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Design of an Energy Efficient Cluster based Localization Algorithm (EECBLA) for Underwater Wireless Sensor Networks

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Abstract: *In underwater Wireless Sensor Networks (UWSN) the node mobility is higher as the nodes drift with the water so identifying the exact location of the nodes is a challenging task. Terrestrial WSN use Global Positioning System (GPS) to locate the nodes, but the same cannot be applied for UWSN as they do not propagate under water. Underwater uses acoustic channel for communication which suffers from low bandwidth, high propagation delay, high bit error rate, high node mobility and variable sound speed which makes localization a challenging task. Hence there is an evolving requirement for energy efficient localization algorithm. To overcome these problems we propose an Energy Efficient Cluster Based Localization Algorithm (EECBLA) to minimize the energy utilization and identify an accurate location of the sensor nodes.*

EECBLA is a cluster based localization protocol where the GPS enabled high power anchor nodes are utilized to estimate the location of the un localized sensor nodes. To improve the localization accuracy it is necessary to improve the network connectivity. Network connectivity can be improved by increasing the lifetime of the sensor nodes. EECBLA proposes an energy efficient localization scheme where the node operates in active and sleep mode to efficiently utilize the available energy. In this research work we take a sample example and demonstrate how the location is estimated through TOA and Euclidean distance. Accuracy of TOA is measured as 8.36, 4.76, 13.21, 14.85, 16.26 and 3.60. The average estimated localization error of EECBLA is around 4m to 6m. EECBLA localization error is compared with other localization algorithms like 3DUL whose average localization error is 5m to 10m, SDMA whose average localization error is around 24% and localization error of Hybrid RSS ranges from 4.69m to 15.85m. When compared with these methodologies there is a decrease in localization error by 3%, and the increase in accuracy by 5% in EECBLA protocol.

Keywords: *Underwater Communication; Underwater Wireless Sensor Networks (UWSN), Energy Efficient Cluster Based Localization Algorithm, Localization Algorithm (EECBLA).*

I. INTRODUCTION

The majority of earth surface is covered with water in different forms and names like in the form of glaciers, oceans, seas, etc. [1].

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The noisy environment of water makes it more challenging to do any type of research work in water bodies and thus need for underwater localization schemes. The position of nodes in the underwater environment keeps on changing thus it makes the use of wireless sensor network underwater. Thus, in other way, UWSN is a fusion process of wireless technology with smart sensing, intelligent computing and communication capabilities.[2-4]

Radio frequency communication and optical communication get attenuated underwater and GPS is restricted to only surface nodes. Hence there is a need for localization algorithm to identify the exact location of the submerged nodes in order to communicate with the surface buoys. Underwater localization protocols must fulfill the following properties.

1. High accuracy: The location of the sensor nodes identified by the localization algorithm must be accurate and non ambiguous. The localization error must be minimized.
2. Fast: As the nodes underwater continuously drift with water. The localization algorithm must be fast enough to identify the exact location of the nodes when the data is sensed.
3. Localization coverage: The localization algorithm must ensure that all nodes deployed are localized properly.
4. Energy efficient: As the nodes are deployed for longer duration and the battery of the nodes cannot be easily charged, an energy efficient localization algorithm must be proposed. [5-7]

   In this research work we propose an Energy Efficient Cluster Based Localization Algorithm (EECBLA) for Underwater Wireless Sensor Networks.

The major contributions in this paper are given below:

- We propose a Cluster Based localization algorithm where the high power GPS enabled anchor nodes act as Cluster Head (CH) and remains active to monitor the activities of the network.
- To achieve the energy efficiency the sensor nodes operate in two modes active and sleep mode.
- TOA distance based localization algorithm is proposed to minimize the localization error.

Research work presented in this paper is organized as follows: Section 2 shows the related works. System model is discussed in Section 3. The EECBLA proposed system is explained in Section 4. Details of simulation setup, results and discussions are discussed in section 5. Conclusions and summary of the research work carried out using EECBLA are highlighted in section 6.

II. RELATED WORKS

Zhong[8] proposed a localization scheme where the entire process is divided into two sub process. In the first sub process all the anchor nodes identify their location with the help of the surface buoys. As the surface buoys are GPS enabled they work as like a satellite for the entire network. Using advanced signal processing techniques anchor nodes can accurately find their location with the surface buoys. In the second sub process all the ordinary node location are identified. The anchor nodes help to identify the location of the ordinary nodes. It sends the localization and beacon message. Localization message is used to exchange the information between ordinary and anchor nodes and beacon message is used to estimate the distance between ordinary and anchor node. Euclidean distance estimation is used to estimate the location of the ordinary nodes.

Talha [9] proposed a three dimensional localization algorithm which works in two phases. In the first phase sensor nodes identifies the distance between itself and the anchor nodes. In the second phase it uses the pair wise distance identified in the first phase with the depth information to identify the location of the anchor nodes. Once the location of the anchor nodes are identified it assists the other non localized nodes to identify their location. Here the sensor nodes should be equipped with temperature, depth and connectivity sensors to estimate the sound speed.

Majid Hosseini [10] proposed a Received Signal Strength (RSS) based localization algorithm where received signal strength is used to measure the distance. The proposed algorithm do not require time synchronization. The algorithm is divided into three steps. In the initial step all the sensor nods maintain the received signal strength and in the second step it sends it back to the reference node in order to calculate the distance. Finally the sink node calculates the position of the sensor nodes.

Wei Nuo [11] proposed a localization algorithm where the anchor nodes at regular interval broadcast their location information to all the other sensor nodes. The sensor node stores the received information and then estimates its current location based on the received parameters. If the sensor node has already calculated its location then it forwards it to the next nearest neighbor. The simulation of the proposed algorithm is done in Mat lab with 20 sensor node deployed in a range of 100m * 100m and the localization error equals to 24%.

Zhiwen Zhu [12] proposed a multi hop localization algorithm (MLA) which has five phases. In the first phase every node identifies the distance to its one hop neighbor node. Upon receiving information from first phase it estimates the shortest path to the anchor node and maintains in the table. In the third phase it identifies the three anchor nodes nearest to it. The acoustic transmitter and receiver on node rotate anticlockwise in the horizontal direction and then record the angle between the receiving messages and the sending messages.

Ying Guo [13] proposed an anchor free localization where relation between the adjacent nodes is used to solve the problem of lacking anchor nodes. The proposed algorithm works for both static and mobile networks. Here every node is allowed to move within the restricted area only. In active restricted area center is the anchor node and the radius is taken as the cable length.

Shaochen Zhang [14] proposed a Symmetric correction based localization algorithm for UWSN. Three surface buoys are placed on the sea surface with GPS positioning. These buoys periodically send their location information. After receiving the message from the buoys the sensor nodes estimate their position. The initial estimated position is obtained by the traditional LSE algorithm. Then, the correction position is as curtained by using the symmetry of the estimated position and the actual target, so that the positioning accuracy is greatly improved. Through simulation set up author analyzes the sound velocity change and the mobility problem of the unknown target.

AUVs are used to continuously move underwater and transmit the location information to the non localized nodes. Ranging errors are increased when AUVs are used because the AUV do no remain at the same location from where it has sent the signal. So Jing Li [15] proposed a self localization algorithm with accurate sound travel solution. The proposed algorithm does not require time synchronization. Ranging and localization accuracy is increased.

III. SYSTEM MODEL

Identifying the exact location of the nodes underwater is a difficult task as the nodes drift with the water pressure. So an energy efficient cost effective localization algorithm is the urgent need for underwater wireless communication. In this paper we propose a cluster based energy efficient localization algorithm. The proposed system consists of GPS enabled high powered anchor nodes which act as the cluster heads, sensor nodes which are used to sense and transmit the data, surface buoys and base station.

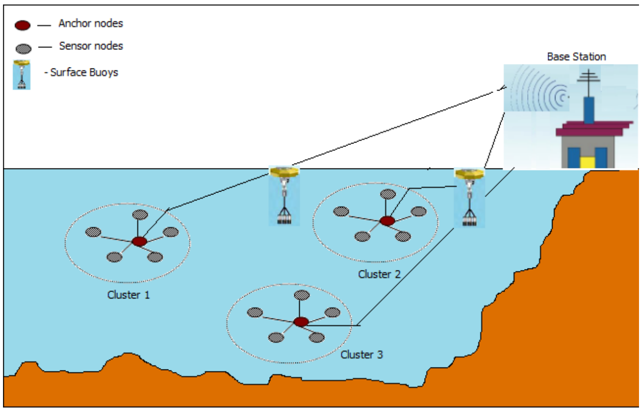

Fig 1: Architecture of EECBLA

Recharging the batteries of the nodes underwater is a difficult task. The number of active nodes in the network increases the network connectivity. Energy availability and network connectivity are the two important factors on which the performance of localization algorithm depends. High network connectivity can be achieved by allowing more number of nodes to be active which in turn improves the performance of the localization algorithm.

Figure 1 shown above depicts the energy efficient UOWSN setup where n numbers of sensor nodes are deployed deep inside the sea and are responsible for sensing the data and forwarding it to the anchor nodes.

The high power GPS enabled anchor nodes can identify their location on their own and act as the Cluster Heads (CH). The sensor nodes uses Time of Arrival (TOA) method and calculates is location. The anchor node and surface buoys periodically helps the sensor nodes to locate themselves and collects the sensed data from them and forwards it to the base station where the sensed data are processed.

IV. PROPOSED SYSTEM

In the proposed algorithm the anchor nodes are placed randomly and are allowed to move within the predefined cluster range. Sensor nodes are allowed to move freely and they drift with the water pressure. Sensor nodes need to determine their location with the help of anchor nodes.

4.1 Cluster Head Selection Process:

In the initial phase the anchor nodes are the cluster heads. As the anchor nodes are GPS enabled they can accurately estimate their location. Their location information is sent to the sensor nodes using which they estimate their position. The proposed algorithm main task is to improve the network connectivity which can be achieved if the nodes are active for the longer duration. As the anchor nodes are active all the time and periodically sends the message to the sensor node to help them for localization the energy level of the anchor nodes may get degraded after certain time interval. To overcome this problem and to increase the network connectivity some dedicated nodes in each cluster act as backup node.

The backup nodes remain in normal mode until the energy level of the anchor nodes becomes less than the predefined threshold. Once the energy level of the anchor node is below the threshold then the next cluster head selection process takes place.

4.1 Algorithm to select backup Cluster Head

1. for *C Cluster € {1,2,……, S} Sectors*
2. Estimate the energy level of the anchor nodes
3. if the energy level of the anchor nodes is less than threshold
4. then begin the cluster head selection process
5. new_{ch}= $select_{ch}$ {RE, D_{min}, L_{QOS}, LE_{min}}
   Where RE is Residual energy of the node
   D_{min}- minimum distance to the anchor node
   L_{QOS} – Link quality
   LE_{min} – minimum localization error
6. L_{QOS} can be calculated by considering
   BD_{max}- maximum bandwidth
   J_{min} – minimum jitter
   D_{min} – minimum delay in the link
7. End if
8. End for

4.2 Proposed Localization Method:

Efficient energy utilization and maintaining network connectivity are two important considerations in the proposed algorithm. Sensor nodes are placed deep inside the sea and they drift with the water pressure due to which the energy level of the nodes may be degraded. In order to effectively utilize the available energy of the sensor nodes the nodes operate in two modes active and sleep mode.

Anchor ID (AID)	Location	Communication Range	Timestamp	Accuracy of data packet location	….
…	TOA	Accuracy of TOA	Euclidean Distance		

Table 1: Packet format of broadcast message from anchor node.

Anchor node at time t broadcast a message (as in Table 1) which consists of Anchor ID (AID), Anchor nodes location, Communication Range, Timestamp at which the anchor node broadcast the message, Accuracy of data packet location, Time of Arrival (TOA) of the data packet, Accuracy of the TOA which specifies the confidence value of the data packets location and Euclidean distance (EUD).

$$EUD\ (sn_{id},\ a_{id}) = \sqrt{(q1-p1)^2+(q2-p2)^2+(q3-p3)^2} \quad \text{………(1)}$$

Accuracy of TOA can be defined by

$$A_{TOA}(sn_{id}, a_{id}) = \begin{cases} 0 & \text{for } d_{TOA} > R \\ 1-d_{TOA}(sn_{id},\ a_{id})\ /\ R, & \text{Otherwise} \end{cases} \quad \text{…..(2)}$$

where R specifies the communication range. Distance between the anchor node and sensor nodes that lie within the cluster boundary is equal to the current communication range of the anchor node.

It is assumed that sensor node and anchor nodes are both time synchronized. Sensor nodes operate in two modes active and sleep mode to save their energy level. At time t when anchor node broadcast the message it wakes up and keep listening to the broadcast message. When it receives the broadcast message it maintains the received information in the table and estimates its location. After estimation is done it switches back to the sleep mode to save its energy and wakes up at time t2 to once again listen to the broadcast message.

To illustrate we take a sample example

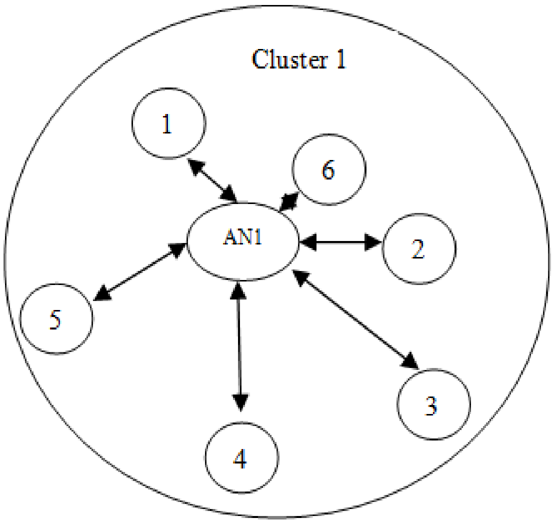

Figure 2 : Cluster 1 sample node deployment

Table 2 : Table initialization for the sample example

Anchor node ID (AID)	Location	Timestamp	Accuracy of data packet location	TOA	Accuracy of TOA	Euclidean distance
AN1	(57.24,37.68)	3	1	n/a	n/a	n/a
1	(50.25,42.27)	3.00201	0.25	6.32	0.47	8.36
2	(62,37.68)	3.00384	0.25	3.41	0.71	4.76
3	(68,30)	3.00562	0.25	11.7	0.03	13.21
4	(55,23)	3.00583	0.25	10.68	0.11	14.85
5	(42,32)	3.00420	0.25	9.86	0.17	16.26
6	(60,40)	3.00112	0.25	2.11	0.82	3.60

Figure 2 depicts sample node deployment for one cluster i.e cluster1. There is an entry in the table for all the nodes that lie within the range of cluster1. Initially the locations of the nodes are set. Anchor node broadcast the message at timestamp 3, each node within the cluster boundary receives the data packet at different timestamp which depends on distance and communication range. Accuracy of data packet location is high initially which may gradually decrease with respect to the time. TOA represents the distance between node and the anchor node. Accuracy of TOA and Euclidean distance is calculated based on the equation (1) and (2).

In Table 2 the Anchor Node (AN1) location is (57.24, 27.68). The confidence value is 1 because it is assumed to be accurate. As the anchor nodes are GPS enabled and can calculate their own location they do not need to correct their location. The confidence value of the data packet location is 0.25 because the last sensor self-localized time is 0, and the data packet observed time is 3. The neighbor nodes of anchor node AN1 include nodes 1, 2, 3, 4, 5 and 6. The ToA distance between nodes AN1 and 1 is 6.32 because the data packet is sent at time = 3 and the data packet was first received by node 1 at 3.00201 and the speed of sound in seawater is 1500m/s. The communication radius is 12 so the confidence value of the ToA distance is 0.47. The Euclidean distance between node AN1 and node 1 is the distance between (50.25, 42.27) and (57.24, 37.68) is 8.36. Further calculation with respect to all the other nodes is listed in Table 2.

V. SIMULATION AND RESULT DISCUSSIONS

In this section, we evaluate the performance of EECBLA using simulations.

5.1 Environment settings

Table 3: Parameters used in EECBLA

Parameters	Value
Network Area	100m * 100m
Node Amount	100
Communication range	25m
Data observed period	1s
No of Anchor Nodes	3
No of Sensor Nodes (SN)	30
No. of iterations	5

The environment settings of EECBLA are shown in Table 3. Around 100 sensor nodes are randomly placed in a 100m * 100m region. There are 5 Anchor nodes which can move randomly within the cluster region. The communication range is 25m. The sample node deployment is depicted in the Figure 3.

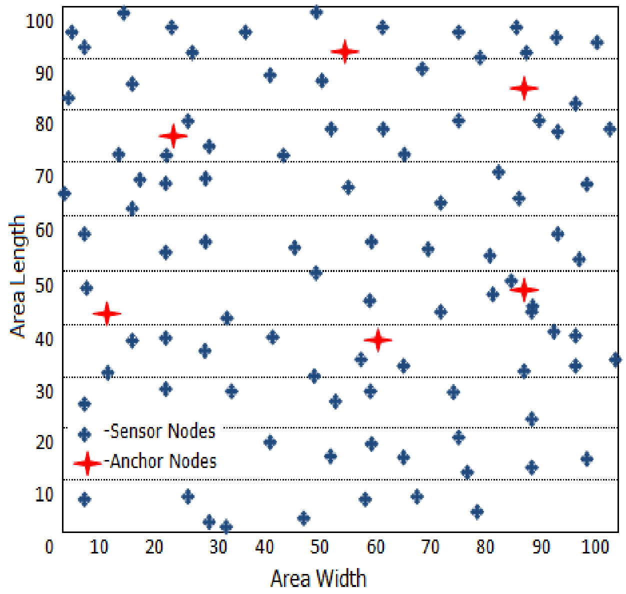

Figure 3 : Sample Deployment of Sensor Nodes

To calculate the mean estimate error of EECBLA first the random location is built where three different anchor nodes are placed randomly within the cluster region. 30 sensor nodes are allowed to move freely within the region. The accuracy of the distance measurement is set to 92 percent. By performing five continuous iterations. The mean estimate error is ranging from 4m to 6m approximately. Figure 4a to 4e depicts the 5 iteration and calculation of mean estimation error of EECBLA.

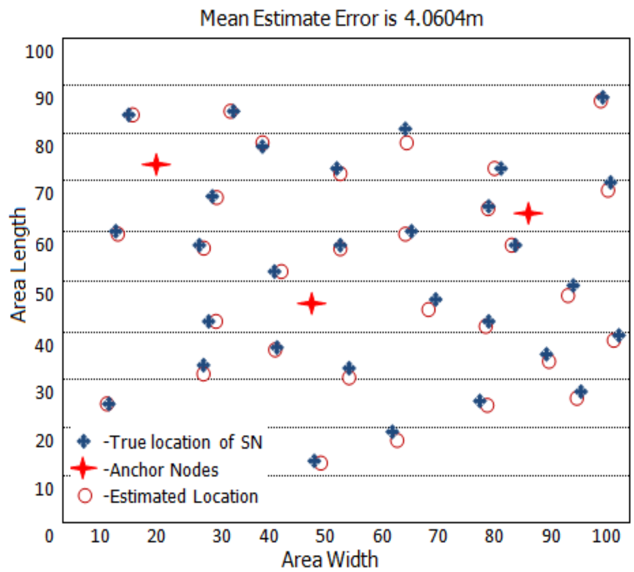

Figure 4a : Estimation error at iteration 1

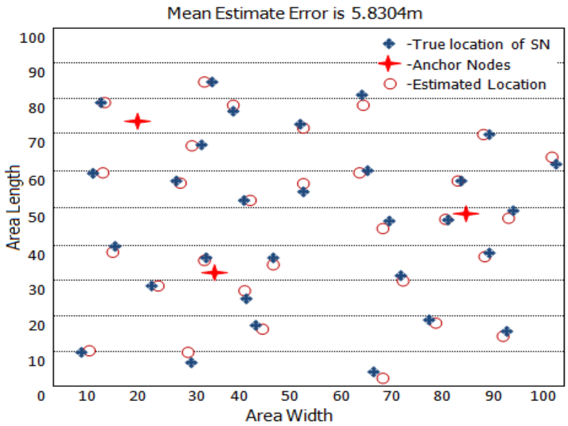

Figure 4b : Estimation error at iteration 2

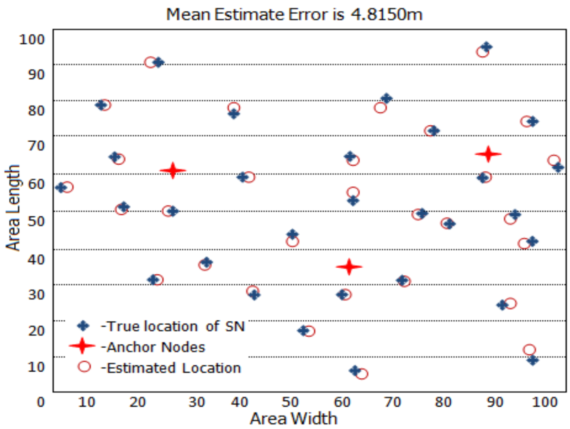

Figure 4c : Estimation error at iteration 3

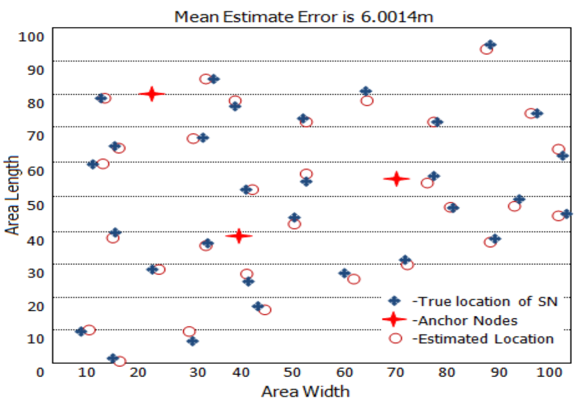

Figure 4d : Estimation error at iteration 4

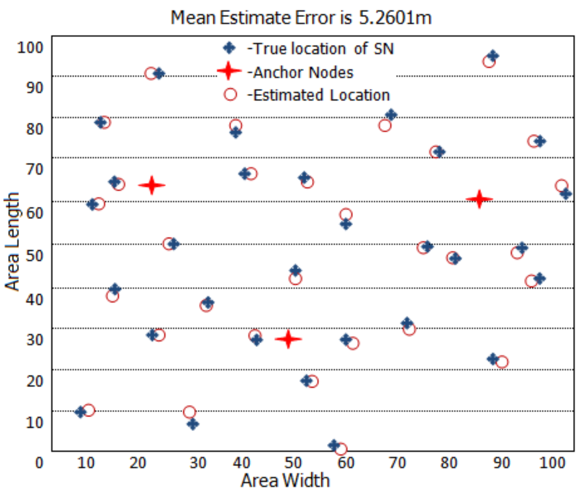

Figure 4e : Estimation error at iteration 5

Table 4: Localization Mean Estimation Error of EECBLA

Iteration	Mean Estimation Error (in meters)
Iteration 1	4.0604m
Iteration 2	5.8304m
Iteration 3	4.8150m
Iteration 4	6.0014m
Iteration 5	5.2601m

5.2 Performance Comparison with related work

Here we compare EECBLA with the related work. Building an energy efficient and accurate localization algorithm is the urgent requirement of UWSN. The localization errors of the EECBLA are compared with other protocol is depicted in Table 5 given below:

Table 5: Comparison of EECBLA with other protocols

Localization Algorithm	Communication Overhead	Localization Error	No of anchor nodes
Zhong [7]	Node density small low communication cost as node density increases cost also increases	Average error = 25% when AN=5 and Error=5% when AN =25	5
3DUL [8]	Communication cost is constant	5m to 10 m	Unlocalized anchor nodes
Hybrid RSS [9]	Less communication overhead	4.6995503 m – 15.858888 m	-
SDMA [10]	Increases with node density	24%	4
MLA [11]	overhead is increased with the increase in the nodes.	10%	10
EECBLA	Communication cost is reduced as it reduces energy consumption of sensor nodes by put them to sleep mode	4m to 6m	3 Anchor nodes, 30 Sensor nodes

VI. CONCLUSION

Identifying the exact location of the nodes is a difficult task as the node mobility is high underwater. The battery power of the sensor nodes underwater cannot be easily charged so there is a requirement for energy efficient localization algorithm. EECBLA is an energy efficient cluster based localization algorithm where the battery power of the sensor nodes are efficiently utilized by making them to operate in two modes, active and sleep mode. High network connectivity is also the requirement for accurate localization algorithm.

Anchor nodes remain active for the large duration and hence degrade their energy level so some dedicated nodes in each cluster act as backup node for these anchor nodes so improve the network connectivity.

In this research work we simulated the network and analyzed the localization accuracy. We selected only five iteration results because the mean estimation error mostly varies within these iterations. The mean estimation error ranges from 4m to 6m. EECBLA is compared with the other protocols shown in Table 5. It is observed that the communication overhead cost is reduced as it reduces communication cost as it reduces energy consumption of sensor nodes by allowing them to stay in sleep mode. For 3 Anchor nodes, 30 Sensor nodes, the localization error is found to be 4m to 6m.

In this research work we tried to build an energy efficient and accurate localization algorithm. In future we can extend this work and focus on recovery methods to efficiently deal with faults and node failure in the network.

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