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Computer Science and Engineering

Elixir Comp. Sci. & Engg. 56A (2013) 13702-13705

ISSN: 2229-712X

Localization algorithms for wireless sensor networks in recent approaches and future challenges

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ARTICLE INFO

Article history:

Received: 7 August 2012;

Received in revised form:

21 March 2013;

Accepted: 23 March 2013;

Keywords

Distributed localization,

Centralized Localization,

WSN,

Beacon based distributed algorithm.

ABSTRACT

Recent advances in radio and embedded systems have enabled the proliferation of wireless sensor networks. Wireless sensor networks are tremendously being used in different environments to perform various monitoring tasks such as search, rescue, disaster relief, target tracking and a number of tasks in smart environments. In many such tasks, node localization is inherently one of the system parameters. Node localization is required to report the origin of events, assist group querying of sensors, routing and to answer questions on the network coverage. So, one of the fundamental challenges in wireless sensor network is node localization.

Introduction

The massive advances of micro electro mechanical systems (MEMS), computing and communication technology have fomented the emergence of massively distributed, wireless sensor networks consisting of hundreds and thousands of nodes. Each node is able to sense the environment, perform simple computations and communicate with its other sensors or to the central unit. One way of deploying the sensor networks 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. These networks are tremendously being implemented to perform a number of tasks, ranging from environmental and natural habitat monitoring to home networking, medical applications and smart battlefields. Wireless sensor nodes can be designed to detect the ground vibrations generated by silent footsteps of a burglar and trigger an alarm. Since most applications depend on a successful localization, i.e. to compute their positions in some fixed coordinate system, it is of great importance to design efficient localization algorithms. In large scale ad hoc networks, node localization can assist in routing [1], [2], [3].

Problem Definition

Consider the case when we have deployed a Sensor network consist of N sensors at locations $S = \{S_1, S_2, \ldots, S_N\}$. Let $S_x^{\ i}$ refer to the x-coordinate of the location of sensor i and let S^i_y and S^i_z refer to the y and z coordinates, respectively. Constraining $S_z^{\ i}$ to be 0 suffices the 2D version of this problem. Determining these locations constitutes the localization problem. Some sensor nodes are aware of their own positions, these nodes are known as anchors or beacons. So, mathematically the localization problem can be formulated for a given multihop network, represented by a graph G = (V, E), and a set of beacon nodes B, their positions $\{x_b, y_b\}$ for all $b \in B$, we want to find the position $\{x_u, y_u\}$ for all unknown nodes $u \in U$.

Related Work

Localization in WSN is an active area of research. There are some existing techniques which use two localization techniques such as multidimensional scaling (MDS) and proximity based map (PDM) or MDS and Ad-hoc Positioning System (APS). Moreover due to channel fading and noise corruption error propagation comes in picture. To suppress this error propagation a localization scheme has been proposed.

Different Location Discovery Approaches

Existing location discovery approaches basically consists of two basic phases: (1) distance (or angle) estimation and (2) distance (or angle) combining. The most popular methods for estimating the distance between two nodes are described below:

Received Signal Strength Indicator (RSSI): RSSI measures the power of the signal at the receiver and based on the known transmit power, the effective propagation loss can be calculated. Next by using theoretical and empirical models we can translate this loss into a distance estimate. This method has been used mainly for RF signals.

Time based methods (ToA, TDoA): These methods record the time-of-arrival (ToA) or time-difference-of-arrival (TDoA). The propagation time can be directly translated into distance, based on the known signal propagation speed. These methods can be applied to many different signals, such as RF, acoustic, infrared and ultrasound. TDoA methods are impressively accurate under line-of-sight conditions. But this line-of-sight condition is difficult to meet in some environments.

Angle-of-Arrival (AoA): AoA estimates the angle at which signals are received and use simple geometric relationships to calculate node positions. Generally, AoA techniques provide more accurate localization result

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than RSSI based techniques but the cost of hardware of very high in AoA.

For the combining phase, the most popular alternatives are:

Hyperbolic trilateration: It locates a node by calculating the intersection of 3 circles as shown in Fig. 1(a). Triangulation: This method is used when the direction of the node instead of the distance is estimated. The node positions are calculated in this case by using the trigonometry laws of sines and cosines shown in Fig. 1(b).

Maximum Likelihood (ML) estimation: ML estimation estimates the position of a node by minimizing the differences between the measured distances and estimated distances shown in Fig. 1(c).

Different Proposals for Network Management and Control Issues

Research on localization in wireless sensor networks can be classified into two broad categories.

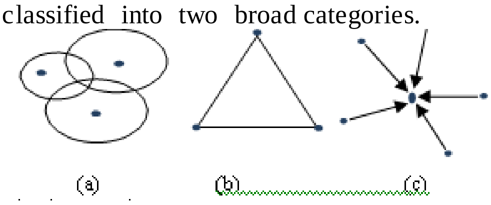

Fig.1. Localization techniques
a) Hyperbolic trilateration b) Triangulation c) Maximum

Centralized Localization: Centralized localization is basically migration of inter-node ranging and connectivity data to a sufficiently powerful central base station and then the migration of resulting locations back to respective nodes. The advantage of centralized algorithms are that it eliminates the problem of computation in each node.

Distributed Localization: In Distributed localizations all the relevant computations are done on the sensor nodes themselves and the nodes communicate with each node. other to get their positions in a network.

Centralized localization

MDS-MAP

In [5] the authors present a centralized algorithm called MDS-MAP which basically consists of three steps.

1. Computes shortest paths between all pairs of nodes in the region of consideration by the use of all pair shortest path algorithm such as Dijkstra's or Floyd's algorithm.
2. The classical MDS is applied to the distance matrix, retaining the first 2 (or 3) largest eigenvalues and eigenvectors to construct a 2-D (or 3-D) relative map that gives a location for each node.
3. Based on the position of sufficient anchor nodes (3 or more for 2-D, 4 or more for 3-D), transform the relative map to an absolute map based on the absolute positions of anchors which includes scaling, rotation, and reflection.

Localize node based on simulated annealing

In [6] the authors propose an innovative approach based on Simulated Annealing to localize the sensor nodes in a centralized manner. Since the algorithm is centralized, it enjoys the access to estimated locations and neighborhood information of all localizable nodes in the system. Let us consider a sensor network of m anchor nodes with known locations and n-m sensor nodes with unknown locations. As the proposed algorithm is implemented in a centralized architecture, it has access to estimated locations and neighborhood information of all localizable nodes in the system. The proposed scheme is based on two stages. In the first stage simulated annealing is used to obtain an estimate of location of the localizable sensor nodes using distance constraints. Let us define the set Ni as a set containing all one hop neighbors of node i. The localization problem can be formulated as:

Min Σi=m+1 to nΣj€Ni $(d\hat{}ij - dij)^2$, dij is the measured distance between node i and its neighbor j; d^ij = $\sqrt{\{(x\hat{}i - x\hat{}j)^2 + (y\hat{}i - y\hat{}j)^2\}}$ is the estimated distance; (x^i, y^i) and (x^j,y^j) are the estimated coordinates of node i and its one hop neighbor j respectively and the cost function CF =Σi=m+1 to nΣj€Ni $(d\hat{}ij - dij)^2$. Then according to Simulated Annealing coordinate estimate (x^i, y^i) of any chosen node i is given a small displacement in a random direction and the new value of the cost function is calculated for the new location estimate. If $\Delta(CF) \leq 0$, ($\Delta(CF)$ = CFnew − CFold) then the perturbation is accepted and the new location estimate is used as the starting point of the next step. Otherwise the probability that the displacement is accepted is $P(\Delta(CF)) = \exp(-\Delta(CF)/T)$. Here T is a control parameter and P is a monotonically increasing function of T.

A RSSI-based centralized localization technique

In [7] the authors propose a scheme which localizes nodes through RF attenuation in Electromagnetic waves. The scheme basically consists of three stages:

1) RF mapping of the network: It is obtained by conveying short packets at different power levels through the network and by storing the average RSSI value of the received packets in memory tables.

2) Creation of the ranging model: Let a generic tuple (i, j, P_{tx}, P_{rx}) comes from the RF mapping characterizing stage, where i is the transmitting node and j is the receiving node. Now first the algorithm corrects the received power as $P_{rx}^{/} = f(P_{rx}, P_{tx})$, f() is a function which takes into account the modularity effects. So, the estimated distance between the nodes will be

$r_{ij}^{0} = m^{-1} (P_{rx}^{/})$

3) Centralized localization model: An optimization problem is solved and provides the position of the nodes. The final result can be obtained by minimizing the function

$E = \sum_{i=1 \text{ to } n} \sum_{j=1 \text{ to } n} (k_{i,j}\, a_{i,j} (r_{ij} - r_{ij}^{0})^2)$,

r_{ij} = d(i, j) when i and j are anchors.Where N is the number of nodes, $a_{i,j}$ is 1 when the link is present and 0 otherwise.

Distributed Localization

Beacon based distributed localization

This can be categorized in Diffusion, Bounding Box and Gradient which are described as follows:

Diffusion

In diffusion the most likely position of the node is at the centroid of its neighboring known nodes.

APIT: In [8] the authors describe a novel area-based range free localization scheme, called APIT which requires a heterogeneous network of sensing devices where some devices are equipped with high-powered transmitters and location information. These devices are known as anchors. In this approach the location information is performed by isolating the environment into triangular regions between beaconing nodes. An unknown node chooses three anchors from all audible anchors and tests whether it is inside the triangle formed by connecting these three anchors. APIT repeats this tests with different audible anchor combinations until all combinations are exhausted or the required accuracy is achieved.

Bounding Box

Bounding box forms a bounding region for each node and then tries to refine their positions.

Collaborative Multilateration

Collaborative multilateration consists of three phases:

Forming Collaborative sub trees: A computation sub tree constitutes a configuration of unknowns and beacons for which the solution of the position estimates of the unknown can be uniquely determined. The requirement of one-hop multilateration for an unknown node is that it is within the range of at least three beacons (see Fig 2(a)). A two hop multilateration represents the case where the beacons are not always directly connected to the nodes but they are within a two hop radius from the unknown node (see Fig. 2(b)).

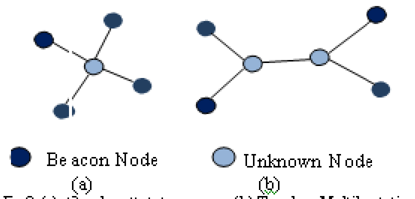

Fig.2 (a) One-hop Multilateration (b) Two-hop Multilaretation

Obtaining initial estimates: This phase is explained by the help of Fig. 3, A and B are beacons where C is the unknown node. If the distance between C and A is a then the x coordinate of C are bounded by a to the left and to the right of the x coordinate of A, x_A – a and x_A + a. Similarly beacon B which is two hops away from C, bounds the coordinate of C within x_B – (b + c) and x_B + (b + c). by knowing the information, C can determine that its x coordinate bounds with respect to beacons A and B are x_B + (b + c) and x_A – a. The same operation is applied on the y coordinates. C then combines its bounds on x and y coordinates, to obtain a bounding box of the region where it lies.

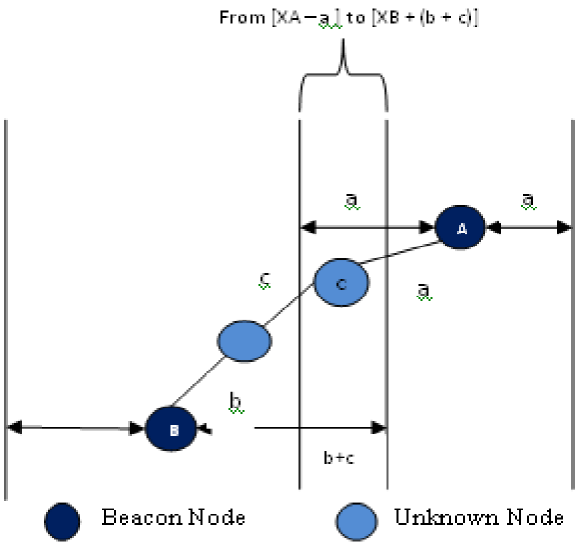

Fig.3. X coordinates bounds for C using initial estimates [9]

Position refinement: In the third phase, the initial node positions are refined using Kalman Filter implementation (mentioned in the Appendix B). Now as most unknown nodes are not directly connected to beacons, they use the initial estimates of their neighbors as the reference points for estimating their locations. As soon as an unknown node computes a new estimate, it broadcasts this estimate to its neighbors, and the neighbor use it to update their own position estimates. As shown in Fig. 4 first node 4 computes its location estimate using beacons 1 and 5 and node 3 as reference. Once node 4 broadcasts its update, node 3 recomputes its own estimate received from node 4. Next node 3 broadcasts the new estimate and node 4 uses this to compute a new estimate that is more accurate than its previous estimate.

The collaborative multilateration enables sensor nodes to accurately estimate their locations by using known beacon locations that are several hops away and distance measurements to neighboring nodes. At the same time it increases the computational cost also

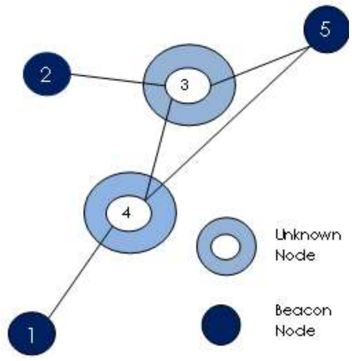

Fig4. Initial estimates over multiple hops

Node localization assuming the region as square box

In [10] the authors frame the localization problem as. They have assumed that in a square region Q = [0, s] x[0,s], called region of operations, N nodes follows S_1, S_N have been scattered and each of which is equipped with an RF transceiver with communication range r > 0. In other words a node S_i can communicate with every node which lies in its communication region, which is the disk with radius r centered at S_i. The nodes form an ad hoc network Ɗ in which there is an edge between S_i and S_j if their distance is less than r. They scheme assume that there are certain positive number of beacons nodes in Q and other are unknown nodes. Now for any integer n > 0, partition Q into n^2 congruent squares called cells of area $(s/n)^2$ and for every known node S, we know the cell which contains S. To make the problem tractable the authors assume that communication range is ρ calls where ρ = [nr/s√2], where [x] denotes the integer part of x, which means that each node S can communicate with every node lying in the square centered at S and containing $(2\rho + 1)^2$ cells. Usually n is large and r is much smaller than n. In particular 2ρ + 1 < n.

Gradient

In this approach ad-hoc sensor nodes are randomly distributed on a two dimensional plane and each sensor communicates with nearby sensors within a fixed distance r, where r is much smaller than the dimension of the plane.

Relaxation Based Distributed Algorithm

Spring Model

This gives an Anchor Free Localization (AFL) algorithm where nodes start from a random initial coordinate assignment and converge to a consistent solution using only local node interactions. The algorithm proceeds in two phases and it assumes the nodes as point masses connected with strings and use force-directed relaxation methods to converge to a minimum-energy configuration.

The first phase is a heuristic that produces a graph embedding which looks similar to the original embedding.

Cooperative Ranging Approach

A cooperative ranging approach that exploits the high connectivity of the network to translate the global positioning challenge into a number of distributed local positioning problems that iteratively converge to a global solution by interacting with each other. In the proposed approach, every single node plays the same role repetitively and concurrently executes the following functions:

•Receive ranging and location information from neighbouring nodes

•Solve the local localization problem by ABC algorithm.

•Transmit the obtained results to the neighbouring nodes.

After some repetitive iteration the system will converge to a global solution.

Coordinate System Stitching

This is explained by the following approaches

Cluster based Approach

This propose a distributed algorithm for locating nodes in a sensor network in which the nodes have the ability to estimate the distance to nearby nodes. Before describing the algorithm we need to know the distinction between non-rigid and rigid graphs.

Cluster based localization supports dynamic node insertion and mobility.

4.2.3.2. Construction of Global Coordinate System in a network of Static Computational nodes from inter node distance

The coordinate system stitching which constructs a spatial map and a distance matrix and then tries to minimize the discrepancies between them by translation, rotation and reflection. A distance matrix of an individual node may acquire some subset of the distance estimates. Now to construct the spatial map from a distance matrix we need to construct an initial map containing a triangle of three non-collinear pair-wise neighboring nodes. Then more nodes are inserted into the map, one at a time, based on distances to nodes already in the map, in an iterative process so that the node must have at least three non- collinear neighbour nodes. The process terminates when all nodes are inserted into the map or when no uninserted node can be inserted.

The advantage of this scheme is that it does not need anchor or beacon nodes for localization.

Conclusions

The performance of any localization algorithm depends on a number of factors, such as anchor density, node density, computation and communication costs, accuracy of the scheme and so on. All approaches have their own merits and drawbacks, making them suitable for different applications.

Some algorithms require beacons (Diffusion, Bounding Box, Gradient, APIT) and some do not (MDS-MAP, Relaxation based localization scheme, Coordinate system stitching). Beaconless algorithms produce relative coordinate system which can optionally be registered to a global coordinate system. Sometimes sensor networks do not require a global coordinate system. In these situations beaconless algorithms suffice.

Certain algorithms are centralized while some are distributed. Centralized algorithms generally compute more accurate positions and can be applicable to situations where accuracy is important. Distributed algorithms on the other hand do not depend on large centralized system and potentially have better scalability.

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