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A weighted centroid localization algorithm for randomly deployed wireless sensor networks

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ABSTRACT

Localization is one of the important requirements in wireless sensor networks for tracking and analyzing the sensed data/events. In most of the applications of wireless sensor networks, the event information without its location information has no significance. The well known traditional Distance-Vector Hop (DV Hop) algorithm and weighted centroid DV Hop based algorithms can be easily implemented in real wireless sensor networks with low cost and no additional hardware requirement, but it has poor localization accuracy and high power consumption. In order to avoid these limitations, a weighted centroid DV-Hop algorithm is proposed in this paper. The proposed algorithm uses weights that consider the influence of different factors such as number of anchors, communication radius, and nearest anchor to determine location of unknown node. Simulation results and theoretical analysis prove that proposed algorithm outperforms the traditional DV-Hop algorithm in terms of localization error and power consumption.

1. Introduction

Wireless Sensor Network (WSN) is an autonomous distributed wireless network composed of cheap, power deficient and randomly deployed nodes called sensor nodes along with a server node called base station (Nayak and Stojmenovic, 2010). These sensor nodes detect event and pass this event information to the base station via their neighbor nodes (Nayak and Stojmenovic, 2010). WSNs are widely used for various applications such as Military and National Security application, Environment monitoring, Medical application, Precision Agriculture, Indoor Climate Control, Fire detection, etc (Nayak and Stojmenovic, 2010; Zhao et al., 2013; Xing and Mišić, 2010). In most of these applications of WSNs, any event information without its location information is meaningless. For example, in Fire detection application, both event (fire) and place (location) where fire is detected are required. Thus, Localization is an important requirement in Wireless sensor networks. Many localization algorithms have been proposed in last two decades to determine location of a sensor node. Based on hardware requirement, the localization algorithms have been classified into two categories: Range-based and range-free localization (Chen et al., 2008; He et al., 2003). Range-based localization algorithms uses exact measurements based techniques and generally require costly equipment to find distance or angle information between neighboring nodes so as to determine location information with high accuracy (Alrajeh et al., 2013; Savvides et al., 2001). Some of range-based localization algorithms are: received signal strength indicator (RSSI) (Girod et al., 2002), time of arrival (TOA) (Harter et al., 2002), time difference of arrival (TDOA) (Cheng et al., 2004), and angle of arrival (AOA) (Niculescu and Nath, 2003), etc.

Range-free localization algorithms apply distance approximation algorithms to determine node's location and do not require any expensive hardware. Range-free localization algorithms use nodes that are aware of their location (anchors) to find the location of unknown nodes. There are many range-free localization algorithms such as centroid algorithm (Bulusu et al., 2000), DV-Hop (Niculescu and Nath, 2001), amorphous (Nagpal, 1999), multidimensional scaling (MDS) (Shang and Ruml, 2004) and approximate point-in-triangulation (APIT) (Zhang et al., 2012).

Although range-based algorithms give accurate results, still range-free localization algorithms are preferred due to their low cost and feasibility for large-scale wireless sensor networks. In this paper, we focus on range-free DV-Hop algorithm that is more

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popular among all other range-free localization algorithms due to its simplicity, low cost and robustness. But, DV-Hop algorithm also has some limitations such as low localization accuracy, high power consumption and high communication overhead. Previous works have tried to improve localization error in DV-Hop algorithm, but very little work has been done to improve power consumption. We have proposed an improved DV-Hop based algorithm which not only improves its localization error, but also reduces its power consumption. Simulation results show that the proposed algorithm improves the localization accuracy and reduces power consumption as compared with previous algorithms.

This paper makes three contributions to the localization problem in WSNs. First, we present a simple, energy efficient and highly accurate localization scheme for WSNs when compared with DV-Hop algorithm and other weighted localization algorithms. Secondly, we explore the influence of nearest anchor nodes on localization performance. Third, we explore the influence of broadcasting range on energy consumption.

The rest of this paper is organized as follows. In Section 2, we briefly review localization algorithms related to our proposed algorithm. In Section 3, our proposed algorithm is explained. In Section 4, the simulation results and discussion are given. Finally, we present our conclusions in Section 5.

2. Related works

For benchmarking of our study, this section provides a brief background about few algorithms related to ours.

2.1. DV-Hop algorithm

The DV-Hop algorithm was first reported by Dragos Niculescu and Badri Nath in Niculescu and Nath (2001). The main idea of this algorithm is to determine approximate distance between two nodes by multiplying average hop distance with number of hops between them. It consists of three phases. In first phase, each anchor sends its location information and *hop count* value (initially set to 0) in the form of packet to its neighbor nodes. Then the nodes that receive this packet, send the given packet to its neighboring nodes after increasing *hop count* value by 1. In this way, all the nodes in the network get the minimum value of *hop count* from each anchor and location information of every anchor in the form of *hop count* table.

The second phase involves calculation of average distance in a hop (*AvgHopDistance*) by every anchor using Eq. (1) and broadcasting this information to all nodes in the network.

$$AvgHopDistance_i = \frac{\sum_{i=1 i\neq j}^{m}\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}{\sum_{i=1 i\neq j}^{m} h_{ji}} \quad (1)$$

where m is total number of anchors in the given network, i is the id of each anchor, h_{ji} is the minimum number of hop counts between anchor i and anchor j, (x_i, y_i) and (x_j, y_j) represents coordinates of anchors i and j, and $AvgHopDistance_i$ is the average distance of a hop computed by anchor i. Then, each unknown node u computes approximate distance from anchor node i using Eq. (2).

$$d_{ui} = AvgHopDistance_i \times h_{ui} \quad (2)$$

After getting distance from each anchor, in the third phase, the unknown node determines its location using multilateration method (Niculescu and Nath, 2001). This multilateration method uses least-squares technique (Niculescu and Nath, 2001) that works as follows:

Let the coordinates of unknown node u and anchor A_i be (x_u, y_u) and (x_i, y_i). Then, the following system of equations can be derived:

$$\left.\begin{array}{c}(x_u - x_1)^2 + (y_u - y_1)^2 = d_{u1}^2\\(x_u - x_2)^2 + (y_u - y_2)^2 = d_{u2}^2\\ \vdots \\(x_u - x_m)^2 + (y_u - y_m)^2 = d_{um}^2\end{array}\right\} \quad (3)$$

Eq. (3) can be transformed to Eq. (4).

$$\left.\begin{array}{c}x_1^2 - x_m^2 + y_1^2 - y_m^2 - d_{u1}^2 - d_{um}^2 = 2\times x_u \times (x_1 - x_m) + 2\times y_u \times (y_1 - y_u)\\x_2^2 - x_m^2 + y_2^2 - y_m^2 - d_{u2}^2 - d_{um}^2 = 2\times x_u \times (x_2 - x_m) + 2\times y_u \times (y_2 - y_u)\\ \vdots \\x_{m-1}^2 - x_m^2 + y_{m-1}^2 - y_m^2 - d_{u(m-1)}^2 - d_{um}^2 = 2\times x_u \times (x_{m-1} - x_m) + 2\times y_u \times (y_1 - y_u)\end{array}\right\} \quad (4)$$

Eq. (4) can be written in the form of matrix Eq. (5) as follows:

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

$$\text{where } A = 2\times\begin{bmatrix}x_1 - x_m & y_1 - y_m\\x_2 - x_m & y_2 - y_m\\ \vdots & \vdots \\x_{m-1} - x_m & y_{m-1} - y_m\end{bmatrix},\quad X_u = \begin{bmatrix}x_u\\y_u\end{bmatrix},$$

$$\text{and } B = \begin{bmatrix}x_1^2 - x_m^2 + y_1^2 - y_m^2 - d_{u1}^2 - d_{um}^2\\x_2^2 - x_m^2 + y_2^2 - y_m^2 - d_{u2}^2 - d_{um}^2\\ \vdots \\x_{m-1}^2 - x_m^2 + y_{m-1}^2 - y_m^2 - d_{u(m-1)}^2 - d_{um}^2\end{bmatrix}$$

Eq. (5) can be converted to Eq. (6) as follows:

$$X_u = (A^T A)^{-1} A^T B \quad (6)$$

Eq. (6) is solved to find the coordinates of the unknown node by using Least Square method (Niculescu and Nath, 2001).

2.2. Centroid algorithm

The Centroid Localization Algorithm (Bulusu et al., 2000) was proposed by Nirupama Bulusu, John Heidemann and Deborah Estrin. This algorithm consists of two phases. In first phase, all anchor nodes broadcast their location information in the form of packet to all other nodes that come under threshold region. In second phase, each unknown node u determines its location (x_u, y_u) by taking arithmetic mean of all coordinates of all the anchor nodes that are within threshold region of unknown node. This is described using Eq. (7).

$$x_u = \frac{\sum_{i=1}^{m} x_i}{m},\quad y_u = \frac{\sum_{i=1}^{m} y_i}{m} \quad (7)$$

where (x_i, y_i) are the coordinates of anchor node i and m is total count of anchor nodes that are within threshold region of unknown node u. This algorithm is easy to implement, but does not give accurate results and requires a complex method to determine threshold value.

2.3. Weighted centroid algorithm based on DV hop

In Zhang et al. (2012), Zhang et al. proposed a weighted Centroid Localization Algorithm (WCL) to improve computational complexity and power consumption of DV-Hop localization algorithm. WCL Algorithm consists of two phases. In first phase, each node gets minimum hop count value from each anchor node using first phase of DV-Hop. In second phase, every unknown node u finds its location (x_u, y_u) using Eq. (8).

$$x_u = \frac{\sum_{i=1}^{m} w_i x_i}{\sum_{i=1}^{m} w_i}, \quad y_u = \frac{\sum_{i=1}^{m} w_i y_i}{\sum_{i=1}^{m} w_i} \tag{8}$$

where $w_i = \frac{1}{h_{ui}}$, is the weight of each anchor i, h_{ui} is minimum hop count value of node u from anchor i and m are total anchor nodes.

The weight factor is taken as inversely proportional to number of hops. This has been used to give more weight age to nearest anchor. The anchor with less number of hops is closer to the given node, thus has more impact in determining the location of given node.

Unlike original DV Hop algorithm, this algorithm has only two phases and in its second phase, there is no broadcasting of packets containing average hop distance by anchor nodes to other nodes, thus WCL algorithm has low computational complexity and consumes less power (incurred only because of broadcasting of packets in first phase). But WCL algorithm's localization accuracy needs to be considered. Thus there is a need of a localization algorithm which improves localization accuracy to large extent.

2.4. Improved weighted Centroid algorithms based on DV-Hop

In Zhang et al. (2012), B. Zhang proposed another improved weighted centroid algorithm (IWCL) to increase accuracy. It works in three phases. The first phase and second phase have similar steps as that in first phase and second phase of DV-Hop algorithm. The first phase gives minimum hop count value h_{ij} for each anchor to all nodes. The second phase enables each node to know average hop distance of every anchor. The third phase computes the location of unknown node using Eq. (8) with the difference in computing weight. The weight used in Eq. (8) is computed using Eq. (9).

$$w_i = \left(\frac{1}{h_{ui}}\right)^{\frac{r}{HopSize_{av}}} \tag{9}$$

where $HopSize_{av}$ is average of all these averages of hop distances computed by each anchor using Eq. (1) and r is the communication radius of node.

Simulation results in Zhang et al. (2012) prove that localization accuracy of IWCL is far better than original DV hop algorithm and WCL algorithm. The drawback of IWCL is that it consumes high energy same as that of original DV Hop algorithm because of flooding of large number of packets between nodes in first two phases.

2.5. Improved weighted Centroid DV-Hop algorithm

In Song and Tam (2015), G. Song and D. Tam proposed an improved weighted centroid DV-Hop(IDWCL). This algorithm works in two phases. In the first phase, all nodes get minimum hop count value from every anchor in similar fashion as that in first phase of original DV Hop algorithm. In second phase, every unknown node u gets its location (x_u, y_u) using Eq. (8).

The weight w_i of anchor i is determined by using Eq. (10).

$$w_i = \frac{\sum_{i=1}^{m} h_{ui}}{m h_{ui}} \tag{10}$$

Although this algorithm has low computational complexity because of only two phases and energy consumption taking place only in first phase, but it does not improve localization accuracy to a satisfactory level.

2.6. Optimized weighted Centroid algorithm

In Blumenthal et al. (2005), J. Blumenthal, F. Reichenbach and D. Timmermann proposed an optimized WCL algorithm (Optimized WCL) which was mainly developed to reduce computational complexity and to improve localization accuracy and connectivity of the localization algorithm. It utilizes Eq. (8) to compute coordinates of non-anchor nodes. It has also derived optimum transmission range used by sensors and the given value gives 100% of connectivity. The optimum radius is computed using Eq. (11).

$$r_{op} = \frac{\sqrt{18}}{2} a \tag{11}$$

where a is the distance between sensor nodes. Simulation results prove that the given algorithm scales well and is most appropriate for large scale networks.

2.7. Need for an alternate solution

It is observed from all these related works that there is strong need for an alternate localization algorithm which can improve localization accuracy and also reduce power consumption. Thus, we proposed an enhanced weighted localization algorithm which takes into consideration both these performance factors. The algorithm does not consider all the anchor nodes to determine location of unknown node, but only considers anchors near to the given unknown node. This idea of using only near anchors improves localization accuracy. Further, to reduce power consumption, the algorithm places a limit on broadcasting of packets. In all above related works, the broadcasting of packets is done in such a way that it should reach all the nodes in the network. In our proposed algorithm, we have limited the broadcasting range to t hops in first and second phase. If the packet of an anchor goes t hops far from the given node, then that packet is discarded. The simulation results in Section 4 show that the localization algorithm is striking a good balance between requirements of localization accuracy and power consumption.

3. Proposed weighted centroid DV Hop algorithm

In this section, we present an enhanced Weighted Centroid DV-Hop (EWCL) algorithm. In EWCL algorithm, the weighted centroid algorithm (Zhang et al., 2012) is enhanced by considering a novel way for weight computation. EWCL algorithm calculates the weight by considering different factors such as influence of different anchors, communication radius and near anchors of a given node. In previous works (Niculescu and Nath, 2001; Zhang et al., 2012; Song and Tam, 2015; Blumenthal et al., 2005), almost all improvements in traditional DV hop algorithm have addressed the issue of localization error, but very few works have addressed the problem of power consumption which is the main consideration in power constrained wireless sensor networks. The proposed EWCL algorithm not only improves localization error, but also reduces power consumption. It is assumed that the given algorithm will work for isotropic environment. The whole tasks in the proposed algorithm are explained using the flowchart as illustrated in Fig. 1. The algorithm is composed of three phases.

Phase 1: Determining minimum number of hop counts by each node from every anchor

In the first phase, the nodes will not broadcast in whole network, but will broadcast within t hops only. The value of t varies from 2 to h_{max}. The simulation results in section 4 prove that the best value of t is 2. This change will reduce power consumption. The power consumption depends upon the total number of packets transmitted in the network. More the number of packets transmitted, more the energy consumed. Thus to limit this power consumption, we limit the broadcasting of packets in first phase within t hops. This change also reduces localization error. In the original DV Hop algorithm, the localization error is large as more number

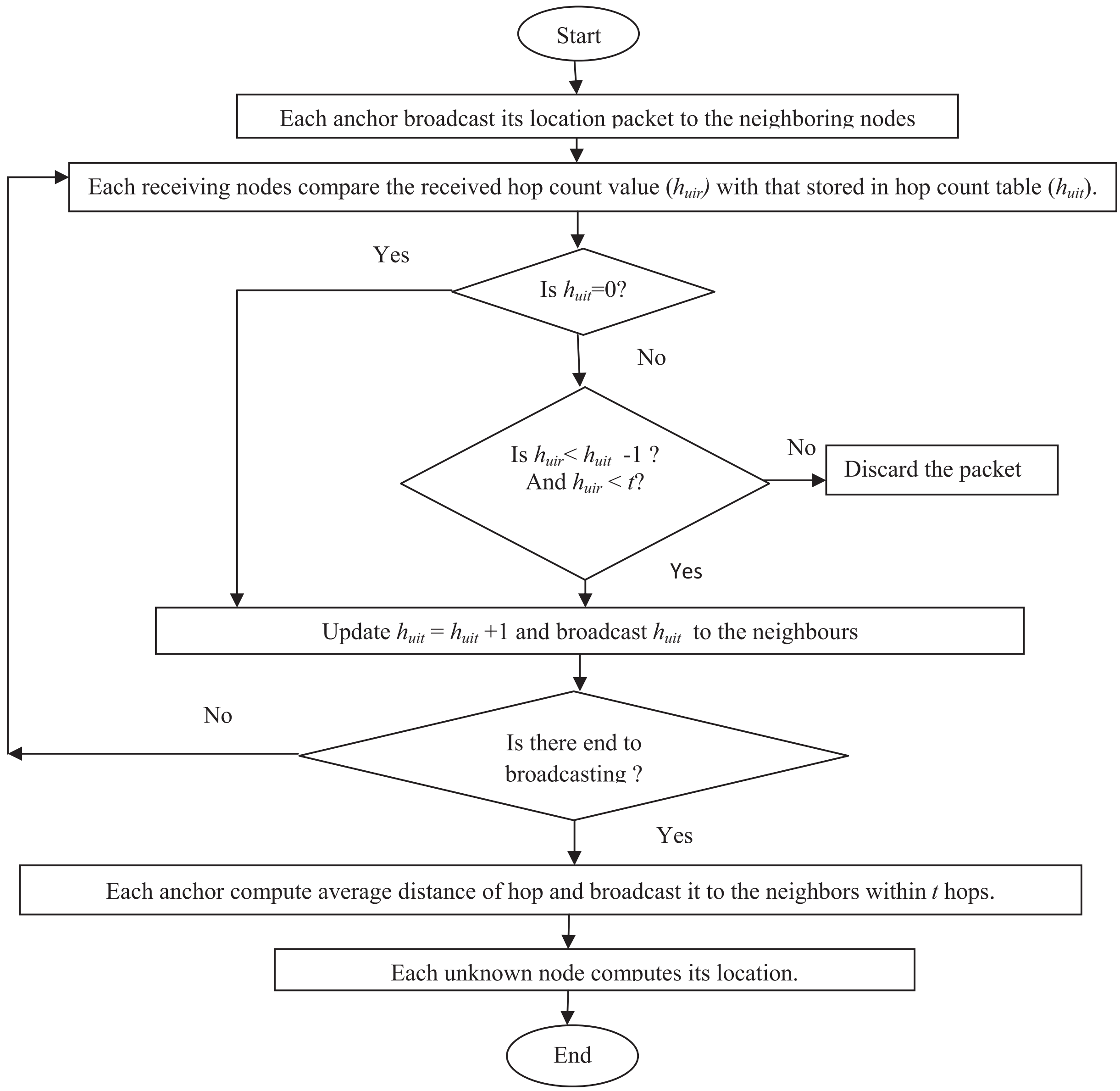

Fig. 1. Flowchart of enhanced weighted centroid DV Hop algorithm.

of anchor nodes is used to determine location of a node. Thus if only selected anchors (near anchors within t-hops) are used in determining the location of a node, then it is expected to give better localization accuracy. The working of first phase is as follows:

Firstly, each anchor node broadcasts its location information in the form of packet to its neighbor nodes within t hops. The packet contains $< x_i, \ y_i, \ h_{ui} >$ information where x_i,y_i are x and y-coordinates of anchor i and h_{ui} represents hop count value. The initial value of h_{ui} is *0*. Each node u maintains its *hop count* table containing $<i, x_i, y_i, h_{ui}>$ for each anchor i within t hops. When the packet is received by any node, it checks its own table and if the value of h_{ui} stored in its table is less than h_{ui} value received by it and h_{ui} value is less than t, then it ignores that received value, otherwise it increments h_{ui} value by 1 and stores the new value of h_{ui} for anchor i in its table. After saving this value, it forwards the packet with updated value of h_{ui} to all its neighbors. In this way, after first phase, each node u gets minimum hop count (h_{ui}) from every anchor node i which are within t hops and has updated *hop count* table containing entries of only those anchors nodes which are within t hops.

Phase 2: Determining average distance per hop by each anchor:

For the second phase, the broadcasting is done within t hops only. In this phase, each anchor A_i estimates average distance per hop ($AvgHopDistance_i$) using Eq. (1). After computing average hop distance, each anchor A_i broadcasts it to other nodes within t hops. As broadcasting range is limited, thus energy consumption is further reduced. The unknown nodes store only that packet containing average hop distance($AvgHopDistance_j$) of closest anchor which comes first and discards all other packets.

Phase 3: Determining location of unknown node:

In third phase, the unknown nodes compute their location $<x_u, y_u>$ using Eq. (8).

The weight used in Eq. (8) is computed using Eq. (12).

$$w_i = \left(\frac{\sum_{i=1}^{m} h_{ui}}{m \times h_{ui}} \right)^{\frac{r}{AvgHopDistance_j}} \tag{12}$$

where $AvgHopDistance_j$ is the average hop distance of its nearest anchor j to the unknown node u and r is the communication radius of node. The weight factor utilized in Eq. (8) relies on the distance parameter between anchor node and given node. If the anchor is close to the given node (having lesser hop count), then it has higher impact than other far anchor nodes. But, we cannot directly relate distance with hop counts. For example: In Fig 2, A1 is 30 m away from N and A2 is 40 m away from N. Assuming communication range as 50 m, both A1 and A2 are 1 hop away from node N. Thus, it is not reasonable to use hop counts to replace with distance. Thus a factor equivalent to average hop distance per hop computed by nearest anchor to the given node divided by its communication range is used as power with hop count to get the distance.

In this phase, only anchors which are within t hops determine the location of node. Thus this improves localization accuracy of EWCL algorithm.

3.1. Working of EWCL algorithm with an example

Fig 3 depicts a WSN having anchor nodes and unknown nodes. Let nodes with ids 1–5 are anchors and rest all are unknown nodes. Let the value of $t = 2$ hops. Table 1 shows the location of all anchors in given WSN.

In Phase 1, all these five anchors broadcast their location information along with hop count value (initially set to 0) to all other nodes within t hops. Thus after first phase, all the unknown nodes get their minimum hop count value from anchors within t hops and have updated hop count table. For example, for unknown node 9, the anchors within its $t = 2$ hops range are anchors with *id* 1, 2, 3 and 5 only and anchor 4 is not considered. Thus, after Phase 1, the unknown node 9 has updated *hop count* table as shown in Table 2.

Similarly, other nodes have their updated *hop count* table containing anchors within 2 hops from the given node after phase 1.

In phase 2, all the anchor nodes compute their *average hop distances* and then broadcast it to all other nodes in the network within t hops. Now the anchor nodes know only the anchor nodes within t hops. For example, for anchor node $A1$, the average hop distance is computed using Eq. (2) that uses only 2 anchors $A2$ and $A5$(that are within $t = 2$ hops). Let the average hop distances computed by each anchor is $AvgHopDistance_i$. All the anchors then broadcasts these average hop distances to all other anchor nodes (within $t = 2$ hops). In phase 3, all the unknown nodes compute their location information using Eq. (12).

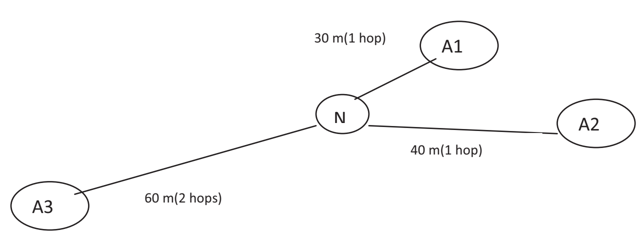

Fig. 2. Example of EWCL Hop Algorithm.

Table 1
Location information of anchors in WSN.

Anchor i	x_i	y_i
1	323	25
2	120	55
3	23	25
4	100	67
5	50	50

Table 2
Table containing <i,x_i,y_i,h_{i9}> for each anchor i within $t = 2$ hops maintained by node 9.

Anchor id	*x coordinate*	*y coordinate*	*Hop counts*
1	323	25	1
2	120	55	2
3	23	25	2
5	50	50	1

3.2. Theoretical analysis of EWCL algorithm

In this section, we analyze the performance of our proposed EWCL Algorithm theoretically in terms of energy consumption and localization accuracy. This section discusses the theoretical analysis based on the network scenario as shown in Fig.4.

3.3. Analysis in terms of energy consumption

Energy consumption depends upon the communication overhead generated in the network (Chen and Rowe, 2013). The communication overhead is equal to total number of packets transmitted in the network. As the flooding range is limited within t hops only, thus total number of packets transmitted is reduced. For example, Fig 4 depicts wireless sensor network with broadcasting range of $t = 2$ hops. Now if anchor node $A1$ broadcast its packet containing its location to other nodes, then that node should be within 2 hops to get that packet. If it is not within 2 hops, then that packet gets discarded and no further broadcast takes place. Thus, this mechanism reduces number of packets transmitted between nodes which in turn, reduce energy consumption.

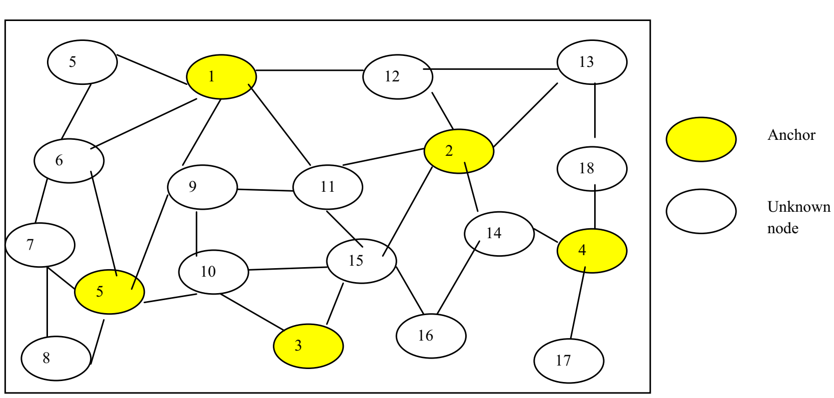

Fig. 3. Example of EWCL Hop Algorithm.

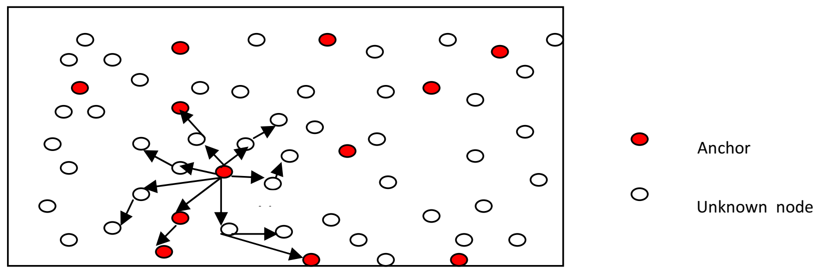

Fig. 4. Example of WSN with t = 2 hops.

4. Simulation results and discussion

In this section, first we have discussed performance metrics such as localization error ratio and average energy consumption that are used for comparison purpose of proposed scheme with original DV-Hop algorithm (Niculescu and Nath, 2001), IWCL (Zhang et al., 2012) and IDWCL (Song and Tam, 2015). Next, we describe an extensive performance comparison of EWCL algorithm by varying number of anchor nodes, communication radius of nodes(r) and total number of nodes in the network. The algorithms EWCL, original DV-Hop algorithm (Niculescu and Nath, 2001), IWCL (Zhang et al., 2012), IDWCL (Song and Tam, 2015) have been simulated in MatLab2007 (Chapman, 2015).

In the simulation environment, unknown nodes and anchor nodes are randomly deployed in an area of $500 \times 500\ m^2$. The value of *t* varies from 1 to maximum hop value (h_{max}) derived in original DV Hop algorithm. To get better accuracy, each scenario is run 50 times, and the presented results are the average of the 50-time run. The simulation parameters used are shown in Table 3.

Table 3
Simulation parameters.

Simulation Parameters	Value
WSN Area	$500 \times 500\ m^2$
Total Nodes	Vary from 400 to 900
Anchor Nodes	Vary from 50 to 200
Total iterations	50
h_{max}	Maximum hop value in the original DV Hop algorithm
T	Vary from 2 to h_{max}
R	Vary from 100 to 150

4.1. Performance metrics

For performance analysis of the proposed algorithm and its comparison with other algorithms, two performance metrics have been used and described as follows:

i. *Localization Error ratio:* A localization algorithm should give accurate estimation of sensor location. Accuracy is the most important part of localization for various location aware applications such as search, rescue, target tracking, disaster relief, etc (He et al., 2003). Localization Accuracy can be measured in terms of *localization error* (He et al., 2003) which is the difference between absolute location and estimated location. The accuracy is checked by varying parameters such as, anchor ratio, node density, and communication radius of network (Tomic and Mezei, 2016; Yu and Li, 2012; Kumar and Lobiyal, 2016; Kumar and Lobiyal, 2013; Yang and Zhang, 2016a,b; Reichenbach et al., 2006; Blumenthal et al., 2005).

$$Localizationerror = \frac{1}{n \times r}\sum_{i=1}^{n}\sqrt{(x_a - x_u)^2 + (y_a - y_u)^2} \qquad (13)$$

where *n* is the total number of unknown nodes,$\langle x_a, y_a \rangle$ are the actual coordinates and $\langle x_u, y_u \rangle$ are the estimated coordinates of unknown node and r is the communication radius of sensors.
The localization accuracy improves as the *localization error* decreases. The *Localization error ratio* is *localization error* of given algorithm divided by sum of localization errors by all other algorithms used for comparison.
Average Energy Consumption: Most of the energy is consumed during exchange of control and data packets between nodes (Kumar and Lobiyal, 2016). Thus energy consumption used in localization process can be reduced by reducing packet transmission between nodes. It depends on total number of packets transmitted and received by each node. In original DV-Hop algorithm (Niculescu and Nath, 2001), it may be expressed as:

$$Energy\ Consumption = 2 \times (n - 1) \times m \times E \qquad (14)$$

where *n* is total number of nodes, *m* is the total number of anchor nodes, *E* is the average energy used to transmit a packet. It is multiplied by 2 because transmission of packets takes place in two phases.

4.2. Effect on localization error ratio by varying the anchor ratio

In this experiment, we have compared the performance of EWCL algorithm with other four algorithms in terms of localization error ratio by varying anchor ratio. The anchor ratio is total number of anchor nodes divided by total number of nodes. We have deployed 500 nodes in a $500 \times 500\ m^2$ network and the communication radius is set to 100. Then the *anchor ratio* has been increased to see the effect on *localization error ratio* for different values of *t*. The comparison between algorithms for different values of t is shown in Figs 5–8.

As seen from the Fig 5, the *localization error* decreases with the increase in the number of anchor nodes. It can also be seen that the localization error of EWCL algorithm is less than all other algorithms. Thus, EWCL Algorithm outperforms in terms of localization error when compared with other four algorithms. The reason for this is that EWCL algorithm uses the impact of nearest anchors to determine the location of unknown node. Unlike, IWCL algorithm which uses average of average hop distances computed by each anchor, EWCL algorithm uses *Average Hop distance* of nearest anchor to the unknown node to compute its location. Another change in EWCL algorithm is that the unknown node does not uses all the anchor nodes in determining their location. If the anchor node is more than *t* hops from the given unknown node, then that anchor node is excluded from the calculation of its location. These small changes have improved localization accuracy of EWCL algorithm when compared with original DV Hop by 5–25% for different values of *t*.

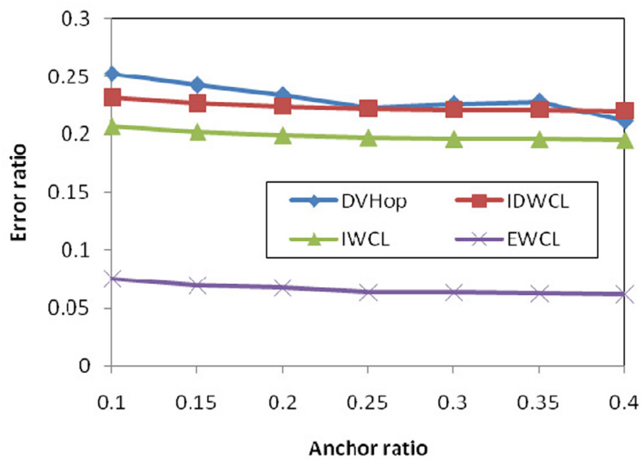

Fig. 5. Comparison by varying anchor ratio ($t = 2$).

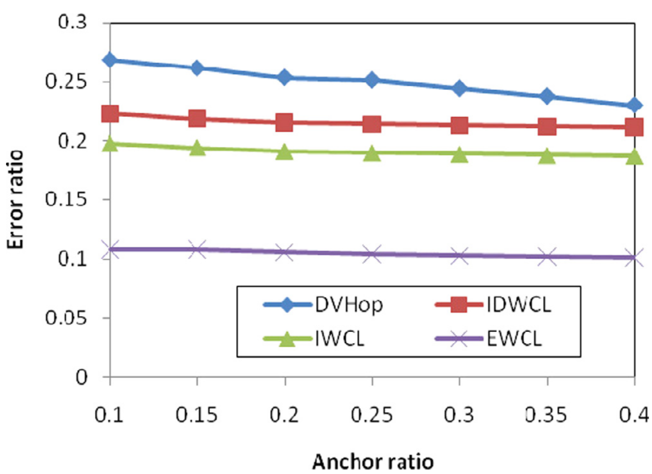

Fig. 6. Comparison by varying anchor ratio ($t = 3$).

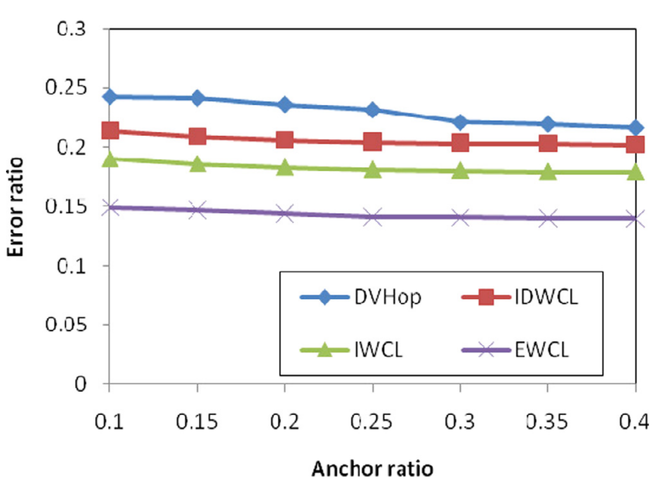

Fig. 7. Comparison by varying anchor ratio ($t = 4$).

4.3. Effect on localization error ratio when varying communication radius

In this simulation, the comparison is made in terms of *localization error* as the communication radius is changed. The simulation setup has 500 nodes deployed *in* $500 \times 500\ m^2$ network and total number of anchor nodes is 50. The communication radius varies

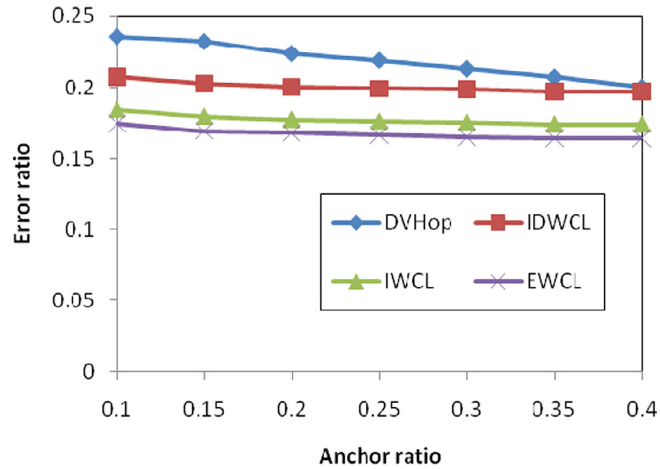

Fig. 8. Comparison by varying anchor ratio ($t = 5$).

from 100 to 150. The value of t is 2. Fig 9. shows that EWCL Algorithm performs best with least *localization error* when we take different values of communication radius.

4.4. Effect on localization error when varying total number of nodes

In this simulation, total number of nodes (*node count*) is changed and the performance is checked in terms of *localization error ratio*. We have deployed initially 400 nodes in $500 \times 500\ m^2$ network and communication radius is set to 100 m. The value of t is set to 2.Then we have tried to increase total number of nodes by keeping *anchor ratio* constant (0.1%) and get the results in different situations. The comparison between algorithms is shown in Fig.10.

Fig 10. shows that EWCL Algorithm gives results with least *localization error*. It is also observed that all these algorithms have no affect if total numbers of nodes are increased if the anchor ratio is constant.

4.5. Effect on average energy consumption

As we know, that the energy consumed depends upon total number of packets transmitted in the network. In original DV Hop, The total number of packets consumed are equal to $2 \times (n + m - 1) \times m$, where n and m are total unknown nodes and anchor nodes. For WCL and IDWCL algorithm, the energy consumption is reduced by 2 as the broadcasting is done only in first phase and is equal to $n \times m \times E$.

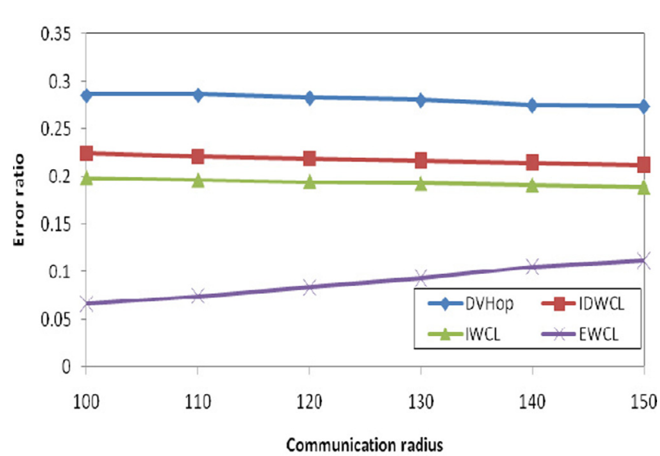

Fig. 9. Comparison in terms of localization error by varying communication radius.

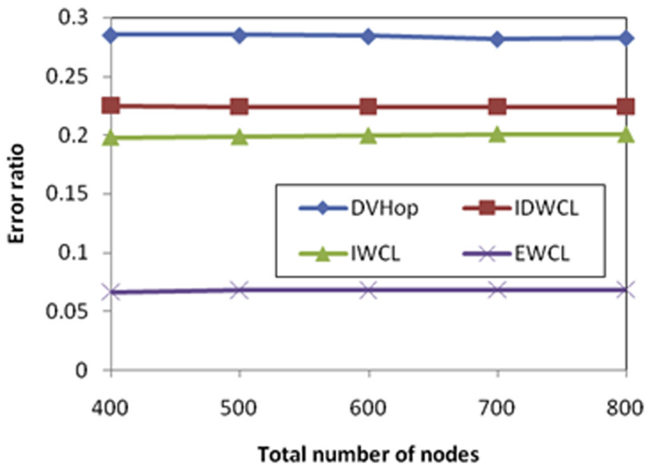

Fig. 10. Comparison in terms of *localization error* by varying total number of nodes.

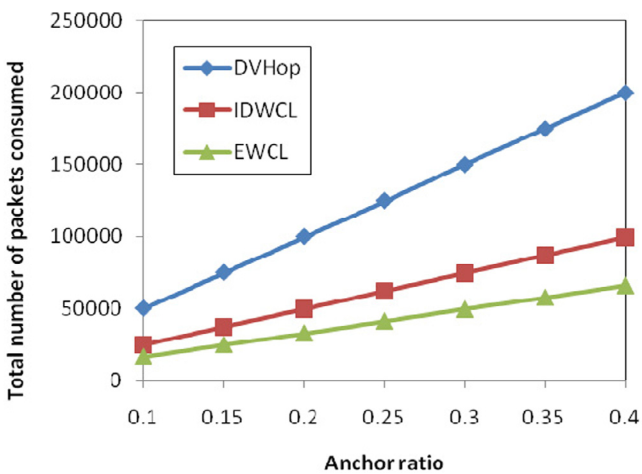

Fig. 11. Comparison in terms of total number of packets by varying *anchor ratio* ($t = 2$).

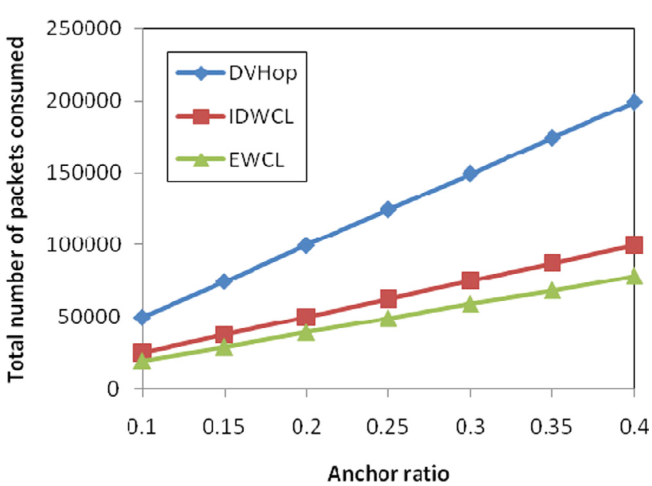

Fig. 12. Comparison in terms of total number of packets by varying *anchor ratio* ($t = 3$).

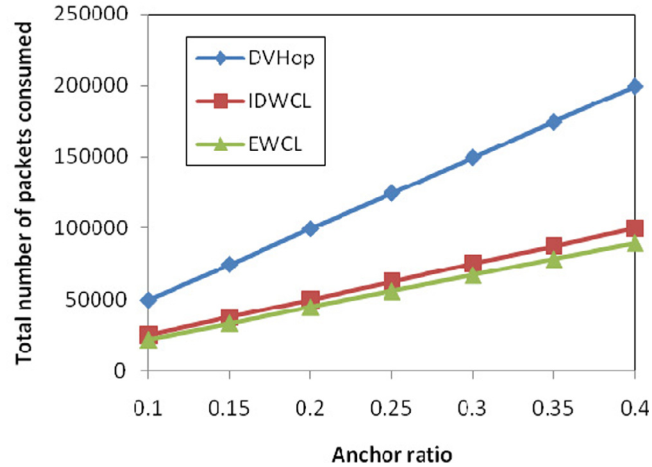

Fig. 13. Comparison in terms of total number of packets by varying *anchor ratio* ($t = 4$).

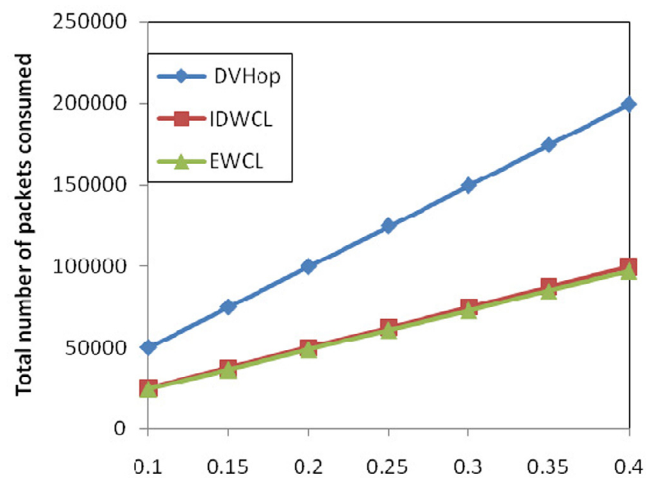

Fig. 14. Comparison in terms of total number of packets by varying *anchor ratio* ($t = 5$).

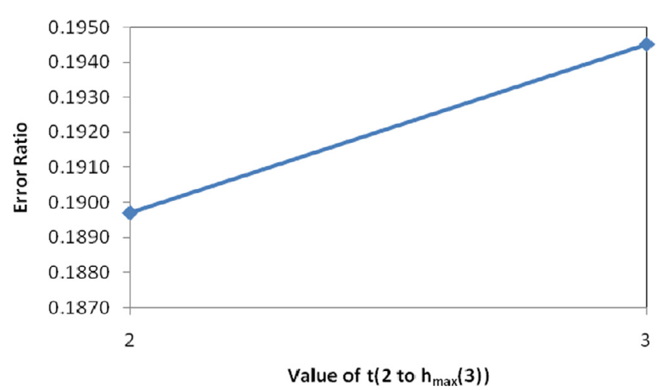

Fig. 15. Localization error of EWCL when varying value of *t*(First case).

IWCL algorithm uses broadcasting in first two phases, thus broadcast almost same number of packets as that in original DV-Hop algorithm. In EWCL algorithm, total number of packets transferred is expressed as:

$$Total\ number\ of\ packets = 2 \times t \times C_{av} \times m$$

where C_{av} is the average number of nodes within 1 hop.

Thus in the EWCL algorithm, the energy consumed is reduced by $\frac{(n+m-1)}{t \times C_{av}}$ factor. The larger the value of t, the more the packets used. Figs 11–14 shows comparison of EWCL algorithm in terms of total number of packets by varying anchor ratio for different values of *t*.

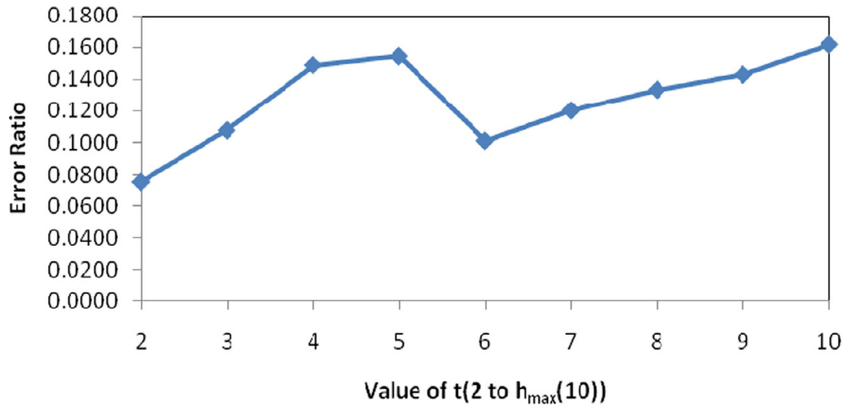

Fig. 16. Localization error of EWCL when varying value of *t*(Second case).

Simulation results prove that if the broadcasting range is reduced by *t* factor, then total number of packets is reduced by a number that depends upon *t* factor. The value of *t* lies in 2 to h_{max}(10 in this case). If the value of *t* is 2, then the packets required are almost reduced by 3 as compared to original DV Hop algorithm and 2/3 factor when compared with IDWCL algorithm. As the value of *t* is increased, more the number of packets are consumed for transmission. Simulation results illustrate that as compared with other four algorithms (Niculescu and Nath, 2001; Zhang et al., 2012; Song and Tam, 2015), our proposed EWCL algorithm can save considerable energy and give more accurate results.

4.6. Effect on localization error when varying value of t for given network

In first and second phase of our EWCL, we have limited the broadcasting range by *t* hops. The main issue of EWCL algorithm is that what value of *t* should be taken. To determine the value of *t*, we have taken different cases and tried to find the optimal value of *t*. In first case, we have deployed 100 nodes in 100 × 100 network with 10% anchor nodes.

In second case, 500 nodes are deployed in 500 × 500 network with 10% of anchor nodes.

From Figs. 15 and 16, it is observed that if broadcasting range is increased, then there is very little effect on localization accuracy. The value of t decides the amount of consumed power.

If the value of $t(t = 1)$ is too low, less power is consumed, but it will give inappropriate results or error as some known nodes do not have sufficient number of anchor nodes(=3) to determine position of unknown node. If we take very large value, them more power is consumed. Thus the value of *t* should be such that the given algorithm reduces power consumption and also achieves higher accuracy. The value of *t* should be from 2 to h_{max}. The main objective of EWCL algorithm is to reduce energy as much as possible without loss of precision. Thus, the value of *t* should be 2 if the anchors are uniformly distributed in the wireless sensor network and the anchor ratio is 10% of total nodes. If the previous two conditions are not satisfied, then the value of *t* should be middle value between 2 and h_{max}. It is also observed from the simulations that the value of *t* depends upon various factors such as *anchor ratio*, *communication radius* and *border area* of the network.

5. Conclusions

The main issues with the DV-Hop algorithm and other weighted centroid DV Hop algorithms is its low accuracy and high power consumption. In order to overcome with these issues, we have presented our EWCL Algorithm which improves the localization accuracy by taking influence of communication radius and nearest anchor node and reduces the amount of power consumption by limiting the broadcasting range by *t* hops in first two phases. The weight factor used in the EWCL algorithm is a function of hop count, average hop distance and transmission radius. Through theoretical analysis and simulation results, it is proved that the EWCL algorithm performs better than other algorithms in terms of localization accuracy and energy consumption. The EWCL algorithm achieves localization accuracy by 5–25% when compared with DV Hop for different values of *t*. It is also observed that optimal value of *t* is 2. The energy consumption that mainly depends upon number of packets transmitted in the network is reduced to half by using EWCL algorithm when compared with DV Hop algorithm. In the future, we will try to find the relation of *t* with respect to number of anchor nodes, total number of nodes and communication radius so that to determine exact value of *t*. Also we will try to extend our work in 3D WSN.

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