LOCALIZATION SCHEME FOR THREE DIMENSIONAL WIRELESS SENSOR NETWORKS USING GPS ENABLED MOBILE SENSOR NODES

Vibha Yadav, Manas Kumar Mishra, A.K. Sngh and M. M. Gore

Department of Computer Science & Engineering,
Motilal Nehru National Institute of Technology, Allahabad, INDIA
(cs0706, rcs0701, singhak, gore)@mnnit.ac.in

ABSTRACT

Location awareness among the participating nodes is one of the crucial requirements in designing of solutions for various issues related to Wireless Sensor Networks (WSNs). This paper discusses about a range free localization mechanism for WSN that operate in a three dimensional space. in this scheme, the sensor network is supposed to be comprised of mobile and static sensor nodes. Mobile sensor nodes are assumed to be equipped with GPS enabled devices and are expected to be aware of their position at any instance. These mobile nodes move in the network space and periodically broadcast beacon messages about their location. Static sensor nodes receive these messages as soon as they enter the communication range of any mobile node. On receiving such messages the static nodes calculate their individual position based on the equation of sphere. The proposed scheme gains in terms of computational and memory overhead as compared to existing approaches. The proposed scheme is simulated using Sinalgo, and the performance of this is compared with the chord selection approach. The simulation results validate the gain in localization time, its accuracy, and the resulted overhead.

KEYWORDS

Localization, Mobile Sensor Nodes, GPS, Range Free, Connectivity Range

1. INTRODUCTION

A wireless sensor network consists of a large set of inexpensive sensor nodes with wireless communication interface. These sensor nodes have limited processing and computing resources. Thus, algorithms designed for wireless sensor networks need to be both memory and energy efficient. In most of the algorithms for wireless sensor network, it is assumed that the sensor nodes are aware of their locations and also about the locations of their nearby neighbors. Hence, localization is a major research area in wireless sensor networks. But, this problem has not been studied extensively in three dimensional WSNs because of its complexity reasons. However, in some real world application scenario the deployed sensor network operates over a three dimensional volume rather than in a two dimensional area. Deployment of WSNs for surveillance of terrains, study of underwater ecosystem, space monitoring & exploration, etc; are examples of such applications. But, so far only a few researchers have addressed the problem of localization for these 3D scenarios.

Localization in sensor networks can be defined as ``*identification of sensor node's position*''. For any wireless sensor network, the accuracy of its localization technique is highly desired.
The existing algorithm for localization can be broadly classified into two basic categories:

1. Range Based Technique
2. Range Free Technique

In range based mechanisms, the location of a sensor node can be determined with the help of the distance or angle metrics. These metrics are Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), Received Signal Strength Indicator (RSSI). Range based techniques are highly accurate but, they are equipped with highly expensive hardware and requires a lot of computation. It increases the cost of the network and is inefficient in terms of computations. The various range based techniques are Radio Interferometric Measurement (RIM) [3], Multidimensional Scaling (MDS) [11], 3D - Landscape [14], DV-distance, DV-hop, Euclidean distance [15] etc.

In range free techniques, the position of sensor node is identified on the basis information transmitted by nearby anchor nodes or neighboring nodes, based on hop or on triangulation basis. The various range free techniques are APIT [1], chord selection approach [2] , three dimensional multilateration approach [5], SerLOC [6], centroid scheme [7] etc . Many more techniques are discussed in [4][8][13][15][17][18] . The range free techniques have an error in accuracy up to 10% of the communication range of individual node [2]. But, these techniques are much cheaper than the range based techniques.

In [2], Ou and Ssu have proposed a range free localization approach for three dimensional wireless sensor networks. In this approach a GPS equipped flying anchor is moved around a region under surveillance and it continuously broadcasts its position information. These messages help other sensor nodes to compute their location. This scheme was proved to be better than any existing range free localization scheme for three dimensional wireless sensor networks. The basic assumption in this work is that the nodes are static. Thus, for every run of the algorithm the flying anchor will be required to fly in the network. As, the flying anchor node is not a participating node in the WSN, it is impractical to be used in case of applications where sensors are more prone to displacements. In such applications, the network needs to have the ability to self-localize, whenever required. For this purpose, we need have few GPS enabled sensor nodes within the region to be monitored. These nodes will help other nodes to determine their location based on the positional information about themselves. Further, in case of any discrepancy, the sensor nodes may send an error message to base station regarding its dislocation. The base station will generate a query message to other stations. The GPS enabled sensor nodes will broadcast their locations. With the help of these location information, the displaced node can compute its new location. The above discussed strategy can be achieved by two schemes:

1. Enable a few static sensor nodes in the network with GPS equipped devices. These nodes will help in locating their neighbors depending on the placement strategy. The rest of sensor nodes will collectively get localized with the help of their respective neighboring nodes.
2. Take a few GPS enabled mobile sensor nodes to move within the network and help in locating the other sensor nodes.

The main drawback in using static sensor nodes is that, these nodes get their location computed with the help of locations of their neighboring nodes as proposed in [5]. If there is an error while computing the nodes location, this error gets rippled in computations related to next tiers of neighbors and so on. Hence, the anchor nodes which are the most vital part of the localizing scheme must be a part of the network and preferable mobile in nature.

This paper discusses a range free localization technique. It works on the above discussed second approach. We use the basic principle of three-dimensional geometry, that is ``*if any point is at the surface of sphere then it will satisfy the sphere equation*''. Suppose we have a few GPS enabled mobile wireless sensor nodes in the vicinity and they continuously broadcast their location. The static nodes on receiving such a broadcast message will record it. Then they can compute their locations with the help of four more such messages, assuming that these satisfy the sphere equation representing the transmission range of individual mobile node. Here we have assumed that, all the mobile sensor nodes deployed in a field have same the radio communication range.

In section 2, the related work is presented. Section 3 deals with the assumptions and goals of the work and presents the problem statement. In section 4, we present the localization scheme and the basis of this scheme. In section 5, we analyze the algorithm based on the computation and space requirements against existing approaches. In section 6, we present the simulation results to validate the scheme. And finally, section 7 presents the conclusions drawn and the proposed future work on the algorithm.

2. RELATED WORK

Localization in three dimensional wireless sensor networks is still under explored. Only a few researchers have tried to address the problem using both range based and range free techniques in [2][5][14].

In [14] Zhang, Zhou and Cheng have proposed a range based technique namely ``3D - landscape''. The scheme addresses the application domain of 3D terrains. In the scheme location - unaware nodes compute their location from the moving location - aware nodes. It works on Unscented Kalman Filter (UKF) - based algorithm.

In [5] Tian, Liu, Jin, Wang and Mo addressed a scheme for underwater acoustic sensor network. This scheme localizes the sensor nodes deployed over three dimensional volumes in underwater with time synchronization. In the scheme sensors are deployed in distributive manner over a three dimensional underwater space. This space is partitioned into equal sized non-overlapping cells. These cells are truncated octahedron in shape (as it resembles most with sphere [9]). In order to maintain the connectivity, the distance between two consecutive nodes in neighboring tier are made not to exceed their transmission range. [17]. The scheme uses multi-lateration and acoustic ranging techniques for localization. Firstly, a set of anchor nodes are placed at the surface of water. The nearby un-localized nodes get localized and synchronized with the help of these anchor nodes. These newly localized nodes now become new anchor nodes and thereafter broadcast newer synchronization packets. The process gets repeated tier to tier. Thus, the whole network gets localized in short latency. The major drawback with this approach is that in the localization process, the localization error at any level or tier is added further tier by tier. Also, it reaches very high if the network goes beyond the fifth tier.

In [2] Ou and Ssu have proposed an approach based on range free technique. In this scheme, a GPS enabled flying anchor is moved around the region under surveillance with the help of helicopter or aerial robot. All other sensor nodes will compute their location from the beacons received from the flying anchor. This approach works on basic principle that, ``*a perpendicular line passing through the center of a sphere's circular cross section also passes through the center of that sphere*''. The flying anchor continuously broadcasts beacon messages about its location in the region. Static sensor nodes receive the beacon messages whenever the flying anchor position instance falls in the sensing range of the former node. It records the beacon messages that are at the surface of its sensing range. When four such beacon messages are received, it builds two circular cross sectional areas and chords passing through the respective centers. These cross sectional areas help in location computation. The approach follows a constraint in selecting the beacons for the circular cross sectional areas i.e. chords built with these beacons must have angle greater than 10 degrees between them. It is assumed that static sensor nodes are aware of their sensing range sphere radius. It will result in three unknown variables, if the position coordinates of the flying anchor nodes are fed into the corresponding sphere equation. To solve for the value of three unknown variables, we need a minimum of three equations. Hence, we can save one beacon message and its related overhead.

3. PROBLEM STATEMENT

3.1. Assumptions

- **Static Nodes:** All static sensor nodes are homogeneous in nature. This means that, all the nodes have identical sensing ability, computational ability, and the ability to communicate. We also assume that, the initial battery powers of the nodes are identical at deployment.
- **Mobile Nodes:** It is assumed that a few number of GPS enabled mobile nodes are part of the sensor network. These nodes are homogeneous in nature. But, are assumed to have more battery power as compared to the static nodes and do not drain out completely during the localization process. The communication range of mobile sensor nodes are assumed not to change drastically during the entire localization algorithm runtime and also not to change significantly with in the reception of four beacon messages by a particular static node.
- **Spherical Communication Range**: All nodes have identical communication range '*r*'. Communication is Omni-directional and is broadcast in nature. The connectivity region of each node can be represented by a sphere of radius '*r*', having the sensor node at its center.
- **Quick Hearing:** Mobile sensor nodes will continuously broadcast their location. As soon as any static sensor node comes within its communication range, it will receive the broadcast message.
- **Random Deployment:** All the sensor nodes both static as well as mobile are deployed randomly over the surveillance volume.

3.2. Goals of the Work

To design a localization scheme that localizes the randomly deployed sensor nodes with low computation and communication overhead.

4. LOCALIZATION SCHEME

4.1. The Basis

The standard equation of sphere having its center at (x_1, y_1, z_1) and radius '*r*' can be expressed as

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = r^2 \qquad (1)$$

In this paper, we are going to use the equation of sphere where (x_1, y_1, z_1) will be the location of mobile sensor node. Communication range of the mobile sensor node is represented by '*r*'.

4.2. Communication Range

In [2][14] for localization in three dimensional wireless sensor networks, the authors have considered the sensing range of the participating nodes as the basis for their algorithms. These approaches were location unaware node centric localization schemes, in terms of detection of the position of location aware nodes and reception of their position information. And, the presence of any location aware node is detected by the location unaware nodes whenever the former comes with in the sensing range of the later ones. However, in [18] Wang and Tseng stated that, the coverage is affected by sensor's sensing distance, while connectivity is determined by its communication distance. Also [16] discussed that, for efficient connectivity, coverage and fault tolerance, connectivity range of node is generally greater than its sensing range. Thus, instead of sensing a GPS enabled mobile node in the sensing vicinity of a static node, we can utilize connectivity range of the mobile node for localization. As the connectivity range is greater than the sensing range, the volume covered by each instance is larger than the sensing range approach. This results in a faster localization. In our approach, the mobile nodes will continuously broadcast their location. As soon as any static node comes within the connectivity range of the mobile node, it will receive and record the message regarding the position of the mobile node. The static node again records the beacon message while it leaves the connectivity range of the mobile sensor node. Hence, all nodes get localized with lesser number of mobile sensor nodes.

4.3. Beacon Selection

Mobile sensor nodes continuously broadcast their location. Only the first and last beacon messages received from the mobile node is recorded. All other received beacon messages are discarded.

4.4. Maintaining the Table

Initially, when sensor nodes were randomly deployed, the mobile sensor nodes with GPS equipped device will move in the whole region to be monitored. The static sensor nodes will maintain a table that will have entries for recently accepted beacon messages from the mobile node. These nodes receive a beacon message from each of the moving mobile nodes which is in its vicinity that is, set with the values of mobile node location along with its ID and lifetime.

4.5. Computing the Sensor Node's Position

Let the first beacon message received by static sensor node is broadcasted from position (x_1, y_1, z_1) and that of second, third and fourth are from (x_2, y_2, z_2), (x_3, y_3, z_3), (x_4, y_4, z_4).

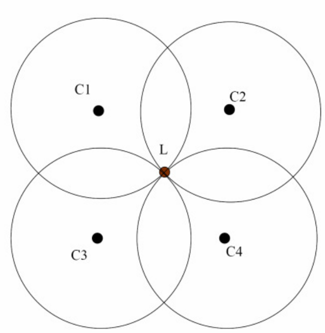

Figure 1. Location Calculation where Static Sensor Node is at the Surface of Connectivity Range of Mobile Sensors

Let L be the location of sensor node and 'r' be the communicating range of all the mobile sensor nodes. According to standard equation of sphere we have,

$$(x-x_1)^2+(y-y_1)^2+(z-z_1)^2=r^2 \qquad (2)$$

$$(x-x_2)^2+(y-y_2)^2+(z-z_2)^2=r^2 \qquad (3)$$

$$(x-x_3)^2+(y-y_3)^2+(z-z_3)^2=r^2 \qquad (4)$$

$$(x-x_4)^2+(y-y_4)^2+(z-z_4)^2=r^2 \qquad (5)$$

As we assumed that communication range of all the mobile sensors are equal. Substituting the values of r^2 from equation (2) to equation (1) and equation (3), and from equation (3) to equation (4), we get

$$(x-x_1)^2+(y-y_1)^2+(z-z_1)^2=(x-x_2)^2+(y-y_2)^2+(z-z_2)^2 \qquad (6)$$

$$(x-x_2)^2+(y-y_2)^2+(z-z_2)^2=(x-x_3)^2+(y-y_3)^2+(z-z_3)^2 \qquad (7)$$

$$(x-x_3)^2+(y-y_3)^2+(z-z_3)^2=(x-x_4)^2+(y-y_4)^2+(z-z_4)^2 \qquad (8)$$

On solving equation (5), equation (6), equation (7) for x, y and z using matrices, we get

$$x=\begin{bmatrix} \frac{(x_1^2-x_2^2)+(y_1^2-y_2^2)+(z_1^2-z_2^2)}{2} & y_1-y_2 & z_1-z_2 \\ \frac{(x_2^2-x_3^2)+(y_2^2-y_3^2)+(z_2^2-z_3^2)}{2} & y_2-y_3 & z_2-z_3 \\ \frac{(x_3^2-x_4^2)+(y_3^2-y_4^2)+(z_3^2-z_4^2)}{2} & y_3-y_4 & z_3-z_4 \end{bmatrix}/\Delta \qquad (9)$$

$$y=\begin{bmatrix} x_1-x_2 & \frac{(x_1^2-x_2^2)+(y_1^2-y_2^2)+(z_1^2-z_2^2)}{2} & z_1-z_2 \\ x_2-x_3 & \frac{(x_2^2-x_3^2)+(y_2^2-y_3^2)+(z_2^2-z_3^2)}{2} & z_2-z_3 \\ x_3-x_4 & \frac{(x_3^2-x_4^2)+(y_3^2-y_4^2)+(z_3^2-z_4^2)}{2} & z_3-z_4 \end{bmatrix}/\Delta \qquad (10)$$

$$z=\begin{bmatrix} x_1-x_2 & y_1-y_2 & \frac{(x_1^2-x_2^2)+(y_1^2-y_2^2)+(z_1^2-z_2^2)}{2} \\ x_2-x_3 & y_2-y_3 & \frac{(x_2^2-x_3^2)+(y_2^2-y_3^2)+(z_2^2-z_3^2)}{2} \\ x_3-x_4 & y_3-y_4 & \frac{(x_3^2-x_4^2)+(y_3^2-y_4^2)+(z_3^2-z_4^2)}{2} \end{bmatrix}/\Delta \qquad (11)$$

$$\Delta=\begin{bmatrix} x_1-x_2 & y_1-y_2 & z_1-z_2 \\ x_2-x_3 & y_2-y_3 & z_2-z_3 \\ x_3-x_4 & y_3-y_4 & z_3-z_4 \end{bmatrix} \qquad (12)$$

If the mobile beacons received are in one plane that is parallel to the basic axes x, y, and z, then the computed value of $\Delta = 0$. Thus, we need to remove the last entry of mobile sensor node's location and look for another value. In other cases the algorithm will execute as normal and no special consideration is needed. The obtained values of x, y, and z specifies the location of static sensor node *L*. Also, once a node has calculated its location, the beacon messages will be automatically removed as their lifetime expires.

5. ANALYSIS

There are only few papers addressing the range free localization in three dimensional WSNs. And as the approach presented in [2] has been proved by the authors to be the best scheme, we analyze and compare our approach with their approach to check the better of the two.

5.1. Number of Computations

The numbers of computations required in previously proposed approaches were quiet high. In [2] number of computation required for computing a sensor's location is 153 (i.e. 88 multiplications and 65 additions). However, in our proposed approach the number of computations is 98 (i.e. 54 for multiplying and 44 addition). Thus, we have reduced the number of computation required by 33% which is an additive gain in case of sensor networks.

5.2. Space Complexity

While comparing our approach with the chord selection approach [2], it is found that our approach takes lesser space than chord selection approach. As in [2] it takes 34 variables to compute the location of a sensor node. However, in our approach it takes 28 variables. Thus, it also saves memory resource to a little extent.

5.3. Chord Selection Criteria vs. Points in a plane

In [2] Ou and Ssu have considered the chord selection criteria to avoid beacons. This criterion selects those chords that are built with these beacons having angle greater than 10 degrees between them. Otherwise, it will lead to the location of the center of the sphere above or below the actual center. This problem will also be there for larger angle between them. But, in our approach occurrences of all coplanar beacons only lead to non determination of the center. Only one non-coplanar beacon will be sufficient to determine the center effectively. Hence, there is a low probability of discarding any position information obtained through beacon messages which results in saving of time, computation and communication overheads.

6. SIMULATION AND RESULTS

We have performed simulation on Sinalgo-0.75.3-Regular Release [12] which provides a simulation framework for three dimensional sensor networks. We have implemented our approach and chord selection approach mentioned in [2]. And the comparative results are presented in the subsequent subsections.

6.1. Simulation Environment

The simulations are performed on a region of surveillance with a volume of $100 * 100 * 100m^3$. In this region, we have randomly deployed 300 static sensors with GPS enabled mobile sensor nodes of 1%, 2%, 3%, 4%, 5% of total number of deployed sensor nodes respectively, for the analysis.

The mobile sensor nodes are moved according to random way point method and random direction walk. In random way point technique, the mobile nodes are deployed randomly. They randomly choose any destination and move in that direction with constant speed. Once they reach the destination they repeat the whole process. The random direction walk is similar to random way point walk. The only difference is the choice of the target. Instead of picking a random point from the deployment field, the random direction chooses a direction in which the node should walk, and how long the node should walk in this direction. If the node hits the boundary of the deployment area, it is reflected just as a billiard ball.

6.2. Simulation Settings

The other parameter settings for the simulation are summarized in Table 1.

Table 1. Simulation Parameters

Synchronous Mode	True
Interference Model	No
Distribution Model	Random
Connectivity Model	UDG (r_{max} = 10 m)
Reliability Model	Reliable Delivery

6.3. Performance Metrics

In [2], Ou and Ssu have defined following metrics to evaluate performance of the localization mechanism:

- ***Average localization error:*** The average distance between the estimated location (x_e, y_e, z_e), and actual location (x_L, y_L, z_L) i.e.

$$AverageLocalizationError = \frac{\sum \sqrt{(x_e - x_L)^2 + (y_e - y_L)^2 + (z_e - z_L)^2}}{no\ of\ sensor\ nodes}$$

  It checks whether the computed location is correct or not.

- ***Average localization time:*** The average time required for all sensor nodes to compute their locations i.e.

$$AverageLocalizationTime = \frac{\sum Localization\_time}{no\ of\ sensor\ nodes}$$

- ***Beacon Overhead:*** The average number of beacon messages transmitted during the total localization time, i.e.

$$Beacon\ Overhead = \frac{no\_of\_beacon\_messages}{no\ of\ mobile\ sensor\ nodes}$$

  In any sensor node most of the energy is consumed in computation and in message transmission and reception. For localization nodes need to be active until localized. Thus, the above two metrics defines energy efficiency.

6.4. Results

Using these metrics following results were observed.

6.4.1. Rate of Localization

Simulation is performed on various data sets i.e. deploying different number of static nodes. It is observed that for first 75% nodes localization process takes 3% of total time taken. However, next 10% nodes take 15% time of total time taken. The rest of time taken is consumed to locate the remaining nodes that are far placed or placed in sparsely dense regions. The result is shown in Figure 2.

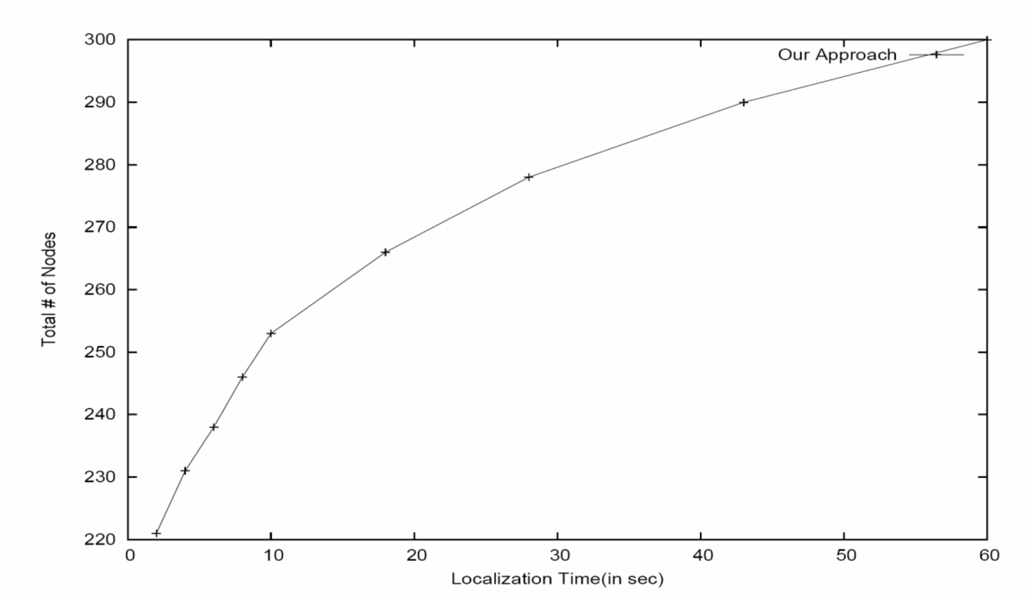

Figure 2. Time of Localization vs. No. of nodes localized using Random Way Point Walk

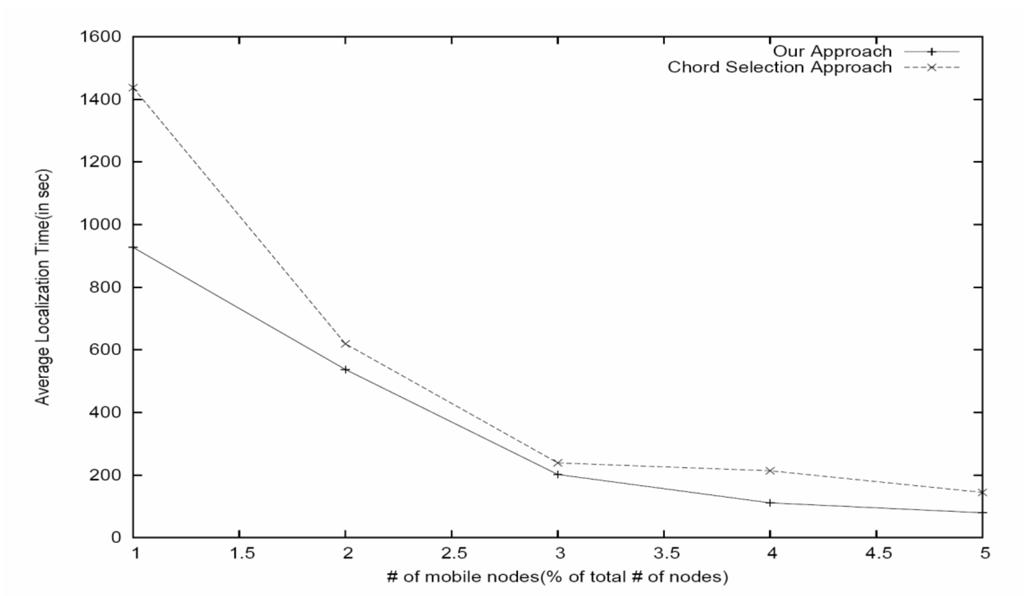

Figure 3. Average Time of Localization vs. % of mobile nodes for Random Way Point Walk

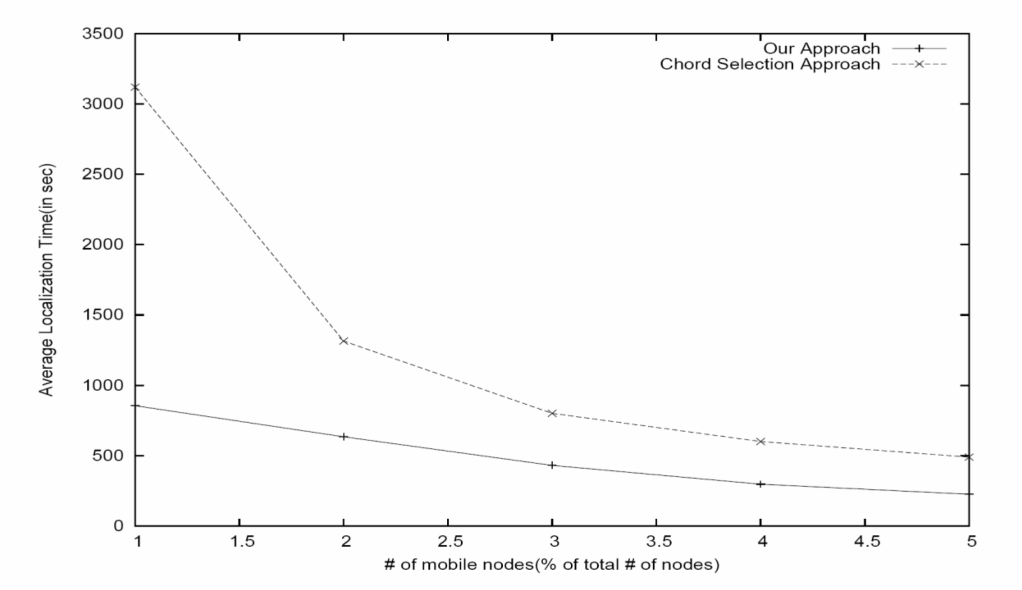

Figure 4. Average Time of Localization vs. % of mobile nodes for Random Direction Walk

6.4.2. Localization Error

There is no constraint other than the selected beacon. It should be at the surface of connectivity range. Thus, if the selected beacon message is at the surface of connectivity range, experiments have shown that there is no localization error i.e. the computed location of sensor is accurate.

The location computed may have error if either the GPS device determines its location wrong or if there is a sudden change in the communication range of mobile sensor nodes between the reception of first and last beacon messages.

6.4.3. Number of Mobile Nodes and Beacon Overhead

In [2], Ou and Ssu have proved that Chord Selection is better than previously proposed Centroid and Constraint range free schemes. However, experimental results shown in Figure 3, Figure 4, Figure 5, and Figure 6 illustrate that our approach is better than chord selection approach in terms of both beacon overhead and localization time for both the mobility models for mobile sensors. As we are not discarding any beacon message received at the surface of connectivity range because of any selection constraint. From our results, it can also be inferred that with the increasing number of mobile nodes in the vicinity, the localization time as well as beacon overhead is reduced significantly.

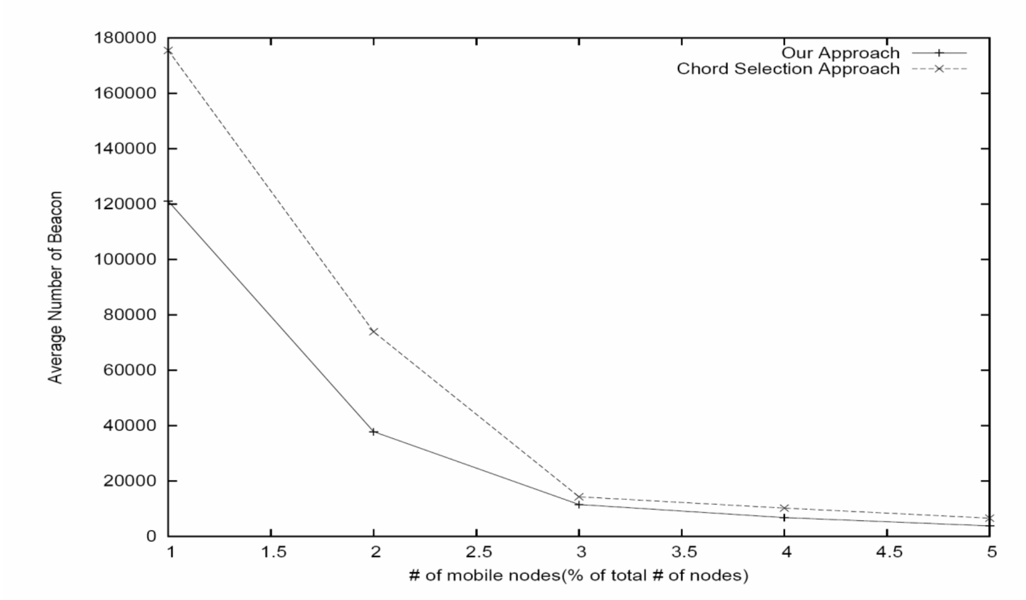

Figure 5. Beacon overhead vs. % of mobile nodes for Random Way Point Walk

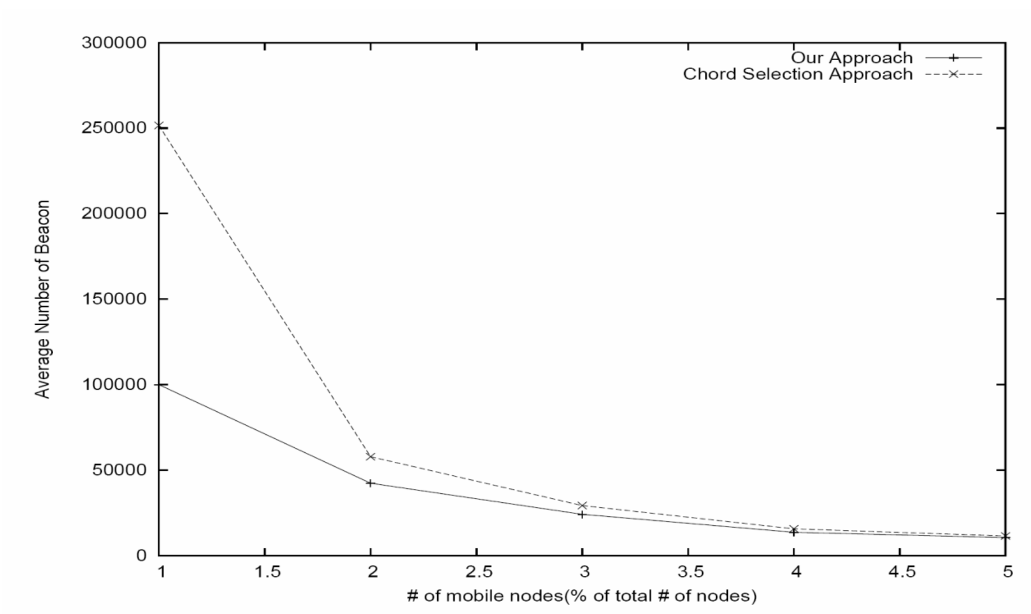

Figure 6. Beacon overhead vs. % of mobile nodes for Random Direction Walk

7. CONCLUSIONS AND FUTURE WORK

The results show that our approach is better than the previously proposed approaches for range free localization techniques for three dimensional wireless sensor network in terms of beacon overhead, localization time, localization error, computation and space required for any percent of mobile sensor nodes. In future work, we would like to modify this approach to make the already position aware static nodes to participate in localization. Also the consideration of changing communication range for the mobile nodes is seen as a potential area for future work.

REFERENCES

[1] Brian M. Blum, John A. Stankovic, Tarek Abdelzaher, Tian He and Chengdu Huang (2005) "Range-free localization and its impact on large scale sensor networks" In *ACM Transactions on Embedded Computing Systems*, volume 4, pages 877 -- 906, November 2005.

[2] Chia-Ho Ou and Kuo-Feng Ssu. (2008) "Sensor position determination with flying anchor in three dimensional wireless sensor networks." In IEEE *Transactions on Mobile Computing*, pages 1084--1097, September 2008.

[3] Davide Merico and Roberto Bisiani. (2006) "Positioning, localization and tracking in wireless sensor network." *Technical report, DISCo, NOMADIS*, March, 2006.

[4] Guoqiang Mao, Barics Fidan, and Brian D.O. Anderson. (2007) "Wireless sensor network localization techniques." In *Computer Network: The International Journal of Computer and Telecommunications Networking*, ACM, 51:2529--2553, July 2007.

[5] Jiang Jin, Yi Wang, Chen Tian, Wenyu Liu and Yijun Mo. (2007) "Localization and synchronization for 3d underwater acoustic sensor networks." In *Springer, Ubiquitous Intelligence and Computing 2007*, pages 622--631, Hong Kong, China, July 2007.

[6] Loukas Lazos and Radha Poovendran. (2005) "SeRLoc: Robust localization for wireless sensor networks." In ACM *Transactions on Sensor Networks*, pages 73--100, August 2005.

[7] Marcelo Martins, Hing Cheung So, Hongyang Chen, Pei Huang and Kaoru Sezaki.(2008) "Novel centroid localization algorithm for three-dimensional wireless sensor networks." In *IEEE Transactions on Wireless Communication, Networking and Mobile Computing*, pages 1--4, October 2008.

[8] Rong Yu, Zhi Sun and Shunliang Mei. (2006) "A power aware and range free localization algorithm for sensor network." In *IEEE Transactions on Communications*, pages 1--5, August 2006.

[9] S.M. Nazrul Alam and Zygmunt J. Haas. (2006) "Coverage and connectivity in three dimensional networks." In *ACM Transactions on Mobile Computing and Networking*, pages 346--357, September, 2006.

[10] S. M. Nazrul Alam and Zygmunt Haas. (2006) "Topology control and network lifetime in three dimensional wireless sensor networks." In CORR *cs.NI/0609047*, 2006.

[11] Santosh Pandey and Prathima Agarwal. (2006) "A survey on localization techniques for wireless networks." *Technical report*, Auburn University, 2006.

[12] "Sinalgo : Simulator for network algorithms", *http://dcg.ethz.ch/projects/sinalgo*, 2009.

[13] Tian He, Radu Stoleru and John A. Stankovic. (2006) "Range free localization." *Technical report*, University of Virginia, 2006.

[14] Xiaobo Zhou, Liqiang Zhang and Qiang Cheng. (2006) "Landscape-3d: A robust localization scheme for sensor networks over complex 3d terrains." In *Proc. 31st IEEE International Conference Local Computer Networks*, pages 239--246, November, 2006.

[15] Youssef Chraibi. (2005) "Localization in wireless sensor network." *Master's thesis*, KTH Stockholm, Sweden, 2005.

[16] Yuanfang Zhang, Chenyang Lu, Robert Pless, Christopher Gill, Guoliang Xing and Xiaorui Wang. (2005) "Integrated coverage and connectivity configuration for energy conservation in sensor networks." In *ACM Transactions on Sensor Networks*, pages 36--72, August, 2005.

[17] Yu-Chee Tseng, You-Chiun Wang. (2008) "Efficient placement and dispatch of sensors in wireless sensor network." In *IEEE Transactions on Mobile Computing*, pages 262--274, February, 2008.

[18] Yu-Chee Tseng, You-Chiun Wang. (2008) "Distributed deployment scheme in mobile wireless sensor networks to ensure multi level coverage." In *IEEE Transactions on Parallel and Distributed Systems*, pages 1280--1294, September, 2008.