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## A Mobile Anchor-assisted Adaptive Localization Algorithm using Anchor-density-based Clustering for Wireless Sensor Networks

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**Abstract:** A new distributed mobile anchor-assisted localization algorithm using anchor-density-based clustering for wireless sensor network was proposed. In the algorithm, the mobile anchor equipped with Globe Position System (GPS) move around in the Wireless Sensor Network (WSN) field, the network was divided into many clusters and each cluster was belong to one of three grade by core density. Mobile anchor node was played different role in different cluster grade, in high-density cluster, mobile anchor only was used for error correction; in low-density cluster, mobile anchor was used to computing average distance and error correction; while in sparse-density cluster, mobile anchor only was used to compute average distance. Simulation results show that the localization accuracy of the proposed algorithm in irregular network is better than the DV-Hop algorithm and the average traffic is lower than the traditional DV-HOP algorithm.

**Key words:** Wireless sensor networks, mobile anchor-assisted, clustering, anchor density

### INTRODUCTION

Localization of sensor nodes has been an active research area in WSNs. Position information of nodes is a vital requirement in many WSN applications including monitoring, tracking and geographic routing (Aloor and Jacob, 2010). But in WSNs, node positions may not be known prior to or at the time of deployment. The process of estimating the unknown node positions within the network is referred to as localization (Patwari *et al.*, 2005). The limited power supply, size and cost considerations in sensor networks may prohibit the use of a GPS (Hofmann *et al.*, 1993) (Global Positioning System) module at each sensor node. Therefore, it is often the case with a general assumption that the positions of some nodes (called anchors), are known, so that it is possible to find the absolute positions of the remaining nodes (called unknown nodes) in the WSNs.

The localization system's architecture influences the outcome of a localization system. It plays a more important role especially when we have mobile nodes or/and mobile anchors in the network. The architecture of a localization system has a significant impact on its scalability, its ability to preserve user location privacy, its ease of deployment and its accuracy. The indoor localization architectures in the presence of mobile nodes or/and mobile anchors can be classified into two different indoor localization architectures, namely the mobile active architecture and the passive mobile architecture (Smith *et al.*, 2004). The active mobile architecture has an active transmitter on each mobile node which periodically

broadcasts a message on a wireless channel. Receivers deployed in the infrastructure (anchors) listen for such broadcasts and estimate the distance to the mobile node on each broadcast they hear. Typically, each receiver propagates this distance information to a central database (sink) that then updates the location of each mobile node (Gholami *et al.*, 2012).

### RELATED WORK

In the past several years, a number of localization protocols have been proposed. We classify the existing localization algorithms into two categories: The stationary anchor localization algorithms and the mobile anchor localization algorithms. The deployment and number of anchor nodes could greatly influence localization accuracy (Savvides *et al.*, 2001). However, the more anchor nodes are, the larger the cost of deployment network is. Once all the nodes are located, anchor nodes will be not so important. So, we could use a mobile Anchor Node (AN) dynamic moving in the network to assist location which can reduce cost of computation and communication. Furthermore, since the AN can move to blind areas where static anchor nodes do not cover, it may communicate with all the nodes directly which could enhance localization accuracy (Zhong *et al.*, 2010).

Stationary anchor location algorithm use stationary anchor information for localization which can be classified as range-based and range-free. The range-based algorithm uses absolute point-to-point distance or angle estimates for calculating the location which are relatively precise but

require additional hardware and their cost is relatively high (Savvides *et al.*, 2001). Common approaches for distance or angle estimation include Received Signal Strength Indicator (RSSI) (Wu *et al.*, 2005); Time of Arrival (TOA) (Priyantha *et al.*, 2000); Time Difference of Arrival (TDOA) (Ko and Vaidya, 2000) and Angle of Arrival (AOA) (Savvides *et al.*, 2001). Maximum Likelihood Estimation (MLE) is an alternative used in AHLOS system (Ad-Hoc Localization System) (Priyantha *et al.*, 2000), whose aim is to minimize the differences between the measured distances and estimated distances to determine the position of nodes. While producing fine grained locations, range-based protocols remain cost-ineffective due to the cost of hardware for radio, sound, or video signals, as well as the strict requirements on time synchronization and energy consumption. Range-based approaches can obtain more accurate measurements but they require complex and expensive hardware.

Due to the hardware limitations of sensor devices, range-free localization algorithms are a cost-effective alternative to the more expensive range-based approaches (Hu and Evans, 2004). There are two main types of range-free localization algorithms that were proposed for sensor networks: (1) Local techniques that rely on a high density of land marks so that, every sensor node can hear several land marks, each node estimates its location by calculating the center of the locations of all anchors that it hears. If anchors are deployed regularly, the location error can be reduced, although this is almost impossible in WSN deployments (Bulusu *et al.*, 2000). Galstyan *et al.* (2004) proposed a distributed on line algorithm in which sensor nodes use geometric constraints induced by both radio connectivity and sensing to decrease the uncertainty of their position. The sensing constraints which are caused by a commonly sensed moving target, are usually tighter than connectivity-based constraints and lead to a decrease in the average localization error overtime. Different sensing models, such as radial binary detection and distance-bound estimation, are considered. Ssu *et al.* (2005) proposed a localization scheme using a mobile anchor. Each anchor, equipped with the GPS, moves in the sensing field and broadcasts its current position periodically. The sensor nodes that obtain the information are able to compute for their locations. (2) Hop-based techniques that rely on flooding a network. To provide localization in networks where land mark density is low, hop-based techniques propagate location announcements through out the network. The DV-Hop (Niculescu and Nath, 2003) uses a technique based on distance vector routing. Each node maintains a

counter denoting the minimum number of hops to each land mark and updates that counter based on beacon packet received. Landmark location announcements propagate throughout the network. When a node receives a new land mark announcement and its hop counter is lower than the stored hop count for the land mark, the recipient updates its hop count to the new value and retransmits the announcement with an incremented hop count value. The known positions of the land marks as well as the computed ranges are used to perform a triangulation to obtain the estimated node positions. Many multi-hop WSN localization algorithms, both connectivity based (range-free) and distance based, have been formulated as non-linear optimization problems.

Mobile anchor localization algorithms also compute node-to-node distances by RSSI, TOA, TDOA and AOA. Zhang *et al.* (2008) proposed very low energy consumption wireless sensor localization for dangerous environments with single mobile anchor node. But this algorithm cannot ensure each node receives three non-collinear anchor coordinates. Koutsounikolas *et al.* (2007) studied the problem of path planning for mobile anchor to reduce localization error. Zhang *et al.* (2008) proposed a range-free localization scheme using mobile anchor nodes. When running once, this algorithm only located a part of nodes. In order to increase localization efficiency, the movement mode of the MN needs to be improved. Mobility introduces a real-time component to the localization algorithms. Wireless sensor networks are usually considered delay-tolerant. To the contrary, mobility makes a sensor network delay intolerant: information gathering and location calculation should happen in a timely manner, dependent on the speed of both the nodes and the anchors. This means that in a mobile wireless sensor network, methods relying on global knowledge such as calculating the number of hops or distances to all the anchors in the network are to be avoided. Similarly, a mobile node cannot really benefit from iterative localization techniques where the location estimation is refined whenever a node receives more information from the network. Besides possible information decay, a localization algorithm deployed in a mobile wireless sensor network should be able to cope with the temporary lack of anchors. In other words, the algorithms should be able to produce a location estimate in such conditions if the application layer has a need for it. In such cases, the location estimation could easily be tagged as uncertain, providing a mean for the application to assess how much the results of the localization algorithm should be trusted (Baggio and Langendoen, 2008).

## NETWORK MODEL

There are a set of anchor nodes and a set of sensor nodes in a WSN. A fixed number of anchor nodes are placed with the regions of coverage overlapped and serve as reference points, broadcasting periodic anchor signals. The sensor nodes are distributed randomly in the sensing field and receive messages from anchor nodes. The main responsibility of the anchor nodes is to send out beacon signals to help the sensor nodes to locate themselves. Each sensor node listens for a fixed time period and collects the RISS information of all beacon signals from adjacent anchor nodes. In this environment, it is assumed that (Yun *et al.*, 2009):

- The network is a static randomly deployed network. It means a large number of sensor nodes are randomly deployed in a two-dimensional geographic space, forming a network and these nodes do not move any more after deployment
- There exists only one Sink node which is deployed at a relative static place outside the WSNs
- There are N static anchor nodes which their positions are known through GPS or by other means such as pre configuration and M unknown nodes and there is a mobile Anchor Node (AN)
- The radio propagation is perfectly spherical and the transmission ranges for all radios are identical
- The whole area has been divided into many  $k \times k$  fields, namely, cluster which the cluster head only generates from anchor nodes in its cluster

We define the real geographic distance between two anchor nodes  $S_{ai}$  and  $S_{aj}$  as:

$$d_{an_i, an_j} = \sqrt{(x_{an_i} - x_{an_j})^2 + (y_{an_i} - y_{an_j})^2} \quad (1)$$

We adopt a simple disk model for network connectivity: Nodes  $S_{ai}$  and  $S_{aj}$  can communicate with each other if and only if  $d_{sai, saj} \leq r$ , where  $r$  is the connectivity range.

## MOBILE ANCHOR-ASSISTED ADAPTIVE LOCATION ALGORITHM USING ANCHOR-DENSITY-BASED CLUSTERING

Mobile anchor-assisted adaptive location algorithm using anchor-density-based clustering has three phases, first is generates cluster head based on maximum core density; second is cluster grading; third is adaptive location algorithm.

**Cluster head based on maximum core density:** In initialization, in cluster  $C_i$ , each anchor node  $an_i$  broadcasts packet including ID,  $(x_{an_i}, y_{an_i})$ ,  $n_{an_i}$  et al,  $n_{an_j}$  is the neighbor of anchor node  $an_i$ , its initial value is 0, so all anchor nodes in cluster can know other anchor nodes information.

We assume  $N_i(an_i)$  is the ordered set of  $an_i$ 's direct neighbor,  $C_r$  is the threshold of core node number which can be adjusted according to the network node density,  $N_r(C_r)$  is the  $C_r$ th neighbor from anchor node  $an_i$ ,  $d(i, N_r(C_r))$  is the distance between anchor node  $an_i$  and  $C_r$ th node, we define the parameter  $\alpha$  as Eq. 2:

$$\alpha = \begin{cases} d(an_i, N_r(C_r)), N_r(an_i) > C_r \\ r, N_r(an_i) \leq C_r \end{cases} \quad (2)$$

So we define the core density of anchor node is  $\omega$  (i) as Eq. 3:

$$\omega(an_i) = \frac{N_r(an_i)}{\alpha} \quad (3)$$

Each anchor node respectively calculates its core density and sends information to all neighbor anchor nodes including ID,  $\omega(an_i)$  et al, so the anchor node which has the maximum core density will be the cluster head. Head broadcasts information to all nodes in cluster, when received information, each anchor node and unknown node send information to head, so head can calculate the numbers of anchor nodes  $N_{an}$  and unknown nodes in cluster  $N_{un}$ .

**Cluster-density grading:** The location accuracy is closely related to the number of anchor nodes, the more number of anchor nodes, the more accurate locating. In the case of uniform distribution, the ideal number of anchor nodes is the point number which meets triple coverage for the whole region (Koutsounikolas *et al.*, 2007).

- **Theorem 1:** The number of meeting triple coverage is proportional to area

We assume that  $S_{area}$  is the area of cluster,  $r$  is the radius of anchor node, a cluster requires at least the number of anchor nodes as Eq. 4:

$$\omega(an_i) = \frac{N_r(an_i)}{\alpha} \quad (4)$$

We assume that the number of unknown nodes in cluster  $C_i$  is  $N_{un}(C_i)$ ,  $N_{an}(C_i)$  is the number of anchor nodes in cluster, so we define the average cluster density function as Eq. 5:

$$\rho_{3\_cov} = \frac{N_{an}(C_t)}{\frac{N_{an}}{3}} \quad (5)$$

Then the cluster is divided into different grade, we assume  $\tau$  is the threshold parameter, if  $N_{an}(C_t) > N_{an}$  and  $N_{un}(C_t) < \tau \times \rho_{3\_cov}$ , we define this cluster is a high density cluster ( $C_h$ ); if  $N_{an}(C_t) < N_{an}$  and  $\rho_{3\_cov} = N_{un}(C_t) < \tau \times \rho_{3\_cov}$ , we define this cluster is a low-density cluster ( $C_l$ ); if  $N_{an}(C_t) < N_{an}$  and  $N_{un}(C_t) = \tau \times \rho_{3\_cov}$ , we define this cluster is a sparse cluster ( $C_s$ ).

**Mobile anchor-assisted adaptive location algorithm for different grading:** The entire network is divided in many clusters and each cluster has a grade, in order to reduce communication and improve accuracy, our scheme uses a mobile anchor-assisted adaptive locating method for different grades.

- **High-density cluster location:** For high-density cluster  $C_h$ , there are enough anchor nodes to satisfy triple coverage, so using these anchor nodes in cluster can locate those unknown nodes position, at the same time, in order to improve the accuracy, the location information of mobile anchor node used to correct error, the specific method is as follows:

**Step 1:** Each anchor node  $an_i$  calculates its average distance by Eq. 6:

$$Av_{an_i} = \sum_{an_j \neq an_i} d_{an_i, an_j} / \sum_{an_j \neq an_i} h_{an_i, an_j} \quad (6)$$

where  $an_j$  is the neighbor anchor node of  $an_i$ ,  $h_{an_i, an_j}$  is the hops between the anchor node  $i$  and anchor node  $j$  and  $j$  is the neighbor of anchor node  $an_i$ .

**Step 2:** Head uses Eq. 7 calculates the average distance of cluster  $C_h$ :

$$Av(C_h) = \sum_{i=1}^{N_{an}(C_h)} Av_{an_i} / N_{an}(C_h) \quad (7)$$

**Step 3:** Head calculates the whole cluster error through Eq. 8:

$$er(C_h) = \sum_{i=1}^{N_{an}(C_h)} (Av(C_h) - Av_{an_i}) / N_{an}(C_h) \quad (8)$$

**Step 4:** When mobile anchor node  $m_{ob}$  enter cluster  $C_h$ , it send its location information, so anchor nodes and head get these information and anchor nodes compute the distance and send to head, head also

get mobile location and computes its distance. For the high-density cluster, head uses mobile location to correct the average distance. So, head can get the average error through Eq. 9:

$$er_m = Av(C_h) - \sum_{i=1}^k d_{an_i, m_{ob}} / k \quad (9)$$

$k$  is the number of anchor nodes which have received the mobile anchor location information (head is an anchor node)

**Step 5:** Head broadcasts the  $Av(C_h)$ , error  $C_h$  and  $er_m$ , each unknown node  $u$  uses these information and its neighbor anchor information to estimate distance between unknown node  $u$  and neighbor anchor through Eq. 10:

$$d_{est}(u_w, an_i) = Av(C_h) \times h_{u_w, an_i} + \lambda \times er(C_h) + \rho \times er_m \quad (10)$$

where  $u_w$  is the unknown node,  $n_{u_w}$  is the number of 1-hop neighbor anchor node,  $\lambda$  is a variable parameter and can be dynamically adjusted according to network environment,  $\lambda \in [-1, 1]$  and  $\rho$  is a variable parameter and can be dynamically adjusted according to move speed,  $\rho \in [-1, 1]$

**Step 6:** Unknown node  $u_w$  selects three anchor nodes which are not collinear from all neighbor anchor nodes to compute the location by trilateration

- **Low-density cluster location:** The low-density cluster, we assume that is  $C_l$ , the number of anchor nodes is less than the number of triple coverage nodes and there are many unknown nodes, so the anchor in cluster can not locate the unknown nodes accurate location, we use the mobile anchor node to assisted locate, the specific method is as follows

**Step 1:** Head computes the distance  $d_{an_i, an_j}$  between anchor nodes which belong to  $C_l$  and mobile anchor node  $m_{ob}$ , then computes average distance by Eq. 11-12:

$$Av_{mob} = \sum_{i=1}^k d_{an_i, m_{ob}} / k \quad (11)$$

$$Av(C_l) = \left( \sum_{i=1}^{N_{an}(C_l)} Av_{an_i} + Av_{mob} \times k \right) / (N_{an}(C_l) + k) \quad (12)$$

Where  $N_{an}(C_l)$  is the number of anchor nodes including  $C_l$ ,  $k$  is the number of anchor nodes which have received the mobile anchor location information (head is an anchor node)

**Step 2:** The head of  $C_1$  computes the average distance error by Eq. 13:

$$er(c_i) = \left( \sum_{i=1}^{N_{an}(C_i)} (Av(c_i) - Av_{an}) + \sum_{i=1}^k (Av(c_i) - Av_{mv}) \right) / (N_{an}(C_i) + k) \quad (13)$$

where  $N_{an}(C_i)$  is the number of anchor nodes in low-density cluster and  $k$  is the number of anchor nodes which have received the mobile anchor location information (head is an anchor node)

**Step 3:** The unknown node  $u_w$  calculates the estimated distance between unknown node  $u_w$  and anchor  $an_i$  by Eq. 14:

$$d_{est}(u_w, an_i) = Av(C_i) \times h_{uw, an_i} + \lambda \times er(C_i) \quad (14)$$

where  $\lambda$  is a variable parameter and can be dynamically adjusted according to network environment,  $\lambda \in [-1, 1]$ ,  $h_{uw, an_i}$  is the hops between unknown node  $u_w$  and anchor  $an_i$

**Step 4:** The cluster head broadcasts the average distance and average error, all unknown nodes would receive and store these information

**Step 5:** Unknown node  $u_w$  selects three anchor nodes which are not collinear from all static anchor nodes or mobile node to compute the location by trilateration

- **Sparse-density cluster location:** In the sparse cluster  $C_s$ , it can not locate the large unknown nodes location only depend on the static anchor nodes, in order to reduce network traffic, if in a loop, the number of anchor nodes and mobile anchor can not satisfy triple coverage, head should wait on the mobile anchor entering in the next loop. We assume that there is  $k$  location information of mobile anchor node which meeting triple coverage

**Step 1:** Head computes the average distance between anchor nodes or mobile node through the Eq. 11-12

**Step 2:** The cluster head broadcasts the average distance, all unknown nodes would receive and store these information

**Step 3:** In the sparse cluster, the mobile anchor assisted compute the average distance, so the estimated distance of unknown node  $u_w$  can be computed through Eq. 15:

$$d_{est}(u_w, an_i) = Av(C_s) \times h_{uw, an_i} \quad (15)$$

**Step 4:** Unknown node  $u_w$  selects three anchor nodes which are not collinear from all static anchor nodes or mobile nodes to compute the location by trilateration

## SIMULATION RESULTS

This section provides a detailed quantitative analysis comparing the performance of our scheme with traditional DV-HOP.

In our experiments, the deployment area is a square plane of 1000 m by 1000 m. The plane is divided into  $10 \times 10$  cluster. Each cluster is  $100 \times 100$  m, the number of nodes from 1000 randomly deploy in the area and the anchor nodes accounted for 20%, others are unknown nodes, the radius is from 10-30 m, there is a mobile anchor node. In order to effectively compare and analyze the performance of proposed algorithm and DV-HOP, all data is the average values from 10 tests.

Figure 1 is the average error of the different anchor density in cluster, the maximum error of DV-HOP is 0.72, it minimum error is 0.398. But the maximum and minimum error of our scheme is at the lower level. From the simulation results, we can see that there is a large fluctuation in DV-HOP and has a better stability while there is a small fluctuation in our scheme. There is because of using mobile anchor node to add anchor density and increase the average hop distance accuracy.

Figure 2 is the relationship between the ratio of anchor nodes and location accuracy, we can see from picture 3, the location accuracy is increases with the ratio of anchor nodes increasing, radius is 15 m, proposed algorithm has a better location performance under the same anchor ratio, for example, when the ratios is 20%, the location accuracy of proposed algorithm is 0.375 while

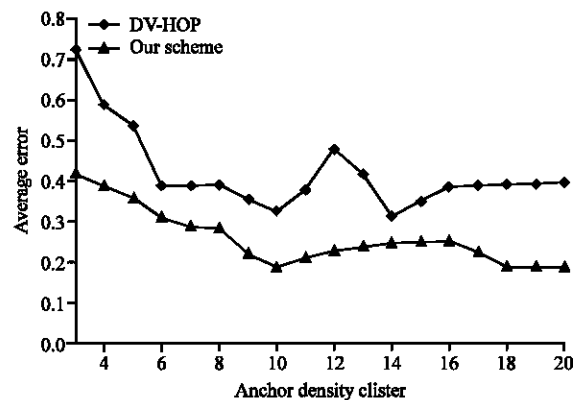


Fig. 1: Comparison results of localization accuracy

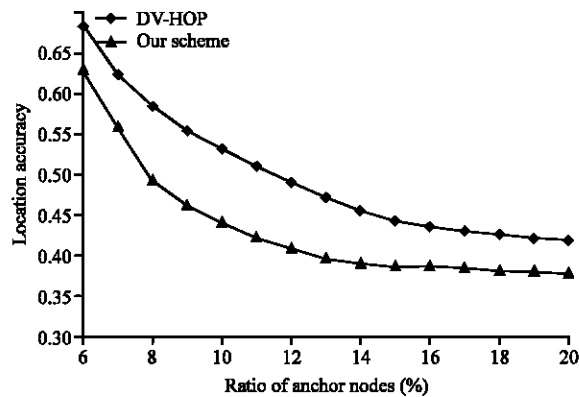


Fig. 2: Relationship between the ratio of anchor nodes and location accuracy

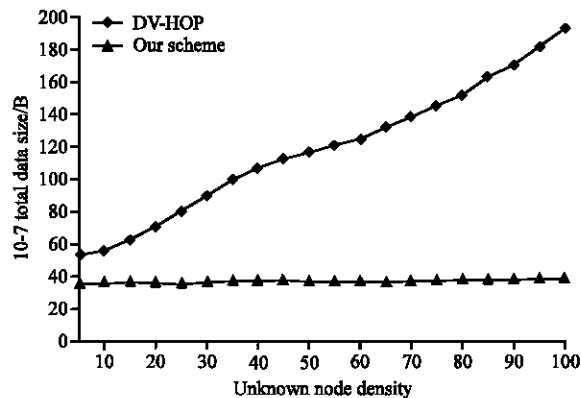


Fig. 3: Comparison results of average traffic

DV-HOP is 0.42. Especially when the ratio of anchor nodes is large than 14%, the proposed algorithm has a better stability.

Figure 3 shows the average traffic of DV-HOP algorithm is rapidly increases along the unknown nodes number increasing while the average traffic of our scheme is always maintained at a lower stable level. This is because of the DV-HOP utilized flooding method to exchange neighbor information in the entire network through hop by hop, this method leads to the average traffic sharp increasing with the network size and unknown nodes. In our scheme, the unknown nodes in high density cluster only using internal anchor nodes can determine the unknown location; for low density cluster, only using one or two times mobile anchor node can locate the unknown location; for spare density cluster, because there are fewer anchor nodes, in order to locate unknown nodes, the mobile anchor node may be repeatedly pooling, so the traffic may be increase but the

average traffic of entire network would not rapidly increase with the network size and the unknown nodes number.

## CONCLUSION

In order to improve the localization accuracy, a mobile anchor-assisted adaptive location algorithm using anchor-density-based clustering for wireless sensor networks was proposed, first, the network was divided into many cluster and each cluster was belong to one of three grade by core density. Mobile anchor node was played different role in different cluster grade, in high-density cluster, mobile anchor only was used for error correction to reduce error; in low-density cluster, mobile anchor was used to computing average distance and error correction; while in sparse-density cluster, mobile anchor only was used to compute average distance. From the results of the simulation, we can see that the localization accuracy of the proposed algorithm in irregular network is better than the DV-Hop algorithm and the average traffic is lower than the traditional DV-HOP algorithm.

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