3D Node Localization Scheme Used in Wireless Sensor Networks with Random Communication Range*

*LIU Yang, XING Jianping**
(*School of Information Science and Engineering, Shandong University, Jinan* 250100, *China*)

Abstract: In wireless sensor networks (WSNs), node communication range is a critical parameter for localization. By this parameter nodes can generate the whole network connectivity. In most localization algorithms, it is usually set as a fixed value for convenience. But this hypothesis is often contradictory with the actual situations. Usually the communication range of each node is difficult to control. It can be influenced by many factors, such as obstacles in the sensing fields, node hardware design, and power consumption. The special situation is taken into account. The optimum space step distance derivation and optimum anchor selection mechanism is introduced. And in order to imitate the real environment, each node is assumed to be a random communication range between 20m and 90m in a 3D field. Finally from the simulation results, we can find the proposed scheme is well suitable for WSNs with random communication range.

Key words: WSNs; random communication rang; optimum space step distance; anchor selection
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随机通信半径下无线传感器网络中三维节点定位算法*

刘　洋, 邢建平*
(山东大学信息科学与工程学院, 济南 250100)

摘　要: 在无线传感器网络三维节点定位问题中, 节点通信半径是一个关键参数, 通过这个参数, 节点建立整个网络的连接度, 以实现自身定位。大多数的定位算法中, 这个参数通常被设定为一个常数, 但这种假设有悖于事实, 一般情况下这个参数很难控制, 它受到很多因素的影响, 比如检测区域中的障碍物阻隔, 节点硬件设计的限制以及功率控制等。正是考虑到了这个特殊的问题, 介绍了一种最优空间跳跃距离获取以及最优锚节点选择机制, 而为了更好的模拟真实环境中的多变情况, 每一个节点的通信半径都被设置为 20 m 至 90 m 之间的一个随机值。在最后, 通过仿真结果, 验证了文中提出的三维节点定位算法非常适合无线传感器网络中节点拥有随机半径的问题。

关键词: 无线传感器网络; 随机通信半径; 最优空间跳跃距离; 锚节点选择
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There has been an increase in the use of wireless sensor networks (WSNs) for intrusion detection, traffic management, space exploration, environmental monitoring and disaster rescue[1]. Typical wireless sensor networks are composed of a large of sensor nodes that collect data and communicate with each other. The collected data will be useless if the node position is unknown. And sometimes lots of special applications are supposed to know node position, such as routing protocols[2] and information dissemination protocols[3]. So position aware is essential in WSNs.

Recently a large number of localization algorithms[4-7] have been proposed. All these algorithms are mainly divided in to two categories. One is range-based and the other is rang-free. The range-based algorithms determine the node position fully based on distance or angular information acquired using the Time of Arrival (TOA), Angle of Arrival (AOA), Time Difference of Arrival (TDOA), or Received Signal Strength Indicator (RSSI) techniques[8-9]. Although these algorithms have high localization accuracy, they require extra hardware and more power consumption and also vulnerable to en-

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vironmental issues, such as noise, temperature and humidity[10]. However range free localization schemes merely rely on the existence of radio connectivity to a neighbor instead of measuring distance or angle to that, which decrease the power consumption and hardware requirements. Range free schemes explore the local topology and the coordinate computation is derived from the locations of the surrounding anchor node positions. Of cause range-free localization accuracy is not as good as that of range-base algorithm.

Each of nodes in these algorithms is supposed to have the same communication range. However in some special situations this assumption cannot be achieved because of obstacles in the sensing fields, node hardware design restrictions, and power consumption. So some localization schemes that can resist influences of random communication range are much needed.

In this paper, a localization algorithm based on optimum space step distance derivation and optimum anchor selection mechanism that can resist influences of random communication range is introduced. Without loss of generality, the parameter of communication range is restricted between 20 m and 90 m in this paper. With the proposed algorithm, the localization error is improved obviously under the condition of random communication range and of cause worse than that of fixed value inevitably.

The remaining paper is organized as follows: Section 1 describes the classic DV-Hop propagation algorithm roughly. The optimum space step distance derivation and optimum anchor selection mechanism respectively, which derived from classic DV-Hop propagation algorithm are given in Section 2 and Section 3 gives the simulation evaluation. We make some conclusions in Section 4.

1 Analysis of DV-Hop

In this section DV-Hop is analyzed in general. Its core idea is to transform the average hop distance between anchor nodes to the distance from unknown nodes to anchor nodes by multiplying hop counts between them.

As Fig. 1 illustrates, A_1, A_2, A_3, and U are three anchor nodes and unknown node respectively in WSN. Based on DV-Hop algorithm, anchors flood their coordinate information. Then each node listens and records the information and corresponding hop counts. First anchors compute the average distance per hop using following equations:

$$A_1:(30+70)/(6+2)=12.50(\text{m})$$
$$A_2:(30+50)/(2+5)=11.43(\text{m})$$
$$A_3:(50+70)/(5+6)=10.91(\text{m})$$

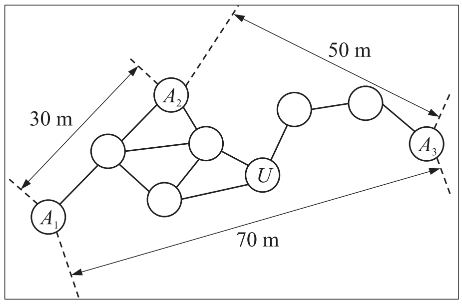

Fig. 1　DV-Hop localization algorithm

When the average hop distance is derived, the unknown nodes can realize self localizing by multiplying the hop count between anchors and themselves. As shown in Fig. 1, U is an unknown node. The algorithm begins once anchor A_1, A_2, and A_3 flood anchor information including coordinates, average hop distance, hop counts, and ID of each anchor. So using this information, node U gets the distances to three anchors respectively by following equations:

$$\text{To } A_1: 12.50\times3=37.50(\text{m})$$
$$\text{To } A_2: 11.43\times2=22.86(\text{m})$$
$$\text{To } A_3: 10.91\times3=32.73(\text{m})$$

That is average hop distance×hop counts.

Once the three distances is derived, unknown node U can compute its own coordinates itself by Triangulation Algorithm or Least Squares Method.

As said above we can find DV-Hop algorithm entirely depends on the connectivity of the whole network and the accumulation of measure errors also happen easily, which induces lots of localization error. And also there are overestimation and underestimation in DV-hop algorithm. Meanwhile communication range of each node is supposed to be a fixed value. If this parameter is set as an uncertain value, the connectivity is much harder to get, which means larger errors. So DV-Hop is restricted in the application fields and is not suitable for situations as we said in the parts before. Based on these drawbacks of DV-Hop and expand its applications under random communication range, the optimum space step distance derivation and optimum anchor selection mechanism are introduced in detail in next part.

2 Optimum Space Step Distance Derivation and Anchor Selection

In this part, we present the principles of the optimum step distance derivation and optimum anchor selection mechanism in detail. Also the reason that they can resist the effects of random communication range of each node is described in this part.

2.1 Derivation of 3D Optimum Step Distance

In a WSN with large number of sensor nodes, there may be a shortest multi-hop path between any two sensors. So by discharging one hop away from the source node, the accumulative distance is likely to be increased by one transmission range[11]. This is also the core idea of DV-Hop propagation algorithm. In this way we can compute the distance to use the equation $d=h\times r_0$. The 3D optimum space step distance is the products of optimizing the hop distance in DV-Hop. By this optimization, the error is reduced obviously.

In 3D condition, we should try to get this optimum space step distance denoted by $E(R)$ and the hop counts between anchor nodes and unknown nodes to use the equation before to obtain the node physical position. Imagine a sensor node S with random communication range r_0 so that all nodes in the sphere with S as its center are node S's neighbors which is shown in Fig. 2. As shown in Fig. 2, if a source node S is given, the optimum space step distance toward the destination D at each step is denoted as R_i which is a random variable. In this situation, we choose n_2 as the optimum step node for $R_1<R_2$. Through selecting the step node, one path from node S to node D could be constructed. Further in order to get relatively accurate distance measurement, one best way is to compute the average step distance for each unknown node in the sphere. In this way, the accumulative distance can be close to the true Euclidean distance between two nodes. So based on the analysis, in 3D space, we can derive an optimum space step distance $E(\mathrm{R})$ using the following equation:

$$E(R)=\frac{\int_0^{\theta}\int_0^{r_0} f_x(L)\,L\cos\alpha\,\mathrm{d}\alpha\,\mathrm{d}L}{\theta} \qquad (1)$$

Where

$$f_x(L)=\frac{\mathrm{d}}{\mathrm{d}L}(p(x\leqslant L))=$$

$$2\pi\lambda L^2(1-\cos\alpha)\,e^{-\frac{2}{3}\pi\lambda(1-\cos\alpha)(r_0^3-L^3)}\ (0<\alpha<\theta)$$

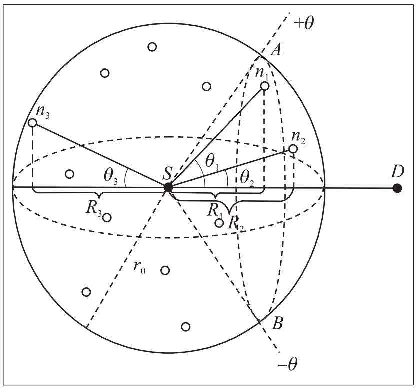

Fig. 2 Relationship of sensor nodes

denotes the probability density function of a sensor node locates in the sphere and θ means the angle between SD and the straight line of unknown node and node S. $E(R)$ is an average value. The right side of the equation indicates the integral of angles and distance divides angles. Once the optimum space step distance $E(R)$ of each node is obtained, position coordinates can be calculated.

2.2 Optimum Anchor Selection Mechanism

A selective anchor node localization algorithm has been proposed in Ref. [12]. As said above, once three distances to three different anchors is obtained, the unknown position can be computed. However, sometimes the three chosen distances may not be the most accurate which means the anchors are not the most suitable for unknown nodes to localize. Based on the potential problems we must select three optimum anchors which have accurate distance information. An optimum anchor selection mechanism is used in this algorithm as illustrated in the Fig. 3.

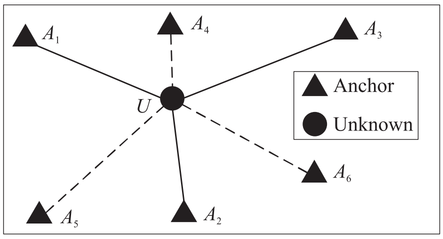

Fig. 3 Optimum anchor selection mechanism

As shown in Fig. 3, U is an unknown node and $A_i(i=1,2,3,4,5,6)$ is anchor node with known position. U is supposed to calculate its own coordinates using A_1, A_2 and A_3. First U derives the optimum step distance to A_1, A_2 and A_3 respectively as described in the last part. Then U can obtain its position by using triangulation algorithm. After that A_1 is set as unknown node and its position will be obtained by using triangulation algorithm three times which U, A_2 and A_3 are reference nodes. Then save the error between the computed value and the real position with the following equation.

$$\text{Error1} = \sqrt{(x_r - x)^2 + (y_r - y)^2 + (z_r - z)^2} \qquad (2)$$

where (x_r, y_r, z_r) is the real position of anchor node in the sensor network.

Similarly, all anchor nodes can be computed for a relative value and get an errori. Finally choose three anchors that hold the least errors as the optimum anchors in the 3D space.

By the method above, three optimum anchors can be found out as reference nodes. The coordinates computed with these anchors have the least error in theory and the final simulation proves this hypothesis. Also optimum step distance derivation and optimum anchor selection mechanism can effectively minish the influences of random communication range.

3 Simulation Evalulation

The simulation is completed in the MATLAB soft-ware and some assumptions are made first in the following:

① The node communication range is a random variable and it is supposed to be varied between 20m and 90m.

② The whole sensor network is made up of 250 nodes and the 3D sensing area is 100 m × 100 m × 100 m, namely side length is 100 m.

③ The main performance indexes of the algorithm are average localization error and standard deviation.

In this paper, each situation is simulated for ten times for better evaluation. As shown in the following Fig. 4, DV-Hop and proposed method are both simulated under random communication range. The proposed method presents a downward trend which is opposite to DV-Hop which means it is much far better than DV-Hop. And the largest different value is nearly 25 m. Meanwhile the standard deviations of the two are similar and hold at a small level. That is to say the two are more or less the same at the stability.

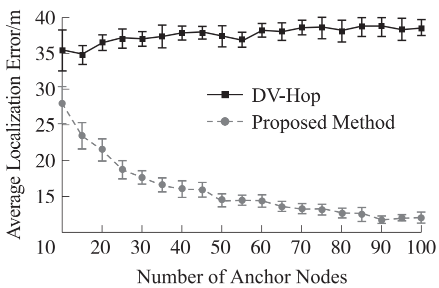

Fig. 4　Comparisons of DV-Hop and proposed method under the condition of random communication range

We also use this method at the condition of fixed communication range and comparisons are given. In Fig. 5, the proposed method is used at the similar condition. One scene has random communication rang but the other has the fixed communication range 30m.

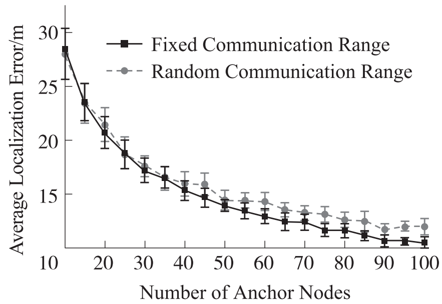

Fig. 5　Communication range is fixed at 30 m

From Fig. 5 we can find the two curves both present downward trend with the increasing of anchor nodes. When the number of anchor nodes is larger than 40, the performance that has random communication range is worse than that has fixed value. This is because random communication brings more uncertain connectivity. But the differences between the two are relative small. That is to say the performance of proposed method under the condition of random communication range does not decrease much at all and is much suitable for random commutation range condition. Similarly we also compare them with R = 50m and 70m as given respectively in Fig. 6 and Fig. 7.

The situation is more or less with that we analyzed above. They all present a downward trend. And when the number of anchor nodes is larger than a special value, the scene with random communication range is worse than that with fixed value as before. But all results are very near. In some special situations the

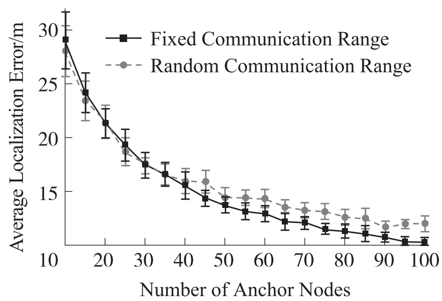

Fig. 6　Communication range is fixed at 50 m

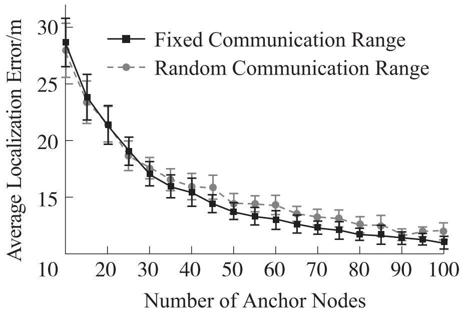

Fig. 7 Communication range is fixed at 70 m

scene with random communication range is better than that with fixed communication range.

From the curves we can find that the proposed method is well suited for the random communication range and can resist the most influences of random communication range.

4 Conclusions

In this paper, the special situation in WSN that each sensor node is supposed to have random communication range is taken into account. The optimum space step distance derivation and optimum anchor selection mechanism is introduced in detail. By simulations in MATLAB software, the proposed method works well under the special situation said above. Moreover from the curves in the figures the performances do not decrease very much as inducing random communication range. It is just a little worse when the number of anchor nodes increase to a certain value. Of cause there is much work to do in the future. The main research focus is how to improve the localization accuracy further under the random communication range condition.

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LIU Yang, male, born in March 1987, received his BE degree in Electronic Information Engineering from Shandong Jiaotong University, China in 2009. He is currently a ME candidate at Shandong university, China. His research interests include wireless sensor networks, localization algorithms and intelligent transportation systems;

XING Jianping, male, born in July 1969 and received the B.S. degree in mathematics from the Shandong University, Jinan, China, in 1992, the M.Sc. degree in control engineering from Shandong University, China, in 1995, and the Ph.D. degree in transport information engineering and control from Beihang University, Beijing, China, in 2009. From 1995 to 2001, he worked as a Senior Engineer at the LUKE Communication Technological Company, he is charge of electric and electronis experiment center as vice dean. His interests include satellite navination, wireless data communication, ITS network information transmission, sensor network and signal processing.