A New Ad Hoc Positioning System

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Abstract— **Localizing sensor nodes is essential due to their random distribution after deployment. To reach a long network lifetime, which strongly depends on the limited energy resources of every node, applied algorithms must be developed with an awareness of computation and communication cost. In this paper we present a new localization method, which places a minimum computational requirement on the nodes. Our method is with time complexity of O(n) which is as accurate as the method used in APS with time complexity of O(n^3).**

Keywords- GPS; range-based; approximate; positioning; WSN

I. INTRODUCTION

The increasing miniaturization of electronic components and advances in modern communication technologies lead to the development of extreme small, cheap, and smart sensor nodes [1]. These nodes consist of sensors, actuators, a low power processor, small memory, and a communication module. Nodes measure conditions of the environment, precalculate, aggregate, and transmit data to a base station. Thousands of these nodes form a large wireless sensor network to monitor huge inaccessible terrains.

Processor performance and available energy of each sensor node are highly limited by its physical size. Therefore, intensive communication and computation tasks are not feasible. Thereby, algorithms in sensor networks are subject to strict requirements covering reduced memory consumption, communication, and processing time.

As a result of the stochastic distribution of all nodes in the deployment phase, a determination of the node's position is required. Then, every measurement can be assigned to its physical position. Basically, a global position can be approximately determined with state-of-the-art positioning systems such as the Global Positioning System (GPS) or the Global System for Mobile Communication (GSM) [2], [3]. These systems are not suitable for tiny sensor nodes because of their physical size and costs as well as their high power consumption resulting from the communication overhead [4]. A better approach is to equip only few nodes with a global positioning system. Then, these nodes determine their own position very precisely and provide this position to other nodes in the sensor network. Based on this approach, we present a new approximate positioning approach for localization in wireless sensor networks.

This paper is structured as follows. In Section II, we give a basic overview of the approaches for positioning in the wireless sensor networks and in Section III, we describe a simplified version of GPS triangulation. Next, In Section IV, we describe our new positioning approach, GPS* method. Then, in Section V, we describe our simulation environment and its parameters. After discussing our simulation results in Section VI, finally we conclude the paper in Section VII.

II. RELATED WORK

For the above-mentioned reasons, existing positioning techniques (e.g. GPS) cannot be integrated on all sensor nodes. The number of nodes with known position has to be limited. These nodes are referred to here as beacons, with the remaining nodes classed as sensor nodes. For the positioning of the sensor nodes we distinguish between approximate and exact approaches [5].

A. Approximate Positioning

Many approximate approaches for the determination of sensor nodes exist in literature. These approaches are often resource-efficient but also result in higher positioning errors than exact positioning approaches, especially when the input parameters have low deviation of their true value. Examples of such approaches are the hybrid approaches [6], the Coarse Grained Localization (CGL) [7], the Approximate Point in Triangulation-algorithm (APIT) [8], the Weighted Centroid Localization (WCL) [9], the EBTB algorithm [10] and the Binary algorithm [11].

WCL is simple, has low complexity, requires a few resources, has rather good accuracy (especially in high noise situations) and is range-based. APIT has more complexity, requires more resources and has lower accuracy than WCL. But, it is range-free. The resource requirement of EBTB is more than WCL and less than APIT and its accuracy is often better than WCL and APIT but it is range-based. CGL is range-free and requires fewer resources than the two previous approaches, but has low accuracy. The resource requirement of Binary is more than EBTB and less than APIT; its accuracy is often better than them and is range-free.

B. Exact Positioning

In contrast to approximate approaches, exact approaches use the known beacon-positions and the distances to the sensor nodes in order to calculate their coordinates through the solution of non-linear equations. Using a minimum of three beacons (in two dimensions), the coordinates of the sensor nodes may be determined by their intersection. The use of more than three beacons gives more information in the system and allows the refinement of the position and the detection and removal of outlying observations. The least squares method (LSM) is used for the solution of the simultaneous equations. The LSM produces accurate results, however it is complex and resource-intensive and therefore it is not feasible on resource-limited sensor nodes. So, this approach is implemented distributed with some communication efforts [12]–[17].

In this paper, we introduce a new positioning algorithm called GPS*. Then, we compare its accuracy and speed of convergence with GPS method which is used in APS [18].

III. GPS REVIEW

In Global Positioning System (GPS) [6], triangulation uses ranges to at least four known satellites to find the coordinates of the receiver, and the clock bias of the receiver. For our node location purposes, we are using a simplified version of the GPS triangulation, as we only deal with distances, and there is no need for clock synchronization. The triangulation procedure starts with an apriori estimated location (which has been acquired using CGL) that is later corrected towards the true location.

In Fig. 1, let $\hat{r}_u$ be the estimated location, r_u the real location, $|\hat{\rho}_i|$ and $|\hat{\rho}_i|$ the respective ranges to the beacon (where $\hat{\rho}_i = r_i - \hat{r}_u$ and $\rho_i = r_i - r_u$). The correction of the range $\Delta\rho_i$ is approximated linearly to accommodate a linear system solving (as opposed to quadratic). If $\hat{I}_i$ is the unit vector of $\hat{\rho}_i$ (where $\hat{I}_i = \frac{r_i - \hat{r}_u}{|r_i - \hat{r}_u|}$) and $\Delta r = r_u - \hat{r}_u$ then $\Delta\rho_i = |\hat{\rho}_i| - |\rho_i| \cong \hat{I}_i \cdot \Delta r$.

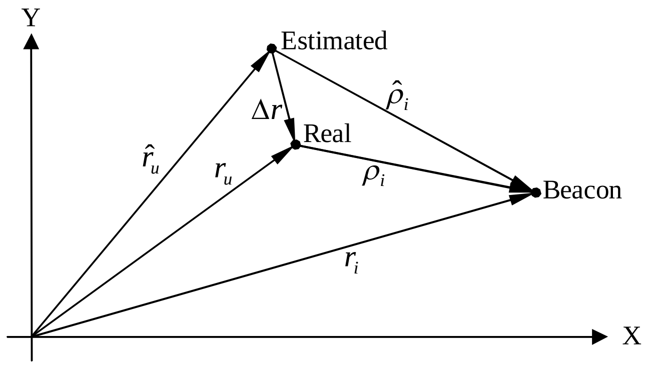

Figure 1. GPS, simplified problem

Performing the above approximation for each satellite independently leads to a linear system in which the unknown is the location correction $\Delta r = [\Delta x \quad \Delta y]$:

$$\begin{bmatrix} \Delta\rho_1 \\ \Delta\rho_2 \\ \Delta\rho_3 \\ \cdots \\ \Delta\rho_i \end{bmatrix} = \begin{bmatrix} \hat{I}_{1x} & \hat{I}_{1y} \\ \hat{I}_{2x} & \hat{I}_{2y} \\ \hat{I}_{3x} & \hat{I}_{3y} \\ \cdots & \cdots \\ \hat{I}_{ix} & \hat{I}_{iy} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

After each iteration, the corrections Δx and Δy are applied to the current position estimate. The iteration process stops when the corrections are below a chosen threshold. Solving the linear system can be done using any least square method (we used QR-Factorization method but the Householder method was used in APS). This method is with time complexity of $O(n^3)$, where n is the number of beacons. Meanwhile, this method has been used in APS.

IV. NEW METHOD (GPS*)

As it is seen in Fig. 1, a new estimated location of the node is a point which exists on the vector $\hat{\rho}_i$ and with distance of $\Delta\rho_i = |\hat{\rho}_i| - |\rho_i|$ from apriori estimated location and in direction of vector $\hat{\rho}_i$. For each beacon, we have another estimated location. If $V_i = \Delta\rho_i \cdot \hat{I}_i$ are the vectors from the apriori estimated location to each new estimated location, sum of these vectors $V = [\Delta x \quad \Delta y]$, is from apriori estimated location to a better estimated location. After each iteration, the corrections Δx and Δy are applied to the current position estimate. The iteration process stops when the corrections are below a chosen threshold. This method which we call GPS* is with time complexity of $O(n)$.

V. SIMULATION

To study the accuracy and the speed of convergence of GPS* method and to compare it with GPS method, we did many simulations in different situations in a square area with sides of 100 m. At the start of each simulation, some beacons (between 10 to 100 beacons, as an input parameter of simulation) and 10,000 nodes were randomly placed with a uniform distribution within the area. Then, the range between connected nodes was blurred by drawing a random value from a normal distribution having a normalized standard deviation with respect to the true range and having the true range as the mean. Maximum transmission range of each beacon, as another input parameter, was assumed between 20 m to 100 m. in the previous section we said that the iteration process stops when the corrections are below a chosen threshold. The threshold, also as another input parameter, was assumed between 0.1 m to 0.5 m.

Then, with a given input parameters, the position of each node was estimated using GPS* and GPS methods. Then, the number of the sensor nodes which could not estimate their position and the average of positioning error of sensor nodes (excluding the sensor nodes which can not estimate their positions) and many other output parameters were registered. To account for the randomness in generating topologies and range errors we repeated each experiment 50 times with a different seeds, and report the averaged results.

Meanwhile, we will present only the results of simulations which were done by maximum transmission range of 50 m.

VI. RESULTS

Fig. 2,3,4 show the accuracy of the proposed algorithm (GPS*) with respect to GPS method, in three situation: when there is not any noise, when the noise is medium and when the noise is high. As it is seen in Fig. 2, in a noiseless situation, when threshold is 0.1, GPS method has a bit better accuracy than GPS* method. But in a real situation (Fig. 3,4), when there is some noise in the environment and threshold is 0.1, its accuracy is almost equal to the accuracy of GPS* method. Meanwhile as it is seen in the Fig. 2,3,4, when the threshold increase to 0.5, the accuracy of GPS method doesn't change but the accuracy of GPS* method decreases(about 0.3 to 0.5 m).

Fig. 5 shows the speed of convergence. As it is seen, the speed of convergence of GPS method is more than GPS* method. Meanwhile, when the threshold increase to 0.5, the speed of convergence of GPS method becomes a bit better, but the speed of convergence of GPS* method becomes much better.

VII. CONCLUSION

When there is some noise in environment and the threshold is adequately small, the accuracy of GPS* method is almost equal to the accuracy of GPS method. As it was said, GPS* method is with time complexity of $O(n)$ and GPS method is with time complexity of $O(n^3)$. ***So, although the speed of convergence of GPS* is lower than GPS, when the connectivity is not very low, the GPS* method will be very faster than GPS method.***

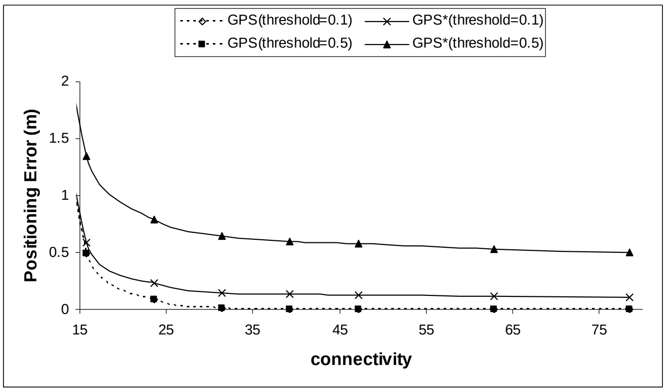

Figure 2. Positioning error in a noiseless situation

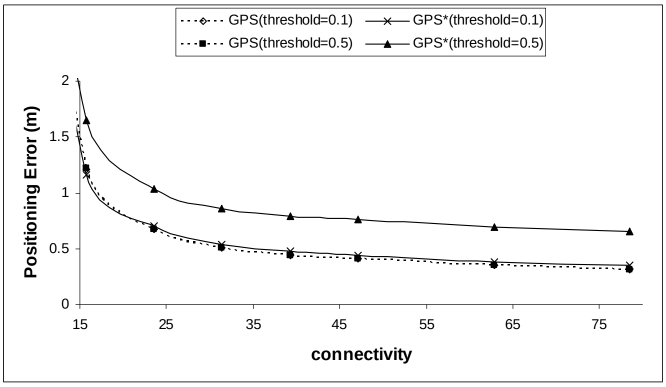

Figure 3. Positioning error when the standard deviation of estimated range is about 0.033

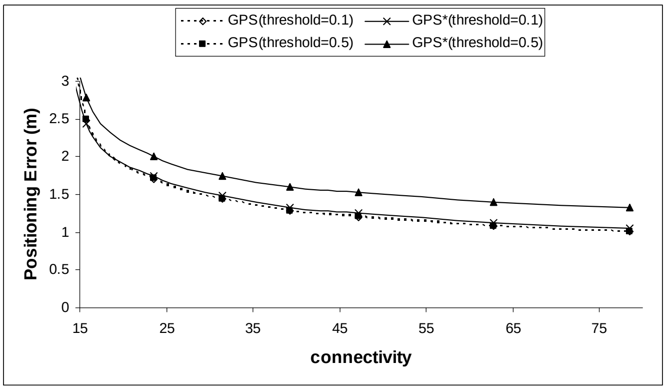

Figure 4. Positioning error when the standard deviation of estimated range is about 0.083

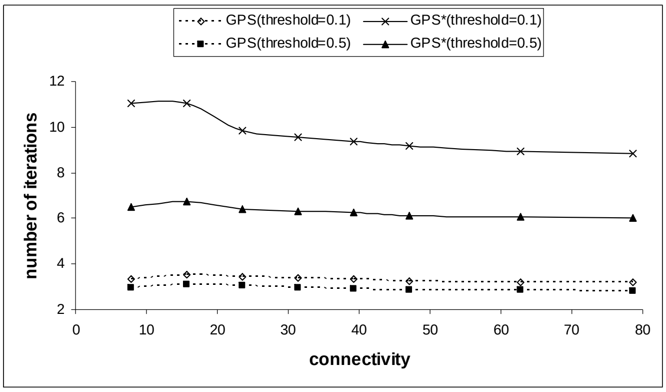

Figure 5. The speed of convergence

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