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Progressive Localization using Mobile Anchor in Wireless Sensor Network

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***Abstract*— Wireless sensor network (WSN) is employed to gather and forward information to the destination. It is very crucial to know the location of the event or collected information. This location information may be obtained using GPS or localization technique in wireless sensor networks. Randomly deployed WSN needs a large amount of GPS-enabled sensor nodes for localization, this necessitates progressive approach. However, nodes with sparse connectivity remain unlocalized. In this paper, a progressive mobile anchor based technique is proposed for node localization. Initially, sensor nodes are localized using anchors in the neighborhood, then these localized nodes progressively localized remaining nodes using multilateration. Mobile anchor node moves randomly in field and broadcast position information. It localized nodes with sparse connectivity. Simulation results show that proposed approach localize all sensor nodes with good accuracy.**

I. Introduction

In WSNs, sensor nodes are deployed in the real geographical environment and observe some physical behaviors. WSNs have many analytical challenges. Sensors are a small device in size, low-cost accounting, and having low process capabilities. WSN's applications attracted great attention interest of researchers in recent years [1]. WSNs have a different application such as monitor environmental aspects and physical phenomena like temperature, audio and optical data, habitat monitoring, traffic control monitoring, patient healthcare monitoring, and underwater acoustic monitoring. Data collection without their geographical positions would be useless. Localization of nodes can be achieved by using GPS (global positioning system), but it becomes very expensive if a number of nodes are large in a given network. So far Many algorithms have been come up to solve the localization issue, but due to their application-specific nature, most of the solutions are not suitable for wide range of WSNs [2]. Ultra wideband techniques are useful for the indoor environment while extra hardware would be required for the acoustic transmission-based system. Both are accurate techniques but expensive in terms of energy consumption and processing. Unlocalized nodes calculate their location from anchor nodes beacon messages, which needs much power. Many algorithms have been proposed to reduce this communication cost. If one node calculates its wrong location, then this error propagates to overall network and further nodes, and this will lead wrong information of anchor nodes location is propagated [3]. Random deployment of the network also leads to sparse connectivity which decreases the probability of localization. In this paper, a progressive localization mechanism has been proposed for the sensor network. In this, the mobile anchor has been used to localized such nodes that have very less connectivity. Simulation results validate the performance of proposed approach.

The rest of the paper is organized as follows. Section 2 discusses related work of localization. Section 3 describes proposed approach in brief. Section 4 provides an overview simulation and results analysis. Section 5 concludes the paper.

II. Related Work

Recently, many localization techniques have been proposed for WSNs, and simultaneously many studies have been done to analyze existing localization techniques and algorithms. In [4], Mao et al. first provide an overview of measurement techniques that can be used for WSN localization. Then the one-hop and the multi-hop localization algorithms based on the measurement techniques are presented in detail, respectively, where the connectivity-based or range-free localization algorithms. In [5], an overview of localization techniques is presented for WSNs. The major localization techniques are classified into two categories: centralized and distributed based on where the computational effort is carried out. Based on the details of localization process, the advantages and limitations of each localization technique are discussed. In addition, future research directions and challenges are highlighted. This paper point out that the further study of localization technique should be adapted to the movement of sensor nodes since node mobility can heavily affect localization accuracy of targets. However, the localization techniques proposed for mobile sensor nodes are not discussed in [5].

In [6] Mustafa Ilhan Akbas, et al. proposed a localization algorithm for wireless networks with mobile sensor nodes and stationary actors. The proposed localization algorithm overcomes failure and high mobility of sensors node by a locality preserving approach complemented with the idea that benefits from the motion pattern of the sensors. The algorithm aims to retrieve location information at the actor nodes rather than the sensors and it adopts one-hop localization approach in order to address the limited lifetime of the WSN. The accuracy of the proposed algorithm can be further improved with RSS or other measurement techniques at the expense of increased energy consumption.

In proposed scheme [7], a subsurface current mobility model is adopted and tailored according to the requirements of the scenario. These mobile anchor nodes move in the network space and periodically broadcast beacon messages about their location. Static sensor nodes receive these messages as soon as they come under the communication range of any mobile anchor node and compute their position based on the range based technique. Another contribution of this paper is to identify the importance of mobile anchor node over static anchor node in localization. The simulation result shows that mobile anchor node provide better accuracy as compared to static anchor node for sensor node localization.

In [8] CamLy Nguyen et al. proposed a maximum-likelihood-based multihop localization algorithm called kHopLoc for use in wireless sensor networks that is strong in both isotropic and anisotropic network deployment regions. Compared to other multihop localization algorithms, the proposed kHopLoc algorithm achieves higher accuracy in varying network configurations and connection link-models. The algorithm first runs a training phase during which a Monte Carlo simulation is utilized to produce accurate multihop connection probability density functions (described later). In its second phase, the algorithm constructs likelihood functions for each target node based on their hop counts to all reachable anchor nodes which it then maximizes to produce localization information. The main advantage of the algorithm is the use of a Monte Carlo initial training phase to generate the multihop connection probability density functions. These are then used to build likelihood functions whose maxima estimate each target node location. Since the algorithm uses full statistical information for the multihop connection probabilities, localization results are significantly more accurate for both in isotropic and anisotropic networks.

In [9] Slavisa Tomic, et al. addresses node localization problem in a cooperative 3-D wireless sensor network (WSN), for both cases of known and unknown node transmit power by investigating the target localization problem in a cooperative 3-D WSN, where all targets can communicate with any node within their communication range. In this by using RSS propagation model and simple geometry a novel objective function derived which is based on the LS criterion, which tightly approximates the ML one for small noise. The results show that the derived non-convex objective function can be transformed into a convex one by applying semidefinite programming (SDP) relaxation technique and the generalization of the proposed SDP estimator is straightforward for the case when the nodes transmit power is not known. Cooperative localization is a very difficult problem, particularly useful for large-scale WSNs with limited energy resources. The proposed scheme involves an efficient estimator based on SDP relaxation technique to estimate the locations of some target nodes simultaneously. The new estimator exhibited excellent performance in a variety of scenarios, as well as robustness to not knowing.

In [10] Juan Cota-Ruiz et al. have presented a routing algorithm useful in the realm of centralized range-based localization schemes which is capable of estimating the distance between two non-neighboring sensors in multi-hop wireless sensor networks. This scheme employs a global table search of sensor edges and recursive functions to find all possible paths between a source sensor and a destination sensor with the minimum number of hops. Using a distance matrix, the algorithm evaluates and averages all paths to estimate a measure of distance between both sensors. In this scheme a recursive algorithm to estimate distances between any two sensors. The proposed algorithm is then analyzed and compared with classical and novel approaches, and the results indicate that the proposed approach outperforms the other methods in distance estimate accuracy when used in random and uniform placement of nodes for large-scale wireless networks.

In [11] Shikai Shen et al. proposed an improved DV-Hop localization algorithm to ensure the accuracy of localization. This localization algorithm first employs distortion function to select the beacon nodes that can estimate average hop distance and then adopt two-dimensional hyperbolic function instead of the classic trilateration/least square method to determine the locations of unknown nodes, which are very close to their actual locations.

In [12] Xihai Zhang et al. proposed An efficient path planning approach in mobile beacon localization for the randomly deployed wireless sensor nodes. The proposed approach can provide the deployment uniformly of virtual beacon nodes among the sensor fields and the lower computational complexity of path planning compared with a method which utilizes only mobile beacons by a random movement. The performance evaluation shows that the proposed approach can reduce the beacon movement distance and the number of virtual mobile beacon nodes by comparison with other methods. In this scheme, a path planning algorithm based on grid scan which is the entire traverse in sensor field is proposed. To improve the localization accuracy, the weighting function is constructed based on the distance between the nodes. Furthermore, to avoid a decrease in the localization accuracy an iterative multilateration algorithm and the start conditions of localization algorithm is also proposed. To evaluate the proposed path planning algorithm, the results of the static beacon randomly deployed and RWP mobile path in sensor field are also provided. It is obtained that proposed scheme by a mobile beacon is significantly better than localization scheme by beacon deployment randomly in localization effects.

In [13] Dexin Wang et al. discuss the benefit brought by cooperation in the context of robust localization against malicious anchors. Cooperation provides improved detection about the existence of malicious anchors, as well as the ability to estimate their true locations. This scheme investigates various loss functions and proposes an accelerated cooperative robust localization algorithm based on Huber loss function. The proposed algorithm offers accuracy comparable to existing cooperative robust localization methods but at significantly reduced computational complexity. An accelerated algorithm FARCoL was proposed based on its characteristics. Compared with CARSDP, FARCoL significantly reduces the computational complexity of the algorithm while preserving similar accuracy.

The related work clearly showed that an optimal algorithm

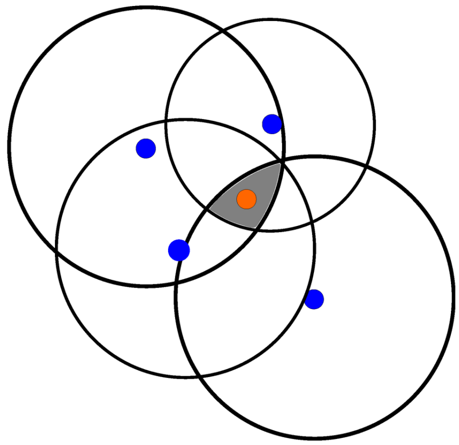


Fig. 1. The performance of proposed approach with varying communication range

could not be defined yet, and thus a suitable localization algorithm needs to be designed on the specificities of the situations, taking into account the size of the network, as well as the deployment method with node density and the expected results. Our proposed method delved into mobile anchor nodes and established that they are energy efficient as well as require less in number than only static nodes. In those systems, only a small number of anchors are necessary for constructing the global coordinates, which significantly reduces the system cost.

III. MULTILATERATION

Within different wireless positioning methods, it is found that the multilateration method is frequently discussed and widely used. Fig. 1 shows the schematic diagram of the conventional multilateration method. To simplify the following analysis, it is assumed that all the nodes (including the anchor nodes and the non-anchor node) are located in the same 2-dimensional coordinate plane. As shown in Fig. 1, blue circle are the A anchor nodes $S_1, S_2, \ldots S_A$ with fixed two-dimensional coordinates $(x_1, y_1), (x_2, y_2), \ldots, (x_A, y_A)$ and S_0 is the non-anchor node with coordinate (x, y). Suppose the distances from the non-anchor node S_0 to each anchor nodes $S_1, S_2, \ldots S_A$ are denoted by $d_1, d_2, \ldots d_A$, respectively. Then we can get

$$\begin{cases} d_1 = \sqrt{(x-x_1)^2 + (y-y_1)^2} \\ d_2 = \sqrt{(x-x_2)^2 + (y-y_2)^2} \\ \vdots \\ d_A = \sqrt{(x-x_A)^2 + (y-y_A)^2} \end{cases} \tag{1}$$

When the distances $d_1, d_2, \ldots d_A$ can be measured correctly, the coordinate (x, y) of the non-anchor node S_0 can then be estimated unbiasedly, which is an ideal case in the applications.

IV. NETWORK MODEL

In this section assumption about the network model is described.

- Sensor nodes and base station are static.
- The base station does not limit by energy.
- Anchor nodes are aware of their geographic location.
- The distributions of sensor nodes are random over the sensing area.
- The sensor nodes are densely deployed in the sensing area.
- Sensor nodes are homogeneous in energy level.
- A mobile node work as anchor node and do not limit to energy.

V. PROPOSED METHOD

In this section, a range-based iterative distributed localization method has been proposed. In this work, we categories all the sensor nodes into two types viz. anchor and non-anchor node. Initially, non-anchor nodes are localized using multilateration technique. After that, an iterative mechanism is used to localized remaining non-anchor nodes progressively. Nodes with less connectivity (less than three neighbors) are localized using a mobile beacon. The proposed method consists three phases: Initial, progressive and mobile. In the first phase, nodes with more than two anchor neighbors are localized using multilateration. In the second phase, localized non-anchor nodes are used as a pseudo-anchor for nodes localization. In the last phase, a mobile anchor node moves randomly and broadcast its position for node localization.

A. Initial Phase

At the very beginning, all the anchor nodes broadcast their position beacon packets within communication range. This beacon packet consists of the anchor node location and the node id. Once a non-anchor node receives the beacon packet, it stores the beacon location along with the RSSI value. After receiving beacon packet from minimum three anchor nodes, each non-anchor sensor node calculates positional coordinates using the multilateration method by taking into considering the distance calculated through the RSSI value of the corresponding anchor node and its coordinates. After that, broadcast computed coordinates within communication range. These coordinates information is useful for non-anchors that do not have neighbor anchor nodes.

B. Progressive localization

In this phase, non-anchor nodes are localized using their neighbor which is already localized. This is an iterative phase in which each non-anchor node wait for three beacon packet, as soon as it gets required number of the packet, computes their coordinate using multilateration. After that, broadcast coordinates which help to other neighbor nodes to compute their location coordinates. In this phase, all nodes get their location which is well connected to the network; it means has more than three neighbors. The remaining nodes are localized in next phase.

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Deployed area	$100 \times 100\ meter^2$
Total deployed nodes	$100 - 1000$
Anchor nodes	10 %
Communication range	20 $meters$
Error in distance estimation	01 % to 20 %

C. Localization using mobile anchor

A non-anchor with less connectivity is not able to compute their location. To solve this problem we used a mobile node as an anchor, which moves randomly in field and periodical broadcast location coordinates. As soon as non-anchor node get three beacon packet from the static or moving anchor, it computes location coordinate.

The selection of beacon coordinates depend on the RSSI value degrades localization accuracy. The topological arrangement of the node is not a constraint. Hence, the all beacon packet considers for location computation. Localized non-anchor nodes may also use new position coordinates to update their estimated location. The process of localization is shown in Fig. 2.

VI. SIMULATION AND RESULTS

In this section, we discuss the performance of the proposed approach. To measure the performance, the proposed approach simulate through MatLab simulator. We varied the different parameters to observe the performance of proposed mechanism. The parameters are a number of nodes deployed in the field, the number of anchor nodes, the communication range of sensor node, the area of interest and error in distance estimation. The measuring metrics for performance are time taken by a mobile anchor for localization, total node localized and Root Mean Square Error (RMSE) [14].

$$RMSE = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}(x_i' - x)^2 + (y_i' - y)^2} \quad (2)$$

A. Total number of deployed sensor nodes

To observe the performance of proposed approach we simulate with anchor nodes as 10% of the total node, deployed area $100m \times 100m$, node communication range is taken as 10% of deployed area. The error in the distance is considered as 10% of the respective distance.

Figure 3 shows the performance of proposed approach increases with increase in the sensor nodes. It is observed that the time taken by mobile node decreases with increase in sensor node as shown in Fig 3(b). It happens because with an increase in sensor node nodes connectivity increases which increases the chance of getting more neighbor for localization as shown in Fig. 3(c). The average error of localization varies for node densities. However, localization accuracy increases with deployed sensor nodes shown in Fig 3(a).

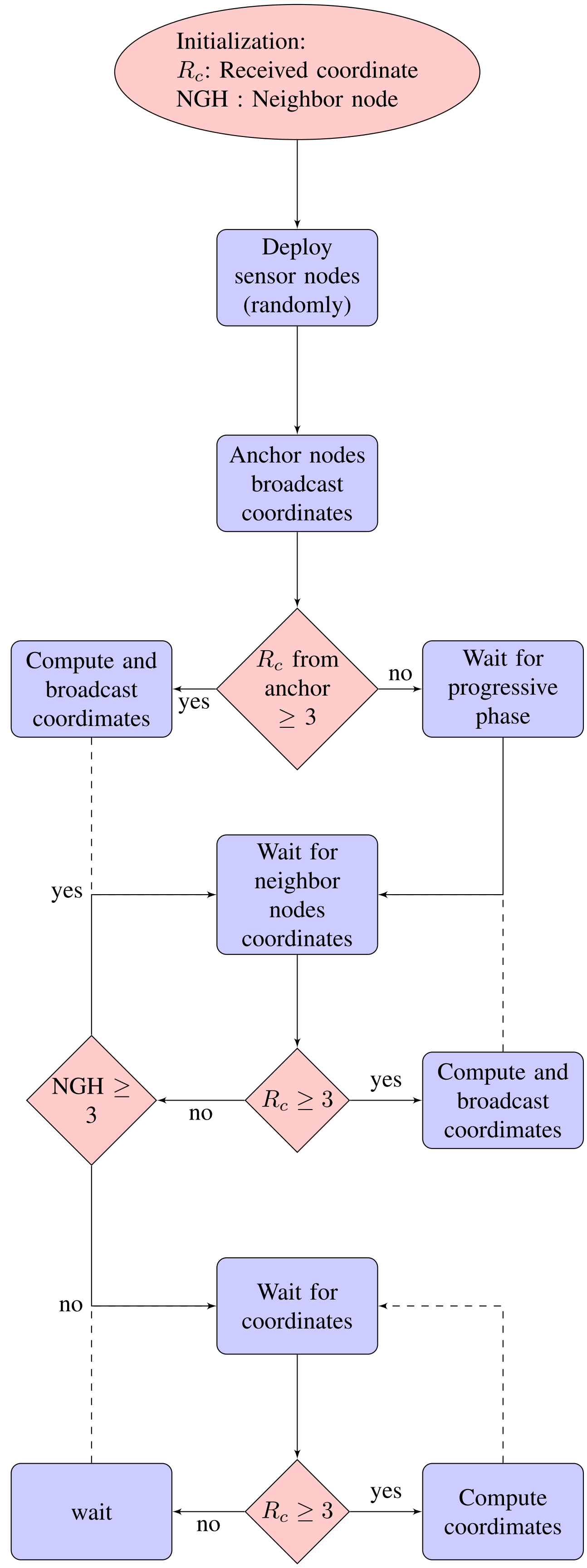
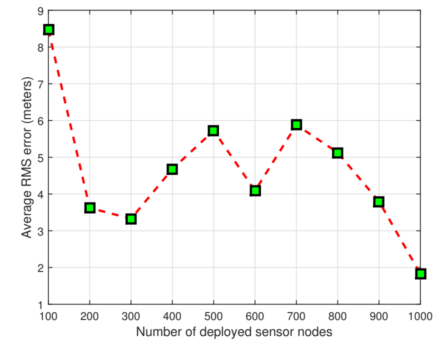
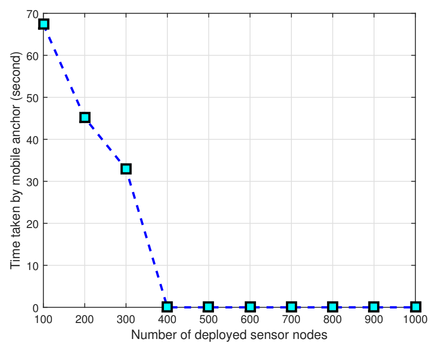


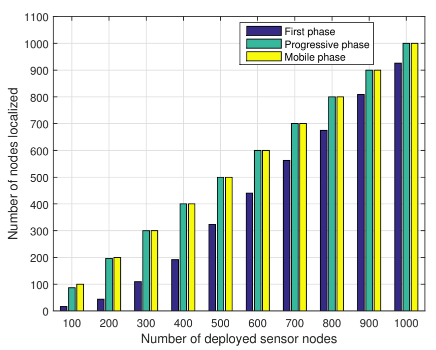
Fig. 2. Flowchart of Proposed Mechanism



(a) Average RMSE



(b) Time for mobile node



(c) Number of node localized

Fig. 3. The performance of proposed approach with total number of deployed nodes

B. Anchor nodes

To observe the performance of proposed approach for varying anchor nodes we deploy 200 sensor nodes in $100m \times 100m$ area with 10 meters radio range. The error in the distance is considered as 10% of the respective distance.

It is observed that the localization error decreases with increase in anchor nodes as shown in Fig. 4. This is because anchor nodes provide the true distances for location computation.

C. Communication range

To observe the performance of proposed approach with varying connectivity, a different value of communication range has been taken for simulation. For this 100 sensor nodes with ten anchor nodes are deployed in $100m \times 100m$ area. The error in the distance is considered as 10% of the respective distance.

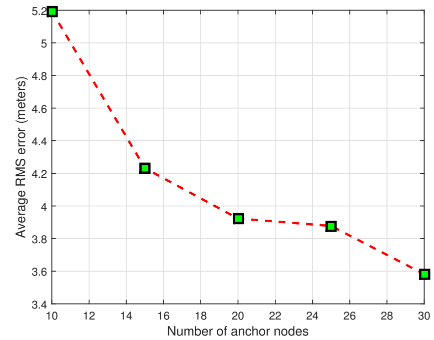


Fig. 4. The performance of proposed approach with anchor nodes

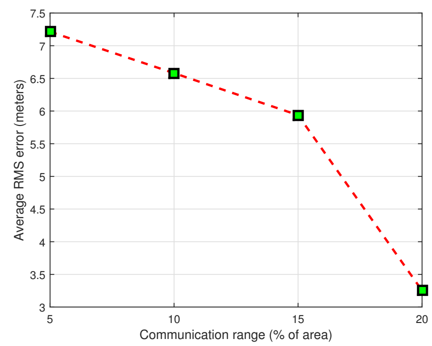


Fig. 5. The performance of proposed approach with varying communication range

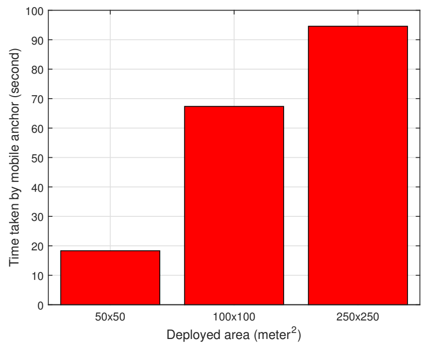
It is observed that the localization error decreases with increase in communication range of the sensor nodes as shown in Fig. 5. This is because the probability of getting more anchor nodes as a neighbor is increased.

D. Deployed area

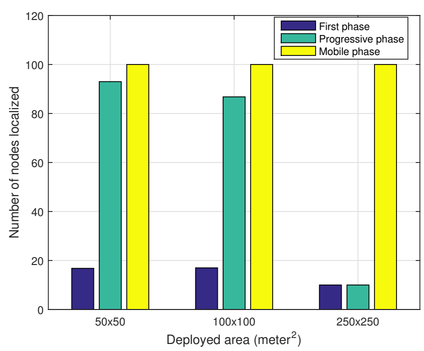
To observe the performance of proposed approach for scalability, different size of deployed area has been taken for simulation. For this 100 sensor nodes with ten anchor nodes are deployed. The communication range of a node is taken as 10% of deployed area. The error in the distance is considered as 10% of the respective distance. Fig. 6(a) shows that the time taken by the mobile node increases with deployed area. It is also observed that increase in deployed area decreases the localized node in initial two phases but finally all the nodes localized. This happens because mobile nodes provide location information of the sparsely connected node.

E. Error in distance estimation

To observe the performance of proposed approach for noise tolerance, a different value of measurement noise has been taken for simulation. For this 100 sensor nodes with ten anchor nodes are deployed in $100m \times 100m$ area. The communication range of a node is taken as 10% of deployed area. It is



(a) Time for mobile node



(b) Total node localized

Fig. 6. The performance of proposed approach with deployed area

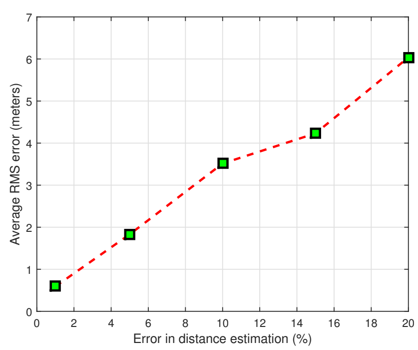
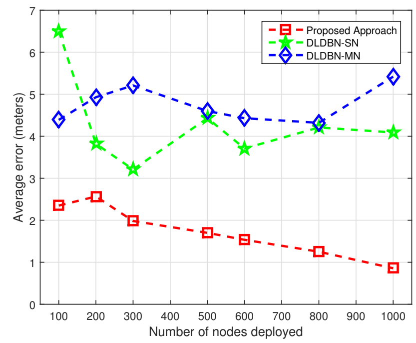


Fig. 7. The performance of proposed approach with varying error in distance estimation

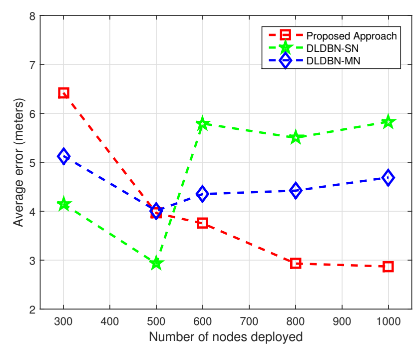
observed that the localization error increases with increase in measurement error in distance estimation as shown in Fig. 7. This is because the probability of getting true distance decreases with measurement error.

F. Performance comparison

In this section, we compare the performance of proposed approach with other existing techniques. The Distributed localization using a Dynamic Beacon Node (DLDBN) [7] taken two scenarios for performance analysis. In the first scenario, the static anchor is considered for localization and in second, mobile nodes as taken as anchor nodes for localization. We simulate the proposed approach with same parameters used in [7].



(a) Area 50x50 m^2



(b) Area 250x250 m^2

Fig. 8. The performance comparison with DLDBN

Fig. 8 shows the performance comparison between the proposed approach and DLDBN [7] for varying node density. The average error in localization is taken as the performance measure. It is observed that proposed approach perform better than existing techniques for a small area as shown in Fig. 8(a). For a large area, proposed approach lacks for low density, but for higher density, it performs far better than existing methods as shown in Fig. 8(b).

VII. Conclusion

In this paper, we proposed a distributed iterative localization algorithm that uses the mobile anchor nodes that move randomly and send location information to their neighbors to compute their approximate location. A progressive technique also helps to localize sensor nodes with low anchor density. The proposed algorithm is based on the multilateration which used the distance between nodes for location computation. It is found that the localization error is further reduced by receiving multiple beacons from the mobile anchor nodes from the different position during their mobility. The most significant advantages of mobile anchor node over static anchor node are that with less number of mobile anchor nodes the localization over the whole network is achieved, which is preferable for energy constrained WSN.

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