Acta Technica 62 (2017), No. 6A, 59–68

A New Localization algorithm in Wireless Sensor Networks Based on Range-free

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Abstract. Wireless sensor networks are a new multi-disciplinary overlapping research field emerging with constantly developing sensor technology, wireless communication technology, information processing technology and varying social demands. Node localization technology which is one of key supporting technologies of wireless sensor network has become a hot issue in wireless sensor networks. There are many different localization algorithms proposed in the literature. Due to the cost and limitation of hardware on sensing nodes, range-free localization schemes are considered more practical. In this thesis, we propose a new localization algorithm with range-free, namely SHR Correction Scheme. Then we build a simulating environment in which we simulate the algorithm proposed in this thesis. By comparing the results of the proposed algorithm and the other range-free distance estimation and localization methods, This new algorithm reduces the range estimation and localization error significantly, reveals the advantage of the algotithm,especially when the number of anchors is low.

Key words. Wireless Sensor Networks, Location Technology, Range-free, SHR.

1. Introduction

Wireless Sensor Network (WSN) is an emerging technology which combines sensor technology, communication technology, micro-electromechanical systems technology and computer technology [1]. It is a low-power, low cost, large-scale wireless network, randomly distributed in the monitored area, forming a self-organizing network that can capture, perceive the data of environment object, and fusion the data, use multi-hop routing to send the data to observers. Location is the key technology

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in Wireless Sensor Networks, for the data collected by nodes without the location information would be meaningless [2]. Then in the wireless sensor network location field, there is no universal method, because some algorithms are of high precision, but the cost is relatively large; while some algorithm has low cost, but the location accuracy is low [3]. So it is depended on the environment and application needs to select the appropriate location algorithm [4].

The application of WSN has become wider and wider, most of which are location dependent. Localization algorithm can be divided into two basic types according to its positioning methods, one is range-based and the other is range-free [5]. Since the range-based localization algorithm is not accurate enough and has high requirements on energy consumption and hardware, it does not meet the requirements of the development of WSN [6].Since range-free assumes that a small part of the sensor nodes, which are called beacon nodes, are aware of their real coordinates, and other unknown nodes can estimate their position coordinates based on the beacon nodes as well as certain localization algorithm [7].

In distance estimation, we formulate this problem into two sub-problems: single hop range estimation and multi-hop range estimation. In single hop range estimation, we compute the average distance to the farthest neighboring node [8]. In multi-hop range estimation, we apply the correction scheme to obtain the multi-hop range from the summation of single hop range estimations [9].

There are three main points in this paper. First, we redefine the Single Hop Range (SHR) and propose a novel concept SHR Correction Scheme (SCS) to estimate the distance between a node and an anchor. Second, we apply SCS to three different localization schemes to examine the performance of these localization algorithms. Third, through extensive simulations, we demonstrate how sensible these three localization algorithms are to the accuracy of distance estimation. Our proposed scheme outperforms the other two well-known localization schemes, especially when the number of anchors is low.

2. A Brief Introduction to Localization Algorithms in WSNs

The localization in wireless sensor networks commonly can be separated into two different stages: range estimation and localization. In general, the range between nodes is first estimated, and then the localization of a node can be performed[10].In range-based schemes, certain techniques are applied to obtain the physical distance between each pair of nodes, such as ToA, TDoA, or RSS.In range-free schemes, a sensor network is composed of two different types of nodes: anchor nodes and normal nodes. Anchor nodes are assumed to be aware of their location through some localization service [11]. This location information is flooded throughout the network. A normal node maintains the number of hop counts to each anchor node.In order to convert hop counts into physical distances, a number of algorithms are proposed to calculate average single hop range. There are three the most well-known range-free localization schemes: Centroid, DV-hop and Amorphous [12].

3. A New Localization algorithm in WSNs Based on Range-free

To estimate the distance between two nodes, two issues need to be addressed. The first issue is single hop range estimation, and the second issue is multi-hop range estimation, which is built on top of the single hop range estimation.

3.1. SHR estimation

First, we redefine the single hop range as the longest distance between two neighboring nodes. When an anchor floods its beacon, each normal node will only retain the minimum hop count value. In other words, the hop count value of each node depends on the location of its farthest neighbor. Consequently, it is natural to regard SHR as the average distance of the farthest neighboring node.

Assuming that the number of neighbors of node A is n, and the communication radius of node A is r. The probability for the farthest neighboring node to be located within the narrow band apart from A by distance x is obtained by Equation 1. (see Figure. 1)

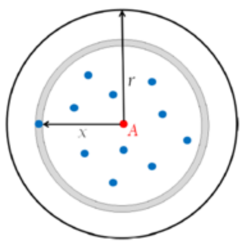

Fig. 1. The location of the farthest neighbor of node A

$$P(X) = \frac{2\pi x}{\pi r^2} dx, \tag{1}$$

The expected distance of the farthest neighboring node (i.e. SHR) can therefore be computed by Equation 2.

$$SHR = \int_0^r C_1^n \times x \times \left(\frac{2\pi x}{\pi x^2}\right) dx = \frac{2n}{2n+1} r. \tag{2}$$

Although we can accurately estimate SHR, we still cannot obtain a good approximation of the distance between two nodes a number of hops away from each other. This is due to the following two reasons.First, when an anchor floods its beacon to a normal node, on the routing path, it is not necessary that the farthest neighbor is chosen to relay the beacon. Second, a path is rarely straight unless the network density is extremely high. When a path is not straight, directly using SHR to estimate the distance between two nodes a number of hops away is not appropriate. After each node calculates its SHR by its local density, each anchor begins to flood its beacon. The beacon includes a SSHR (sum of SHR) field, which keeps track of the distance it has traversed. Each node learns its distance to each anchor when it receives the first beacon relayed from one of its neighbors. The node will increase the SHR field of the beacon by its local SHR value.

4. SHR correction scheme

When a beacon is flooded throughout the network, the relay node between the previous and next hop should be a common neighbor of them. In Figure. 2, node A and node B are two hops away and there are a number of common neighbors between them.

Let node X be the common neighbor of A and B whose distance to $\overline{AB}$ is the longest, the distance between node A and X seems to be close to SHR_A, and the distance between node B and X seems to be close to SHR_B. We can see that the real distance between A and B is shorter than SHR_A+SHR_B.In order to obtain a better estimation of $\overline{|AB|}$,the value of SHR_A+SHR_B need to be corrected. We first map Figure.2 into Figure.3.

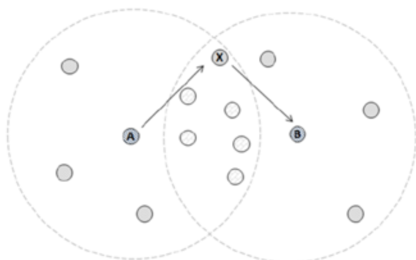

Fig. 2. The common neighbors of node A and B

In Figure.3 we denote the distance of node A and B as $\overline{|AB|}$, $C(i)$ be the communication range of node i, $\angle XAB = \alpha$, $\angle XBA = \beta$,and $\angle PAB = \theta$, where p is the intersection of $C(A)$ and $C(B)$. We can see that $\overline{|AB|}$, $C(i)$ is close $\text{SHR}_A \times \cos\alpha$+$\text{SHR}_B \times \cos\beta$. Since node X is the farthest common neighbor of node A and B, α, β are close to, hence $\overline{|AB|} \cong(\text{SHR}_A+\text{SHR}_B) \times \cos\theta$., Therefore, we can define the corrected SHR, to be SHR$\times \cos\theta$, where $\cos\theta$ is the correction parameter.

To approximate the $\cos\theta$, we can see that $\cos\theta$ has a relationship with the intersection area by Equation 3:

$$|C(A) \cap C(B)| = 2 \times (r^2 \cos^{-1}\theta - \frac{d}{4}\sqrt{4r^2 - d^2}), \tag{3}$$

Where r is the communication range of a node, d is the real distance between A and $B(d = \overline{|AB|})$. The size of intersection area can also be obtained by Equation 4:

$$|C(A) \cap C(B)| = \frac{n_{common}}{\rho}, \tag{4}$$

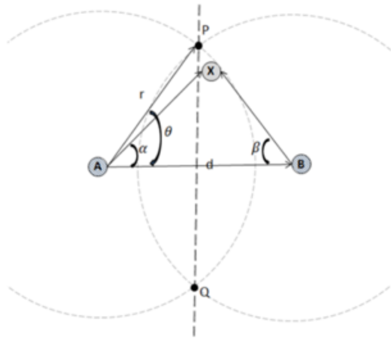

Fig. 3. The concept of the correction scheme

Where n_{common} is number of the common neighbors of node A and B, and ρ is the local density of node A and B. Note that ρ can be computed by Equation 5:

$$\rho = \frac{n_{sum} + 2}{2\pi r^2}, \tag{5}$$

where n_{sum} is the number of neighbors of node A or B. Therefore, we combine the Equation 3 and 4 and 5 into the Equation 6. By solving Equation 6, $d = \overline{|AB|}$ can be computed.

$$n_{common} = 2(r^2 \cos^{-1} \frac{fd}{2r} - \frac{d}{4}\sqrt{4r^2 - d^2}) \frac{n_{sum} + 2}{2\pi r^2}. \tag{6}$$

Figure. 4 shows an example that we can use d (estimate by Equation 6) to compute the distance between two normal node.

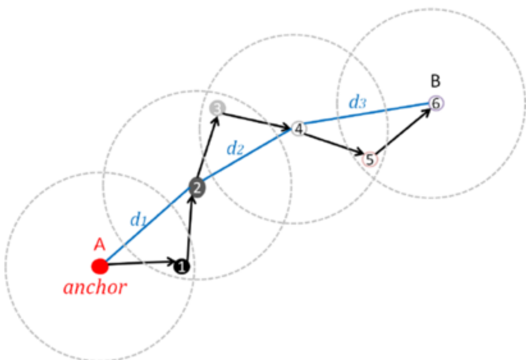

Fig. 4. The example of the correction scheme

In Figure. 4, the sum of d_1, d_2 and d_3 is close to the actual distance between anchor A and normal node B, and this sum is much shorter than the sum of individual SHR. We name this method the SHR Correction Scheme (SCS).In SCS, the estimation of the distance is done for every two hops. If there is one hop reaming, we will calculate SHR by the DV-hop. Obviously, the better estimation the distance is, the more accurate the localization can be achieved.

5. Simulation result analysis

In this section, we present the simulation results and the overhead analysis of different schemes. The scheme we consider include our SCS algorithm, DV-hop, and Amorphous. In the following, we introduce the configuration used in the simulation are presented. The network topology is generated by randomly placing nodes on a square field of side length 10 units. The communication range of each node is fixed at one unit distance. Two environment parameters are controlled in each simulation: 1) anchor percentage (AP) which is defined as the ratio of the number of anchors and the total number of nodes, and 2) node density (ND), which is the average number of neighbors. The performance of different schemes is evaluated by the estimation error, for each given configuration, the different topologies are generated and simulated, the average of estimation error is the average of the estimation errors of all normal nodes in 50 different topologies.

First, we analyze the effect of AP to the distance estimation error for different algorithms. In Figure.5 and 6, we can see our scheme has low estimation errors, when the percentage of anchors is low. Due to the cost and hardware limitations, it is difficult to deploy a large number of anchors in a sensor network. Consequently, these simulation results indicate that our scheme is more practical for sensor networks.

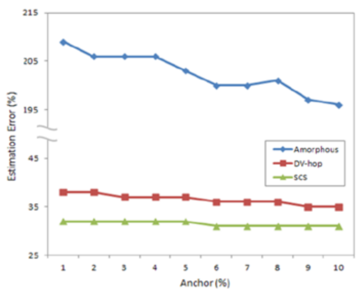

Fig. 5. The average distance estimation error with $ND = 10$

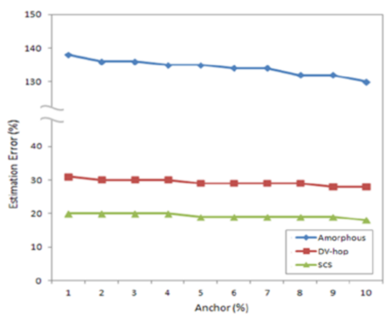

Fig. 6. The average distance estimation error with $ND = 20$

Second, we analyze the average distance estimation error versus ND for different algorithms. In Figure.7 and 8, we evaluate the average estimation error under different node density. When the node density is high, the average estimation error decreases. In a dense network, the multi-hop path is more likely to be straight and consequently can be estimated more accurately. However, regardless normal density, our SCS scheme always outperform on DV-hop and Amorphous.

Finally, we analyze the overhead for different algorithms. In Figure.9, the number of messages in the distance estimation for different algorithms is presented. As

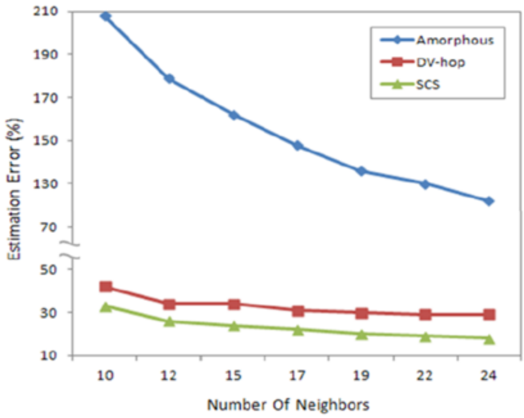

Fig. 7. The average distance estimation error with $AP = 1$

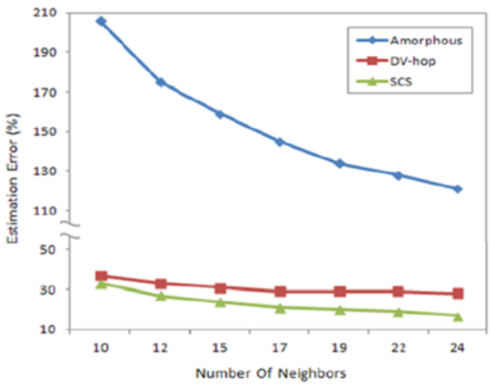

Fig. 8. The average distance estimation error with $AP = 5$

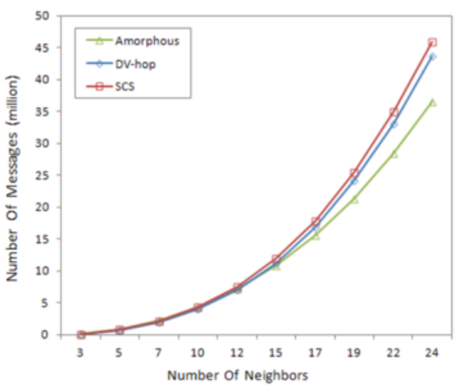

Fig. 9. The messages of different distance estimation schemes

we can see in Figure.9, the number of messages increases when the node density increases. SCS generates more messages than the other two schemes, but the differences are not significant when the average number of neighbors is lower than 20.

6. Conclusion

Localization is one of the most important services in wireless sensor networks. In this paper, we redefine the Single Hop Range and propose a novel SHR Correction Scheme to estimate the distance between a node and an anchor. Second, we use the SCS to incorporate three localization schemes. Through intensive simulations, we show that our proposed range estimation scheme and its application to the three localization schemes can reduces localization error significantly. Our proposed schemes outperform the other two well-known distance estimation by more than 12% percent and reduce localization errors by as much as 19%, especially when the number of anchors is low.

Acknowledgment

This work is supported by Key Scientific and Technological Project of Henan Province (Nos:172102210336 and 172102210339) and Key Scientific Research Projects of Henan Province High Education (Nos:17B510004 and 17B510003).

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Received November 16, 2017