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Rang-Free Localization Schemes for Wireless Sensor Networks

Rania Khadim[1], Mohammed Erritali[2], Abdelhakim Maaden[1]
[1]Laboratory of Mathematics and Applications, Faculty of Sciences and Techniques, Sultan Moulay Slimane University
[2]TIAD laboratory, Departement of Computer Sciences, Faculty of Sciences and Techniques, Sultan Moulay Slimane University
Corresponding author, e-mail: khadimrania@gmail.com, m.erritali@usms.ma

Abstract

Localization of nodes is one of the key issues of Wireless Sensor Network (WSN) that gained a wide attention in recent years. The existing localization techniques can be generally categorized into two types: range-based and range-free. Compared with rang-based schemes, the range-free schemes are more cost-effective, because no additional ranging devices are needed. As a result, we focus our research on the range-free schemes. In this paper we study three types of range-free location algorithms to compare the localization error and energy consumption of each one. Centroid algorithm requires a normal node has at least three neighbor anchors, while DV-hop algorithm doesn't have this requirement. The third studied algorithm is the amorphous algorithm similar to DV-Hop algorithm, and the idea is to calculate the hop distance between two nodes instead of the linear distance between them .The simulation results show that the localization accuracy of the amorphous algorithm is higher than that of other algorithms and the energy consumption does not increase too much.

Keywords: *wireless sensor networks, node localization, centroid algorithm, DV–Hop algorithm, amorphous algorithm*

1. Introduction

Wireless Sensor Network (WSN) is composed of a large number of sensor nodes, which have the ability of sensing, computation, and wireless communication and can monitor and acquire physical information in the distribution detection area in real time.

WSN have attracted worldwide research and industrial interest, because they can be applied in various areas such as hospital surveillance, smart home, and environmental monitoring. For most of these applications, localization is a fundamental issue, because users normally need to know not only what happens, but also where interested events happen or where the target is [1]. For example, in hospital surveillance, the knowledge of where the patient can help the doctors to arrive at the right place as quickly as possible in urgent case [2, 3]; in a disaster relief operation using WSN to locate survivors in a collapsed building, it is critical that sensors report monitoring information along with their location [4-7]. On the other hand, the position parameters of sensor nodes are assumed to be available in many operations for network management, such as routing where a number of geographical algorithms have been proposed [8-10], topology control that uses location information to adjust network connectivity for energy saving [11-13].

The location of sensor nodes is not predetermined or engineered. This allows that sensor nodes can be deployed randomly in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities [14].

In WSNs the localization problem can be intercepted that in a sensor network, the location of multiple nodes has been known (beacon node) and the location of target node (unknown nodes) is obtained by the sensor information and effective localization algorithm [15].

At present, many ideas have been proposed for node localization in wireless sensor networks [16-19]. According to whether or not the network needs to measure the actual distances between network nodes and based on whether accurate ranging is required, WSN

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localization algorithm can be divided into two categories: Range-Based algorithm and Range-Free algorithm. The Range-based schemes [20-24] algorithm mainly includes the measurements of angle and distance (the range information) such as Received Signal Strength Indicator (RSSI) [24], Time of Arrival (TOA) [22], Time Difference on Arrival (TDOA), and Angle of Arrival (AOA) [24, 25], between concerned equipment, and then the calculate the desired position based on trilateration or triangulation approaches. So it needs extra hardware supporting, large computing and communicating with high energy consumption.

While the range-based scheme uses the distance or angle between nodes, the range-free approach only depends on the connectivity information between nodes such as the hops for localization without any extra hardware supporting [26]. In this scheme, the nodes that are aware of their positions are called anchors, while others are called normal nodes. Anchors are fixed, while normal nodes are usually mobile. Normal nodes first gather the connectivity information as well as the positions of anchors, and then calculate their own position [27]. The connectivity information of a node N can be its hop counts to other nodes. The connectivity is used as an indication of how close this node N to other nodes .Since no ranging information is needed the range-free scheme can be implemented on low-cost wireless sensor networks. Another advantage of the range-free scheme is its robustness; the connectivity information between nodes is not easily affected by the environment [28].

Although the localization accuracy of the range-based algorithm is usually higher than that of the range-free Algorithm because of the simple hardware support, the lower consumption, and the antinoise ability, the range-free algorithm is widely used in many applications. As a result, we focus our research on the range-free scheme. The range-free algorithm includes Centroid algorithm, Distance Vector-Hop (DV-Hop), and Amorphous algorithm. It includes Centroid algorithm [29], Distance Vector-Hop (DV-Hop) [30], and Amorphous algorithm [31].

2. Localization Algorithms

2.1. Centroid Algorithm

Bulusu and Heidemann [29] have proposed the centroid localization algorithm, which is a range-free, proximity-based, coarse-grained localization algorithm. The algorithm implementation contains three core steps. First, all anchors send their positions to all sensor nodes within their transmission range. Each unknown node listens for a fixed time period t and collects all the beacon signals it receives from various reference points. Second, all unknown sensor nodes calculate their own positions by a centroid determination from all n positions of the anchors in range. The centroid localization algorithm uses anchor nodes (reference nodes), containing location information (x_i, y_i) to estimate node position. After receiving these beacons, a node estimates its location using the following centroid formula:

$$(x_{est},y_{est})=\left(\frac{x_1+x_2+\ldots+x_k}{k},\frac{y_1+y_2+\ldots+y_k}{k}\right) \quad (1)$$

2.2. DV-Hop algorithm

DV-hop is a distributed hop by hop positioning algorithm proposed by Dragos Niculescu and Badri Nath [30]. This is the most basic scheme; it uses an exchange distance vector so that all nodes in the network are able to calculate the distance between the anchors. Each anchor maintains a table $\{X_i, Y_i, h_i\}$ where $\{X_i, Y_i\}$ are the coordinates of other network anchors and h_i is the number of hops separating the latter from the node. Each anchor calculates the distance to the other anchors in the network, using the location information obtained from a positioning system; it deduces an approximation of the hop distance. This is the hop distance that will constitute the correction information for the entire network. Each anchor node calculates:

$$Hopsize_i=\frac{\sum_{i\#j}\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}}{\sum_{i\#j}h_{ij}} \quad (2)$$

After all unknown nodes have received the hop-size from anchor nodes which have the least hops between them; they compute the distance to the anchor nodes based on two factors: hop-size and minimum hop count (h_{id}) using:

$$d_i = h_{id} * HopSize_i \quad (3)$$

In the third step, unknown nodes calculate their position according to the distance to each anchor node obtained in the second step. Let (x, y) be the coordinates of the unknown node, and (x_i, y_i) the coordinates of anchor i. Let's say d_i is the distance between anchors i to unknown nodes, and then we have:

$$\begin{aligned} (x - x_1)^2 + (y - y_1)^2 &= {d_1}^2 \\ (x - x_2)^2 + (y - y_2)^2 &= {d_2}^2 \\ &\vdots \\ (x - x_n)^2 + (y - y_n)^2 &= {d_n}^2 \end{aligned} \quad (4)$$

Formula (5) can be schemed with the following linear equation:

$$AP = B \quad (5)$$

Where,

$$P = \binom{x}{y} \quad (6)$$

$$A = -2 * \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \cdots & \cdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \quad (7)$$

$$B = \begin{bmatrix} {d_1}^2 - {d_n}^2 - {x_1}^2 + {x_n}^2 - {y_1}^2 + {y_n}^2 \\ {d_1}^2 - {d_n}^2 - {x_2}^2 + {x_n}^2 - {y_2}^2 + {y_n}^2 \\ \vdots \\ {d_{n-1}}^2 - {d_n}^2 - {x_{n-1}}^2 + {x_n}^2 - {y_{n-1}}^2 + {y_n}^2 \end{bmatrix} \quad (8)$$

The position of the unknown node is obtained by using least square method, which can be expressed as:

$$P = (A^T A)^{-1} A^T B \quad (9)$$

2.3. Amorphous Algorithm

Amorphous algorithm is similar to DV-Hop algorithm, and the idea is to calculate the hop distance between two nodes instead of the linear distance between them. Amorphous algorithm is composed of the following three steps [32].

2.3.1. Calculate the Minimum Hop from the Unknown Node to the Beacon Node

Every beacon node sends messages to the unknown nodes by flooding method. Formula (10) is used to calculate the minimum hop from the node i to k.

$$S_{(i,k)} = \frac{\sum_{j \epsilon nbrs(i)} h_{(j,k)} + h_{(i,k)}}{|nbrs(i)| + 1} - 0.5 \quad (10)$$

Where: $S_{(i,k)}$ is the minimum hop from the unknown node i to the beacon node k; $h_{(j,k)}$ is the integer hop from the unknown node j to the beacon node k; $h_{(i,k)}$ is the integer hop from the unknown node i to the beacon node k; $nbrs(i)$: are the neighbor nodes around the unknown node i; $|nbrs(i)|$:is the number of the neighbor nodes around the unknown node i.

2.3.2. Calculate the Distance from the Unknown Node to the Beacon Node

Formula (11) is used to calculate the average distance of one hop:

$$HopeSize=r\left(1+e^{-n_{local}}-\int_{-1}^{1} e^{-(n_{local}/\pi)\left(arcos\ t-t\sqrt{1-t^2}\right)}dt\right) \quad (11)$$

Where r is the wireless range of the node and n_{local} is the average connectivity of the network. The distance d from the unknown node to the beacon node can be calculated on the basis of the average distance of one hop and the minimum hop from the unknown node to the beacon node [31]. It can be expressed:

$$d = HopSize_i \times S_{(i,k)} \quad (12)$$

2.3.3. Adopt the Least Squares Method to Locate

When the estimated distances from the unknown node to three or more than three beacon nodes have been obtained, the location of the unknown node can be calculated. It is shown as:

$$\begin{aligned}(x_1 - x)^2 + (y_1 - y)^2 &= {d_1}^2 \\ &\vdots \\ (x_n - x)^2 + (y_n - y)^2 &= {d_n}^2\end{aligned} \quad (13)$$

The above formula will be solved by the least squares method; the location of the unknown node can be obtained:

$$X = (A^T A)^{-1} A^T b \quad (14)$$

Where $(x_1, y_1), (x_2, y_2), (x_3, y_3) \dots\dots (x_n, y_n)$ are the coordinates of n beacon nodes, (x, y) is the coordinates of the unknown node, and $d_1, d_2, d_3, \dots., d_n$ are the distances from the unknown node to the beacon nodes:

$$A = 2 * \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ \cdots & \cdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \quad (15)$$

$$B=\begin{bmatrix} {x_1}^2 - {x_n}^2 + {y_1}^2 - {y_n}^2 + {d_n}^2 - {d_1}^2 \\ \vdots \\ {x_{n-1}}^2 - {x_n}^2 + {y_{n-1}}^2 - {y_n}^2 + {d_n}^2 {d_{n-1}}^2 \end{bmatrix} \quad (16)$$

The location of the unknown node can be calculated on the basis of (15) and (16).

3. Results and Analysis

3.1. Network Topology

The network topology is an isotropic topology:

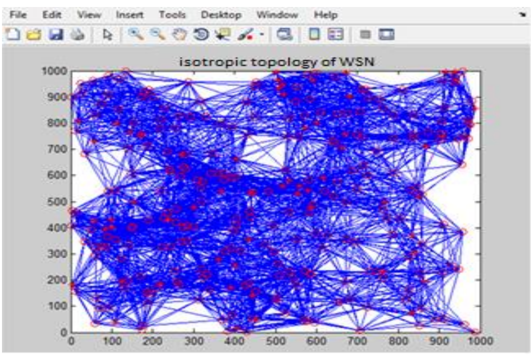


Figure 1. Network isotropic topology

3.2. Transmission Model

As a transmission model we use the reguler model due to its adaptation for wireless sensor networks:

$$P_R(d) = P_T - PL(d_0) - 10\eta log\left(\frac{d}{d_0}\right) \quad (17)$$

Where P_R is the received signal power, P_T is the transmit power and $PL(d_0)$ is the path loss for a reference distance of d_0 and η is the path loss exponent.

3.3. Simulation Platform and Distribution of Nodes

MATLAB simulation software can be used to process the different data and verify the feasibility of the algorithms. Data Network deployment area is 1000 m × 1000 m, the node coordinates are generated randomly, the number is 300, there are 60 beacon nodes, the proportion of beacons is 20%, the wireless range is 300 m, and the communication model used is Regular Model. Distribution of nodes is shown in Figure 2.

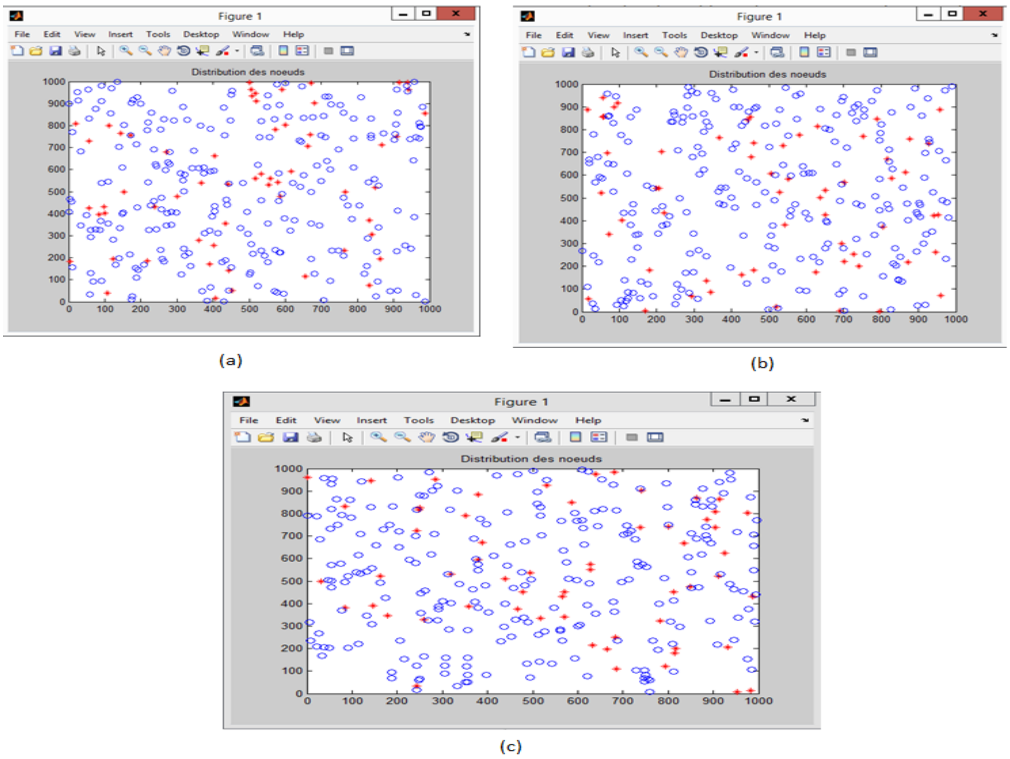


Figure 2. Distribution of nodes figures: (a) Centroid algorithm (b) DV-Hop algorithm (c) Amorphous algorithm

The different algorithms can be simulated to get the localization error shown in Figure 2.

The localization error is an important indicator to evaluate the localization performance. To calculate the localization error we use the following Formula:

$$Localization\ error = \frac{\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}}{R} \quad (18)$$

Where $(x_1, y_1)^2$ is the actual location of the unknown node and $(x_2, y_2)^2$ is the estimated location, where R is the wireless range.

To calculate the localization error for all algorithms we need firstly to generate uniformly distributed random topology within the square area using the following Matlab code:

```
BorderLength=100; //Side length of square regions,
NodeAmount=100; //The number of network nodes
BeaconAmount=8; //Beacon nodes
UNAmount=NodeAmount-BeaconAmount;
R=50; //Communication distance of node
h=zeros(NodeAmount,NodeAmount);//The initial number of hops is 0; BeaconAmount row, NodeAmount
column
X=zeros(2,UNAmount);//Estimated initial node coordinate matrix

C=BorderLength.*rand(2,NodeAmount);//Coordinate of all nodes
//3*NodeAmount matrix; (First row: Serial number for the nodes), (2nd & 3th row : their coordinates)
Sxy=[[1:NodeAmount];C];
//Beacon nodes coordinate
Beacon=[Sxy(2,1:BeaconAmount);Sxy(3,1:BeaconAmount)];

// We Calculate Unknown node coordinates
UN=[Sxy(2,(BeaconAmount+1):NodeAmount);Sxy(3,(BeaconAmount+1):NodeAmount)];
//We Draw node distribution
plot(Sxy(2,1:BeaconAmount),Sxy(3,1:BeaconAmount),'r*',Sxy(2,(BeaconAmount+1):NodeAmount),Sxy(3,(
BeaconAmount+1):NodeAmount),'k.');
xlim([0,BorderLength]);
ylim([0,BorderLength]);%Limitations of the area
title('* Red beacon nodes . Black unknown node')
```

To calculate the localization error, we need to determinate the unknown point coordinates for all algorithms using the Least squares method.The following matlab code present the method:

```
d=Distance; %distance from each unknown node to its nearest beacon node
for i=1:2
for j=1:(BeaconAmount-1)
a(i,j)=Beacon(i,j)-Beacon(i,BeaconAmount);
end
end
A=-2*(a');
% d=d1';
for m=1:UNAmount
for i=1:(BeaconAmount-1)
B(i,1)=d(i,m)^2-d(BeaconAmount,m)^2-Beacon(1,i)^2+Beacon(1,BeaconAmount)^2-
Beacon(2,i)^2+Beacon(2,BeaconAmount)^2;
end
X1=inv(A'*A)*A'*B; % Least Square method
X(1,m)=X1(1,1); % x coordinate
X(2,m)=X1(2,1); % y coordinate
end
UN  %True coordinates of nodes
X   %Estimated coordinates of nodes using DV-HOP
for i=1:UNAmount
error(1,i)=(((X(1,i)-UN(1,i))^2+(X(2,i)-UN(2,i))^2)^0.5);
end
figure;plot(error,'-o');
title('Error of each unknown node');
error=sum(error)/UNAmount;
Accuracy=error/R;
```

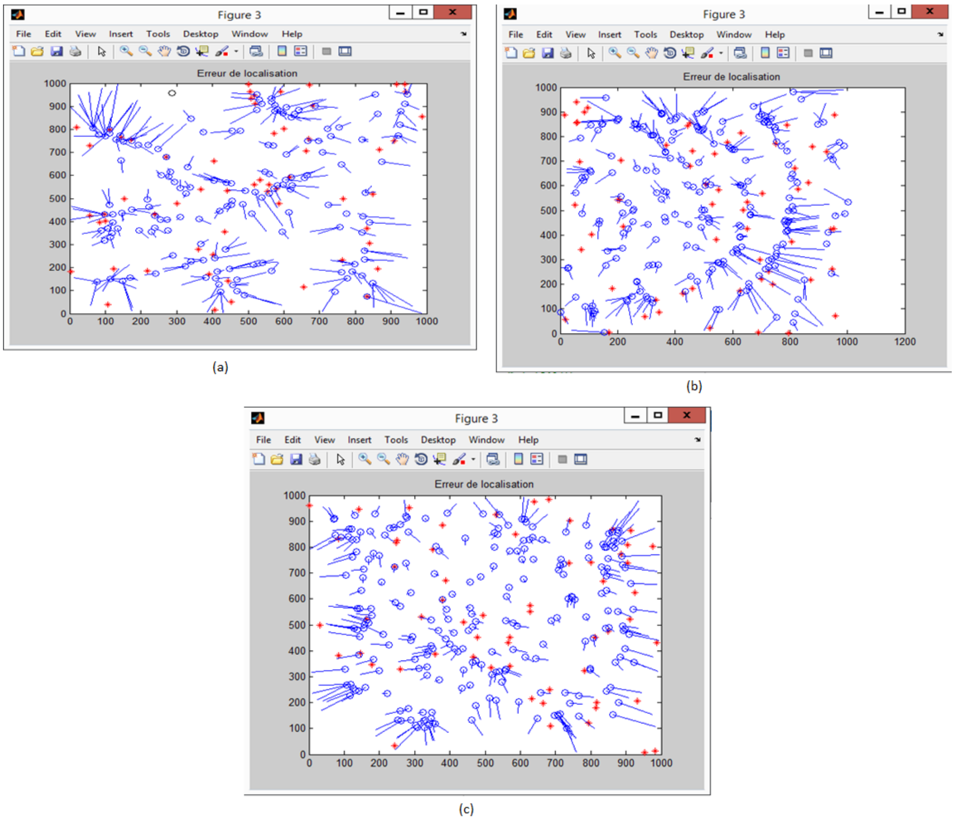


Figure 3. The localization error figures: (a) Centroid algorithm, (b) DV-Hop algorithm, and (c) Amorphous algorithm

In Figure 3, the blue circle represents the estimated location of the unknown node and the blue line represents the localization error of the unknown node.

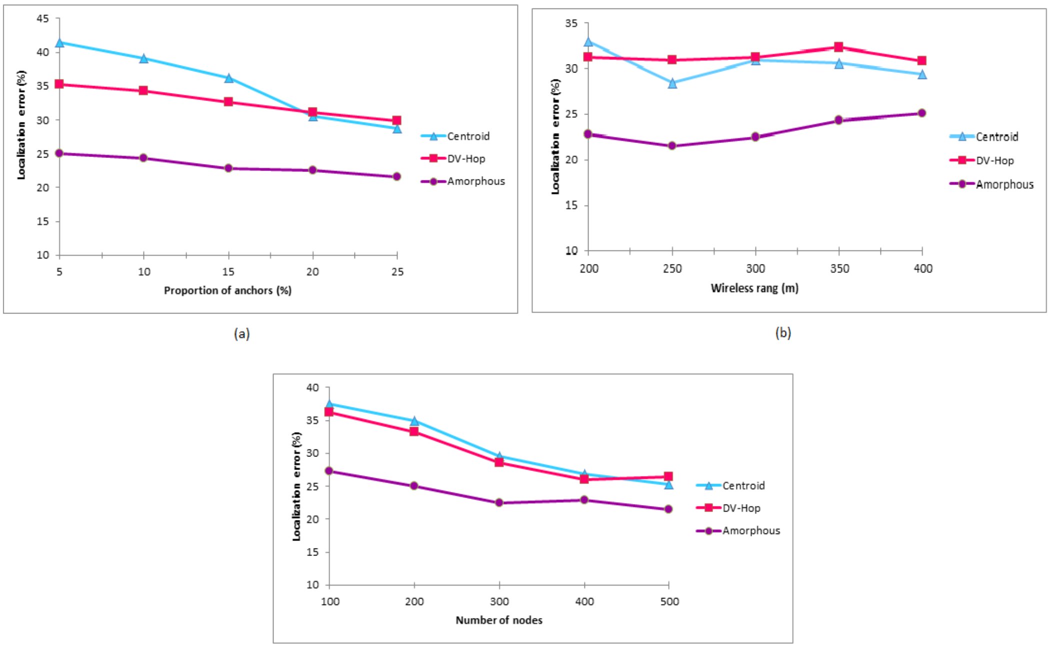
The localization error of Centroid algorithm is 0, 2937. In Figure 4(b). The localization error of DV-Hop algorithm is 0, 3022. The localization accuracy of the Centroid algorithm is higher than that of the DV-Hop algorithm. In Figure 4(c). The localization error of Amorphous algorithm is 0, 2361. We can see that the localization accuracy of the amorphous algorithm is higher than that of the centroid algorithm and DV-Hop algorithm obviously.

To observe the performance of the different algorithms, simulations were performed under different conditions for Centroid, DV-Hop, and Amorphous. All the nodes in the simulation are randomly distributed in the area of 1000 m × 1000 m. Each dataset and set of the condition is run for 1000 times so as to take into account the localization error of different algorithms. For comparison we use the average value of the localization error.

For different proportions of beacons and from figure 4(a), it is clear that the localization error of the three algorithms decreases as the proportion of beacons increases.

Simulating the different wireless range and setting the proportion of beacons by 20%, it is found that as shown in Figure 4(b) the localization error of the algorithms decreases as the wireless range increases. The localization error of the amorphous algorithm increases when wireless range is more than 300m.

Based on different numbers of nodes, the result presented in Figure 4(c) shows that the localization error of the 3 algorithms decreases as the number of nodes increases.



(c)

Figure 4. The localization error under different conditions: (a) proportion of beacons and localization error, (b) wireless range and localization, (c) number of nodes and localization error

Most of the energy consumption is communication that's why computational costs make up only a small part of all energy consumption in WSN. So to extend the lifecycle of network the energy consumption of communication should decrease. In order to decrease the energy consumption of communication, all nodes cannot send the information to a central node to calculate their location, because the energy consumption of communication is too large.

Table 1 compares the average computing time needed by the three algorithms to localize a single node and localization error. All experiments are conducted on the same computer under the same conditions mentioned before and the communication model used is Regular Model. Due to the simple calculation, Centroid algorithm generally requires less computing time than the other four algorithms. Amorphous algorithm is similar to DV-Hop algorithm.

Table 1. Average computing time to localize single node and localization error

Algorithms	Localization error	Computing time
Centroid	0.2937	0.383
DV-Hop	0.3022	0.512
Amorphous	0.2361	0.536

To find out the performance of the algorithm proposed in this paper, the simulations of energy consumption under different conditions are completed for Centroid, DV-HOP and Amorphous algorithm.

To observe the performance of the different algorithms using the energy consumption as an assessment metric we follow the same steps and we use the same data and conditions presented before to study the performance of the three algorithms in terms of the localization error.

The result of energy consumption is shown in Figure 5(a). It is clear that energy consumption of the three algorithms increases as the proportion of the beacons increases. Under the same proportion of beacons, the energy consumption of Centroid algorithm is lowest, because it broadcasts only once. DV-hop algorithm needs to broadcast twice, so the energy consumption of communication is large [13].

The similar result can be got in Figures 5(b) and 5(c). It is certain that accurate localization will bring more energy consumption. So localization algorithm should be designed according to different applications.

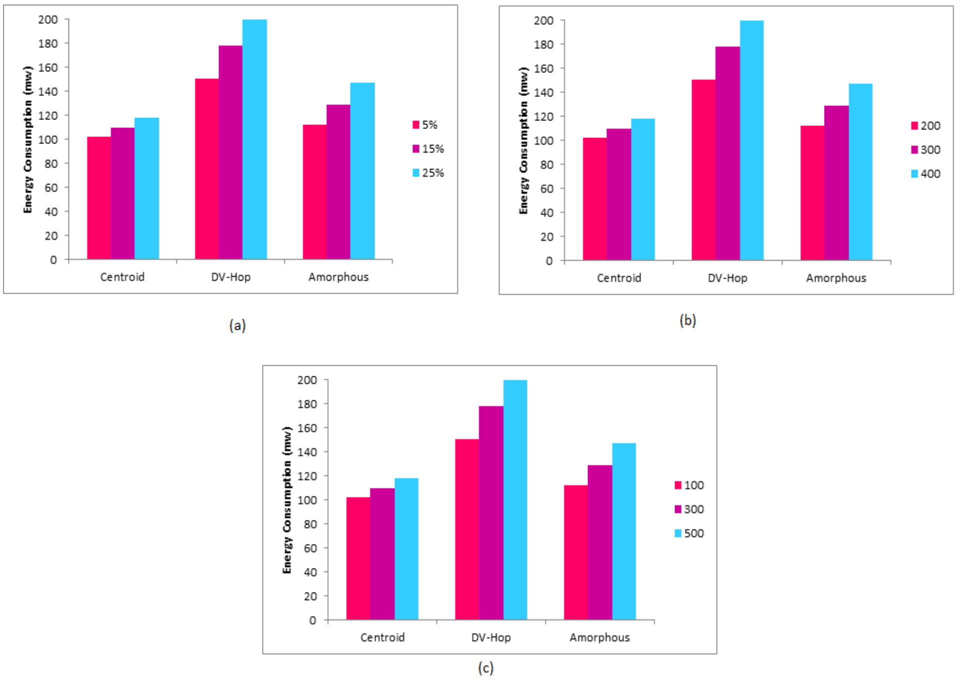


Figure 5. Energy consumption under different conditions: (a) energy consumption on different proportions of beacons , (b) consumption on different wireless range, and (c) energy consumption on different numbers of nodes

4. Conclusion

Positional accuracy is very important indicator for assessing the location of performance. More localization is high precision location of the performance is better. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

In addition, the accuracy of the location of the amorphous algorithm is superior to that of other algorithms and there is not a large increase of energy consumption, which is why it is suitable for the location of network nodes large scale.

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