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A Two-hop Collaborative Localization Algorithm for Wireless Sensor Networks

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Abstract

Localization technology is one of the key supporting technologies in wireless sensor networks. In this paper, a two-hop collaborative multilateral localization algorithm is proposed to localization issues for wireless sensor networks. The algorithm applies anchor nodes within two hops to localize unknown nodes, and uses the minimum range error estimation method to compute coordinates of the unknown nodes. If an unknown node cannot be localized through two-hop anchor nodes, it is localized by anchor nodes and localized nodes within two hops through auxiliary iterative localization method. Simulation results show that the localization accuracy of this algorithm is very good, even in larger range errors.

Keywords*: wireless sensor networks, collaborative multilateral localization, minimum range error estimation, maximum likelihood estimation*

1. Introduction

Wireless sensor network (WSN) consists of a large number of sensor nodes which are highly constrained in terms of their computing power, communication capabilities, and battery power. Its applications cover a wide range from natural monitoring to ambient awareness, from military to surveillance. Basically, each sensor node will monitor its local environment and they collaborate as a whole to provide information about the senseing field to users.

In WSNs, localization technology is one of the key supporting technologies. As far as applications in WSNs are concerned, the node location information is very important. It can be used in identifying the location at which sensor readings originate [1, 2], in communication route protocols based on geographical areas [3, 4], in data storage protocols based on geographical area partition [5, 6], and other services based on location. Location information can come from manual setting or GPS (Global Positioning System) device. However, manual location setting requires huge cost of human time, and GPS location setting requires expensive device cost. Both approaches are not applicable to localization task for large scale wireless sensor networks. Furthermore, in a network of thousands of nodes, it is unlikely that the designer determine the location of each node. In an extreme case, nodes may be dropped from the air and scattered about an unknown area. In order to localize per-node, wireless sensor network usually consists of two category nodes: one is anchor nodes, which can get their location information through GPS or manual location; the other is unknown nodes, whose coordinates are unknown. Unknown nodes get their location information through anchor nodes and communication between nodes

In this paper, A two-hop Collaborative Multilateral Localization Algorithm (CMLA) is proposed for WSNs. The algorithm is implemented through event-driven schemes. It proposes a new method which is used to estimate the distances between two hop nodes, applies anchor nodes within two hops to localize unknown nodes, and uses the minimum range error estimation to compute coordinates of unknown nodes. When an unknown node can not be localized through two hop anchors nodes, it is localized by anchors and localized nodes within two hops.

2. Related Work

So far, many localization algorithms for WSNs have been proposed to provide per-node location information. These algorithms take into account different factors to localization problem such as the network topology, device capabilities, location accuracy and energy requirements.

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Based on whether localization schemes apply range technique, they can be broadly classified into two categories: range-free schemes and range-based schemes.

2.1. Range-Free Localization Schemes

Range-free schemes do not require any technology or equipment to measure the distance or bearing between nodes, they just apply the communication among nodes to localize unknown nodes. The representative schemes are centroid [7], DV-Hop [8], Amorphous [9] and APIT [10]. The advantage of range-free schemes lies in their simplicity, as nodes do not need any additional device to measure range information. But they provide only coarse locations.

Centroid is a coarse grained range free localization algorithm. It uses anchor beacons, containing location information (x_i, y_i), to estimate node position. After receiving these beacons, an unknown node estimates its location (x, y) using the centroid formula.

DV-Hop is a distance vector routing based localization algorithm. In the algorithm, one anchor floods a beacon (containing location and hop-count) throughout the network. Beacons are flooded outward with hop-count values incremented at every intermediate hop. Each receiving node maintains the minimum counter value per anchor of all beacons it receives and ignores those beacons with higher hop-count values. Through this mechanism, all nodes in the network get the smallest hop count to every anchor. Anchors perform this task by obtaining location and hop count information for all other anchors inside the network, and then estimate the average single hop distance. Once a node can calculate the distance estimation to more than 3 anchors in the plane, it uses Maximum Likelihood Estimation (MLE) to estimate its location.

The Amorphous [10] takes a different approach from the DV-Hop to estimate the average distance of a single hop. This algorithm assumes that the density of the network is known a priori, so that it can calculate hop distance in accordance with the Kleinrock and Slivester formula [11]. The main steps of Amorphous are: (1) each node obtains the hop distance to distributed anchors through beacon propagation. Once anchor estimates are collected, the hop distance estimation is obtained through local averaging; (2) each node collects neighboring nodes' hop distance estimates and computes an average of all its neighbors' values; (3) after obtaining the estimated distances to three anchors, unknown nodes uses triangulation to estimate theirs locations.

APIT (Approximate Point-In-Triangulation Test) algorithm is an area coverage based, range-free localization algorithm. Its thinking is: Firstly, anchor nodes broadcast their beacon information, containing node ID, location and signal strength, throughout the network. Unknown nodes receive beacons and exchange their own beacons with their neighbor nodes. Then, the unknown nodes use approximate point-in-triangulation test method to judge that they are inside or outside the triangle formed by three anchors. Finally, each unknown node takes the focus of overlapping area formed by triangles which it is inside as its coordinates.

2.2. Range Estimation Techniques

Common techniques for distance or angle estimation include Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and Received Signal Strength Indicator (RSSI) [12].

The ToA technique measures the distance between nodes according to the signal traveling time. This technique requires precise time synchronization and high-speed sampling of the received signal. GPS [13] is a typical ToA-based localization system. The TDoA technique sends two different speed signals at the same time, and then uses their arrival time difference to calculate the distance between nodes. It requires low speed (for example, ultrasound) signal propagate device. AHLos (Ad-hoc localization system) [14] is a TDoA-based localization algorithm for WSNs. The AoA technique measures the angle of arriving signal from anchor nodes, so it requires an antenna array at anchor nodes. APS (Ad-hoc Positioning System) [15] is an AoA-based localization algorithm for WSN.

Although these techniques can accurately measure the distance or angle between nodes, as they require additional devices, they are not applicable to most of wireless sensor networks.

The RSSI is based on the fact that the received signal power attenuates with distance. Thus, the distance between two nodes can be estimated according to the RSSI. But Radio frequency (RF) based range techniques are inherently dependent on the RF channel whose multipath fading and shadowing effects have a fundamental bearing on the accuracy of distance estimate. However, for WSN, RSSI-based range technique does not require any additional device, and the physical/medium access control (PHY/MAC) layer protocol of IEEE802.15.4 standard [16] defines a function of RSSI measurement in its protocol. In other words, if we construct a wireless sensor network with the IEEE802.15.4 standard, a node can naturally measure the RSSIs from its neighboring nodes through communications. As a result, many researchers study the RSSI-based localization techniques, and propose a lot of the RSSI-based localization algorithm [17~21].

2.3. Range-based Localization Schemes

In range-based schemes, distance or angle measurements between neighboring nodes are required to estimate the location of nodes in the network. In the following, we describe some typical range-based localization algorithms.

The AHLos [14] applies atomic multilateration, iterative multilateration and collaborative multilateration to localize unknown nodes. Unknown nodes which they have enough neighboring anchors estimate their locations through Atomic Multilateration. Once an unknown node estimates its location, it becomes an anchor and broadcasts its location to other neighboring nodes, enabling them to estimate their locations. This process repeats until all the unknown nodes that satisfy the requirements for multilateration obtain an estimate of their position. This process is defined as iterative multilateration which uses atomic multilateration as its main primitive. An unknown node may never have three neighboring anchors therefore it will not be able to estimate its position. When this occurs, a node may attempt to estimate its location by considering use of locations over multiple hops in a process referred to as collaborative multilateration.

The n-hop multilateration primitive [23] is also referred to as collaborative multilateration. It consists of a set of mechanisms that enables nodes found several hops away from anchors to collaborate with each other and estimate their locations with high accuracy. Location estimates are obtained by setting up a global non-linear optimization problem and solving it using iterative least squares. This scheme addresses two issues which exist in the AHLos: (1) iterative multilateration is sensitive to anchor densities and can easily get stuck in places where anchor densities are sparse, (2) error propagation becomes an issue in large networks.

MDS-MAP [24] scheme applies multidimensional scaling (MDS) techniques, which are a set of data analysis techniques that display the structure of distance-like data as a geometrical picture, to estimate unknown nodes location. It consists of three steps: (1) Compute shortest paths between all pairs of nodes in the network and construct the distance matrix for MDS. (2) Apply MDS to the distance matrix to construct a relative map. (3) Given sufficient anchor nodes, transform the relative map to an absolute map based on the absolute coordinates of anchors.

MDS-MAP is a centralized algorithm. Literature [26] introduces a scalable, distributed weighted-MDS (dwMDS) algorithm that adaptively emphasizes the most accurate range measurements and naturally accounts for communication constraints within the sensor network. Each node adaptively chooses a neighborhood of sensor nodes, updates its position estimation by minimizing a local cost function, and then passes this update to neighboring sensors. RSSI and TOA channel measurements are used to demonstrate that the performance of dwMDS is as good as that of the centralized MDS-MAP which applies maximum-likelihood estimator (MLE) to calculate unknown node’s locations in a real-world wireless sensor network.

Convex Position Estimation [26] describes feasible solutions to the position estimation problem using convex optimization. It models peer-to-peer communication or pair wise angles between nodes in the network as a set of geometric constraints on the node positions, and formulates a sensor network position estimation problem as a linear or semidefinite program. It is not only suitable for range-base techniques but also suitable for range-free techniques. However, it is a centralized localization algorithm.

3. Thinking in CMLA

3.1. Overview of CMLA

As the ratio of anchor nodes to all nodes is small, it is difficult to directly localize unknown nodes by their neighbor anchor nodes. Consequently, this Algorithm applies anchors within two hops to collaboratively localize unknown nodes. If an unknown can not localized by anchor nodes within two hops, an auxiliary iterative localization is applied to localize it. In this algorithm, the major localizing steps of each unknown node are as follows:

Step 1: Forming a 2-hop neighbor table.

First, each node and its neighbor nodes communicate with each other to form a neighbor table. Secondly, each node mutual exchanges data of neighbor table with its neighbor nodes to form a table including node information within two hops.

Step 2: computing the distance between nodes within two hops

According to the data in the table, unknown nodes compute the distance to anchor nodes within two hops, see section 3.2 and 3.3.

Step 3: computing the coordinates of unknown nodes

If an unknown node has n(n≥3) anchor nodes within two hops, it applies the coordinates of these anchors to compute its own coordinates, see section 3.4. After an unknown node is localized, it sends its own coordinates to its neighbor nodes.

Step 4: auxiliary iterative localization

If the number of anchors within two hops of an unknown node is less than 3, the unknown node cannot be localized directly. It waits the periodic timer trigger event. Upon the event fired, it checks whether it meets the location condition. If it meets the condition, it calculates the coordinates and sends to its neighbor nodes, or it waits the periodic timer trigger event next round fired.

3.2. The Method of Computing the Distance Between 2-hop Nodes Based on Ranging Technique

Ranging technique can measure the distance between neighbor nodes. If the anchor is an unknown node neighbor node, the distance between them can be directly obtained by measuring technology. The following describes the method of computing the distance between an unknown node and its 2-hop anchor node.

Let *A* is an anchor node, *U* represents an unknown node, node *A* and *U* cannot communicate directly. Node *B* and *C* are common neighbor nodes of node *A* and *U*, as shown in Figure 1.

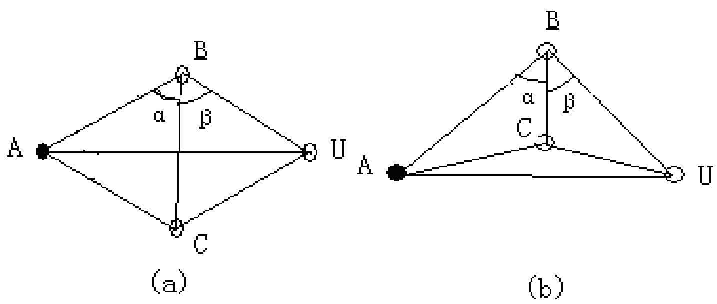

Figure 1. Computing the distance between 2-hop nodes

When *B* is a neighbor node of *C*, i.e. the distance between *B* and *C* is known, as shown in Figure 1 (a) and (b), it is easy to solve the distance between *A* and *U*. If *A* and *U* have many common neighbor nodes such as *B* and *C*, we can apply maximum likelihood estimation to compute the distance between *A* and *U*.

3.3. The Method of Computing the Distance Between 2-Hop Nodes Based on Range-Free Technique

If sensor nodes don't support ranging technique, we estimate the distance between an unknown node and an anchor node within two hops following three steps.

Step 1: Estimating the hop distance of anchor nodes

Let an anchor node V has n anchor nodes within two hops, we apply the following formula to estimate the hop distance d_h of node V.

$$d_h = \sum_{i=1}^{n} d_i / \sum_{i=1}^{n} h_i \tag{1}$$

Where d_i is the distance between V and its i'th($1 \le i \le n$) anchor nodes, h_i is the hops between V and its i'th($1 \le i \le n$) anchor nodes.
Step 2: Estimating the hop distance of unknown nodes
Let an unknown node U has k anchor nodes within two hops, we apply the following formula to estimate the hop distance d_h of node U.

$$d_h = \sum_{i=1}^{n} d_{hi} / k \tag{2}$$

Where d_{hi} is the hop distance of the i'th($1 \le i \le k$) anchor nodes.
Step 3: Estimating the distance between an unknown node and an anchor node within two hops
Let d is the hop distance of an unknown node, h is the hops between the unknown node and an anchor node. Multiply d by h is the distance between these two nodes.

3.4. The Method of Computing the Unknown Node's Coordinates
3.4.1. Maximum Likelihood Estimation
MLE is widely used in some range-free localization algorithms [8, 9] and some range-based localization algorithms [12, 22] to calculate unknown node's coordinates. Its principle is:
Let v be an unknown node, (x, y) represents its coordinates. Let v_i($1<=i<=n$) be the unknown node's neighboring anchor nodes, their coordinates are (x_i, y_i) . The ranged distance between v and v_i ($1<=i<=n$) is d_i.
According to Euclidean distance formula, nonlinear equations are formulated as follows:

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 = d_1^2 \\ (x-x_2)^2 + (y-y_2)^2 = d_2^2 \\ \quad\quad \cdots \\ (x-x_k)^2 + (y-y_k)^2 = d_k^2 \end{cases} \tag{3}$$

Through an equation minus the next equation, they are converted into overdetermined linear equations as follows:

$$\begin{cases} 2.(x_2-x_1).x + 2.(y_2-y_1).y = d_1^2 - d_2^2 + x_2^2 - x_1^2 + y_2^2 - y_1^2 \\ 2.(x_3-x_2).x + 2.(y_3-y_2).y = d_2^2 - d_3^2 + x_3^2 - x_2^2 + y_3^2 - y_2^2 \\ \cdots \\ 2.(x_k-x_{k-1}).x + 2.(y_k-y_{k-1}).y = d_{k-1}^2 - d_k^2 + x_k^2 - x_{k-1}^2 + y_k^2 - y_{k-1}^2 \end{cases} \tag{4}$$

This system of equations has the form $A X = b$ and can be solved using the matrix solution given by

$$X = (A^T A)^{-1} A^T b, \tag{5}$$

where

$$A=\begin{pmatrix} 2(x_2-x_1) & 2(y_2-y_1) \\ 2(x_3-x_2) & 2(y_3-y_2) \\ \ldots & \ldots \\ 2(x_k-x_{k-1}) & 2(y_k-y_{k-1}) \end{pmatrix} \qquad X=\begin{pmatrix} x \\ y \end{pmatrix}$$

and

$$b=\begin{pmatrix} d_1^{\,2}-d_2^{\,2}+x_2^{\,2}-x_1^{\,2}+y_2^{\,2}-y_1^{\,2} \\ d_2^{\,2}-d_3^{\,2}+x_3^{\,2}-x_2^{\,2}+y_3^{\,2}-y_2^{\,2} \\ \ldots \\ d_{k-1}^{\,2}-d_k^{\,2}+x_k^{\,2}-x_{k-1}^{\,2}+y_k^{\,2}-y_{k-1}^{\,2} \end{pmatrix}$$

3.4.2. Minimum Range Error Estimation

In this paper, Minimum Range Error Estimation is used to compute the unknodes' coordinates. Its principle is:

If an unknown node has k (k≥3) anchor nodes with in two hops, we formulate a function as follows:

$$f(x,y)=\sum_{i=1}^{k}\left|\sqrt{(x-x_i)^2+(y-y_i)^2}-d_i\right| \tag{6}$$

Where (x, y) represents the unknown node's coordinates; (x_i, y_i) (1≤ i≤ k) represents coordinates of its i'th anchor node; d_i(1≤ i ≤ k) represents the ranged distance between the unknown node and the i'th anchor node. Obviously, *f(x, y)* is a function which presents the sum of range errors between this unknown node and its all neighboring anchors within 2-hop. When the function *f(x, y)* obtains the smallest value, that is to say, the minimum total of range Errors, the corresponding (*x, y*) is the unknown nodes coordinates. So we call this method Minimum Range Error Estimation (MREE).

We use Nelder-Mead simplex optimization [27] method to find the smallest value of function *f(x, y)*, and correspondingly calculate the unknown nodes' coordinates (*x, y*). However, simplex optimization method starts at an initial estimate, finds the minimum value of objective function. If the initial estimate is improper, it may only give local solutions. Therefore, we solve this problem in two steps.

Step 1: Applying MLE to calculate an initial estimate (x_0, y_0) of the unknown node's coordinates.

Step 2: Applying Nelder-Mead simplex optimization method to find the unknown node' coordinates (*x, y*), starting at initial estimate (x_0, y_0).

4. Implementation of CLMA

This algorithm is implemented through event-driven method. It uses five event types. They are localizing timer event, receiving a neighbor node data package event, receiving a distance data package event, receiving the coordinate data event and the periodic timer trigger event. After initialization, all nodes start localizing timer event at same time and begin the localization algorithm. Algorithm 1 provides a formula description for localizing procedure of a node.

Algorithm 1**:** Collaborative Multilateral Localization Algorithm
input: Neighbor table with neighbor nodes' id, distance
Output: the location of the unknown node
1. initialization;
2. UPON *localizing timer event* FIRED
3. *constructing a neighbor node data package with neighbor's id;*

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    sending  it to neighbor nodes;
UPON receiving a neighbor node data package event FIRED
    comparing to it own neighbor nodes, and find the common neighbor nodes;;
    constructing a distance data package with these common nodes' id, distance, and coordinates;
    sending back the distance data package to the sending node;
UPON receiving a distance data package event FIRED
    appending the receiving data into the 2-hop neighbor node table;
    IF receiving all neighboring distance data package THEN
        IF the number of anchor nodes≥3 THEN
            calculating the distances between the node and anchor nodes within two hops;
            calculating the coordinates of the node;
            sending its  own coordinates data to its neighbor nodes;
            terminating the algorithm;
        ELSE
            rounds=0; // it represents the rounds of auxiliary iterative localization
            firing the periodic time trigger;
        END IF
    END IF
UPON receiving the coordinates data event FIRED
    updating the 2-hop neighbor node table with the received data;
UPON the periodic time trigger event FIRED
    rounds=rounds+1;
    IF  the number of beacons(include anchor nodes and localized nodes) ≥3 THEN
            calculating the distances between the node and beacon nodes within two hops;
            calculating the coordinates of the node;
            sending its  own coordinates data to its neighbor nodes;
            terminating the periodic time trigger event;
            terminating the algorithm;
    END IF
    IF rounds>maxRounds THEN //maxRounds is maximum rounds of iterative localization
            terminating the periodic time trigger event;
            terminating the algorithm;
    END IF
```

5. Experimental Results

In this section, we verify our proposed algorithm and analyze the simulation results from different perspectives. We run the algorithm in Matlab, and apply fminsearch function in optimization toolbox to calculate unknown nodes' coordinates. Range errors are modeled as an independent Gaussian random distribution with zero mean and variance Er. Localization errors are normalized to R, i.e. assuming d* is the distance between estimated coordinates and true coordinates, the localization error is d*/R.

In order to evaluate the performance of CMLA, the algorithm (called it MREE-CMLA) is compare with the same algorithm but applying maximum likelihood estimation to compute unknown nodes' coordinates (called it MLE-CMLA), and MREELA [28].

5.1. Comparing Localization Errors of MREE and MLE

This simulation is used to cpmpare the localization errors of MREE and MLE. In the simulation, we randomly place 10 nodes (as anchor nodes) around a node (as unknown node), and set the range error E_r=0.1. Then, we use all combinations of 3, 4, …, 10 nodes from these anchors to localize the unknown nodes, then calculate the average localization errors respectively. Figure 2 shows average localization errors corresponding to the number of anchors. The experimental results reveal that the average localization errors caused by using MREE is lower than that caused by using MLE.

5.2. Location Errors when Varying Range Error

This simulation is used to study the effect on range error. In the simulation, 200 sensor nodes are placed randomly with a uniform distribution within a 200m×200m square area, and we take the latter 20 nodes as anchors. The range error is from 0.05 to 0.3. Figure 3 shows the effect of range error on localization error.

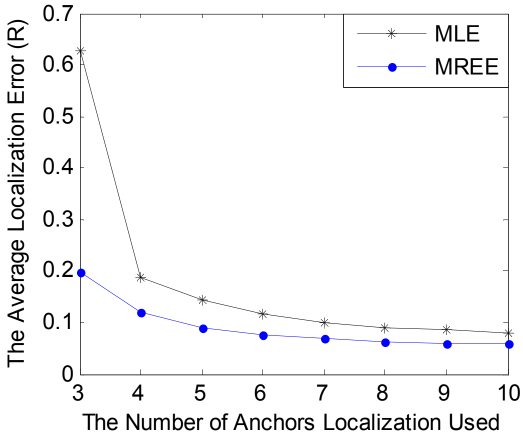


Figure 2. The localization Error of MREE and MLE

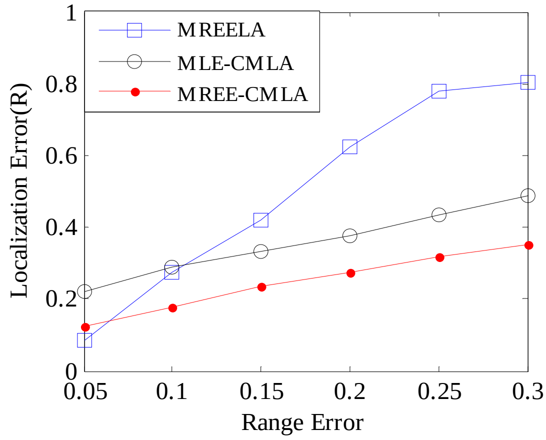
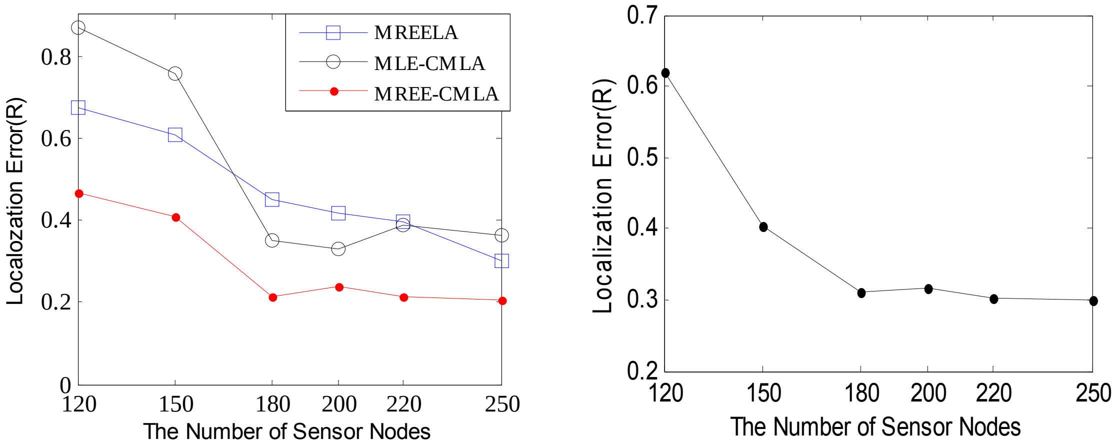


Figure 3. The effect of range error on localization error

5.3. Location Errors When Varying Network Connectivity

This simulation is used to study the effects of network connectivity on location errors. We randomly place 150, 180, 200, 220, 250 280, 300 sensor nodes in a 200m×200m network area, corresponding to the connectivity is about 8.9, 11, 12.4, 13.2, 15.1, 17.3 and 18.6 respectively. The number of anchors is 20; we take the latter 20 nodes as anchors. The range error is 0.15. Figure 4 shows the effect of network connectivity on localization error.



(a) range-based (b) range-free

Figure 4. The effect of network connectivity on localization error

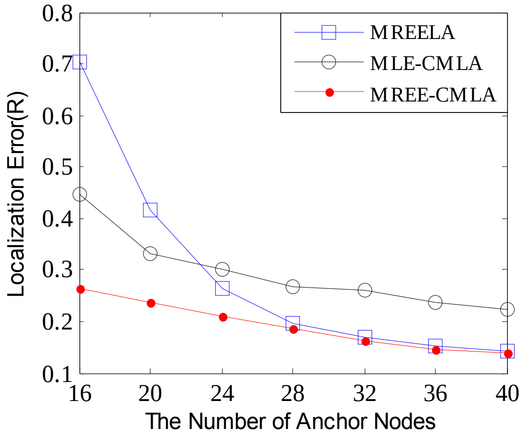


Figure 5. The localization errors on the number of anchor nodes

5.4. Localization Errors on the Number of Anchor nodes

This simulation is used to study the effect of the number of anchors on location errors. We place randomly place 200 sensor nodes in a 200$m \times$200m network area, and take the latter from 16 to 40 nodes as anchors, that is to say the ratio of anchor nodes to total nodes is from 8% to 20% . The range error E_r is set to 0.15. Figure 5 shows the impact of the number of anchors on localization error.

6. Conclusion

In this paper, we propose a collaborative multilateral localization algorithm for wireless sensor network to solve the problem that the range error is large or sensor node does not support range technique. The algorithm is not only a range-based localization algorithm, but also a range-free one. Simulation results show the localization accuracy of this algorithm is very good in the condition of large range error or without range technique. And it does not require special placements for anchor nodes.

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References

[1] Songhwai Oh, Shankar Sastry. Tracking on a graph. in International Conference on Information Processing in Sensor Networks (IPSN), Los Angeles, USA. April 2005: 195-202.

[2] Prasanna Sridhar, Asad M Madni, Mo Jamshidi. Intelligent Object-Tracking using Sensor Networks. *in Sensors Applications Symposium*. San Diego, USA. 2007: 1-5.

[3] X Hong, K Xu, and M Gerla. Scalable routing protocols for mobile ad hoc networks. *IEEE Network magazine*. 2002; 16(4): 12-21.

[4] B Karp and HT Kung. GPSR: Greedy Perimeter Stateless Routing for wireless networks. *The 6th ACM/IEEE International Conference on Mobile Computing and Networking*, Boston, USA. 2000: 243-254.

[5] Jianliang Xu, Xueyan Tang, Wang-Chien Lee. A new storage scheme for approximate location queries in object tracking sensor networks. *IEEE Transactions on Parallel and Distributed Systems*. 2008; 19(2): 262-275.

[6] Ratnasamy S, Karp B. *GHT: Geographic hash table for data-centric storage*. In Proceeding of 1st ACM WSNA. September 2002: 94-103.

[7] N Bulusu, J Heidemann and D Estrin. GPS-less Low Cost Outdoor Localization for Very Small Devices. *IEEE Personal Communications Magazine*. 2000; 7(5): 28-34.

[8] D Niculescu and B Nath. DV Based Positioning in Ad Hoc Networks. *Telecommunication Systems*. 2003; 22(1): 267-280.
[9] R Nagpal, H Shrobe, and J Bachrach. Organizing a global coordinate system from local information on an ad hoc sensor network. *In IPSN '03*, Palo Alto. 2003: 333-348.
[10] T He, C Huang, BM Blum, JA Stankovic, and TF Abdelzaher. Range-free Localization and its impact on Large Scale Sensor Networks. *ACM transactions on Embedded Computing Systems*. 2005; 4(4): 877–906.
[11] L Kleinrock and J Slivester. *Optimum transmission radii for packet radio networks or why six is a magic number*. In proceedings of national Telecomm conference. 1978; 431-435.
[12] N Patwari, JN Ash, S Kyperountas, AO Hero, RL Moses, NS Correal. Locating the nodes: cooperative localization in wireless sensor networks. *IEEE Signal Processing Magazine*. 2005; 22(4) : 54–69.
[13] B Hofmann-Wellenhof, H Lichtenegger, and J Collins. Global Positioning System: Theory and Practice. *Springer Verlag, 4th ed*. 1997.
[14] A Savvides, CC Han, and M Srivastava. Dynamic fine-grained localization in ad-hoc networks of sensors. *in ACM MOBICOM*, Rome, Italy, 2001: 166-179.
[15] D Niculescu, B Nath. *Ad hoc positioning system (APS) using AoA*. In Proceedings of IEEE INFOCOM. 2003: 1734–1743.
[16] IEEE Std 802.15.4TM. *IEEE Standard for Information technology telecommunications and information exchange between systems local and metropolitan area networks specification requirements part 15.4*: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs). 2003.
[17] C Alippi, A Mottarella, and G Vanini. A RF map-based localization algorithm for indoor environments. *In IEEE International Symposium on Circuits and Systems*. Kobe, Japan. 2005: 652-655.
[18] Xiaoli Li, Hongchi Shi, and Yi Shang. A sorted RSSI quantization based algorithm for sensor network localization. *in the 11th International Conference on Parallel and Distributed Systems*, Fuduoka, Japan. 2005: 557-563.
[19] R Zemek, S Hara, K Yanagihara, K-i Kitayama. *A joint estimation of target location and channel model parameters in an IEEE 802.15.4-based wireless sensor network*. in Proceedings of the 18th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Athens, Greece. 2007: 1-5
[20] Pires RP, Wanner LF, and Frohlich AA. *An efficient calibration method for RSSI-based location algorithms*. In Proceedings of the 6th IEEE International Conference on Industrial Informatics (INDIN 2008.), Daejeon, Korea. 2008 : 1183 – 1188.
[21] Guang Han, Gang Qu, Shaoxiong Hua. *A new approach towards solving the location discovery problem in wireless sensor networks*. in Military Communications Conference, 2006, Washington, USA. 2007:1-7.
[22] Erceg V. et al., *IEEE 802.11 document 03/940r4* "TGn Channel Models". 2004.
[23] Andreas Savvides, Heemin Park and Mani B. Srivastava. The n-hop multilateration primitive for node localization problems. *Mobile Networks and Applications*. 2003; 8(4): 443-451.
[24] Y Shang, W Ruml, Y Zhang. Localization from mere connectivity in sensor networks. *IEEE Trans on Parallel and Distributed System*. 2004; 15(11): 961-973.
[25] JA Costa, N Patwari, AO Hero. Distributed weighted multidimensional scaling for node localization in sensor networks. *ACM Transactions on Sensor Networks*. 2006; 2(1): 39-64.
[26] L Doherty, LE Ghaoui, and SJ Pister. Convex position estimation in wireless sensor networks. *In IEEE Infocom*, Anchorage, Alaska. 2001: 3: 1655-1663.
[27] JC Lagarias, JA Reeds, MH Wright, and PE Wright. Convergence properties of the Nelder-Mead simplex method in low dimensions. *SIAM Journal of Optimization*. 1998; (1): 112-147.
[28] S Zhang, G Li. *Simplex Optimization Localization Algorithm for Wireless Sensor Networks*. In Proceeding of International Conference on NSWCTC. 2010; 254-257.