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Scalable DV-Hop Localization For Wireless Sensor Networks

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***Abstract*—Localization is an important problem for Wireless Sensor Networks(WSN). The localization can be categorized as range-free or range-based schemes. Since the sensor nodes are made to be cheap and small, the range-based schemes that use special devices for measurements are unsuitable in WSN. DV-Hop is one of the range-free localization algorithms using average hop-distance and number of hop counts. But it requires heavy communication cost if the number of nodes increases in the network. Therefore, we propose a simple algorithm to reduce the communication cost and its performance is verified via computer simulations.**

I. Introduction

Wireless sensor network(WSN) is an ad hoc network used to monitor areas of interests. This network consists of distributed small, light and cheap sensor nodes. These sensor nodes are being used in military, medical, industrial and environmental fields [1].

One of the important issues in WSN is localization among the sensor nodes. The localization systems are divided into range-free and range-based [2]. In a range-free system, the algorithms do not need hardware for range measurements, and are immune to range estimation errors. On the other hand, the range-based algorithms require more sophisticated hardware to measure range metrics such as Time of Arrival (TOA) [3], Time Difference On Arrival (TDOA) [4], Angle of Arrival (AOA) [4] and Received Signal Strength Indicator (RSSI) [4].

Range-free localization algorithms proposed so far include DV-Hop [5], Centroid [6], and MDS-MAP [7]. In this paper, we begin with the DV-Hop localization algorithm. The DV-Hop algorithm employs classical distance vector exchange so that all the nodes in network gets distances, in hops, to the beacon nodes. Once a beacon node receives a packet from other beacon nodes, it computes an average hop size which is then broadcasted again to the entire network. When this information from beacon nodes is received by an unknown node, the unknown node will estimate its coordinate by multilateration. However, the disadvantage of the DV-Hop localization algorithm is a heavy communication cost of $O(bn)$ where b is the number of beacons and n is the total number of nodes in the network. So, when the number of beacon nodes and unknown nodes increase, the communication cost increases rapidly.

Ad Hoc Positioning System(APS) in [5] used multi-hop and distance vector information. A similar algorithm is Hop-Terrain [8] that computes the node position as in DV-Hop in start-up phase. In refinement phase, the Hop-Terrain algorithm is concerned only with the nodes that exist within a one-hop neighborhood, and it focuses on increasing the accuracy of the position estimates. In CDV-Hop [9], an improved DV-Hop algorithm for unknown nodes positioning without the need of additional hardware is proposed. As a constraint on the range from the unknown node to reference node, it reduces the nodes average localization error.

APS(Near-3) [10] is based on a simple yet effective heuristic approach which chooses the nearest three anchors with respect to each individual sensor node. These works are not concerned with the scalability issue of the DV-Hop algorithm.

The Distributed Voronoi Localization (DV-Loc) [11] is another DV-Hop localization algorithm to reduce the communication cost in large network. This algorithm uses the Voronoi diagrams to limit the range of flooding, and the position estimates of nodes are constrained to remain within their cells. But the DV-Loc algorithm requires high computation load. So, we propose a simple algorithm in which the number of hop counts and average hop size are exploited to divide the network into disjoint cells.

The rest of the paper is organized as follows: Section II describes the proposed algorithm. Simulation results are provided in section III and the conclusions follow at the end.

II. Scalable DV-Hop Localization Algorithm

A. *Description of the SDV-Hop Algorithm*

In the SDV-Hop algorithm, we limit the range of the flooding and uses a simpler method to divide network into disjoint cells compared to the DV-Loc algorithm in [11].

Initially, beacon nodes that have their location information are deployed in the sensor field with other unknown nodes that don't have their location information. These beacon nodes are divided into multiple levels (see Table I). In our paper, there are four beacon nodes in the first level, four nodes in the second level, eight nodes in the third level and so on [11].

TABLE I
Examples of diving beacons into levels

Level	1st	2nd	3rd	4th	…
Number of nodes	4	4	8	8	…
Number of nodes	3	6	9	12	…

The divided beacon levels broadcast their position information in regular sequence. The beacon nodes of the first level start broadcasting and those of the second level receive the position information of first level beacon nodes. Similarly, the beacon nodes of the second level broadcast

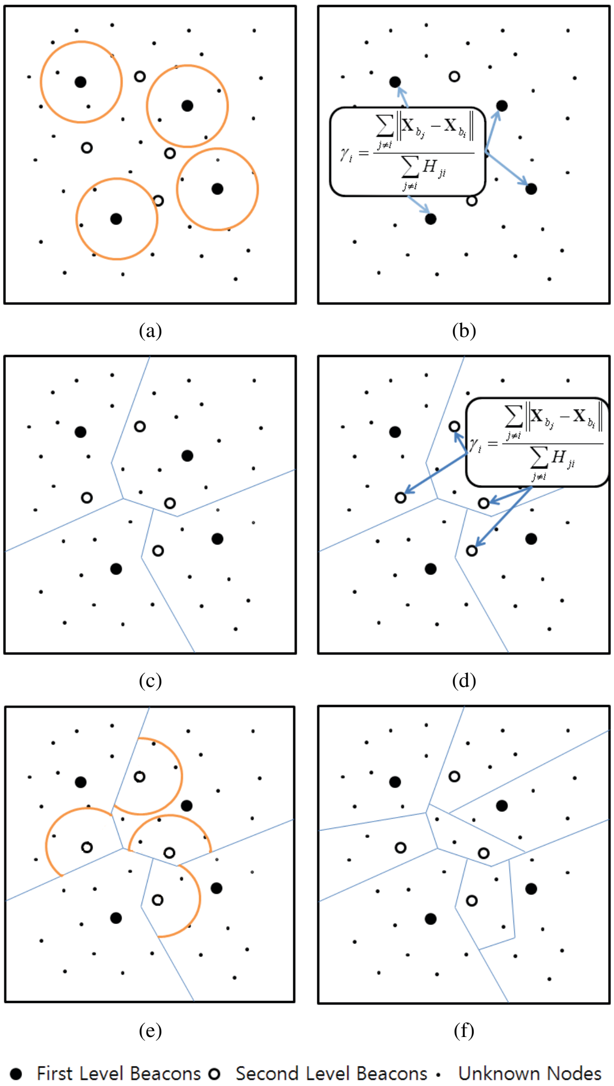

Fig. 1. Different phases of SDV-Hop

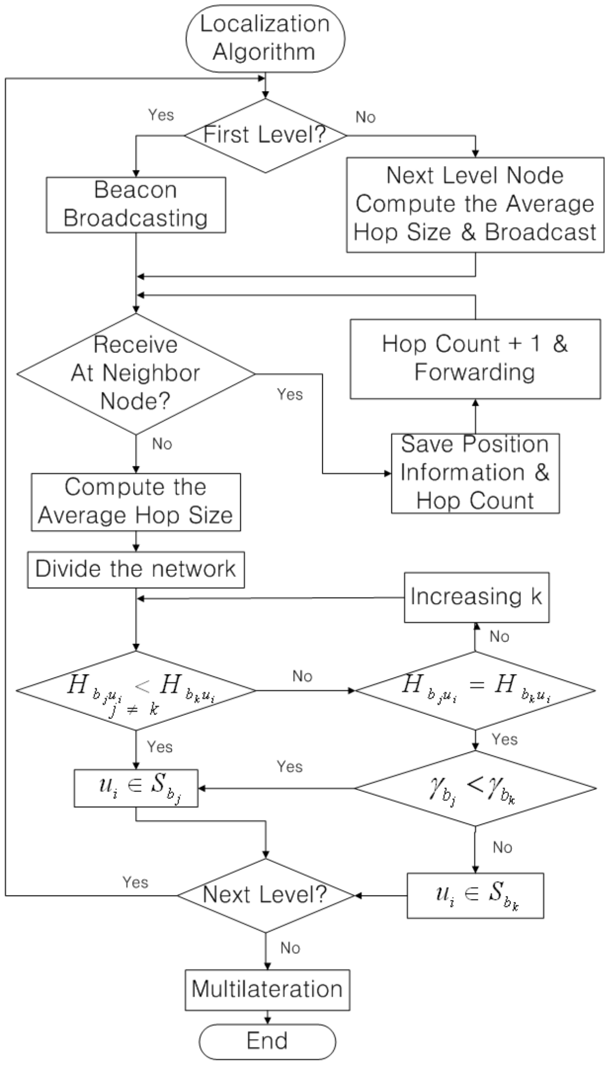

Fig. 2. The flow chart of the localization algorithm

and those of the third level receive the position information of second level beacon nodes and the process continues so on. So it can reduce the communication cost.

The SDV-Hop algorithm consists of the following five steps:

1) The four beacon nodes of the first level start broadcasting their position information (Fig. 1(a)). If a neighboring unknown node receives the position information from a beacon node, it saves the information, increases the hop count by one and forwards the information to surrounding nodes. This process is called flooding. If the information received by a node is the information of a beacon node saved already, the flooding does not occur.
2) When a beacon node in the first level receives the position information from the other beacon node, it computes the average hop size as in the APS algorithm [5] (Fig. 1(b)), and broadcasts this information. The average hop size γ_i for the i-th beacon node is computed as follows:

$$\gamma_i = \frac{\sum_{j \neq i} \| \mathbf{X}_{b_j} - \mathbf{X}_{b_i} \|}{\sum_{j \neq i} H_{ji}}, \forall i \qquad (1)$$

where H_{ji} is the number of hop counts from the beacon node j to the beacon node i and $\mathbf{X}_i$ is two dimensional coordinate of node i,(x_i, y_i).
3) All the nodes except the first level beacon nodes are divided into disjoint cells with the following criterion (See Fig. 1(c)):

$$u_i \in S_{b_j} \text{ if } H_{b_j u_i} < H_{b_k u_i}, \; j \neq k \qquad (2)$$

where u_i is an unknown node, S_{b_j} is the set of the nodes in the cell owned by the beacon node b_j, $H_{b_j u_i}$ is the number of hops (hop count) from the beacon node b_j to the unknown node u_i. If there are two equivalent smallest hop counts or more, the average hop size is also considered to divide the network. Specifically, the cell with the beacon node of the smaller average hop size is chosen as the cell in which node u_i is contained.
4) The beacon nodes in the second level compute the average hop size based on the position information and the hop counts from the first level beacon nodes (Fig. 1(d)). The second level beacon flooding is limited to their own cell (Fig. 1(e)). When the flooding is finished, a cell is divided into subcell by the procedure in step 3. Step 4 repeats for the

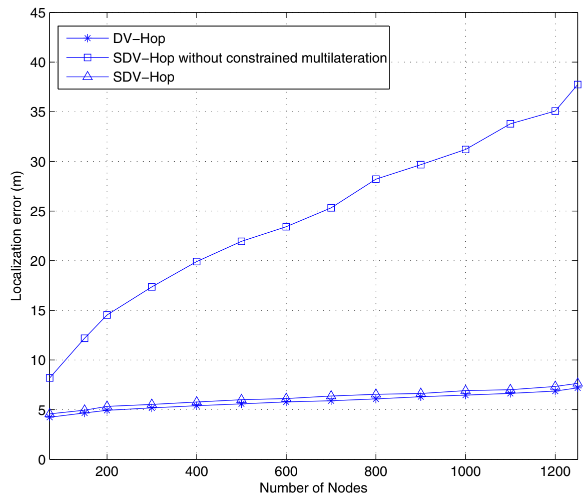

Fig. 3. Localization errors of SDV-Hop and DV-Hop

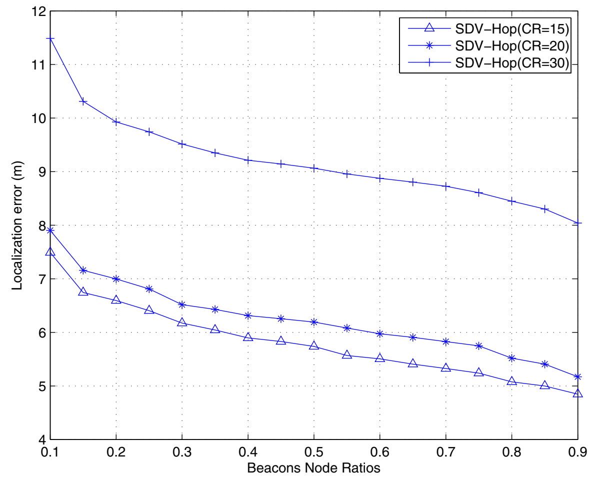

Fig. 4. Localization errors of SDV-Hop

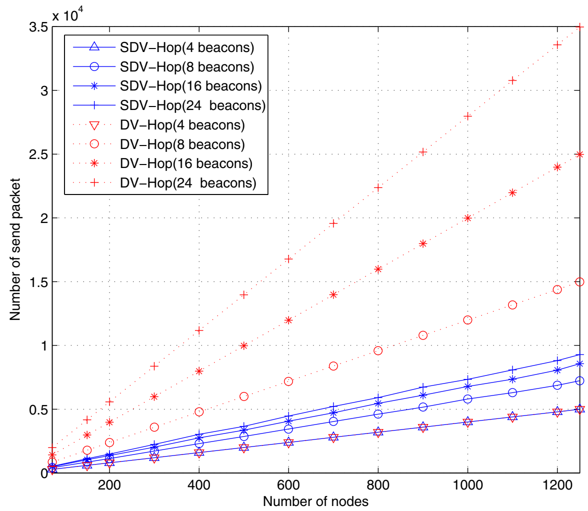

Fig. 5. Number of send packets for SDV-Hop and DV-Hop

beacon nodes in the next levels.

5) After all the beacon nodes finish the flooding and computation of the average hop size, unknown nodes have the information of hop counts and average hop size from surrounding beacon nodes (Fig. 1(f)). Then the final position estimates are obtained by using the following multilateration.

B. Constrained Multilateration

In the SDV-Hop algorithm, the localization error increases when the number of nodes increase as shown in Fig. 3. So, in order to reduce the localization error, we combine SDV-Hop with the constrained multilateration proposed in the CDV-Hop algorithm [9]. In this algorithm we assume that if the hop count from the beacon node b_j to an unknown node u is 1 (i.e., $H_{b_j u} = 1$), the node u is within the communication range of the beacon node b_j, that is $||u - b_j|| \leq D$. If $H_{b_j u} \geq 2$ then $(H-1)D < ||u - b_j|| \leq HD$. Therefore, the constrained multilateration is expressed as follows:

$$\widehat{\mathbf{X}}_u = \min_{\mathbf{X}_u} \sum_{i=1}^{M} \left| \parallel \mathbf{X}_{b_i} - \mathbf{X}_u \parallel - d_{b_i u} \right|$$

$$\text{subject to } (H_{qu} - 1)D \leq \parallel \mathbf{X}_q - \mathbf{X}_u \parallel \leq H_{qu} D, \quad (3)$$
$$\forall q \text{ such that}$$
$$q = \arg\min_{b_i} \{ H_{b_i u} \mid i = 1, 2, \cdots, M \}$$

where $\parallel \mathbf{X}_{b_i} - \mathbf{X}_u \parallel$ is the distance between the beacon node b_i and the node u. $d_{b_j u} = H_{b_i u} \gamma_i$ is the distance estimated with the average hop size and hop count.

Fig. 2 shows the flow chart of the proposed localization algorithm.

III. Simulation Results

We evaluated the SDV-Hop algorithm and compared it with the DV-Hop algorithm. In Fig. 3, the localization error in the SDV-Hop algorithm is more than the error in the DV-Hop algorithm because unknown nodes have much less information of beacon nodes in the SDV-Hop algorithm. The localization error is reduced by employing the constrained multilateration introduced in [9] and its performance is shown to be comparable to the performance of the DV-Hop algorithm.

Fig. 4 shows the localization errors with different numbers of beacons (Beacon nodes ratio = Number of beacons / Total number of nodes). The localization error tends to be smaller when the communication range is smaller since the average hop size can be more accurately estimated with short communication range.

The scalability is evaluated by varying the network size. The total number of nodes randomly distributed in the network are varying from 72 to 1250, and the number of beacons are varying from 4 to 24. Fig. 5 shows the number of packets transmitted in the SDV-Hop and the DV-Hop algorithms. When the number of beacon nodes are 4, the number of send packets in SDV-Hop is the same as the number of send packets in the DV-Hop. However, when the number of beacon nodes are 8 or more, the number of send packets in SDV-Hop are much less than the number of send packets in DV-Hop. We compared the communication cost of SDV-Hop with the communication cost of DV-Hop. The communication cost of DV-Hop is $O(nb)$ where n is the total number of nodes and b is the number of beacon nodes. The communication cost of SDV-Hop is $O(4n+2n\log(b-3))$. It means that the SDV-Hop algorithm can be more scalable in the number of nodes than the DV-Hop algorithm.

IV. Conclusion

We proposed the SDV-Hop algorithm. Unlike the DV-Loc algorithm the proposed algorithm does not need complex computations to divide sensor network into cells. To do that our algorithm only relies on the hop counts and the average hop size. Since the network is divided into multiple disjoint cells, the flooding is limited, hence the communication cost is accordingly reduced, compared to the DV-Hop algorithm. Computer simulation demonstrates that our algorithm exhibits comparable localization performance to the DV-Hop algorithm with much less communication cost. Therefore, the SDV-Hop localization algorithm is well suited for the network with the large number of nodes.

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