Distributed Wireless Sensor Network Localization Algorithm Using Space Standard Normal Vector (SSNV)

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Abstract —In this paper a low cost but effective localization algorithm for wireless sensor networks (WSNs) is introduced. From the proposed scheme unknown nodes only have to listen to three anchor nodes and establish a space standard normal vector (SSNV) to estimate the coordinates of them. Many localization algorithms for WSNs require the exits of extra components, such as a GPS, ultrasonic transceiver, and unidirectional antenna on sensor nodes. Conversely the proposed localization scheme is range-free which means there is no demanding of any extra devices for the sensors. In this scheme, by collecting information from the three nearest anchors a geometric plane surface is built whose standard normal vector is also obtained correspondingly. The estimated location of each unknown sensor is adjusted according to its relative normal vector in the space which belongs to the built plane surface. This paper compares the proposed scheme with the well-known DV-Hop mechanism, Centroid method and the OSSDL algorithm that we proposed before. Simulation results show that the proposed scheme outperforms the other three in localization accuracy, communication cost, and computational complexity. Analysis about the effects of different length of normal vector is also made.

Index Terms—WSNs, Localization algorithm, normal vector, SSNV

I. Introduction

Wireless sensor networks (WSNs) have gained a worldwide attention during recent years. An integrated typical wireless sensor network (WSN) consists of large number of spatially distributed autonomous sensors that cooperatively monitor a deployed region for physical or environmental parameter changes, such as temperature, sound, vibration, pressure, motion, and pollutant.

With the development of recent advances in micro electro mechanical systems (MEMSs) technology, the manufacturing of small and energy efficient sensors has become technically and economically feasible. A sensor node can sense, measure, and gather information from the environment and also based on some local decision process, transmit the sensed data to sinks (or base stations) through a wireless channel by multi-hops.

The transmission power consumed by a wireless radio is proportional to the distance squared or even a higher order in the presence of obstacles. Thus, multi-hop routing is usually considered for sending collected data to the sink instead of direct communication. Most WSN routing algorithms require the position information of sensor nodes. However, for some hazardous sensing environments, it is difficult to deploy the sensor nodes to the required locations. Thus for environments in which it is difficult to plan the location of sensors in advance, localization techniques can be used to estimate sensor positions. The simplest and most common localization technique is to install a GPS receiver on each sensor in the sensor networks. The price of GPS is, however, a so expensive solution in terms of cost, size, and power consumption that it is not suitable for ad hoc wireless sensor networks with limited hardware and energy resources. Although the cost of GPS receivers is falling, they are still too costly, in price and energy consumption, to install in a sensor network.

There are many localization algorithms for WSNs have been proposed [1], [2]. Most of these methods take use of a part of nodes with prior knowledge of their absolute physical positions called anchor nodes, and inter-sensor measurements, to obtain the practical location of nodes with unknown position information called unknown nodes. All these methods can be mainly classified as range-based algorithm and range-free algorithm. The former approaches compute the node position fully based on distance or angular information acquired by using the Time of Arrival (TOA), Angle of Arrival (AOA), Time Difference of Arrival (TDOA), or Received Signal Strength Indicator (RSSI) techniques [3], [4], whose localization accuracy is high but call for more expensive hardware consumption and the whole spending of the network is very high. The latter mainly explores the local network topology and the coordinate computation is derived from the locations of the surrounding anchor node position coordinate information [5], [6]. Their accuracy can reach an accepted level with less consumption compared with the actual localization space in some algorithms [7], [8].

This paper proposes a low cost but effective localization algorithm for wireless sensor networks. From the proposed scheme unknown nodes only have to listen

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to three anchor nodes and use a space standard normal vector (SSNV) to estimate the coordinates of them. This study also compares the performance of the proposed scheme with the DV-Hop [9], Centroid [10] and the OSSDL [11] algorithms to show its superiority.

The rest of this paper is organized as follows. Section 2 reviews related research on WSN localization algorithms especially the three classic algorithms mentioned in this section. Section 3 gives the real algorithm description and the realization progress in detail. Section 4 provides a simulation of the proposed localization scheme and a comparison of its performance with the other three. Finally, Section 5 offers a conclusion.

II. Related Work

Range-based localization may produce fine-grained accuracy but places strict requirements on signal measurements and time synchronization which leads to be unsuitable for being used in WSNs. So we focus on those algorithms based on rang-free methods which are also a hot research area.

The range-free algorithm can be further divided into two categories: local techniques and hop-counting techniques [12]. In the local techniques, a node with unknown coordinates collects the position information of its neighbor beacon nodes with known coordinates to estimate its own coordinate to which Centroid algorithm belongs. A hop-counting technique, called DV-Hop method, was proposed by Niculescu and Nath in [9]. It computes the coordinates of unknown nodes by hop counts and hop distance between unknowns and anchors. In this way the proposed OSSDL algorithm [11] is this kind of localization theory.

In the simple Centroid algorithm proposed in [10], each sensor estimates its position as the centroid of the locations of some neighboring beacons which leads to be unsuitable for the environment with low anchor node density. But it has high localization efficiency because of its simplicity. A density-adaptive algorithm can reduce the number of computation errors if beacons are well positioned [13].

In the DV-Hop method in [9], each unknown node asks its neighboring beacon nodes to provide their estimated hop sizes and then attempts to obtain the smallest hop count to its neighbor beacon nodes using the designated routing protocol. Each unknown node estimates the distances to its neighbor beacon nodes by the hop counts to them and the hop size of the closest beacon node. The unknown nodes then apply tri-lateration to estimate their position based on the estimated distances to three suitable neighbor beacon nodes.

In the 3D-OSSDL algorithm proposed in [11], all nodes are randomly deployed in space and forms arbitrary network parameters. The algorithm is based on an analysis of hop progress in a WSN with randomly deployed sensors and arbitrary node density. By optimizing distances from the network model, the optimum space step distance from nodes to anchors is obtained regarding wireless network parameters and the coordinates of all unknown nodes are derived finally by triangle law.

As analyzed above the proposed method (SSNV) is classified as a range-free and local technique. It requires no distance or angle measurements among nodes. And SSNV method explores the local network topology and the coordinate computation is derived from the locations of the surrounding anchor node position coordinate information with low energy consumption. The total realization of SSNV will be given in the next part.

III. Localization Algorithm using Space Standard Normal Vector

This section presents the proposed localization scheme in detail to realize estimation of the accurate location of unknown sensors in WSNs.

The basic communication protocol used in SSNV algorithm is flooding, which is a simple but very effective mechanism for sending messages between anchors and other sensor nodes. Flooding guarantees that information packages from anchors can reach any target node as long as the network is connective. In this scheme, the flooding mechanism serves as the initial routing step to find out nearest three anchors for each unknown nodes.

A. Network Model and Normal Vector Acquirement

When a WSN is randomly deployed, we cannot assume any regularity in spacing or pattern of the sensors. This is due to the fact that most WSN deployments are performed through low flying airplanes or unmanned ground vehicles. However, anchors (beacon nodes) can be generally arranged in a certain amount across the network so as to help in estimating sensors' positions [14]. The amount of anchors cannot be too high for the character of WSN.

In this way there are two kinds of sensor nodes in network. One is unknown node that is needed to be realized and the other is anchor node with known position information. They are randomly deployed in sensing space and sensing space is set as a cube with a certain value as its side length. Also the portion of these two can be altered manually. The core idea of this SSNV is to obtain a space standard normal vector from a geometric plane surface formed by three nearest anchors. The estimated location of each unknown sensor is adjusted according to its relative normal vector in the space which belongs to the built plane surface. By using this plane surface space standard normal vector can be computed accurately in the expression of the fixed plane.

As shown in Fig.1 there are five points which are seen as sensor nodes in WSN which are node A, B, C, D and E. Especially B, C and D are anchors with accurate nodes coordinates (x_B, y_B, z_B), (x_C, y_C, z_C) and (x_D, y_D, z_D) respectively. In this way three nodes (namely B, C, D) can form a plane as shown in Fig.1. By using three anchors' coordinates the plane expression can be computed as following equation.

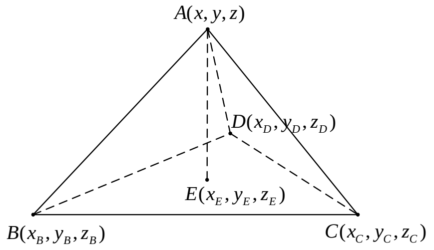

Fig. 1 Derivation of normal vector

$$ax + by + cz + d = 0 \tag{1}$$

Obviously in equation (1) vector (a, b, c) is the normal vector of plane BCD. And also the value of the three could be solved by substituting (x, y, z) with the coordinates of node B, C and D. Point E is the center of BCD and its coordinate can be expressed as follows.

$$E\left(\frac{x_B + x_C + x_D}{3}, \frac{y_B + y_C + y_D}{3}, \frac{z_B + z_C + z_D}{3}\right) \tag{2}$$

So a normal vector can be made by passing point E called vector α and this vector can be expressed as $\alpha(a, b, c)$ (here a, b, c are known) from equation (1). Once the length of this vector is fixed then node A is set as estimated unknown node position. The main point is how to compute the coordinate of node A. From the analysis above we can get following:

$$\frac{x - x_E}{a} = \frac{y - y_E}{b} = \frac{z - z_E}{c} = t \tag{3}$$

Further rearrange equation (3) and then following equation is obtained in which (x_e, y_e, z_e) can also be computed by equation (2).

$$\begin{cases} x = x_E + at \\ y = y_E + bt \\ z = z_E + ct \end{cases} \tag{4}$$

We use d_{AE} to denote the Euclidean distance between estimated unknown node A and center E of plane BCD, namely the length of space standard normal vector. Here d_{AE} is seen as a known quantity and its value will be given behind. Also it can be expressed as following.

$$d_{AE}^2 = (x - x_E)^2 + (y - y_E)^2 + (z - z_E)^2 \tag{5}$$

Put equation (4) into (5) and get the abbreviation formation as equation (6).

$$(a^2 + b^2 + c^2)t^2 = d_{AE}^2 \tag{6}$$

Rearrange the equation above and can get the value of the variable t in the following.

$$t = \pm\sqrt{\frac{d_{AE}^2}{(a^2 + b^2 + c^2)}} \tag{7}$$

So once Euclidean distance length of AE is fixed the value of t is obtained. Then put its value into equation (4) and finally the coordinates of unknown nodes can be computed using equation (8). But there is problem that is how to determine the sign of variable t. Here for convenience we choose its sign randomly.

$$\begin{cases} x = x_e \pm a\sqrt{\dfrac{d_{AE}^2}{(a^2 + b^2 + c^2)}} \\ y = y_e \pm b\sqrt{\dfrac{d_{AE}^2}{(a^2 + b^2 + c^2)}} \\ z = z_e \pm c\sqrt{\dfrac{d_{AE}^2}{(a^2 + b^2 + c^2)}} \end{cases} \tag{8}$$

Above all from equation (8), estimated position of unknown node in WSN can be finally obtained.

B. Feasibility Analysis

In this part we will talk about the feasibility of proposed SSNV scheme. As shown in Fig. 2 A_1, A_2, and A_3 are three anchors respectively that are nearest to the unknown node U. And S is a plane formed by the three anchor nodes. Vector $\overrightarrow{UC}$ is the normal vector of plane S which put unknown node U as one of endpoints.

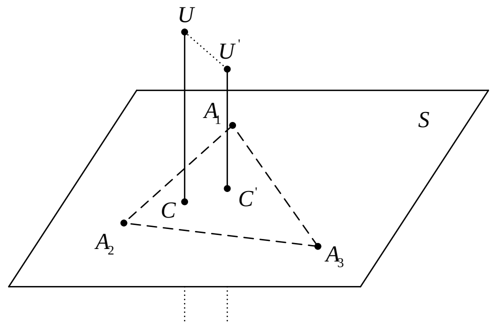

Fig. 2 Feasibility analysis of SSNV

We aim to find a node U' to be as the estimated position of unknown node U. First the center of $\triangle A_1A_2A_3$ is found on plane S based on the coordinates of the three nodes themselves which is indicated as C' in Fig. 2 by using equation (2). If the coordinates of three anchors are given, the normal vector $\overrightarrow{U'C'}$ can also be obtained. Obviously $\overrightarrow{UC}$ and $\overrightarrow{U'C'}$ are parallel. In this way once the length $U'C'$ is given we can derive the coordinates of U' which is to be seen as position of unknown node U. Because in most situations projection of U on plane S is not C' as well as uncertainty of length of $U'C'$ there are difference between the estimated position and its real coordinates which introduces localization error. But we can still put $U^{'}$ as the true estimated position of unknown node U.

From analysis above we can conclude that if three nearest anchor nodes' information can be received by any unknown node it can finish the localization progress and determines its estimated position. Also its localization accuracy is decided by the length of $CC^{'}$ and $U^{'}C^{'}$. Concrete realization progress of SSNV is presented in the next part.

C. SSNV Localization Scheme

In the proposed localization scheme, called space standard normal vector based localization scheme (SSNV) all sensor nodes are deployed randomly which simulates the real application environment. They are assumed to be homogeneous and also the network is connective.

The SSNV consists of three major steps: compute center node coordinates namely node E in Fig. 1, derive normal vector α and mean distance between three nearest anchors, and finally estimate the position information for each unknown node.

Step 1 (Compute center node coordinates namely node E in Fig. 1). First anchor nodes flood their information packages to the whole network which include ID and accurate position coordinate of each anchor. For those unknown nodes they only have to listen to these packages and we assume that once packages enter communication range then can be recognized by unknown sensors. After three anchors are recorded unknown nodes begin to compute the center E of them in Fig. 1 by using equation (2). As assumptions before the information packages are spread from node to node in the network as multi-hops. In this way the first three anchors whose information packages arrive to unknown nodes as early as possible are seen as the nearest. In ideal channel and network environment this assumptions are feasible.

Step 2 (Derive normal vector α and mean distance between three nearest anchors). When three anchors' coordinates are stored for one unknown node this node will compute average distance that is indicated as $\bar{d}$ between them by using following equation.

$$\frac{1}{3}\sum_{i=1}^{2}\sum_{j=i+1}^{3}\sqrt{(x_i-x_j)^2+(y_i-y_j)^2+(z_i-z_j)^2} \qquad (9)$$

In equation (9) (x_i, y_i, z_i) $(i=1,2,3)$ is the coordinates of three anchors.

Correspondingly by using their accurate coordinates the space standard normal vector $\alpha(a,b,c)$ can be formulated by solving the following equations.

$$\begin{bmatrix} x_1-x_2 & y_1-y_2 & z_1-z_2 \\ x_1-x_3 & y_1-y_3 & z_1-z_3 \\ x_2-x_3 & y_2-y_3 & z_2-z_3 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix}=\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \qquad (10)$$

(x_i, y_i, z_i) $(i=1,2,3)$ is also the coordinates of three anchors.

Step 3 (Estimate position information for each unknown node). When *Step1* and *Step 2* are finished normal vector $\alpha(a,b,c)$ and average distance $\bar{d}$ of three anchors are obtained. As to be listed in equation (7) there is still an unknown parameter d_{AE}. Here we make following settings, $d_{AE}=\frac{1}{2}\bar{d}$. The sign of t is determined randomly.

In this way combining equation (7), (2) and (4) the estimated position of unknown node can be finally computed. The whole flowchart of SSNV scheme is given in Fig. 3.

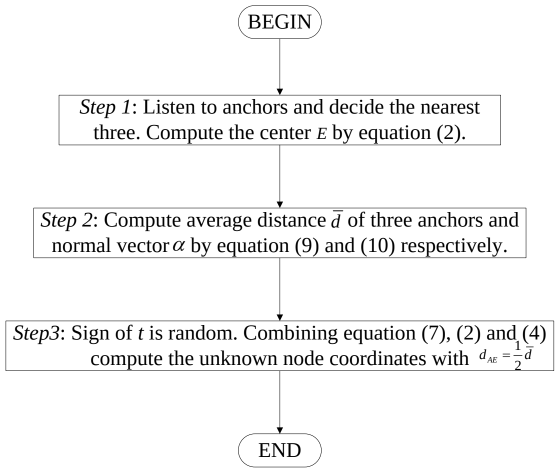

Fig. 3 Flowchart of SSNV scheme

Simulation results and performance analysis will be given in the next part.

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

This section compares the three algorithms, namely DV-Hop, Centroid and OSSDL. We simulate the three methods separately in MATLAB software and compare their localization performance, including the location error and localization time. The location error and localization time appeared are as follows.

$$\begin{aligned} &Error=\sqrt{(x^{'}-x)^2+(y^{'}-y)^2+(z^{'}-z)^2} \\ &Localization\ \ Time=\sum_{i=1}^{N}t_i \end{aligned} \qquad (11)$$

In equation (11) $(x^{'}, y^{'}, z^{'})$ and (x,y,z) are estimated and true location of unknown node respectively. t_i is localization time of each node and N is the total number of unknown nodes.

A. Accuracy Analysis of SSNV

We made simulations under the simulation model which is designed as follows.

- Monitoring space is set as a cube with boundary length as $100m$ with the volume $100\times100\times100m^3$.
- All sensors including anchors and unknowns are deployed randomly in the monitoring space.

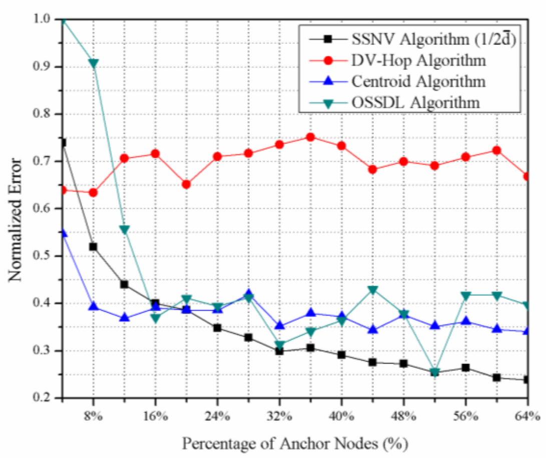

Fig. 4. Performance comparisons with space standard normal vector length as $1/2\bar{d}$

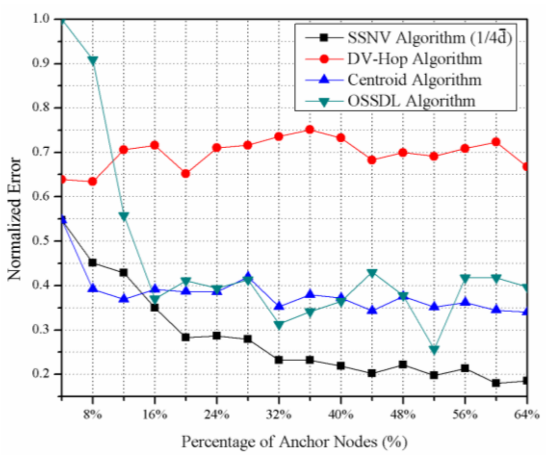

Fig. 5 Performance comparisons with SSNV's space standard normal vector length as $1/4\bar{d}$

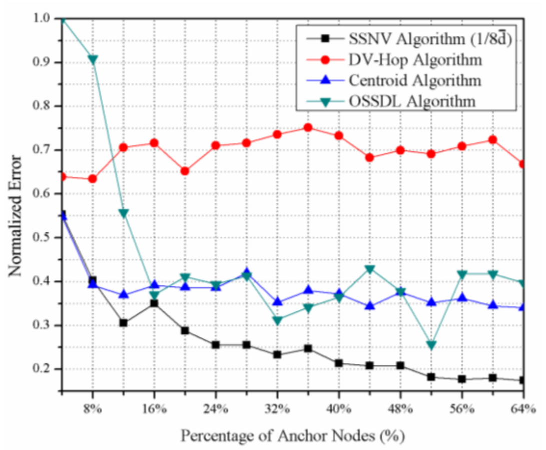

Fig. 6 Performance comparisons with SSNV's space standard normal vector length as $1/8\bar{d}$

- 250 sensor nodes in all are deployed in the monitoring space and percentage of anchors is altered manually from 4%-64%.
- No communication range is taken into account because there is no use of it in SSNV scheme.

As listed in flowchart of SSNV scheme (Fig. 3) the length of normal vector $\overrightarrow{AE}$ is $1/2\bar{d}$. So under this condition Fig. 4 gives accuracy comparisons (normalized error) of DV-Hop, Centroid, OSSDL and SSNV with different percentages of anchor nodes under the same network parameter settings. Obviously all these are in a downtrend except DV-hop which stays at a high level. DV-Hop is the worst of the four with lowest accuracy as the percentage of anchors increasing. Localization error of OSSDL is high at the beginning but it decreases suddenly as anchors increases to 16%. Still it holds on a stable level and much smaller than DV-Hop. Centroid is more or less the same with OSSDL. The only difference is that it is smaller than OSSDL when percentage is under 12%. In some situations OSSDL is better than Centroid.

There is no doubt SSNV scheme is the best when anchors are more than 18%. Not only it has the best accuracy but also it is the steadies without any jump points. It is 29%, 38% and 63% better on location accuracy compared with Centroid, OSSDL and DV-Hop respectively in the best situation. Even in some bad conditions SSNV is more or less the same with DV-Hop and Centroid. But the error is relatively low. Also there is no need of high percentage of anchors (18% is enough) in the network that can be concluded from the figures.

In order to explore algorithm performances when the length of normal vector $\overrightarrow{AE}$ changes into difference values we set it as $1/4\bar{d}$ and $1/8\bar{d}$ further as shown in Fig. 5 and Fig. 6.

As shown in Fig. 5 and Fig. 6 the length of normal vector in SSNV scheme is changed to $1/4\bar{d}$ and $1/8\bar{d}$ respectively without any changes in other parameters and compared with the same three algorithms. In the figures above no matter how the length is changed SSNV scheme both show superiority than the other three. It presents the same property as in Fig. 4. Especially in Fig. 6 namely the length of normal vector in SSNV scheme is decreased to $1/8\bar{d}$, SSNV becomes the best on the accuracy regardless of the percentage of anchors in the network. From the two figures we can conclude the SSNV is stable and still is the best compared with the three.

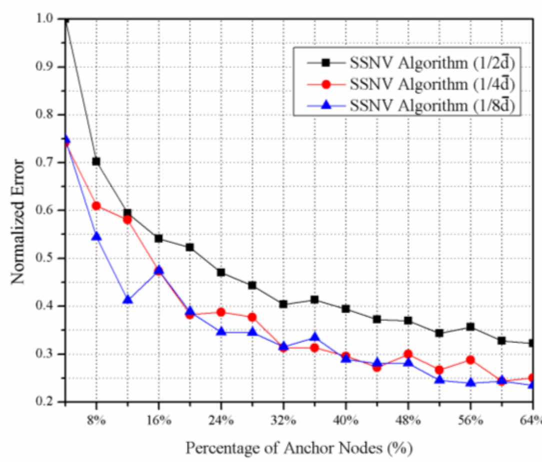

Fig. 7. Performance comparisons under different space standard normal vector length

Further to investigate the effects of the changed length $d_{\overrightarrow{AE}}$ we give Fig. 7.

As listed in Fig. 7 the space standard normal vector length is set as different values. It's easy to find the three possess the same character and trend. Actually as the length is getting smaller the normalized localization error is becoming smaller, too. When it is set at $1/2\overline{d}$ it has the highest location error. The two are more or less the same when the length is set as $1/4\overline{d}$ and $1/8\overline{d}$. So from the curves we can define that the smaller of normal vector length, the better accuracy of SSNV scheme. There will be fewer differences when the length is decreased to some extent. The best improvement can nearly reach 29% between them.

B. Localization Efficiency Comparisons

Here we compare the localization time of the three when the space standard normal vector length is set at $1/2\overline{d}$ to discover the localization efficiency and energy consumption of the three. Localization time can stand for the efficiency. Of cause little time needed means high executing efficiency and low energy depletion. And the computational method has been given in equation (11). Fig. 8 gives the simulation results.

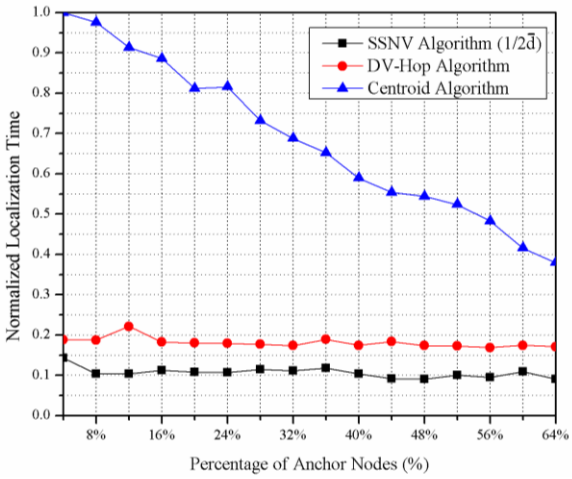

Fig. 8. Analysis of efficiency of different algorithms

Centroid algorithm changes the most fiercely and presents linear decrease when percentage of anchors increases. But the least time it cost is still the most in Fig. 8. DV-Hop and SSNV stays horizontal and both of them have little time consumption compared with Centroid. However SSNV is also better than DV-hop in the localization efficiency. It needs least time of them. All in all SSNV is 56% and 85% better compared with DV-Hop and Centroid respectively at most. So SSNV has the least time consumption which leads to the best localization efficiency which could prolong the lifetime of the whole network.

There is no complicated calculation in this algorithm except simple space vector transform as introduced in Section III. No accurate distance information is needed between anchors and unknowns which results in no range error accumulation. Only three anchor information packages will be marked and saved. Some special center coordinates will be used in the whole algorithm. So SSNV algorithm gets better localization accuracy compared with DV-Hop, Centroid and OSSDL algorithms and better localization efficiency. Simulation results also improve the analysis above.

V. Conclusions

Many studies have attempted to solve the range-free localization problems of WSNs. Most of them demand high percentage of anchors and use the multi-lateration method, which requires complex computation, high energy consumption and a variable number of iterations to estimate the location of sensors. In this paper a low cost but effective localization algorithm for wireless sensor networks (WSNs) is introduced. From the proposed scheme unknown nodes only have to listen to three anchor nodes and establish a space standard normal vector (SSNV) to estimate the coordinates of them. Also this paper compares the proposed scheme with the well-known DV-Hop mechanism, Centroid method and the OSSDL algorithm that we proposed before. From the simulation results we can find that there is no doubt SSNV scheme is the best when anchors are more than 18%. Not only it has the best accuracy but also it is the steadies without any jump points. It is 29%, 38% and 63% better on location accuracy compared with Centroid, OSSDL and DV-Hop respectively in the best situation. In localization efficiency SSNV is 25% and 85% better compared with DV-Hop and Centroid respectively at most. SSNV can get well localization accuracy at 18%.

References

[1] G. Mao, B. Fidan, and B. D. O. Anderson, “Wireless sensor network localization techniques,” *Computer Networks*, vol. 51, pp. 2529-2553, 2007.

[2] S. Gezici, “A survey on wireless position estimation,” *Wireless Personal Communications*, vol. 44, pp. 263-282, 2008.

[3] S. G. Zhang, J. N. Cao, Y. P. Zeng, Z. Li, L. J. Chen, and D. X. Chen, “On accuracy of region based localization algorithms for wireless sensor networks,” *Computer Communications*, vol. 33, no. 12, pp. 1391-1403. 2010.

[4] L. Wang and D. H. Fan, “RSSI-based node location algorithm for WSN,” *COAL TECHNOLOGY*, vol. 29, no. 9, pp. 233-238, 2010.

[5] F. K. W. Chan and H. C. So, “Efficient weighted multi-dimensional scaling for wireless sensor network localization,” *IEEE Transactions on Signal Processing*, vol. 57, no. 11, pp. 4548-4553, 2009.

[6] J. A. Costa, N. Patwari, and A. O. Hero, “Distributed weighted multidimensional scaling for node localization in sensor networks,” *ACM Transactions on Sensor Networks*, vol. 2, no. 1, pp. 39-64, 2006.

[7] S. Srirangarajan, A. H. Tewfik, and Z. Q. Luo, “Distributed sensor network localization using SOCP relaxation,” *IEEE Transactions on Wireless Communications*, vol. 7, no. 12, pp. 4886-4895, 2008.

[8] A. Boukerche, H. Oliveira, E. Nakamura, and A. Loureiro, “DV-Loc: A scalable localization protocol using Voronoi diagrams for

wireless sensor networks," *IEEE Wireless Communications*, vol. 16, no. 2, pp. 50-55, 2009.

[9] D. Niculescu and B. Nath, "Ad hoc positioning system (APS)," in *Proc. IEEE Global Telecommunications Conference*, San Antonio, 2001, pp. 2926-2931.

[10] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less low-cost outdoor localization for very small devices," *IEEE Personal Communications*, vol. 7, no. 5, pp. 28-34, 2000.

[11] Y. Liu, J. P. Xing, and R. Wang, "3D-OSSDL: Three dimensional optimum space step distance localization scheme in stereo wireless sensor networks," *Advances in Intelligent and Soft Computing*, vol. 112, pp. 17-25, 2011.

[12] F. Liu, X. Cheng, D. Hua, and D. Chen, "TPSS: A time-based positioning scheme for sensor networks with short range beacons," in *Proc. Wireless Sensor Networks and Applications*, New York, 2008, pp. 175-193.

[13] N. Bulusu, J. Heidemann, and D. Estrin, "Adaptive beacon placement," in *Proc. 21st IEEE International Conference on Distributed Computing System*, Mesa, 2001, pp. 489-498.

[14] Y. Wang, X. Wang, B. Xie, D. Wang, and D. P. Agrawal, "Intrusion detection in homogenous and heterogeneous wireless sensor networks," *IEEE Trans. Mobile Computing*, vol. 7, no. 6, pp. 225-229, 2008.

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