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Abstract

This paper studies the node localization algorithm of the wireless sensor network. This localization algorithm can efficiently position a node. The improved algorithm introduces the mobile signal node into DV-Hop localization algorithm. This mobile signal node moves in the defined network path and continuously broadcasts information on self nodes to form multiple virtual beacons. This paper studies the weighted algorithm of the average hop distance and dynamic selection algorithm of beacon node to reduce localization cost and network deployment complexity and improve localization precision and efficiency of a node. The test results indicate that the improved localization algorithm improves localization precision, reduces communication consumption of the localization algorithm and improves the localization efficiency of the nodes in the wireless sensor network.

Key words: Wireless Sensor Network, Optimized Path, Node, DV-Hop Localization Algorithm.

1 Introduction

The wireless sensor network integrates the sensor, embedded computing, distributed information processing and radio communication technology. Many same or different sensor nodes can be organized by self via wireless communication to form a distributed ad hoc. This ad hoc breaks through the traditional point-to-point data information interaction and brings a brand-new information acquisition and processing mode. The deployment of the nodes in the sensor network is out of control. E.g. generally nodes are deployed in a large area in a large wireless sensor network application. The positions of most nodes in the network are unknown and can not be identified in advance, but most applications of the wireless sensor network need know the positions of nodes in the network to get the location of event occurrence and information source in the network, so localization is one of main application areas in the wireless sensor network. For most applications, the data which are sensed without node position information are meaningless. Only after the sensor nodes are correctly positioned, the applications can identify the specific position of the events and information monitored by the sensor nodes. The node poisoning is an important research area in the wireless sensor network.

Self localization of a sensor node indicates to identify the node position by estimating the distance to the neighbor node or neighbor number and exchanging information among nodes. Self-localization of a node is regarded as one of basic capabilities and services in a sensor network. for WSN, manual deployment or GPS equipping of all network nodes will be restricted by cost, power consumption and scalability, so many research organizations and scholars study how to realize WSN self localization.

The localization method is divided into range-based localization and range-free localization [5] by measuring the distance among nodes or not in localization in the wireless sensor network. The former method will measure the absolute distance or direction between two adjacent nodes and then identify the position of an unknown target node by using this actual distance. The latter method only computes the position of the target node by using association of distances among nodes. The range-based algorithm can position a node by measuring actual distance or direction between adjacent nodes. The distance can be measured by many methods, including Time of Arrival(TOA), Time Difference of Arrival(TDOA), Radio Signal Strength(RSSI) and Angle of Arrival(AOA).

This paper proposes an improved node localization algorithm. The improved algorithm introduces mobile signal nodes in DV-Hop localization algorithm. a mobile signal node moves in the defined path in the network and continuously broadcasts self node position to form multiple virtual beacons. The improved algorithm studies the weighted algorithm of average hop distance and dynamic selection algorithm of a beacon node and how to reduce localization cost and network deployment complexity.
and improve localization precision and efficiency of a node. The test results indicate that the improved localization algorithm can improve localization precision, reduce the communication consumption of a localization algorithm and improve the localization efficiency of the nodes in the wireless sensor network.

2 DV-Hop localization algorithm in sensor network

2.1 DV-Hop localization algorithm

This algorithm requires no range measurement localization technology and additional hardware. Compared to the range-based localization algorithm, DV-Hop localization algorithm features low cost, small power consumption and strong immunity to measurement noises and can reach certain localization precision, so many researchers study it. The distance-independent localization algorithm can estimate or identify the position of an unknown node by estimating the distances among nodes or identifying the possible area of an unknown node. Now many researchers propose many localization algorithms without range measurement.

Dragos Niculescu from American Rutgers University proposes the DV-Hop localization algorithm by using distance vector route and GPS localization idea. This algorithm includes three phases. First, all nodes in the network get the hops of the beacon. Secondly, after positions and hop distance of other beacons are obtained, the beacon will compute the average hop distance of the network, assign a lifecycle to it and broadcast this correction value with a lifecycle in the network. The unknown nodes will record the first received correction value and forward it to the adjacent node. This strategy can guarantee that most nodes can receive the average hop distance from the nearest beacon. Finally the unknown nodes can compute hop distance to the beacon according to the recorded hops.

The DV-Hop algorithm can compute the position of the unknown nodes remote from the beacon and require no additional information, but the error will differ by the route bending degree. A unknown node can get hops via a path, so it will compute self position by the average distance of each hop and lead to bigger position computing error. Assume that a DV-Hop model is shown as the figure 1.

![Figure 1 DV-Hop algorithm model](image)

Figure 1 DV-Hop algorithm model

L1, L2 and L3 indicate the beacon. A indicates a unknown node. The distance among L1, L2 and L3 is 30, 30 and 40. The distance from the point A to point L1 is 15. The hop frame number is 1. The number of hop frames from the point A to L2 and L3 is 3. The average of each hop is 10.

First, the beacon broadcasts the data packets with the position information and mark starting with 1. When the signal is transmitted to another node, the number of hop frames will automatically increase by 1, so each node can compute the distance to the beacon. After a beacon receives signals to another beacon, it will compute average hop distance. The average hop distance of L1, L2 and L3 is computed as follows:
After the average distance is computed, the beacon will broadcast it to other nodes. After an unknown node gets the average hop distance, it will compute the distance to the beacon, namely $L_1$, $L_2$, and $L_3$ will broadcast distance 7.5, 7 and 7. There is only one hop from the point A to the point $L_1$, the average hop distance received by the point A is 7.5. The point computes the distance to the point $L_1$, $L_2$ and $L_3$, namely $AL_1=7.5$ and $AL_2=AL_3=7*3=21$. The node A can be positioned according to three-edge measurement method. In fact, the distance is $AL_1=15$, but the distance estimated by using DV-Hop is 7.5. The error is bigger. After three-edge measurement, the difference between the computed position and actual position is bigger [11].

The nodes are positioned differently in the wireless sensor network. The localization method is divided into localization based on the beacon node and localization independent of beacon node (they are divided into non anchor node and anchor node in some paper. The signal node is also called as anchor node). The localization method independent of beacon node belongs to relative localization. The localization algorithm based on beacon can know the absolute coordinate of unknown nodes. Now most node localization algorithms assume that the network includes a small number of beacon nodes for absolute localization of the whole network.

2.2 Analysis on DV-Hop algorithm

DV-Hop localization algorithm proposed by Niculescu D will not directly measure the distance between nodes. This algorithm features simplicity and high localization precision and is one of a series of distributed localization methods based on the distance vector route and GPS localization idea. This algorithm computes the distance from the unknown node to the beacon node by multiplying the average hop distance of nodes in the network with the hops to beacon node. The node position can be measured by using three-edge method.

The DV-Hop (Distance Vector-Hop) localization method is similar to the distance vector routing in the traditional network. The distance vector localization method includes three phases:

Phase I: the unknown nodes will first compute the minimal hops to the beacon node. The beacon node will broadcast the self position packet to the adjacent nodes, including the hop field with the initial value 1. The receiving node will record the minimum hops to each beacon node, ignore the packet with bigger hops from a beacon node, increase the hops by 1 and forward it to the adjacent node. All nodes in the network can record the minimum hops to each beacon node by using this method.

Phase II: compute the actual hop distance between the unknown nodes and beacon node. Each beacon node will estimate actual hop distance by using the equation (3.1) based on positions and adjacent hops of other beacon nodes recorded in the phase I.

\[
\text{HopSize}_i = \sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} / \sum_{j \neq i} h_{ij}
\]  

(\(x_i+y_i\)) and (\(x_j+y_j\)) indicate the coordinate of the node i and j. \(h_{ij}\) indicates the hops between the node I and j (j\(\neq\)i). The beacon node will broadcast the computed average hop distance to the network by using a packet with the lifecycle field. The unknown nodes only records the first average hops distance and forwards it to the adjacent nodes. After the unknown nodes receive the average hop distance, it will compute the hop distance to each beacon node according to the recorded hops.

Phase III: the unknown nodes compute self coordinate by using the hop distance to beacon nodes recorded in the phase II and three-edge measurement method or maximum probability method.
This paper proposes a sensor network node localization algorithm based on mobile beacon which can reduce the localization cost and complexity of the wireless sensor network and improve the localization precision. Based on DV-Hop localization algorithm, a mobile beacon node with GPS localization device moves in the defined path and continuously broadcasts self position to form multiple virtual beacons. The unknown node records hops to each virtual beacon and weight the average hop distance broadcasted by the mobile beacon to re-calculate the average network hop distance for local area, multiplies it with the hop to get the distance to virtual beacon and finally computes the position by using the improved three-edge measurement method for accurate node localization.

Only one mobile beacon is used and no other beacon nodes are deployed in the network, so it can reduce the localization cost and network complexity. Finally simulation proves that this algorithm can improve the localization precision, reduce the algorithm’s computing workload and improve the localization efficiency.

To improve localization efficiency and reduce the network deployment complexity, this paper proposes a localization method based on the mobile beacon. The beacon node with the localization device is loaded to the mobile platform or mobile robot to get a mobile beacon. The mobile beacon can get self position in real time during regular movement and periodically broadcast self position to assist localization of unknown nodes.

### 3.1 Mobility model of beacon node

How a mobile beacon node can span whole network in a proper manner is focused by many researchers. The sensor nodes are randomly distributed in the network. The node positions are unknown. To position these nodes, a movement model should be designed to make the movement track of mobile beacons span the whole network in a period as short as possible and transmit enough localization information to unknown nodes for localization. Now the mobile modes for the wireless sensor network include S type, RWP(Random Way Point) model and Gauss-Markov model. These modes are extensively applied in the ad hoc network. RWP model features lower hardware requirement and random path. When the movement speed gradually decreases, probability of the movement track in the network center area is higher. S model requires higher hardware.

So this paper selects Gauss-Markov motion model which can cover most areas in a network. Compared to RWP model, this model can avoid mutation of movement track, reduce edge belt and require lower hardware. It can be expressed as follows:

$$v_k = \alpha v_{k-1} + (1 - \alpha) v_{\text{mean}} + \gamma \sqrt{1 - \alpha^2}$$  \[5\]
\begin{align*}
v(k) \text{ and } d(k) & \text{ indicate the speed and direction of the mobile beacon at the time } k. \ a \text{ indicates the random direction adjustment parameter. The value is from } 0 \text{ to } 1 \ (0 \leq a \leq 1). \ V_{\text{mean}} \text{ and } d_{\text{mean}} \text{ indicate the mean speed and average motion direction. } \\
& \gamma_v \text{ and } \gamma_d \text{ indicate the Gauss random variant. The movement speed and direction at next time is computed from the current speed and direction.} \\
& v_\gamma = v_{k-1} + v_{k-1} \times \cos(d_{k-1}) \quad (7) \\
y_\gamma = y_{k-1} + v_{k-1} \times \sin(d_{k-1}) \quad (8)
\end{align*}

The beacon node computes the movement speed and direction at each time according to Gauss-Markov model. The localization device can get the coordinates of the current movement position and broadcast it to the network.

3.2 Localization process based on mobile beacon node algorithm

The beacon node moves in the network and periodically broadcasts the position information to the network. The broadcasting information includes the current movement point, current position coordinate, network hop (the initial value is 0). The unknown nodes within the communication range of the mobile beacon node can receive the localization data packets of the beacon node at this position. After each node receives the localization information, it will increase the hop by 1 and broadcast it. When each node receives the broadcasting values of multiple adjacent nodes, it will compare them with the self-recorded value. If the broadcasting value is less than the self-recorded hop, this broadcasting packet will be discarded.

This process is like DV-Hop localization algorithm. The difference is described as follows: when an unknown node determines the position of the beacon node of the received broadcasting packet. For the first position, the node will not broadcast it temporarily till the broadcasting packet from the beacon at second position is received. At this time, the node will broadcast the localization information packet at the first position, save the received broadcasting packets at second position and broadcast it after broadcasting packet from next position. Others are deduced by analogy. The localization information is broadcasted as follows:

Step 1: the mobile beacon gets the current position information at the first position and encapsulates the position information broadcasting packet (LIDi, xi, yi, HOPs). LIDi indicates the position of the current broadcasting packet. xi and yi indicates the coordinate of the current position. HOPs indicate the hop which is initialized as 0.

Step 2: all adjacent nodes of the mobile beacon within the communication range of the first position receive the localization packets. The receiving node will compare it with the self data packet, get the smaller hop, discard the bigger hop, increase the hop by 1, record this hop and wait for next localization information packet.

Step 3: the mobile beacon moves to the next position, adds position information by 1, broadcasts this new localization information packet, receives the broadcasting information from different nodes, gets the packet which hop is less than it of the previous position, divides the distance between two positions by the hop to get the average hop distance (Di) and broadcasts it to the network.

Step 4: repeat the step 3 till the position number reaches the preset threshold K which depends on the required virtual beacon density. If the grid includes N unknown nodes, you can get the virtual beacon percent q according to the precision and \( K = N \times q \).

Step 5: the nodes can correct the value by weight according to the average hop distance of received virtual beacons, compute the distance to different virtual beacon by the recorded hops, select the optimal virtual beacon node distance information and compute self position by the optimal three-edge
measurement method.

4 Simulation test and result analysis

To validate performance of this algorithm, we simulate our algorithm on matlab platform and perform auxiliary analysis on the test data by using MATLAB. 100 sensor nodes are randomly distributed in a 50x 50 area on matlab platform. The node communication radius is 10. The network includes a mobile beacon which can get the self position and move according to Gauss-Markov model. The average speed is 5 and the initial direction angle is set as 90°. The factor is converted at the edge, namely \( \alpha = 0.75 \) in the equation (4.5). The broadcasting calculator of the mobile beacon is set as 2s, namely the mobile beacon node broadcasts the localization information in the network every 2s. To make the simulation results approximate to the actual condition, the simulation results are average of 20 independent simulation results.

4.1 Analysis on localization precision and localization coverage rate

The mobile beacon moves by the predefined movement model and periodically broadcasts the localization information packet, namely with speed growth of the virtual beacon, more the virtual beacons are and higher the localization precision is, more the spent localization time is. Their relation is shown as the figure 3.

The relation in the figure is obvious. with elapse of time, longer the movement distance of the mobile beacon in the network is, more the broadcasting localization information is, more the virtual beacons are and smaller the localization error is. Similarly, when the track of the mobile beacon covers many places, more and more unknown nodes get the localization information packets and compute self position. The localization coverage will also continuously increase.

![Figure 3 Localization error and localization coverage rate](image)

4.2 Influence from localization information broadcasting cycle T of beacon node

When the mobile beacon node moves by Gauss-Markov model with fixed parameters, if the broadcasting cycle is smaller, the virtual beacons are dense, namely the virtual beacons in unit area are more. it must increase the communication consumption and error of the node. When the cycle T increases to a limit, if T continues increase, the broadcasting localization information is too few and the information for localization virtual beacon is too few, so it increases the localization error. The optimal localization cycle depends on the communication radius of the nodes. When the communication radius increases, the broadcasting cycle will also increase. When the broadcasting cycle T changes under same movement model, the relation between the localization error and T is shown as the figure 4.
4.3 Comparison of localization errors

The algorithm performance is assessed by the localization error. The mobile beacon broadcasts the localization information packets with 2 s cycle, namely construct a virtual beacon in the network. The simulation results are compared as the figure 5.

Figure 5 Broadcasting cycle $T$ and average localization error of mobile beacons

Shown as the figure 5, the error of two localization algorithms will decrease with increase of the beacon nodes. When the beacon nodes are more, the error of our algorithm reduces obviously because the weight is used to compute the average hop distance of unknown nodes. When a node gets more average hop distances computed by the surrounding virtual beacons, the weighted average hop distance will approximate to the true network conditions.

5. Conclusions

To improve the localization precision of the wireless sensor network node, reduce the network localization cost and improve localization efficiency, this paper proposes the wireless sensor network node localization algorithm based on the mobile beacon optimization path. This algorithm introduces the mobile beacon node into the wireless sensor network. The mobile beacon node can broadcast self position to assist the unknown nodes in the network in localization. Based on the typical localization algorithm DV-Hop localization algorithm without range measurement, this algorithm computes the average hop distance in the network for network localization by dynamically selecting the beacon nodes and constructing virtual beacon nodes in the network.
6. References


