Proceedings of the 2009 IEEE
International Conference on Mechatronics and Automation
August 9 - 12, Changchun, China

A Beacon Selected Localization Algorithm for Ad-Hoc Networks of Sensors

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***Abstract* - Aiming at the positioning problem of Ad-Hoc networks of sensors node location, a beacon selected localization algorithm (BSLA) is proposed in this paper. The proposed method considers sufficiently both the topology relationship among beacons and the topology relationship between beacon nodes and unknown nodes. We introduce the concept of collinearity and apply it into the localization of the multihop networks. Through selecting best anchor terns by using collinearity parameter, node position estimate can be attained with a weighted estimate mechanism. A well-established data analysis technique--- Pauta Criterion is used to filter out the erroneous position estimate to achieve higher localization accuracy. Simulation results show that the performance of BSLA outweighs the traditional DV-Hop and DV-distance algorithms whether in regular networks or in irregular networks (C shape networks).**

Index Terms - Wireless sensor networks, Localization, Beacon selected, DV-Hop, DV-distance

I. INTRODUCTION

With the development of sensor techniques, low-power electronic and radio techniques, low-power and inexpensive wireless sensors networks have appeared and been put into application. Many applications of WSN are based on sensor self-positioning, such as battlefield surveillance, environments monitoring, indoor user tracking and others, which depend on knowing the location of sensor nodes. Because of the constraint in size, power, and cost of sensor nodes, the investigation of efficient location algorithms which satisfy the basic accuracy requirement for WSN meets new challenges [1].

Some previous works [2] [3] [4] study the effect of the localization accuracy with the different node deployment, especially the effect of beacon placement. Savvides [5] investigates how the deployment geometry affects localization accuracy and concludes the localization error in the perimeter of the network is usually large because the angles to each beacon are very small. C. Poggi [6] studies when anchors are much aligned (but not totally) a little distance estimation error could cause great position error due to the intersection point between circumferences could be very far from the real sensor position. In [7] [8] [9] [10], they all research node localization in irregular networks such as C shape networks because most of localization algorithms have unsatisfying performance in irregular networks.

In this paper, we present a novel and robust method, which can be incorporated into the distance-based algorithms that mostly use multilateration to localize node positions such as DV-Hop and DV-distance algorithms. The proposed method considers sufficiently the topology relationship among beacons and the topology relationship between beacon nodes and unknown nodes, and introduces the concept of collinearity and applies it into the localization of the multihop networks. By adding a beacon selected process, we pick out a set of good anchor terns to localize unknown nodes with the weighted estimate mechanism. We also introduce a well-established data analysis technique--- Pauta Criterion to filter out the erroneous position estimate to achieve higher localization accuracy. Simulation results prove that the performance of BSLA outweighs the traditional DV-Hop and DV-distance algorithms whether in regular networks or in irregular networks (such as C shape networks).

The rest of this paper is organized as follows: Section II discusses related work in localization. Section III describes DV-Hop and DV-distance algorithms and analyzes the error resources of them. In section IV, we describe our algorithm and the patch for the proposed algorithm. The Section V evaluates the algorithm performance by simulations and makes experiments to validate our algorithm. And Section VI draws the conclusion.

II. RELATED WORK

Based on whether it is required to measure the actual distance between nodes or not, the localization algorithms can be divided into two categories: Range-based and Range-free. The range-based algorithms need some extra-hardware to measure the exact distance or orientation between unknown nodes and anchor nodes, and then use the information to localize nodes. Range-free algorithms use estimated distance instead of range distance to localize nodes.

A. Range-based Localization Algorithm

Time of Arrival (TOA) [11] can obtain distance information by recording transmit time of the signal. Despite

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of a high precision, it requires high-speed process ability of the nodes and accurate timing equipment. Time Different of Arrival (TDOA) [12] launches two different signals, and computes their time difference of arrival, it can translate the difference into distance based on their transmit speed. Angle of Arrival (AOA) [13] estimates the neighbor signal direction and combines antenna array or acceptor, in order to obtain distance between neighbors. Received Signal Strength Indicator (RSSI) [14] estimates the distance between two sensors by measuring the attenuation of the wireless signal transmitted from sender to receiver.

B. Range-free Localization Algorithm

In order to overcome the problems such as high cost in Range-based algorithm, Range-free algorithm have been put forward, aiming to estimate the distance from unknown nodes to anchor nodes to reduce the dependence of the extra-hardware.

At present, there are many such algorithms: Centroid algorithm [15], APIT algorithm [16], DV-hop algorithm [17], and MDS-MAP algorithm [18]. In Centroid algorithm, the position of the unknown nodes is estimated to be the centroid of the anchor nodes from which it can receive beacon packets. This algorithm is simple but needs too many anchor nodes to achieve better localization accuracy. In [16], authors proposed APIT in which any sensor node can be located if it lies inside the triangle induced by three given anchor nodes. In this localization scheme each sensor node performs numerous PIT tests with different combination of audible anchor nodes and infers its location as the center of gravity of the intersection area of all the triangles in which the node lies in. Niculescu and Nath [17] have proposed DV-hop which is a distributed, hop by hop positioning algorithm, which works as an extension of both distance vector routing and GPS positioning in order to provide approximate location for all nodes in a network where only a limited fraction of nodes have self location capability. In [18], Yi Shang proposed MDS-MAP algorithm, which is based on classical multidimensional scaling. In this algorithm, firstly compute shortest paths between all pairs of nodes in the region of consideration, and then apply classical MDS to the distance matrix to construct a relative map. At last, the coordinates of the anchors are mapped to their absolute coordinates through a linear transformation.

III. THE ERROR ANALYSIS OF APS

A. The Fundamental of APS

In [17], Niculescu and Nath proposed APS algorithm which consists of DV-Hop, DV-distance and Euclidean algorithm. In this paper, we focus on the first two algorithms. We firstly introduce the DV-Hop algorithm because DV-distance is similar with DV-Hop with actual measurement distance instead of estimate distance.

In the first step, each anchor node broadcasts a beacon to flood through the network containing the anchors location with a hops value initialized to one. Each receiving node maintains the minimum hops value per anchor of all beacons it receives. Beacons with higher hops values to a particular anchor are defined as stale information and will be ignored. Through this mechanism, all nodes in the network will get the minimal hops to every anchor node.

In the second step, once an anchor gets hops value to other anchors, it estimates an average distance for one hop, which is then flooded to the entire network. When they have the hop-distance and hops to other anchors, they will estimate the distance from themselves to all anchors that they can calculate by multiplying average hop-distance by hops. The average hop-distance is estimated by anchor i using the following formula:

$$C_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_i}, \text{ all other anchors j} \qquad (1)$$

where (x_i, y_i) , (x_j, y_j) are coordinates of anchor i and j , h_i is the hops between beacon i and all other beacons.

Each anchor node broadcasts its average hop-distance to the network using controlled flooding. Every unknown node will receive the first correction as its average hop-distance and throw away the other correction from other anchors.

In the last step, Let (x, y) be the unknown node M location and (x_i, y_i) is the known location of the i 'th anchor node receiver. Let's define the i 'th anchor node distance to unknown nodes if d_i , well then, there is the following formula:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^{\ 2} \\ (x - x_2)^2 + (y - y_2)^2 = d_2^{\ 2} \\ \quad \vdots \\ (x - x_i)^2 + (y - y_i)^2 = d_i^{\ 2} \end{cases} \qquad (2)$$

The coordinates of M is computed by the following formula:

$$A = -2 \times \begin{bmatrix} x_1 - x_n & \mathrm{y}_1 - y_n \\ x_2 - x_n & \mathrm{y}_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & \mathrm{y}_{n-1} - y_n \end{bmatrix} \qquad (3)$$

$$B = \begin{bmatrix} d_1^{\ 2} - d_n^{\ 2} - x_1^{\ 2} + x_n^{\ 2} - y_1^{\ 2} + y_n^{\ 2} \\ d_2^{\ 2} - d_n^{\ 2} - x_2^{\ 2} + x_n^{\ 2} - y_2^{\ 2} + y_n^{\ 2} \\ \vdots \\ d_{n-1}^{\ \ 2} - d_n^{\ 2} - x_{n-1}^{\ \ 2} + x_n^{\ 2} - y_{n-1}^{\ \ 2} + y_n^{\ 2} \end{bmatrix} \qquad (4)$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix} \qquad (5)$$

Because $AX = B$, so we can obtain the solution:

$$X = \left(A^T A\right)^{-1} A^T B \qquad (6)$$

The DV-distance algorithm is similar with the DV-Hop algorithm with the difference that distance between neighbor nodes is measured using radio signal strength and is propagated in meters rather than in hops. This approach is less coarse than the previous one, but affected by measurement errors.

B. The Error Source of APS

After the second step of DV-Hop and DV-distance, unknown nodes will have the position information and distance estimates of all anchor nodes. Then, they will choose three or more than three anchors to execute trilateration or maximum likelihood estimation to get the position. Generally speaking, the more anchors the unknown nodes choose, the better accuracy position estimate they can get. However, unfortunately, many situations are not that case. In fact, the topology relationship among anchors as well as among anchor nodes and unknown nodes will affect the localization of unknown nodes to a great extent. When beacons are much aligned a little distance estimation error could cause great position estimation error due to the intersection points between circumstances could be very far from the real sensor position. Another situation that produce the same results consider two or three close beacons all far from the sensor where been the third. On the contrary, if the reference points surround the sensor, we obtain good position estimation.

To solve these problems, in the last step of DV-Hop or DV-distance, we do not use the traditional maximum likelihood method to solve the location of the unknown node, but single out best available anchor terns satisfied with the specified threshold, and then proceed to localize nodes by performing trilateration. The results may have a series of position estimates, and we use our weighted estimation mechanism to get the node ultimate location through setting their collinearity degree as their weight.

IV. THE PROPOSED ALGORITHM

The paper [6] analysed the effect of location with the relationship of the topology of anchors, and selected anchor terns with good triangular shape by using the parameter of collinearity to enhance the localization accuracy. However, this method has not been applied to multihop node localization. The proposed algorithm not only redefined the collinearity and introduced it into node localization of multihop sensor networks. Our algorithm achieves the goal of improving location accuracy and does not require any additional hardware.

A. Collinearity

The paper [6] adopted the minimum of the three heights of the triangle formed by the anchors as collinearity of one tern. However, in fact, the more fundamental parameter about the shape of the triangle is the interior angle of the triangle. As a result, our collinearity parameter is very simple and a constant, which can be used in many other occasions and do not have to make any change.

Collinearity is the maximum of the three Cosine of interior angle of the triangle composed by a set of anchors. Thus, the process of calculation is very simple. We can be convenient to use triangular law of cosines to obtain:

$$C_A = \left| \frac{b_{C,A}{}^2 + c_{A,B}{}^2 - a_{B,C}{}^2}{2 b_{C,A} c_{A,B}} \right| \tag{7}$$

$$C_B = \left| \frac{a_{B,C}{}^2 + c_{A,B}{}^2 - b_{C,A}{}^2}{2 a_{B,C} c_{A,B}} \right| \tag{8}$$

$$C_C = \left| \frac{a_{B,C}{}^2 + b_{C,A}{}^2 - c_{A,B}{}^2}{2 a_{B,C} b_{C,A}} \right| \tag{9}$$

And A, B, C represents the angles that are composed by the anchor node A, B, C. $a_{B,C}$ ， $b_{C,A}$ ， $c_{A,B}$ represents the sides responding to angle A, B, C. Therefore, we can at once get the collinearity of anchor terns:

$$NC = \max\left\{C_A, C_B, C_C\right\} \tag{10}$$

Due to the collinearity represents the cosine of minimum angle of the triangle its scope is 0.5 to 1.0 (corresponding angle is from 0° to 60°). If NC equals to 0.5, the triangle is equilateral triangle and in this case the localization will be best theoretically. If NC equals to 1, the anchor tern is totally aligned and results in the worst localization.

B. The Basic BSLA

After the unknown node collects all anchor nodes information, we will establish an especial threshold value to choose good anchor terns. If this threshold value is too large, this leads very few anchor node terns to be selected to complete the localization. If this threshold value is too small, this causes the collinearity to lose capability to select good anchor terns and thus makes the collinearity no sense. After set a good threshold value of the collinearity, it can be able to implement the trilateration to get a corresponding position estimate. We can obtain a set of positions because we may get many anchor terns that meet the special threshold. Therefore, based on the collinearity we put forward a weighted estimate mechanism to get a final estimate of the location. The overall algorithm process is as follows:

a) Implement the first two stages of the DV-Hop and DV-distance, each of the unknown nodes collects all the anchor nodes location and distance information they can.

b) Calculate the NC of each tern, and then select the good terns with NC smaller or equal to special collineartiy threshold. If the distance between anchor nodes is too closer such as shorter than 1m, drop this anchor tern.

c) Get a set of locations through using trilateration with selected anchor node terns, and record the NC of each tern.

d) Calculate the reciprocal of each NC and record them, and then compute corresponding weight W_i of each tern.

$$W_i = \frac{\frac{1}{NC_i}}{\sum_i \frac{1}{NC_i}} \tag{11}$$

e) Obtain the final position estimate by multiplying a set of locations by their corresponding weight.

$$Position = \begin{bmatrix} X \\ Y \end{bmatrix} W' \tag{12}$$

C. *Beacon Selected Mechanisms*

As long as the networks are connected, nodes in the DV-Hop and DV-distance can attain anchor nodes information forwarded by other nodes. It seems that unknown nodes can have sufficient information so that most of nodes can get adequate useful anchor nodes to achieve their localization. However, we find that it also causes large location error in our initial simulation because of the obvious reason that the more hops (distance), the larger error of the distance estimate. Therefore, we will set a restriction on the hops that the unknown nodes can collect. If the hop between unknown node and anchor node is beyond the given threshold value, we give up the anchor nodes information. Although this mechanism can improve the accuracy of the localization, it also results in the poor coverage. Fortunately, as the improvement of the networks connectivity and the radio of anchor nodes, coverage can quickly increase to good percentage. An appropriate threshold value of hops will find a good balance between the location accuracy and the location coverage.

D. *Patches for Basic BSLA (BSLA(P))*

After we get a set of anchor terns, we can use them to localize nodes by executing the trilateration. However, some of them may have bad position estimate in some cases where the nodes deployment in the networks is not uniform, especially in lower connectivity and irregular networks. Because a set of locations estimate theoretically obey the Gauss distribution, we apply Pauta Criterion [19] to filter the location results to eliminate exceptional results. Pauta Criterion is the most widely used in the measure techniques.

We assume that the positions estimate comply with Gauss distribution. There are a set of observation values x_1, …, x_n, and then we calculates mean value $\overline{x}$ and residual value $v_i = x_i - \overline{x}$ corresponding to each position estimate x_i . According to Bessel Formula, we can get the standard error of each observation value:

$$\sigma = \left[\sum v_i^2 / (n-1)\right]^{1/2} \tag{13}$$

If the residual value v_d of some observation value x_d meets the condition:

$$\left|v_d\right| > 3\sigma \tag{14}$$

We think that the observation value x_d is an exceptional value and must be weed. Thus, for each node, we will use Pauta Criterion to obtain better position estimate. We call this method BSLA (p) as a patch for basic BSLA.

V. SIMULATION RESULTS

To validate our algorithm, sensor networks consist of 100 sensor nodes distributed in an 60×60 m2 region. The connectivity of sensor networks is controlled by the radio range of sensor node. Range error among the nodes is 5%. We will simulate the DV-Hop and DV-distance algorithms and our algorithms in random deployment, in uniform deployment and in C shape deployment networks.

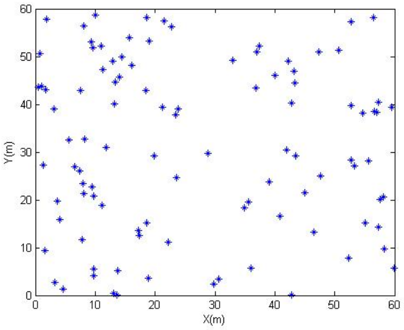

Fig. 1 Random Distribution

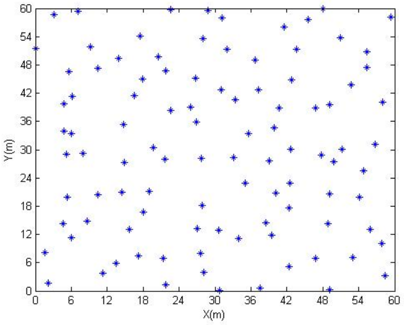

Fig. 2 Uniform Distribution

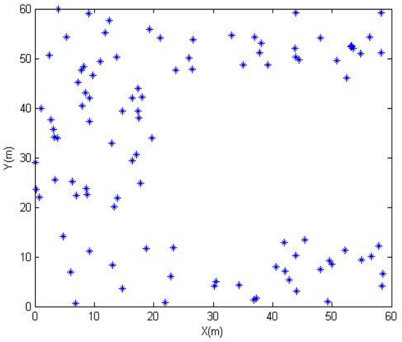

Fig. 3 C-Shape Distribution

Firstly, we validate the performance of our algorithm in the regular networks. As shown in Fig.4, 5, 6, 7, the performance of BSLA and BSLA (p) algorithms are compared with that of DV-Hop and DV-distance algorithms with varying the ratio of anchor nodes in random deployment networks and uniform deployment networks. The proposed algorithm can achieve the better localization accuracy than the DV-Hop and DV-distance algorithms. For the same ratio of anchor nodes and connectivity, position accuracy is much better when BSLA and BSLA (p) applied in same WSNs environment than the DV-Hop and DV-distance algorithms. For example, in the Fig.4 and Fig.5, with 20 anchor nodes (20%) and connectivity 8, BSLA has an average error of about 0.42R in random networks and 0.33R in uniform networks, where the DV-Hop has an average error of about 0.79R in random networks and 0.44R in uniform networks. In the Fig. 6 and Fig. 7, in the same case, BSLA has an average error of about 0.40R in random networks and 0.18R in uniform networks, where the DV-distance has an average error of about 1.18R in random networks and 0.38R in uniform networks.

When the connectivity and the radio of anchor nodes increase, the performance of BSLA is improved significantly, especially in lower networks connectivity and higher ratio of anchors. The BSLA (p) can achieve slightly better than BSLA, particularly in random networks and low networks connectivity where there are worse node positions estimate. Furthermore, the placement of anchor nodes will affect the CBLA and APS algorithms. The nodes localization error in the uniform networks can decrease about 50% than in the random networks, whether for DV-Hop or DV-distance. In CBLA, the localization accuracy also improves about 40% in uniform networks than that in random networks.

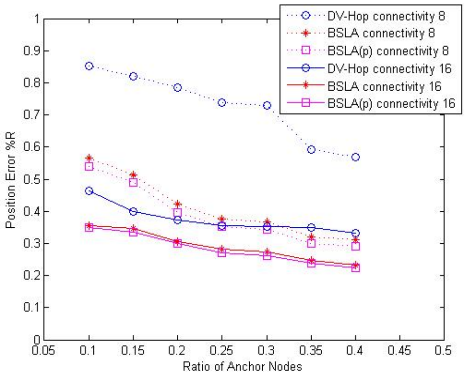

Fig. 4 BSLA VS DV-Hop in Random Networks

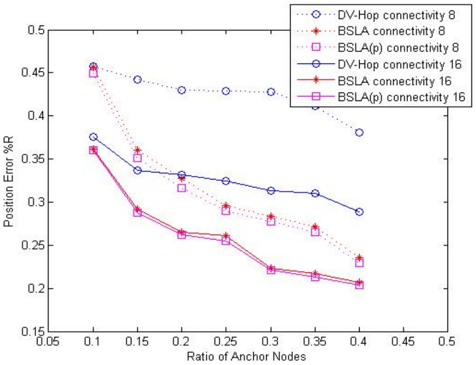

Fig. 5 BSLA VS DV-Hop in Uniform Networks

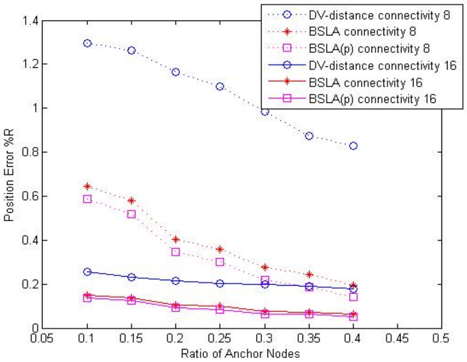

Fig. 6 BSLA VS DV-distance in Random Networks

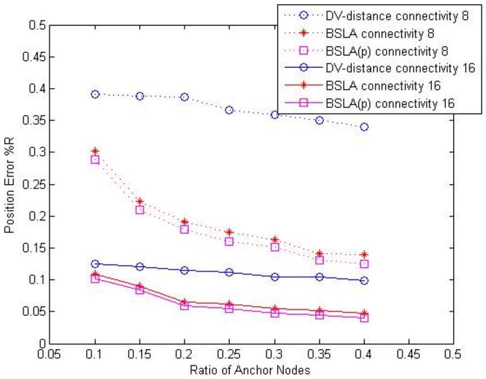

Fig. 7 BSLA VS DV-distance in Uniform Networks

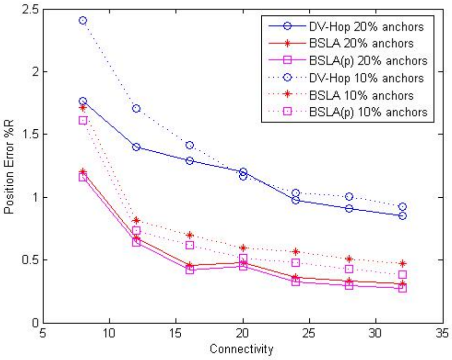

Fig. 8 BSLA VS DV-Hop in C Shape Networks

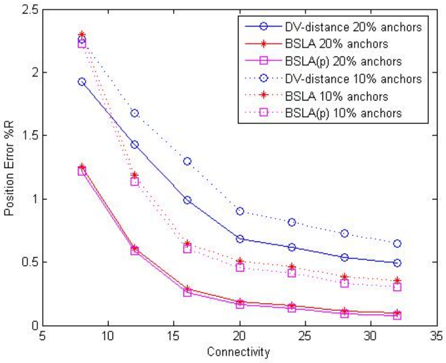

Fig. 9 BSLA VS DV-distance in C Shape Networks

Now, we validate the performance of our algorithm in the irregular networks. In order to ensure that the location coverage of the nodes in our algorithm can always maintain a ratio of more than 95%, we dynamically adjust the number of anchor nodes that an unknown node can collect according to the total number of anchor nodes in the networks. For instance, the connectivity from 8 to 32 with the step size 8 has the corresponding hops (distance) of neighbour anchor nodes unknown nodes can collect is 8, 6, 4, 3, 3, 3, 2. As seen in Fig.8 and Fig.9, the performance of BSLA in irregular networks outweighs significantly that of DV-Hop and DV-distance algorithms. When the networks connectivity exceeds 24 with 20% anchors, the positioning error of BSLA can be achieved less than 0.25R and 0.1R separately in Fig.8 and Fig.9. This trend is consistent with other algorithms. The reason is that increasing connectivity will lead the unknown node to collect more sufficient good anchor terns so as to reduce the average positioning error. Moreover, the BSLA (p) can achieve slightly better than BSLA, particularly in low ratio of anchor nodes where there are worse node positions estimate.

VI. CONCLUTIONS

We present a novel robust and distributed algorithm for solving the problem of localization in wireless sensor networks. The DV-Hop and DV-distance algorithms are described and the error resources of them are analyzed. Then we introduce a new parameter (NC) and apply it into node localization of multihop sensor networks. By adding a beacon selected process, we choose best available anchor terns to achieve accurate node localization. We also apply a widely used data analysis techniques---Pauta Criterion to filter out the erroneous position estimate to achieve higher localization accuracy. Whether in regular networks or in irregular networks, the simulation results have proven the validity of our method.

REFERENCES

[1] Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless Sensor Networks: A Survey”, Computer Networks, vol. 38, no. 4, Mar. 2002, pp. 393–422.

[2] Tian He, Chengdu Huang, Brian M. Blum, John A. Stankovic, Tarek Abdelzaher. "Range-Free localization schemes in large scale sensor networks", Proc of the 9th Annual Intl.Conf.on Mobile Computing and Networking, 2003.81-95.

[3] L. Doherty, K. Pister, and L. EI Ghaoui. “Convex position estimation in wireless sensor networks”, In IEEE Infocom 2001, Anchorge, Ak, April 2001

[4] Girod L, Estrin D. Robust range estimation using acoustic and multimodal sensing. In: Proc. of the IEEE/RSJ Int’l Conf. on Intelligent Robots and Systems (IROS 01). Vol.3, Maui: IEEE Robotics and Automation Society, 2001.

[5] A. Savvides, W. Garber, S. Adlakha, R. Moses, and M. Srivastava. On the error characteristics of multihop node localization in ad-hoc sensor networks. In IPSN, 2003.

[6] PoggiC, Mazzini G. Collinearity for sensor network localization. Proceedings of 2003 IEEE 58th Vehicular Technology Conference[C]. Piscataway, NJ, USA: IEEE, 2004. 3040-3044.

[7] Y. Shang and W. Ruml, “Improved MDS-Based Localization,” in INFOCOM, 2004

[8] C. Wang, L. Xiao, and J. Rong, “Sensor localization in an obstructed environment,” in DCOSS, 2005.

[9] C. Wang, L, Xiao, “Locating Sensors in Concave Areas” in INFOCOM, 2006

[10] Wanming Chen, Tao Mei, et al, Localization Algorithm Based on a Spring Model (LASM) for Large Scale Wireless Sensor Networks, Sensors 2008, 8: 1797-1818

[11] J. Caffery, “A new approach to the geometry of TOA location”, Proc. Of IEEE Vehicular Technology Conference (VTC), pp. 1943-1950, September 2000.

[12] A. Savvides, C. C. Han and M. B. Srivastava, Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors, In Proceedings of MOBICOM ’01, 2001, Rome, Italy, July2001.

[13] Niculescu D, Nath B. “Ad hoc positioning system (APS) using AOA”, Proc 22nd Annual Joint Conf of the IEEE Computer and Communications Societies (INFOCOM'2003), 2003, 3: 1734- 1743.

[14] T.S.Rappapport, Wireless Communications: Principles and Practice.Prentice Hall: New Jersey, pp.50-143, 1996.

[15] Bulusu N, Heidemann J, Estrin D. “GPS-less low-cost outdoor localization for very small devices”, Personal Communications, IEEE, 2000, 7(5):28 – 34.

[16] T. He, C. Huang, B. M. Blum, J. A. Stankovic, and T. F. Abdelzaher, “Range-Free Localization Schemes in Large Scale Sensor Networks,” in MobiCom, 2003.

[17] D. Niculescu, B. Nath. "Ad Hoc Positioning System (APS)," Proc. of the IEEE GLOBECOM 2001, San Antonio, pp. 2926-2931, 2001.

[18] Y Shang , W. Ruml , K. Zhang , and M. Fromherz . Localization from mere connectivity[C]//ACM MobiHoc, Annapolis, MD, June 2003: 201-212.

[19] M. Xiao, Experiment Error Estimate and Data Processing, Science Press, 1980.3, 142-143 (in chinese)