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Comparative Performance Study of Localization Schemes in Wireless Sensor Networks

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Abstract

Localization is one of the most important tasks for location-aware applications in wireless sensor networks (WSNs). The accuracy of positioning information gives the applications a great number of advantages and, thus, it is very important to choose a localization scheme with the highest accuracy. In this paper, we review three typical localization schemes for WSNs and, then, compare their performance via computer simulation in terms of localization accuracy. The simulation study shows that the probability grid localization scheme achieves the best performance with the minimum location error rate.

Keywords: *Wireless sensor network, location awareness, localization, positioning, location error*

1. Introduction

Wireless sensor networks (WSNs) are popularly used for various applications such as search, rescue, disaster relief, and environment sensing thanks to their cost effectiveness and ease of deployment [1-3]. In WSNs, the memory and energy resources of sensor nodes are limited. Several challenges are still needed for exploring WSNs further. One important problem is how to obtain the location information of sensor nodes [4].

The problem of localization in WSNs is that it seems impossible for all the sensor nodes to be equipped with the additional hardware such as the global positioning system (GPS). The GPS [5] is well known today. It is also widely used in both military and civil applications. However, it is still so expensive to be equipped in disposable and cheap sensor nodes. As an alternative, the received signal strength indicator (RSSI) [6] for determining the distance to known landmarks is popularly used in WSNs. If a receiving node knows the transmission power of a transmitting node, it can estimate the distance between the two communicating nodes by measuring the received signal strength.

In this paper, three typical localization schemes for WSNs are reviewed and their performance is compared with each other in terms of localization accuracy. They are the distance vector hop algorithm (DV-Hop) [7], the probability grid localization scheme [8], and the localization algorithm using expected hop progress (LAEP) [9]. DV-Hop is very famous one and LAEP is an extension of DV-Hop. On the other hand, the probability grid localization scheme gives another way to handle the localization problem. In [10], directional antennas are used for localization, but it results in high cost. In this paper, we compare the three typical localization algorithms to see which one is the best for localization in WSNs.

This paper is organized as follows: In the following section, the three typical localization schemes are summarized and reviewed. In Section III, the performance of the three

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localization schemes is evaluated and compared via computer simulation. Finally, the paper is concluded in Section IV.

2. Localization Schemes

2.1. Distance Vector Hop Algorithm (DV-Hop)

The DV-Hop scheme was proposed by Niculescu and Nath [7]. All nodes get the minimum hop-count values to all anchor nodes. Each anchor node broadcasts a packet to be flooded throughout the network. Once an unknown node gets the packet, it adds one to the hop-count value in its own location table and broadcasts it to neighboring nodes. The packets with higher hop-count values from the same anchor will be dropped. Through this method, all nodes in the network get the minimum hop-count to every anchor node.

The estimated distance between an unknown node and an anchor node can be calculated. Once an unknown node i gets the minimum hop-count value to an anchor node j and the anchor j has the position information, the average hop length $l_{i,j}$ between i and j is estimated by

$$l_{i,j} = \frac{\sum \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}}{\sum h_{i,j}}, \quad (1)$$

where (x_i, y_i) and (x_j, y_j) are coordinates of nodes i and j, respectively, and $h_{i,j}$ is the number of hops between i and j.

Each anchor node broadcasts its hop length to the network. Unknown nodes receive hop length information, but they save only the first arrived one and then transmit the hop length to their neighbor nodes. This strategy ensures that most of the nodes receive the hop length from the anchor that has the least number of hops between them. Once the unknown nodes receive the hop length, they multiply it with the minimum hop-count value recorded in their own location table, and then the distance from the unknown node to the anchor is computed. The coordinate is calculated through triangulation method or multi-alteration method. The unknown node calculates its own coordinate using the estimated distances recorded in the second step of DV-Hop through triangulation method or multi-alteration method.

2.2. The Probability Grid Localization Scheme

The probability grid localization scheme was developed by Stoleru and Stankovic [8]. The anchor nodes represent only a small percentage, and they either are equipped with GPS or can acquire their location information through other means. No other assumptions on the anchor nodes are made in terms of hardware capabilities. The communication range of anchor nodes is the same as that of other nodes. Except for anchor nodes, the remaining sensor nodes are unaware of their location. A controlled deployment of sensor nodes is assumed; *i.e.*, the sensor nodes are deployed in a grid topology and the unit length of grid is known to all the nodes in the network.

Let the sensor nodes deployed in an $M \times N$ grid topology. Let S be the set of all the nodes in the sensor network, and let A be the set of all the anchors in the network. Both S and A are sets of ordered pairs (i, j) representing the grid points where the nodes are located. For any k belong to $S - A$, the probability vector F_k of an $M \times N$ matrix is given by

$$F_k = \begin{pmatrix} f_{11}^k & \cdots & f_{1n}^k \\ \vdots & & \\ f_{m1}^k & \cdots & f_{mn}^k \end{pmatrix}, \quad \forall k \in S - A, \tag{2}$$

where f_{ij}^k is the probability that sensor k exists at location (i, j).

The probability grid localization scheme is similar to the DV-Hop scheme, but it improves localization accuracy by exploiting deployment information. The anchors flood the network with packets containing their ID, their location and a hop count. The flooding is either a global flooding (if the network size is small) or controlled flooding (if the network size is large). Through the flooding, all nodes are expected to hear from at least three anchors. During the flooding period, sensor nodes keep track of the shortest distance (the minimum number of hops) to each of the anchors they heard from. Once an anchor node receives beacons from several other anchors, an estimate for the Euclidian distance of one hop is calculated. This estimation is called a correction factor, and it is propagated in a second phase through a controlled flooding. The correction factor CF_i computed by an anchor i positioned at (x_i, y_j) is given by

$$CF_i = \frac{\sum_f \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2}}{\sum_{\mathrm{j}} \tau_j}, \tag{3}$$

where τ_j is the number of hops between the current anchor positioned at (x_i, y_i) and the anchor positioned at (x_j, y_j).

2.3. Localization Algorithm Using Expected Hop Progress in WSNs (LAEP)

Wang *et al.*, [9] extended the DV-Hop scheme by using expected hop progress. At the initial stage of LAEP, each sensor in a WSN exchanges hello packets with its neighbors to obtain the local connectivity (*i.e.*, the number of neighbors in its transmission coverage area). The exchange of hello packets between neighboring sensors is limited in one hop communication, and no relaying of hello packets is allowed. This information can be obtained from the hello packets from its neighbors. For example, each hello packet contains the identification (ID) of the sender. Any sensor in transmission range can get the hello packet, and it checks if the received packet is a duplicate packet. If so, it just ignores the packet; otherwise, it updates its local database.

After the network initialization, the process of LAEP starts with the broadcasting from anchors. In other word, each anchor launches the algorithm by initiating a broadcast containing the location information called `Info`. After receiving the packet broadcasted from the anchor, any sensor that is one-hop away from the anchor records the anchor's information, updates its database, and then performs another broadcast to its neighbors. The new broadcast packet contains the anchor's constant information. This process of anchor's `Info` packet broadcasting continues until the packet arrives at any other anchor(s).

In addition, each sensor keeps track of the number of anchors, whose `Info` packet has already arrived at least once, represented by a variable `Count`. Initially, `Count` is set to 0. The event of `Count` beyond 3 triggers the trilateration algorithm to compute a sensor's own location. The procedure for each sensor responding to the event of `Info` packet arriving is summarized as follows: If a `Info` packet comes, the sensor first checks the packet's origin. If it is from a new anchor, it increases its local variable `Count` by 1. It then rebroadcasts the new `Info` to its neighbors. Otherwise, it just ignores the packet. Unlike DV-Hop, LAEP broadcasts the anchor coordinates and the corresponding estimated distance to each sensor at the same time. It uses the following equation to estimate the transmission range, so that it can calculate the hop-size range and uses triangulation method to finally locate the position of the node:

$$d = h \times E(R), \tag{4}$$

where d and h are the distance and the hop count between an anchor node and the node to be evaluated, respectively, and $E(R)$ means the expected hop progress calculated by

$$E(R) = 2k\sin(\theta)\int_0^{r0} l^2 * e^{\left(-\frac{Ec+1}{\pi}\theta\left(1-\frac{l^2}{r0^2}\right)\right)}, \tag{5}$$

where k is node density, θ is the transmission angle of antenna. r_0 is the transmission range, l stands for radius of potential forwarding zone, and E_c is average connectivity given by

$$E_c = k\pi r_0^2 - 1. \tag{6}$$

3. Performance Evaluation and Comparison

3.1. Simulation Environment

The performance of the three localization schemes are evaluated and compared with each other via the MATLAB simulation. 20 nodes are deployed in the 20 m × 25 m area as illustrated in Figure 1. The colored dark nodes are anchors and their positions are already known. Each node calculates its position by using the three localization schemes in our simulation.

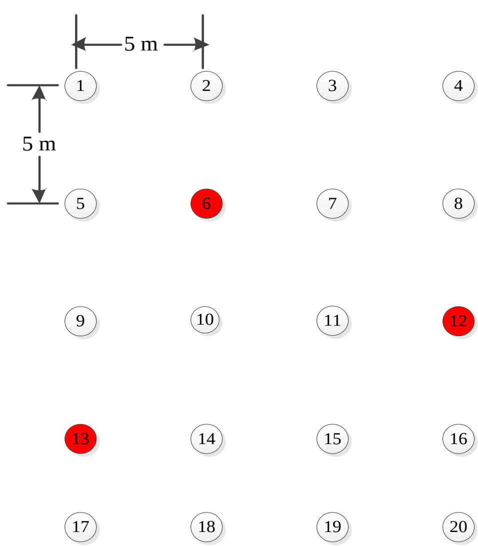

Figure 1. Node Deployment in the Simulation

The location error rate *LER* can be calculated by averaging the *x*-axis location error rate LER_x and the *y*-axis location error rate LER_y. LER_x, LER_y and *LER* are calculated by

$$LER_x = \frac{\sum_{i=1}^{n} |x_i - x_i^{'}|}{\sum_{i=1}^{n} x_i}, \quad (7)$$

$$LER_y = \frac{\sum_{i=1}^{n} |y_i - y_i^{'}|}{\sum_{i=1}^{n} y_i}, \quad (8)$$

and

$$LER = \frac{LER_x + LER_y}{2}, \quad (9)$$

respectively, where x_i is the correct *x*-axis position, x_i' is the estimated *x*-axis position, y_i is the correct *y*-axis position, and y_i' is the estimated *y*-axis position.

3.2. Simulation Results and Discussion

Figure 2 shows the simulation results of the location error rate for the three localization schemes. The location error is measured by increasing the number of anchor nodes. As the number of anchors is increased, the localization error rate is decreased for all the three localization schemes as shown in the figure. The LEAP algorithm achieves about 40% improvement compared to DV-Hop on the average. And, the probability grid algorithm achieves about 67% improvement compared to the LAEP algorithm on the average. In summary, the probability grid algorithm should be the choice if the location error rate is the primary concern. Again, the location error rate is the most important parameter in localization schemes in WSNs and, thus, it can be concluded that the probability grid localization scheme outperforms the other two schemes of DV-Hop and LEAP.

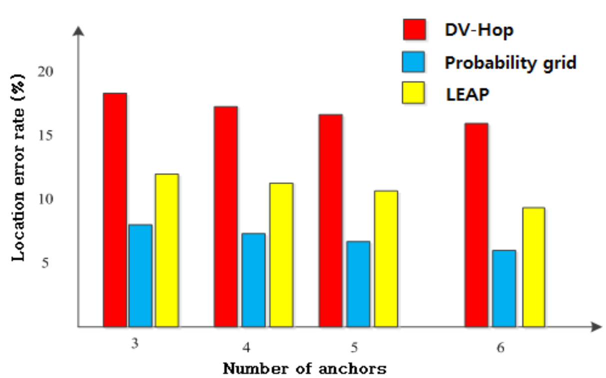

Figure 2. Location Error Rate of Three Schemes

4. Conclusion

The accuracy of localization is very important to location-aware applications and, thus, it is very important to choose a localization scheme with the highest accuracy. In this paper, the three typical localization schemes of DV-Hop, the probability grid localization scheme, and LAEP for WSNs have been reviewed and compared with each other in terms of localization accuracy. According to our simulation study, the probability grid localization scheme achieves the best performance of localization with the lowest error rate.

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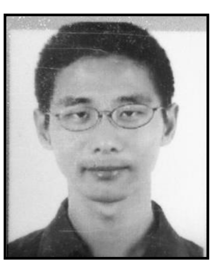

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