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Location estimation scheme with improved accuracy

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Abstract

Advancement in Micro Electro-Mechanical Systems (MEMS) technology has enabled the proliferation of Wireless Sensor Networks. Wireless Sensor Networks are widely been used in many tracking and monitoring scenarios such as disaster relief, vehicle tracking, Environmental and Health Monitoring. To make Wireless Sensor networks fulfill the criteria for these scenarios, it is very necessary to determine the location of nodes which involves collaboration between sensor nodes. The process of determining the physical location of nodes is called "Localization". The Proposed work addresses the problem of location discovery of the nodes in wireless sensor network. A localization technique has been proposed by means of which a sensor node can determine its location with enhanced accuracy. The scheme has employed RSSI technique that does not add complexity to the construction of system and positions are estimated with MDS-based mapping method to obtain best results.

Keywords

Node Localization, Received signal strength indicator, Multi-dimensional scaling, Accuracy, Localization error.

1. Introduction

The proliferation of Micro-Electro-Mechanical Systems has motivated the development of smart sensors, which is the main component of Wireless Sensor Network. These sensors are small in size, with limited processing and computing resources, and they are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user terminal. WSNs have great potential for many applications in scenarios such as military target tracking and surveillance, natural disaster relief, biomedical health monitoring, and hazardous environment exploration.

To fulfill the criteria for many of the applications mentioned above, we need to know the position or location of the sensor nodes as the nodes are placed randomly in an area and initially we do not know the location co-ordinates. The process of determining the physical positions of nodes is called Localization. The straight forward solution is to equip each sensor node with a GPS receiver that can provide exact location. This is, however not a feasible solution from economic point of view, since sensors are often deployed in very large numbers and manual configuration is too complex and so not feasible. So, there is another way by means of which we can estimate the location of sensor nodes not as accurately as GPS does but with sufficient precision. For this to be done, many localization techniques and algorithms have already been proposed.

Based on the application requirement and availabilities, these can be classified as:
1) Range-based and
2) Range-free localization techniques.
In simple words, range based localization is based on peer-to-peer distance between nodes using some special features such as Received Signal strength (RSS), Angle of Arrival (AoA), Time of Arrival (ToA), Time difference of Arrival (TDoA). Whereas, range free localization is based on the connectivity information only with less accurate distance estimation to infer the location of unknown node. Some of the important localization techniques based on range-free approach are Multidimensional Scaling Map (MDS-MAP), Centroid, Amorphous, APIT localization algorithm. When a scheme is designed to perform localization, many factors are there that are considered. The method should be accurate, cost efficient and secure [1].

2. Related Work

Localization is an active area of research in wireless sensor networks and so there are many existing methods on this topic. In one such work A. Savvides et al. have proposed a localization system [2] AHLoS (Ad-Hoc Localization System) based on TDOA. In AHLoS, the Anchors broadcast position information periodically over RF and ultrasound signals simultaneously. A normal node receives the RF signal earlier than the ultrasound signal and based on this time difference it measures the distance of the Anchor. Due to several factors such as multi-path fading, noise interference, the measurements may not be accurate. Further drawback of TDOA technique is its reliance on energy consumption and expensive hardware leading to its less suitability for resource-constrained nodes in WSN. Shang Yi et al.[3] proposed a localization method based on multidimensional scaling (MDS). It determines the positions of nodes given only basic information that is likely to be already available, namely, which nodes are within communication range of which others. Only on the basis of available communication range, the positions estimated are far away from accuracy. To achieve accuracy, they have employed a position refinement technique that adds much complexity and cost.
Niculescu D. and Nath B. [4] have proposed localization algorithm APS (Ad hoc Positioning Systems) based on AOA. Each node receives radio signal from beacons and estimates its own position by bearing/angular separation between beacons and itself. More specifically, the location of a node is determined by the intersection of all bearings and the distance between node and beacon. Once the nodes become localized it acts as a beacon and that information is forwarded in a hop by hop fashion to localize the others nodes. This algorithm is suitable for indoor location aware applications only.
Most of the existing localization methods require specialized equipment such as antenna arrays, global positioning system (GPS) etc. A few of the existing methods, which do not require the use of such expensive equipment, are based on Received Signal Strength Indicator (RSSI). This fact motivates to use such method to reduce localization error and system cost.
The rest of the paper is organized as follows:
The system model including objective and assumptions of the present work is presented in section 3. The proposed localization scheme is presented in Section 4 with description of RSSI and MDS-Map. In section 5, the performance of the scheme is evaluated based on quantitative analysis and comparison with an existing scheme is done. Finally in section 6, the paper is concluded with discussion about the future scope of the work.

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3. System Model

A square random model is considered for the deployment of sensor nodes. The nodes are distributed randomly over an area. For the topology of network, a regular model is chosen. In this model, the radio range is a circle [5]. Presence of special nodes, called Anchor or Beacons is also considered. These are the nodes which are already localized either by GPS or some other means. A communication range, degree of irregularity (DOI), anchor communication range is defined under topology of WSN.

3.1 Objective

The objective of this work is to propose an accurate location estimation technique by means of which nodes in wireless sensor network can compute their locations with reduced localization error and the system remains cost efficient.

3.2 Assumptions

We assume that nodes are distributed randomly on a two dimensional network area. The nodes that do not have global knowledge of the topology or their physical locations and they are static in nature. All nodes are homogeneous in terms of initial energy, computational and communication abilities. A set of nodes within the communication distance of a node is called its communication neighborhood. We also assume the presence of some beacons that are deployed within the network area. This amount of beacons can be varied as per requirements. Beacons are identical to the other nodes in capabilities, except that they are preprogrammed with their global positions.

4. Proposed location estimation scheme with improved accuracy (LESIA)

It is assumed that there are one or more beacons initially present in the network area. The process initiates as a beacon starts sending a message to its neighbors. This message carries the information about the location of the beacon by whom it is been sent. Once the message is received by the neighboring nodes of the beacon, to start with, the neighboring nodes store the message and measure the Received Signal Strength (RSS). The other beacons wait for a random time interval and one by one transmit message. When all beacons are done with message broadcasting, a set of neighboring nodes have received broadcast message from at least one beacon. This set of nodes performs node localization in two steps:

- In the first step, each node calculates its distance estimation from the beacons using the RSSI method [6].
- In the next step, MDS-MAP [3] method is used to combine the estimated distance from all anchors and anchor locations to find the relative and then absolute map of all nodes with resolved location estimation.

Our scheme also works when there is no beacon present in the network. It utilizes communication range to find the neighbors and get the connectivity information.

4.1 Description of RSSI method

It is a range-based method of distance calculation and is based on the fact that signal strength decreases with increase in distance. The principle of distance measurement is to change the attenuation of signal strength into distance of signal transmission, using functional relation between attenuation of the signal and the distance approximately. Some formulae related to this are:

$$Ld = L1 + 10 \times \eta \times \log d + v \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$L1 = 10 \log Gt\, Gr\, (c/f \div 4\pi)^2 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Gt and Gr are gain of transmitting and receiving antenna, c is the velocity of light, f is the carrier frequency, η is the channel attenuation coefficient (2~6), v is the Gaussian random variable which considers the shadow effect, d is the distance, Ld is the channel loss after distance d. When we practically perform the calculations, we get the relation between RSS and the distance through measurement of transmitted power and received power. For this purpose, the formula is as:

$$PR = PT / rn \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

After the conversion:

$$PR\ (dBm) = A - 10 \times n \log r \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Here PR is the received power of the signal, PT is the transmitted power, n is the propagation factor, r is the distance between transceiver unit, A is the receiving signal power when signal transmit 1m. The numerical value of A and n determine the relation between received signal strength and signal transmission distance [7].

This way, based. on the RSS values, the distance between beacons and other neighboring unknown nodes are calculated. Now we have the distance matrix that consists of the values of distance of every node from its neighboring beacon. The matrix that contains all these values is Neighbor matrix. Now using these estimated distance values, the second phase of the localization comes.

4.2 MDS-MAP method

MDS stands for Multi-Dimensional Scaling and MDS-MAP is a mapping method with multi-dimensional scaling as base. The main advantage of this scheme is to minimize the computation cost. For MDS-MAP, the complexity is O (n3) where n is number of nodes. This method in collaboration with RSSI can perform both types of localization:

1. Range-based Localization (in presence of beacons)
2. Range-Free Localization (in absence of beacons)

For range free localization, it uses connectivity information only. i.e. Who is within communications range of whom—to derive the locations of the nodes in the network. MDS-MAP generates relative maps that represent the relative positions of nodes when there are no beacon nodes that have known absolute coordinates. We assume that all the nodes being considered in the positioning problem form a connected graph. If an outlying node is not within communications range of any other nodes, we obviously cannot estimate its position. This method can work well in applications that only require relative positions of nodes, such as in some direction-based routing algorithms. There are many types of MDS techniques, including metric MDS and non-metric MDS, weighted MDS, replicated MDS, probabilistic and deterministic MDS. Here, a classical metric technique has been employed in which proximities are treated as distances in a Euclidean space and it can work well for large matrices. In this case, all we get is a relative map that gives a relative estimate of the positions. A mapping range R is defined always. For each node, neighbors within R hops are involved in building its local map.

In range-based scenario, when we have certain beacons or Anchor nodes, we can take advantage of additional data, such as estimated distances between neighbors or known positions for certain anchor nodes. In proposed work, we have the estimated distance values from RSSI calculations. When the positions of a sufficient number of anchor nodes are known, e.g., 3 anchors for 2-D localization, MDS-MAP then determines the absolute coordinates of all nodes in the network. It often outperforms previous methods when nodes are positioned relatively uniformly in space, especially when the number of anchors is low. MDS-MAP uses the distance or connectivity information between all nodes at the same time, whereas previous triangulation-based methods localize one unknown node at a time and only use the information between the un-localized and anchor nodes. The change introduced in MDS approach avoids using shortest path distances between far away nodes, and only the local maps are constructed based on local information. Another advantage of the proposed method is that it works in a distributed way, i.e. every node is responsible for its location estimation. This way the communication complexity is reduced which makes it appropriate for large-scale networks. Here, the output is an absolute map. The task of finding an absolute map is to determine the absolute geographic coordinates of all the nodes. This is needed in applications such as geographic routing and target discovery and tracking. The communication cost in a distributed implementation of MDS-MAP is proportional to the sizes of the local maps.

4.2.1 Relative and Absolute maps

First shortest paths between all pairs of nodes are computed using RSSI neighbor matrix. The shortest path distances are used to construct the distance matrix for MDS. Classical metric MDS is applied to the distance matrix, from which first 2 or 3 largest Eigen values and eigenvectors are retained to construct a 2-D relative map.

Then relative positions coordinates of the nodes are calculated. This scheme works for the applications that do not require much accuracy in location information. In present work, the obtained relative position coordinates for say, nine nodes are shown in table 1.

Table 1. Relative position coordinates

X-coordinates	-7.99	-160.6	-250.1	91.09	5.37	-72.6	-2.08	235.58	177.41
Y-coordinates	149.52	-157.6	-59.63	22.01	58.77	75.68	135.01	-74.04	16.39

In next step of the scheme, the positions are resolved to find the best solution. For three given anchors, the positions are resolved to find best solution. The best linear transformation between the absolute positions of the anchors and their positions in the relative map is computed. The deviation among coordinates for relative and absolute map can be seen from the values in the table below table 2.

Table 2. Absolute position coordinates

X-coordinates	99.95	173.88	0.80	306.39	185.05	87.50	117.64	537.44	404.14
Y-coordinates	339.37	4.82	30.22	296.15	274.97	242.50	331.29	304.73	342.50

Two maps are merged together based on their common nodes. The best linear transformation (minimizing conformation errors) is computed to transform the coordinates of the common nodes in one map to those in the other map. This computation can be done efficiently and gives more accuracy.

5. Results and Discussions

This section of the paper shows the results obtained by trying simulation for different number of sensor nodes, different dimensions of Network area, variation in population of anchor nodes values etc. the implementation of the proposed scheme has been done in MATLAB.

5.1 Results for different population of sensors Localized with variation in number of Beacons
Here, number of normal sensor nodes is varied and correspondingly, quantities of beacons and networks dimensions are changed. This is done for small scale, medium and dense networks.

5.1.1 For Small Scale Networks: Location estimation when number of nodes is 50, considered is (450x450)m, no. of anchors or beacons from 3 to 10. Here, the objective is to show that the proposed scheme performs well for small number of beacons. Here, experiment is done with different no. of beacons.

Table 3. Localization Error Corresponding to no. of Beacons (Small scale WSNs)

No. of Beacons	3	4	5	6	7	8	9	10
Mean Localization Error	0.1209	0.1222	0.1354	0.7445	1.562	1.1362	0.7045	0.8931

From the values given in table, it is observed that for smaller number of beacons i.e. 3, we have minimum mean localization error. It shows that this scheme works well for small scale WSNs and is cost efficient. For three beacons, the localization error can be seen as:

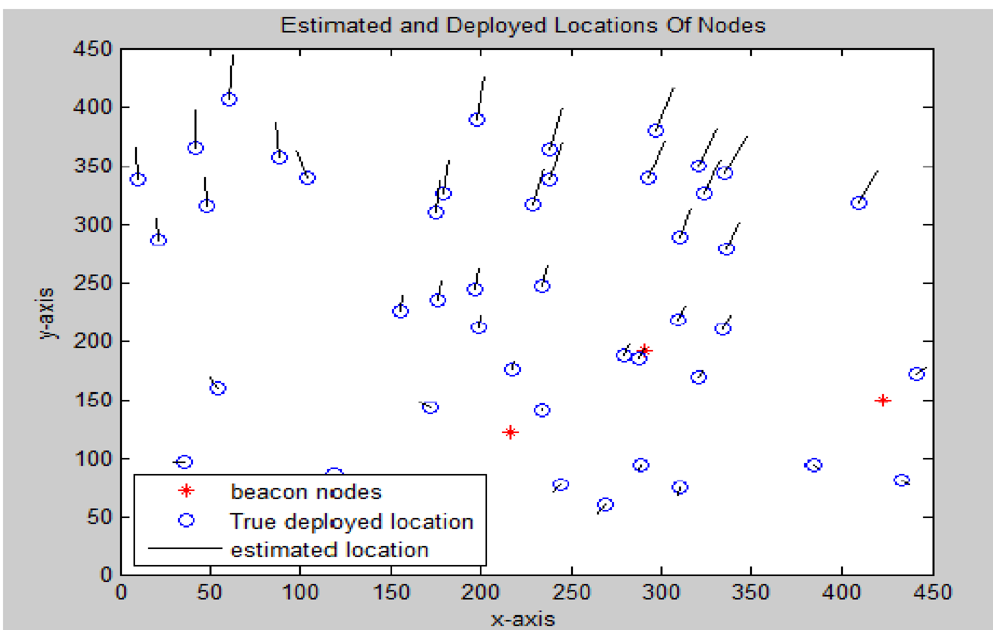


Figure 1. Localization Error: Deviation among Deployed and Estimated location points

5.1.2 For Medium Scale Networks

For number of nodes = 200 and variable amount of beacons from 3 up to 30, Area to be covered is (1000 × 1000) m. The values of Localization error are given in the table below:

Table 4 Localization Error corresponding to number of Beacons (Medium size WSNs)

Number of Beacons	3	5	8	10	20	30
Localization Error	1.2637	0.5231	0.1510	0.0244	0.0364	0.0248

It can be concluded from the values of localization error given in the table 4 that for medium scale Sensor Networks, as the number of beacons increases, the accuracy of the system is improved i.e. Estimation error is reduced. So, proposed scheme is not cost efficient for medium sized WSN as more number of GPS systems are needed to be installed.

5.1.3 For Dense Networks

Area to be covered = 2000 × 2000 sq. meter, Number of deployed nodes = 500. All other parameters are the same. Number of anchors is varied from 5 to 60 and the corresponding values are given in table5.

Table 5 Localization Error corresponding to number of Beacons (Dense WSNs)

Number of Beacons	5	10	20	30	40	60
Localization Error	0.7422	0.9226	0.11538	3.8039	1.8011	0.082243

It can be concluded from the above acquired values that for n=500, if we keep the number of beacons low as 5, the localization error is as small as 0.74225 and for large value 60, the results gets better i.e. 0.082243 which is the least value among all. It can be concluded that when no. of beacons is small, the error is not much high. This means that the proposed method LESIA performs well even with few number of anchors. Whereas, to improve it further, the amount of anchors can be increased.

The acquired results prove efficiency and accuracy of the proposed scheme even for large scale wireless Sensor Networks. It is also seen that the overall results are much better than other approaches. This method performs well in irregular terrains as well. To prove this, we have considered path loss and degree of irregularity.

5.2 Comparison of LESIA with an existing localization method LELA

To better prove the Accuracy and Efficiency of proposed localization method, a comparison is performed based on available data. LELA stands for _Localization with Enhanced Location Accuracy' and LESIA is Location Estimation Scheme with Improved Accuracy'.

Table 6 Comparison between two techniques

Localization Scheme	LESIA	LELA
Distance Calculation Method	RSSI	RSSI
Location Estimation Method	Trilateration	Multidimensional Scaling with distance information available
System Complexity	Low	High
Hardware Cost	Low	High

5.2.1 Results for redundancy factor Vs Localization error

On the basis of different experiments conducted for evaluation of the performance of LESIA, the comparison is as below:

In our first experiment, initially we have deployed 400 nodes randomly and area to be covered is 2000 × 2000 sq. m. Number of beacons are 3. Taking these values into considerations, we have measured localization error varying with redundancy factor. _Redundancy Factor' can be defined as the ratio of number of nodes in the network to the minimum number of nodes required to cover the network.

i.e. Redundancy Factor = Total no. of nodes / no. of nodes required to cover the network

Figure 2 shows the variation of localization error with increase in redundancy factor. For example, let the total no. of nodes is 125 and minimum no. of nodes is 100, the value of redundancy factor is 1.25. In our experimentation, it is concluded that as the redundancy factor increases, localization error goes high. The comparison graph makes this conclusion very clear. Here, the no. of nodes is varied from 250 to 450 so that redundancy factor range from 1.25 to 2.25.

Figure

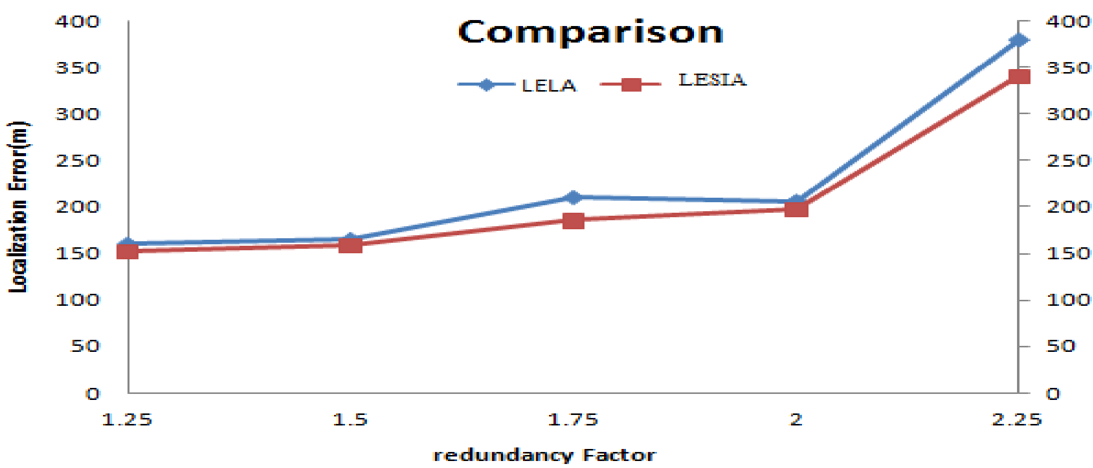
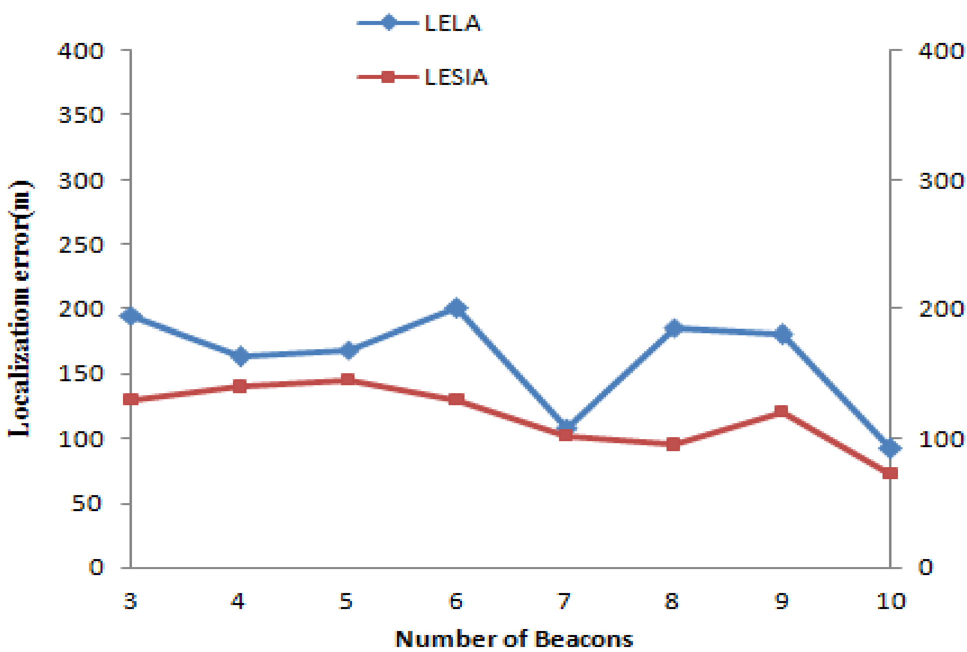


Figure 2. Redundancy Factor Vs Localization Error

Localization Error: Localization error is measured as the average Euclidean distance between location of nodes when deployed and the estimated locations.

5.2.2 Number of Beacons Vs Localization Error

In the second set of experiment, effect of varying the number of initial beacons on localization accuracy is analyzed. Localization error is measured providing different number of beacons and results are plotted in figure 3. We have deployed 400 nodes and numbers of beacons are varied from 3 to 10.



From the plot, it is observed that LESIA gives better results than LELA. The performance is significant for small no. of Anchors and is less sensitive to the change in number beacons. From 3 to 6, it gives almost static localization error. It is very much clear that it gives better performance (Accuracy) than LELA for even few numbers of Beacons. For n=3, it gives nearly 33% better accuracy. If overall error values are compared, LESIA gives 26% more accuracy than LELA.

6. Conclusions and future work

Accurate node localization in wireless sensor networks has become a need to fulfill criteria for many applications. To achieve accurate results, we proposed a scheme that outperforms previous methods in case of accuracy and system cost. The cost of the system is cut as RSSI does not require extra hardware for its implementation. MDS-MAP works well with few beacons and so, it ultimately cuts the cost as amount of GPS setup is reduced. When compared with an existing scheme LELA, LESIA gives overall 26% better accuracy when no. of beacons is varied.

In future, The absolute locations can be further resolved using some new mapping techniques and the objective can be expanded considering communication complexity.In further research, some simulation platforms like QualNet, Network Simulator (NS) etc. can be used.

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