor node. What we propose is to use every beacon lying out of the intersection area between the circles centered at the two candidate positions of the sensor. Formally, if S′ and S″ are the two candidate positions of sensor S and R is the mobile anchor's communication range, every beacon received T_i satisfying one of the following conditions has the right to vote for either S′ or S″ as the sensor's estimated position:

1. The distance between S′ and T_i is smaller than R, and the distance between S″ and T_i is greater than R.
2. The distance between S′ and T_i is greater than R, and distance between S″ and T_i is smaller than R.

Beacons matching the first condition vote for S′ as the sensor position and beacons that match the second condition vote for S″. The voting process starts from the moment the beacon points are found, and every beacon received before this time will be used for doing an initial voting and estimating the node position if possible (viz, there is at least a beacon matching one of those two conditions). Every beacon received afterwards

satisfying one of the conditions also votes. The estimated location of the node changes if the winner of the voting process is different. By doing this, the sensor can still locate its position with very little information but at the same time, the extra information received is used to improve the estimated position. In case of a tie, the estimated position with the smaller average distance to its voters wins.

Our proposal does not require any extra storage from the sensor since only S′, S″, the votes received by S′, the votes received by S″, the sum of the distances from S′ to its voters, and the sum of the distances from S″ to its voters, are stored. Despite that, some special considerations need to be taken into account in the case of the MAP-M&N approach. This is because the position of a located sensor needs to be broadcast to all its one-hop neighbors. However, according with our approach, the estimated position of a sensor changes over time. Since the goal here is to improve the localization accuracy, every time a sensor position changes, its new position is broadcast in order to correct the error made by sending a wrong position to neighbors. This means an extra consumption of energy for communication since every time the winner of the voting changes, the new estimated position must be broadcast to the one-hop neighbors.

4. Simulation Study

We validate our approach via simulations, by comparing the extended MAP algorithms, i.e. MAP *with mobile anchor and voting* (MAP-M-V) and MAP *with mobile anchor, neighbor and voting* (MAP-M&N-V), with their canonical forms, MAP-M and MAP-M&N, respectively.

4.1. Simulation Setup

The simulation setup follows the one in [8], in order to evaluate our heuristic in scenarios as similar as possible to the ones used with the original MAP. We randomly distributed 500 sensors in a rectangular area of 20m × 20m for all the simulations. Anchors broadcast beacons every second and move around the target area at speeds varying between 0.2 and 0.8 m/s according with the *random waypoint mobility model* explained below. For simplicity, all nodes have the same communication range R. The

number of anchors will be fixed to one, the communication range to 1 meter (m) and the execution time to 1,000 seconds (s). We change these parameters, one at a time, to analyze their impact on the localization error.

4.2. Mobility Model

For planning the paths of the mobile anchor nodes we resorted to the *random waypoint mobility model*, a commonly adopted model for emulating the behavior of mobile nodes in ad hoc networks [16]. The anchors start at random positions and move between random positions located inside the area of interest at a random speed uniformly distributed between 0.2 and 0.8 m/s. This approach is more realistic than making anchors move at a constant speed, which is highly unlikely to happen in practice.

4.3. Simulation Results

By using the localization error measure, we discuss the performance of the MAP algorithms in several scenarios, which are defined by different network configurations.

Varying communication range. We experiment with three values of communication range; results are shown in Figure 2 (left). The voting strategy outperforms the basic MAP approach in all the situations, especially as the communication range increases. This is because the higher the communication range is, the larger the distance between the two candidate positions of a sensor is. This fact strengthens the impact of the wrong position selection issue, and therefore increases the localization error.

Varying number of mobile anchors. Figure 2 (right) illustrates the results obtained by modifying the number of mobile anchors in the network. Methods using our heuristic perform better than their basic MAP counterparts in every scenario. Besides, they reach best results with a higher number of anchors. Having more mobile anchors means more generated beacons. MAP only benefits from that by locating more nodes, but our extended versions also reduce localization error, since more beacons represent more votes.

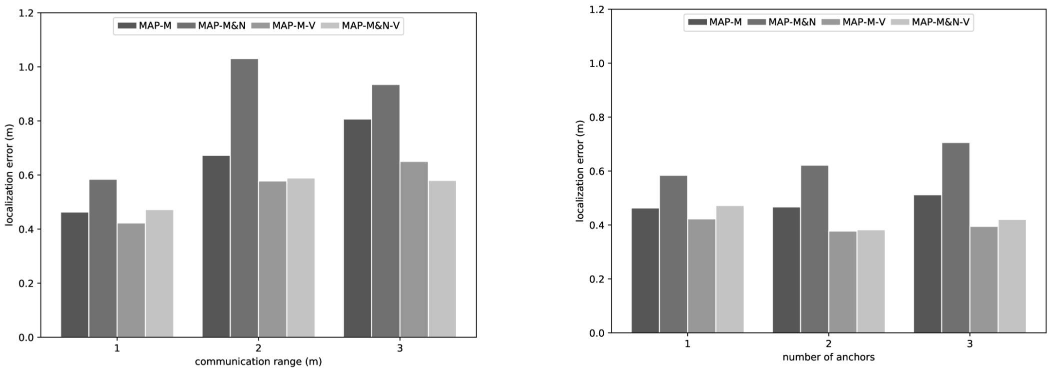

Fig. 2. Simulation results varying communication range (left) and number of anchors (right)

Varying the execution time of the algorithm. Delaying the end of the simulation is equivalent to increasing the number of anchors, as more beacons need to be broadcast. Then again, having more beacons means more votes, thus resulting on a better performance when using our strategy. Figure 3 depicts a comparative graph.

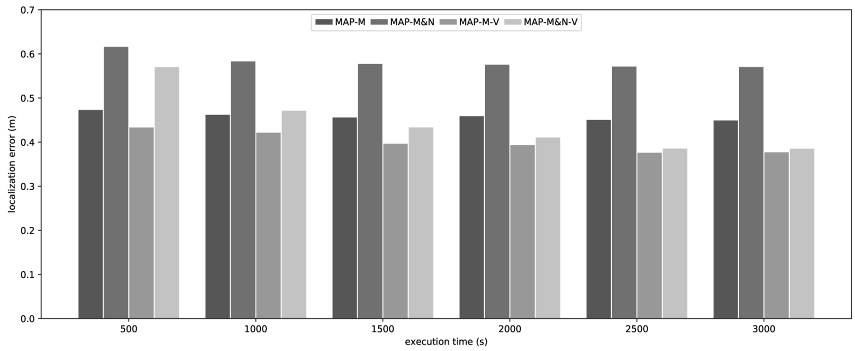

Fig. 3. Simulation results varying the execution time of the algorithm

5. Conclusions and Future Work

We put forth a simple voting heuristic to mitigate the wrong position selection issue in MAP and therefore reduce the localization error. We evaluated our approach by means of numerical simulations in a study that includes both extended and baseline MAP-based techniques running with several WSN configurations. Results corroborate the efficacy of the voting strategy, in particular in those cases where a larger number of beacons were generated. Using our heuristic strategy in the MAP-M&N method is

especially effective, since locating a sensor using the estimated position of its neighbors could lead to higher localization errors. Despite that, studying the impact on the energy spent by using our heuristic with MAP-M&N could help improve its efficiency.

Analyzing the performance using different mobility models and how they could improve both the number of localized nodes and the overall localization error is one of our next research pursuits in this topic. Besides, we plan to devise further strategies –not strictly related with the wrong position selection issue– that take advantage of the extra beacons received by a sensor node once it has been localized.

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