# A Weight-based DV-HOP Improved Localization Algorithm for Wireless Sensor Networks

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***Abstract*—DV-Hop is one of the range-free localization algorithms using hop-distance estimation. However, it suffers from a large localization deviation and low localization accuracy. This paper proposed a weight-based DV-HOP improved algorithm. It improves the traditional DV-HOP algorithm mainly in the following aspects. First, it increases the calculation accuracy of hop counts. Second, it corrects the average hop distance calculated by the anchor node by using least square method. Third, the un-located nodes calculate the distance to other anchor nodes based on the link state with weights. The simulation results showed that the proposed algorithm significantly reduces the localization deviation, with a small increase in the node's computation and communication cost. It is superior to the existing DV-HOP algorithm.**

***Index Terms*—Localization, range-free, weight-based, DV-HOP algorithm, WSN**

## I. INTRODUCTION

Wireless sensor networks include a large number of sensor nodes deployed in the destination area, establishing the communication link in an ad hoc manner. With the rapid development of wireless communication, micro-electromechanical systems, on-chip systems and low-power embedded technologies, wireless sensor networks bring about a revolution through its low power consumption, low cost, distributed, self-organization and other characteristics for the field of information perception.

Wireless sensor networks combine different kinds of technologies, including wireless communications, sensing, distributed information processing, embedded computing, and so on. Sensors are able to monitor geology, waves, temperature, humidity, pressure, soil erosion, waves, light, object shape, movement, angle and many other types of data. After deployed in the monitoring area, they cooperate to collect required information and transmit calculated data to sinks through multi-hops [1]. However, a message full of information yet lacking of corresponding location may be meaningless for many applications. Thus the accurate localization of the collected information is one of the most important premises for wireless sensor networks [2].

The localization methods can be divided into range based and range free localization. Range-based algorithms calculate the location of nodes by measuring the angles of signal arrival or the distance between nodes, such as Received Signal Strength Indicator (RSSI) [3], Angle-of-Arrival (AOA) [4], Time of Arrival (TOA) [5], Time Difference of Arrival (TDOA) [6], etc. By using additional hardware approaches to measure the angles or distance between nodes, range-based methods can get better positioning accuracy, but usually are not energy efficient. Range-free localization methods can calculate the location of nodes by obtaining the relative distances through the connectivity of the network, without any hardware supporting, such as DV-HOP [7,13], centroid algorithm [8,12], convex programming [9], MDS-MAP [10] and so on. They may have some positioning deviation, but within an acceptable range. They usually require lower energy consumption than the range-based ones, and are more applicable for most scenarios.

Distance Vector Hop (DV-HOP) localization algorithm is one of the APS Series distributed localization algorithms, which utilize distance vector routing and GPS positioning strategy for nodes localization. All the un-located nodes in the network receive hop count to anchor nodes. The distance length is obtained by multiplying the hop count with the average hop distance. Finally, trilateration method, triangulation method, maximum likelihood estimation method, or other mathematical methods are applied to calculate the required coordinates [2].

DV-HOP algorithm uses hop distance instead of linear distance. The calculation deviations will constantly be accumulated due to the irregular topological structure in actual environment. The localization precision of algorithms is closely related to specific factors in actual environment. In isotropic networks, by increasing the number of nodes inside the network area, the deviation of calculated average hop distance can be reduced and reach to a satisfied accuracy range. However, in sparse or irregular network, the localization precision goes down quickly.

To avoid the main drawbacks of DV-HOP algorithm, which is the low accuracy of hop count and high deviation of average hop distance, this paper made a significant improvement over the existing DV-HOP algorithm, and proposed an enhanced method. By introducing transmit power control and link weight, the algorithm can reduce the deviation between the average hop distance and the actual distance, and increase the localization accuracy.

The rest of the paper is organized as follow. Section II gives a comprehensive review of DV-HOP algorithm. It illustrates the proposed method in Section III. The performance of the proposed method is evaluated in Section IV. A conclusion is presented in Section V.

## II. DV-HOP REVIEW

DV-HOP algorithm execution process generally has three steps. In the first stage, each unlocated sensor is required to obtain the minimum hop distance from itself to each anchor node. First, the anchor node broadcasts a packet to all neighbors that contains the anchor node's ID, position information and hop count initialized to 0. The unlocated node receiving the packet, records the anchor's ID number, the location, and the hop distance. It then increases the hop count and retransmits all the information to its neighboring nodes [11]. Eventually, every node in the network gets all anchor nodes' position information and corresponding hop counts. Unlocated node may receive many data packets from the same anchor node, because there are many transmission paths in the network. It will store only the minimum hop count and discard other packets. Finally, each node can record their minimum hop counts to all anchor nodes. The distance vector exchange protocol is applied during the procedure.

In the second phase, anchor nodes compute the network average hop distance denoted as *hop_size*. Anchor nodes' coordinate positions are known, and from the first stage they obtain the hop counts to other anchor nodes. Dividing the actual distance between anchor nodes by hop number, the distance of each hop [4] can be obtained. For anchor node $i$ and node $j$, the coordinates are denoted as $(x_i, y_i)$ and $(x_j, y_j)$ respectively. Hop count between the two nodes is $hop_{i,j}$, and the average distance per hop calculated by the anchor node $i$ is $hop\_size_i$. Then

$$hop\_size_i = \frac{\sum_{i \neq j} \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}}{\sum_{i \neq j} hop_{i,j}} \quad . \qquad (1)$$

Anchor nodes will broadcast the average distance per hop to networks. The unlocated node receiving the information will forward it to their neighbors in the similar manner. In a large scale network, you can set TTL to reduce network traffic [2]. Eventually, all nodes in the network get each anchor node's average distance per hop. Unlocated nodes estimate the distance to the anchor nodes according to the following formula, where $d$ is the estimated distance.

$$d_i = hop\_size_i \times hop_i \qquad (2)$$

In the third phase, the unlocated node obtains three or more anchor nodes' estimated distance. It uses the maximum likelihood estimation method to calculate its own coordinates. Supposed that the number of anchor nodes is $k$, then the coordinates of all anchor nodes are $(x_1,y_1)$, $(x_2,y_2)$,..., $(x_k,y_k)$. And the distances between the unlocated node and anchor nodes are $d_1, d_2,..., d_k$. Then according to the following equation (Formula (3)), the coordinates of the unlocated node $(x,y)$ can be calculated combining the least squares estimation method.

$$\begin{cases} \sqrt{(x_1 - x)^2 + (y_1 - y)^2} = d_1 \\ \vdots \\ \vdots \\ \sqrt{(x_k - x)^2 + (y_k - y)^2} = d_k \end{cases} \qquad (3)$$

Then, each equation minus the last equation and get the following results.

$$\begin{cases} x_1^2 - x_k^2 - 2(x_1 - x_k)x + y_1^2 - y_k^2 - 2(y_1 - y_k)y = d_1^2 - d_k^2 \\ \vdots \\ \vdots \\ x_{k-1}^2 - x_k^2 - 2(x_{k-1} - x_k)x + y_{k-1}^2 - y_k^2 - 2(y_{k-1} - y_k)y = d_{k-1}^2 - d_k^2 \end{cases}$$

Matrix is described as AX=b.

$$A = \begin{bmatrix} 2(x_1 - x_k) & 2(y_1 - y_k) \\ . & . \\ . & . \\ 2(x_{k-1} - x_k) & 2(y_{k-1} - y_k) \end{bmatrix}$$

$$b = \begin{bmatrix} x_1^2 - x_k^2 + y_1^2 - y_k^2 + d_1^2 - d_k^2 \\ . \\ . \\ x_{k-1}^2 - x_k^2 + y_{k-1}^2 - y_k^2 + d_{n-1}^2 - d_k^2 \end{bmatrix}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix}$$

The coordinate of the unlocated node by using standard MMSE method is $(A^T A)^{-1} A^T b$.

## III. DV-HOP IMPROVEMENT

To avoid the main drawbacks of DV-HOP algorithm, an enhanced method is proposed in this paper. By introducing transmit power control and link weight, the algorithm can reduce the deviation and make a big improvement for the localization accuracy.

### *A. Variation of Transmission Power*

Each node within the transmission radius of the anchor node is considered to be one hop away from the anchor. As the actual distance between the neighboring node and the anchor node is usually not the same, one hop fails to distinguish the distance difference between two neighboring nodes. Thus the average hop distance will cause a large deviation as the estimated distance.

Based on this, first improvement on the first stage of DV-HOP algorithm is made as follow. Neighboring nodes with one hop away from the anchor node are further divided into two types. By tuning the transmission power, the hop number of receiving nodes that can receive full power and half power are denoted as 1 and 1/2 respectively. By this kind of transmission power variation, the unlocated node's hop count to the anchor node is more precisely. It decrease the deviations caused by the increase of hop count.

So the procedure of distance vector exchange, the first stage of the proposed algorithm, is improved as follows:

1. Each anchor node broadcasts a data packet to its neighboring nodes, with full and half transmission power respectively. The packet contains the ID and the location information of the anchor itself, and the hop count which is initialized to 0. The transmission power state is recorded in the packet.

2. After an unlocated node receives the packet, it adds the ID number and coordinates information of anchor node in its database. If the transmission power state is *half,* then the hop count is increased by 1/2; otherwise the hop

count is increased by 1. If the unlocated node already has some information about the anchor node, then it compares the hop count in the packet with the stored value, and keeps the smaller one.

3. After the unlocated node finishes the operations stated above, it broadcasts the data message to its neighbors in the similar manner, i.e. with half-power and full power respectively. The process continues until all nodes receive the packets. Finally, all nodes record the minimum hop count to each anchor nodes.

### B. Correction of Average Hop Distance

In the second stage of DV-HOP algorithm, anchor nodes calculate average hop distance by (1). Because (1) is based on the unbiased estimation criteria, there will be no deviation on average hop distance. But in a real situation, the measurement deviation should be considered. As the main idea of Least Squares is to calculate and obtain the optimal value of the target function by minimizing the quadratic sum of deviation, it is used to further correct the average hop distance.

After an anchor node receives the location information of other anchor nodes, the actual distance between them can be calculated. Suppose there are two anchor nodes $s_i$ and $s_j$. Their actual distance will be $d_{i,j} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}$. Estimated distance is average hop distance multiplying by hop count, which is $d'_{i,j} = hop\_size_{i,j} \times hop_{i,j}$. The relationship between the actual distance and estimated distance should be $d_{i,j} = d'_{i,j} + \varepsilon_{i,j}$, where $\varepsilon_{i,j}$ represents for the measurement deviation. When $\varepsilon_{i,j}$ gets minimum, the deviation of average hop distance $hop\_size_{i,j}$ can be minimum. Based on Least Squares, $\sum_{i \neq j} \varepsilon_{i,j}^2$ is the total deviation. Then the following equation can be obtained.

$$\sum_{i \neq j} \varepsilon_{i,j}^2 = \sum_{i \neq j} (d_{i,j} - hop\_size_{i,j} hop_{i,j})^2$$
$$= \sum_{i \neq j} (d_{i,j}^2 - 2hop\_size_{i,j} d_{i,j} hop_{i,j}$$
$$+ hop_{i,j}^2 hop\_size_{i,j}^2)^2.$$

Let $\frac{\partial \sum_{i \neq j} \varepsilon_{i,j}^2}{\partial hop\_size_{i,j}} = 0$, then the average hop distance of anchor node $s_i$ can be $hop\_size_{i,j} = \frac{\sum_{i \neq j} (d_{i,j} hop_{i,j})}{\sum_{i \neq j} hop_{i,j}^2}$. By this method, the deviation of average hop distance will be decreased.

### C. Weighted Calculation of Average Hop Distance

In DV-HOP algorithm, the calculation of average hop distance only considers distance from anchor nodes. Because the link state of each unlocated node is different, using a global average value to estimate the distance of each unlocated node will lead to deviation accumulation. When a node locates in an area with densely distributed anchor nodes, localization that is based on the actual link state with these anchors can be more precise than using the global average value. However, on the other hand, when a node locates in an area with sparsely distributed anchors, the distance between a node and its nearest anchor node can still be far. So the localization in this case depends more on the global information.

According to the analysis stated above, the second stage of DV-HOP algorithm can be further improved. The main idea is that each unlocated node calculates its own average hop distance, and adaptively allocates the local and global information with different weights. During the procedure, anchor nodes disseminate hop distance information into the network. After receiving multiple location information of anchor nodes and figuring out its own link state in the network area, each unlocated node makes a comprehensive comparison of average hop distance and hop count to multiple anchor nodes, so as to find out its relevance to each anchor node. Then different weights are allocated to multiple anchor nodes information and the global information according to their different relevance. Finally, based on trilateral method, unlocated nodes' coordinates can be obtained.

The average hop distance of unlocated nodes is calculated from two parts, global distance and local distance. Global distance $C_i^g$ is calculated by each anchor node through distance vector protocol. After the first stage of DV-HOP algorithm finishes, every anchor node broadcasts a data packet to its neighboring nodes again using distance vector exchange protocol. Suppose there is an anchor node $s_i$, and the data packet contains the ID number *i* of the anchor node, the average hop distance (i.e. global distance) $C_i^g$ of the anchor node, the hop count to other anchor nodes $\sum_{i \neq j} hop_{i,j}$, and the actual distance to other anchor nodes $\sum_{i \neq j} d_{i,j}$. After an unlocated node receives the data packet, if there is no coordinates' information of anchor node $s_i$ in its database, it means the data packet of the anchor node $s_i$ hasn't been received in the first stage. Thus there is a great probability that this node is located far away from the anchor nodes $s_i$. Therefore, the unlocated node discards this data packet. Otherwise, all the information including the average hop distance (i.e. global distance) $C_i^g$ of the anchor node, the hop count to other anchor nodes $\sum_{i \neq j} hop_{i,j}$, and the actual distance to other anchor nodes $\sum_{i \neq j} d_{i,j}$ are updated in the node's memory. Then it establishes a tuple for the anchor node $s_i$, which is denoted as storage-set$_i$ $=\{i, (x_i, y_i), hop_i, C_i^g, \sum_{i \neq j} hop_{i,j}, \sum_{i \neq j} d_{i,j}\}$. For any anchor node, as long as the unlocated nodes receive the data packet it broadcasts and have the entry for this anchor, the information will be stored. If there is already storage-set of the anchor node $s_i$ in the memory, the repeat information will be discarded.

The location relationship of communication link between unlocated nodes and anchor nodes has many types. For example, if an unlocated node resides in the shortest path between two anchor nodes, then the average hop distance calculated from the two anchor nodes is properly the best way to present the link state of the unlocated node. But if the unlocated node is far away from the shortest path, then local average hop distance has little influence on the node. The global average hop distance calculated from the whole network is more conducive to improve the localization accuracy.

The distance from an unlocated node $n_a$ to an anchor node $s_i$ is denoted as $d_{a,i} = hop_{a,i} \times C_{a,i}$, where the average hop distance $C_{a,i}$ is calculated as follow:

$$C_{a,i} = w_a^g C_i^g + \sum_{i \neq j} w_{i,j}^a C_{i,j}^l \quad (i \in S \setminus P, j \in S \setminus P) \quad (4)$$

Here, two anchor nodes $s_i$, $s_j$ are in the database of the unlocated node $n_a$, and $C_{i,j}^l$ is the average hop count in the shortest path between the anchor node $s_i$ and the anchor node $s_j$.

$$C_{i,j}^l = \frac{d_{i,j}}{hop_{i,j}} = \frac{\sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}}{hop_{i,j}} \quad (5)$$

The shortest distance between the unlocated node $n_a$ and the anchor node $s_i$ or $s_j$ affects the weight value $w_{i,j}^a$. Let the hop number between the node $n_a$ and the anchor node $s_i$ be $hop_{a,i}$, the hop number between the nod $n_a$ and the anchor node $s_j$ is $hop_{a,j}$, the hop number between the anchor node $s_i$ and $s_j$ is $hop_{i,j}$, and $diff_{i,j}^a$ is the sum of the hop number between the node $n_a$ and the anchor node $s_i$ and $s_j$, then minus the hop number between the anchor node $s_i$ and $s_j$.

$$diff_{i,j}^a = hop_{a,i} + hop_{a,j} - hop_{i,j} \quad (6)$$

If the value of $diff_{i,j}^a$ is 0, that means the node $n_a$ locates in the shortest path of the anchor node $s_i$ and $s_j$. If the value of $diff_{i,j}^a$ is k (k>0, k∈R), that means the node $n_a$ locates in the position that is about k/2 hop away from the shortest path of the anchor node $s_i$ and $s_j$. The weight of $C_{i,j}^l$ denoted as $w_{i,j}^a$, is significant to reflect the feature of the area where node $n_a$ resides in. The closer the $diff_{i,j}^a$ is, the bigger value of $w_{i,j}^a$ in calculating the average hop distance between the node and the anchor node $s_i$. Therefore, before calculating the $n_a$ value of $w_{i,j}^a$, the shortest link $diff_{i,j}^a$ between the node $n_a$ and anchor nodes in database needs to be calculated, i.e. *diff-set*={ $diff_{i,1}^a, diff_{i,2}^a, diff_{i,3}^a, \ldots, diff_{i,j}^a$ }. The farther the unlocated node is away from the anchor nodes, the larger the globle weight $w_a^g$ is. Let *k* be the number of values contained in the *diff-set*, and $diff_{\max}^a$ is the maximum one, then

$$w_a^g = \frac{\sum diff_{i,j}^a}{k \times diff_{\max}^a}. \quad (7)$$

Let $r_{i,j}^a = \dfrac{1}{diff_{i,j}^a + 1}, r_{i,j}^a \in (0,1]$. Since $diff_{i,j}^a$ is inversely proportional to $r_{i,j}^a$, the ratio of $r_{i,j}^a$ and $r_{i,k}^a$ reflects the ratio of the distance between the node $n_a$ and link *e (i, j)* and the distance between the node $n_a$ and link *e (i, k)*. The weight of $C_{i,j}^l$ is $\dfrac{r_{i,j}^a}{r_{i,k}^a}$ times than that of $C_{i,k}^l$.

$$w_{i,j}^a = (1 - w_a^g) \times \frac{r_{i,j}^a}{\sum r_{i,j}^a} \quad (8)$$

According to the weight-based approach, the weight sum should aside by $w_a^g + \sum_{i \neq j} w_{i,j}^a = 1$. The average hop distance $C_{a,i}$ of the unlocated node can be reflected from the state of network link. Based on different link state, weight is adjusted adaptively, so the average hop distance of the unlocated node is closer to actual average hop distance in network.

In conclusion, by (6) the average hop distance $C_{a,i}$ of the link passed from the node $n_a$ to the anchor node $s_i$ can be calculated. The estimated distance $d_{a,i}$ can be got through (9).

$$d_{a,i} = C_{a,i} \times hop_i \quad (9)$$

The unlocated node chooses at least three anchor nodes in database, and works out the estimated distance to anchor node based on stored information, and then works out its coordinates using (3).

### *D. Algorithm Processes*

1. Each anchor node uses half-way power and full power respectively to broadcast packets to all neighbors, including the anchor node's ID, location and hop count initialized to 0. The unlocated node receives the packet and records information. The hop count is incremented and continues to be forwarded to other nodes. A hop count of 10 is set to stop forwarding and control flooding. Each node records the minimum hop count to all the anchor nodes that are able to communicate. In the simulation, when the distance between nodes is shorter than half of the communication radius, the transmission power is defined as half-power; when the distance between nodes is between half and the whole communication radius, it is defined as full-power.

2. According to information from other anchor nodes, each anchor node uses (1) to calculate the average hop

distance and corrects it by the least squares method. Then it broadcasts a packet that contains the average hop distance and hop count with other anchor nodes to all neighbors.

3. Each unlocated node receives the packet, records the packet's information and continues to forward it to neighbors.

4. Unlocated nodes use improved algorithms and (4) to calculate the average hop distance. If the second step does not receive any information, then the weight of global average hop distance is set to 1.

5. According to (9), unlocated nodes calculate the distance between the anchor nodes and obtain their own coordinates.

## IV. SIMULATION RESULTS AND ANALYSIS

The performances of the proposed Improved DV-HOP algorithm and the original DV-HOP algorithm are compared in simulations. MATLAB is used for simulation experiments. Wireless sensor nodes are randomly distributed in a 200×200 two-dimensional region. They are static after the deployment. Anchor nodes are randomly selected. The area has no communication interference. The maximum number of nodes is 200. Each network is generated randomly whenever any parameter is reset. Each point drawn in the diagrams below is at least an average of 30 separate runs, with 95% confidence intervals.

### A. *The Impact of Anchor Nodes Number*

The number of anchor nodes is varied from 10 to 100, and fix the transmission radius R at 30 m, in order to see the impact on the localization accuracy. All the anchor nodes are deployed randomly.

Then the transmission radius R is set to 40 m and other parameters do not change. The result is shown in Fig. 1 and Fig. 2.

When transmission radius is 30 m, the average network connectivity is 11.82. As is shown from Fig. 1 and Fig. 2, the localization deviations of both algorithms fall down as the increase of the anchor nodes ratio. But the proposed improved-DV-HOP has a lower deviation. When there are fewer anchor nodes, the algorithm localization deviation rate is higher because nodes cannot obtain enough position information. When the number of anchor nodes is five percent of the number of nodes and the deviation rate of the two algorithms is basically the same, the average number of neighboring anchor nodes is only 0.58. This is because lacking of enough anchor nodes makes the most of unlocated nodes have to go through multiple hops to reach the anchor node. The accumulative distance deviation increases as the number of hops continues to grow. With the increase in the number of anchor nodes, the positioning accuracy of two algorithms is increased. The improved DV-HOP algorithm's positioning deviation rate should be lower compared to original DV-HOP algorithm. When the number of anchor nodes is 25 percent, the reduction of deviation rate has been very limited and gradually maintained at a relatively stable level. This is because of the limitation of range-free based algorithm. Finally, the increase of transmission radius from 30 to 40 helps to reduce the localization deviation.

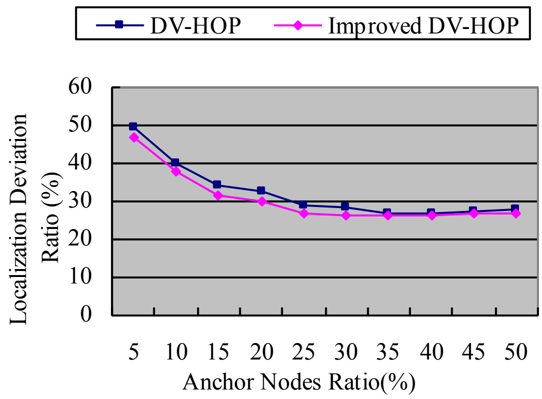


Figure 1. Localization deviation vs anchor nodes number (R=30 m)

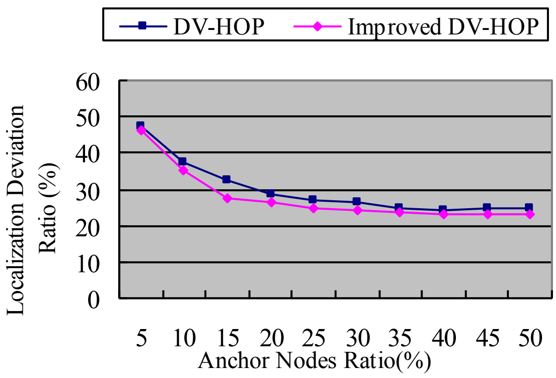


Figure 2. Localization deviation vs anchor nodes number (R=40 m).

### B. *The Impact of Transmission Radius*

In this set of simulation, the number of anchor nodes is fixed at 30 (Fig. 3). When the transmission radius is shorter than 25 m, it is very hard to generate a connected network. So the value of transmission radius varies from 25 to 55. All unconnected network graph will be discarded.

Then the number of anchor nodes is fixed at 50, and vary the transmission radius. The networks are generated randomly again. The experimental results are shown in Fig. 4.

When the number of anchor nodes is 30, as shown in Fig. 3, the localization deviation decreases with the increasing of transmission radius. It shows that when the transmission radius is 25 m, the localization deviation is quite high. This is because shorter radius leads to smaller coverage, and leads to smaller number of neighboring nodes. The algorithm may not be able to obtain enough location information from enough neighbors. As the number of directly communicated nodes decreases, the whole network hops increases, which also increases the localization deviations. When the transmission radius is 30m, the localization deviation remains within the normal range. As the transmission radius increases, the deviation can be further reduced. Noted that when the transmission radius is larger than 45 m, the localization deviations begins to increase because of the larger number of neighboring nodes. The calculating distance between neighboring

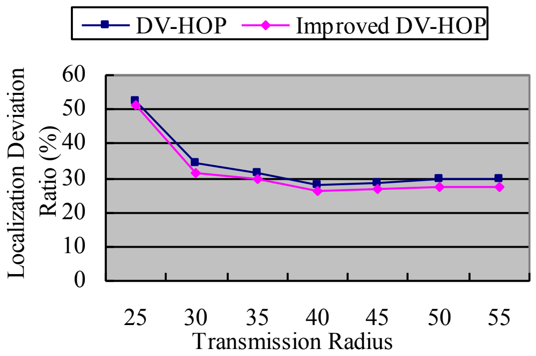


Figure 3. Localization deviation vs transmission radius (the number of anchor nodes is 30).

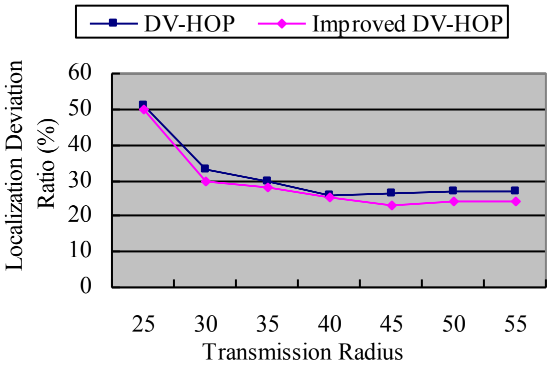


Figure 4. Localization deviation vs transmission radius (the number of anchor nodes is 50).

nodes and anchor nodes is usually greater than the actual distance. This effect is especially obvious when the number of hops is small. So the transmission radius should keep within a certain range. With the increasing of the number of anchor nodes, it helps to reduce localization deviations.

## V. CONCLUSIONS

This paper first described the characteristics of localization in wireless sensor network and several localization classifications. Then it specifically analyzed the drawbacks of original DV-HOP algorithm, and proposed an improved weight-based scheme. The scheme calculated and allocated different weights to different unlocated nodes according to their link state in the network. By using different weights, the distance calculation can make full utilize of anchor nodes' location information, so that the localization accuracy can be significantly risen up without increasing too much communication overhead. The performances of proposed method and traditional DV-HOP algorithm are compared by simulations. As are shown from the results, with the variation of propotion of anchor nodes and transmission radius, the proposed method can always achieve lower error deviation, which is superior to existing method.

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