Performance Evaluation and Cost Analysis of Beacon-based Dis-tributed Algorithms for Localization of WSNs

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Abstract— In wireless sensor network, for transmitting the data, it is desirable to know the location of sensors. In WSNs, for obtaining this kind of information we need localization techniques. In this paper, we first analyze the key aspects that have to be considered when designing or choosing a solution for the localization problem. Then, we present the types of current beacon-based localization algorithms, making a broad comparison among the most relevant algorithms. The overview of the schemes proposed by different scholars for the improvement of localization in wireless sensor networks is also presented. Also it is also dis-cussed that APIT scheme performs best when we simulate irregular radio patterns and random node placements. It also works well when low communication overhead is desired. Future research directions and challenges for improving node localization in wireless sensor networks are also discussed.

Key words: Localization, Wireless Sensor Network, Beacons, Sensor Nodes, RSSI, Radio Hop Count, TDoA, AoA, APIT, Centroid

I. Introduction

Recent advancements in the field of wireless communication, microelectronics, and low-cost sensor technologies have enabled the emergence of wireless sensor networks (WSN) as a new paradigm of computer networking. It has evolved as over the time and abundantly used to attain various objectives. From tactical surveillance and target tracking to environmental monitoring and space exploration, the applications of sensor networks are limited only by our imagination.

In 1996, the US Federal Communications Commission (FCC) required that all wireless service providers be able to provide location information to Emergency 911 services. Cellular base stations are now used to determine the position of the users. In 1993, the global positioning system, based on 24 NAVSTAR satellites, was deployed. Since that time, it has become the standard way to do localization whenever a GPS receiver can be used.

Wireless Sensor Network is a collection of sensor nodes, each of the sensor nodes accommodate various sensors, actuators etc. Apart from sensing various type of data, these nodes are also capable of processing the data and short range wireless communication. This processing capability comes packed in one or more micro-controllers, DSPs or CPU chips. It may contain multiple types of memory, Data, Program and Flash memories. These sensors are generally equipped with smaller power sources eg. batteries, solar cells etc and obviously, a RF transceiver, which is usually with a single omnidirectional antenna.

For most applications, sensed data without spatial and temporal coordinates is of very limited use. because the location information is quite critical to use the data obtained by theses sensors and appropriate actions. Sensor nodes have to be aware of their location to be able to specify“where”a certain event takes place. For example, if a WSN is deployed in disaster relief operations or inaccessible terrains, it must be able to provide position information aka localization to actually make a useful decision over data.

Initially during deployment, each sensor node can have some location reference. This is either done manually or with GPS device attached with the node. But this is not possible in case of larger networks because of workforce involved and excessive cost. In order to overcome this problem, we would suggest to make a coordinative system in which nodes can identify their positions themselves with the help of neighboring nodes.In such scenarios, some handful of nodes have their location reference defined manually or with GPS devices while deployment of network. These location aware sensor are termed as Beacons. The position of remaining sensors is computed in distributed fashion using the beacons.

There are many efficient and cheaper algorithms have been developed over time to locate sensors. Our aim is to compare, simulate and study such algorithms. We will also be making an attempt to give a cost-benefit analysis of these algorithms and establish a selection index for such algorithms.

II. Related work

The problem of localization is very important for many engineering fields and has been researched for many years.
Amitangshu Pal [2] talks about different approaches of node localization discovery in wireless sensor networks. It has given the overview of the schemes proposed by different scholars for the improvement of localization in wireless sensor networks.

Azzedine Bourkerche [3] divided the localization systems into three distinct components — distance/angle estimation, position computation, and localization algorithm — besides providing a didactic viewpoint, he shows that these components can be seen as subareas of the localization problem that need to be analyzed and studied separately. He addresses the localization problem from the viewpoint of a WSN. In the other sections he briefly present an overview and definition of localization systems for WSNs and their components. He shows the main methods used by localization systems to estimate distances and angles. He shows the techniques that can be used by a node to compute its position, and how all the estimated information of distances and positions can be manipulated in order to allow most or all of the nodes of a WSN to estimate their positions.

Bulusu et al localize unknown nodes by simply averaging the positions of all beacons with whom the node has radio connectivity [1]. Thus, it assume that nodes have no way of ranging to beacons. This method is attractive in its blinding simplicity; however, the resulting positions are not very accurate, particularly when beacon density is low, or nodes fall outside the convex hull of their audible beacons.

Niculescu and Nath [5] suggest using a correction factor calculated by comparing the actual distance between beacons to the shortest path distances computed during gradient propagation. Each unlocalized node simply applies the correction factor from its closest beacon to its gradient distance estimate. He also suggests propagating AoA information along links.

III. Localization schemes

There are many techniques available for finding the location of sensor nodes in WSN. These can be classified into Anchor Based or Anchor Free, Range Based or Range Free, Fine Grained or Coarse Grained, Stationary Sensor Nodes or Mobile Sensor Nodes, and Centralized or Distributed.

GPS based technique is also available but it is not suitable for most of the WSN applications, as it GPS receiver has to be fixed with each and every node which is quite expensive.

In Anchor/Beacon based algorithms position of few nodes is known, which are called anchors or beacons. Position of other nodes is determined with the help of anchor nodes.

In contrast for Anchor/Beacon Free algorithms, No anchor node is there so position of nodes is determined using various algorithms and their relative positions are calculated.

Range Based algorithms use angle estimation and distance estimation. In Range Free algorithms, Nodes communicate via radio connectivity to determine the position of each other.

Fine grained techniques generally use the received signal strength, whereas Coarse grained techniques do not depend on received signal strength.

In stationary sensor nodes type localization schemes, all nodes are stationary and are fixed at one place. In contrast, Mobile Sensor Nodes type localization schemes, have all nodes mobile.

In Centralized Algorithms, all the data is transferred to one central node known as base station or sink node. On this sink node, all the data is computed and relative positions of nodes are determined

In Distributed Algorithms, nodes communicate directly with anchor nodes and individually responsible for determining their position.

A. Beacon Based Algorithms

We will be considering seven majorly used beacon based distributed algorithms for localizing a wireless sensor network.

Diffusion: The basic concept used here is a node is expected to be located at the centroid of its one-hop neighbors. It is a very simple algorithm in which location of a node is estimated repeatedly by averaging the position of its peers until it converges to a steady state or a predefined number of iterations have occurred.

Gradient: This algorithm works on the principle of Multilateration (navigation technique which is based on differences in distance to 2+ nodes at known locations), which helps in finding the most approximate value of the location of unknown node.

APIT(Approximate Point-In-Triangulation): This algorithm works on the principle of variation of received signal strength from beacons over varied distances. The node is assumed to be listening signal from all beacons and forming beacon triangles. Then based on the signal strength, it determines the triangles in which the node is located and reports the centroid of the intersection of all such possible beacon triangles as shown in figure below.

Moving Sensor: A beacon is randomly walked in the grid, and is broadcasting it’s new coordinates continuously to nodes, in it’s node range.Every time a node senses the beacon, it generates a new quadratic constraint that it uses to further reduce the uncertainty in its position.

Moving Target: All the targets are randomly moved inside the grid. whenever a targets comes in the range of beacon, it makes a bound on its position by superimposing a rectangular box at position shifted by(-x,-y), where (x,y) is the displacement of target in the grid. At last intersection of all the bounds is taken and centroid of that region is taken as the target position

Centroid: In this algorithm, nodes are made to listen from all beacons and triangles containing the node are added to a set. Now, based on the area of the triangles a 1/Area weight is given to each triangle, because the larger the area the least it should contribute in determining the location of the node. Then the location is calculated by giving these weights to the centroids of the triangle. It works fine with uniformly distributed beacon nodes

IV. Simulation framework

Numerous simulation tools for wireless sensor networks are available. We will be using Pymote. Pymote’s main goal is to provide framework for fast implementation and simulation of distributed algorithms. In its current state, it is mainly targeted at algorithms for wireless (sensor) networks but it can be applied to any distributed computing environment (e.g., distributed systems, grid networks, internet, etc.)

A. Major Factors in Simulation

Wireless sensor networks (WSNs) are typically instrumental in measuring one or more physical phenomena in a widely distributed area. In most of such WSN applications, the measured sensor values are tagged with both a timestamp and the location of a given sensor. The noticeable point here is that required accuracy of this location information is completely application-dependent. A structural monitoring system might require centimeter-scale accuracy, while a forest fire warning system works well with a hundred-meter of uncertainty. This makes Accuracy as one of the design drivers of localization. We have considered Average Error as the base for accuracy comparison.

Another major decisive factor is processing power consumption. The processing time is directly related to battery consumption. Any WSN application or service needs to be energy-efficient, and localization is no exception.We have considered number of localization calls as the comparison metric for measuring power consumption.

The speed of localization is also an important factor. It may be needed to spend minutes localizing nodes for a static, long-term deployment since it only needs to be done once. For mobile applications, on the other hand, the localization needs to keep up with the mobility. We, therefore, consider the processing time as major analysis base for different localization schemes.

B. Algorithmic Process of Simulation

All localization algorithms are a two-step process:
1) Collection of Data
2) Computation of Location on the basis of data.

Collection of data is a very essential and crucial part of localization process. To better grasp the complexity of this task, we establish an ontology of the localization algorithm based on the following factor
1) The type of ranging data (time, power, connectivity, multi-modal, etc.),
2) The error distribution of the ranging data (under or overestimates, noise),
3) The amount of a priori information (anchor nodes, planar deployment),
4) The mobility of the nodes (static vs. mobile)

Computation of Location on the basis of data is dependent on the algorithm used in localization process.

C. Methodology

We have assumed a grid of 10000 X 10000 unit length for our simulation space. The grid contains 1000 node. These nodes are assumed to be distributed randomly on each iteration.

Due to the random time simulation results cannot explain the problem. Therefore, For each different conditions, 100 times simulation was performed and the average estimate are considered for analysis.

We will be considering different set of parameters to simulate the real life localization use cases. When we talk about physical parameters then there are two factors on which we can play - One is Obstacles and Second is Resources/Beacons. The analytical measures possible are Average Estimate Error, MAP (mean average precision), Computing Time, Standard Deviation of Error.

In simulation, different percentage of beacons are considered keeping the obstacles percentage fixed. In next part, different percentage of obstacles are considered keeping the different percentage of beacons.

V. RESULT ANALYSIS

A. Computation Time

Table I contains the analysis of computational time over percentage beacons is depicted. The trend in graph shows that the the localization algorithms like APIT are very much reliant on beacon data, as the percentage of beacon increases the computational load increases. This lead to sharp increase in localization time with increase in percentage of beacon nodes.

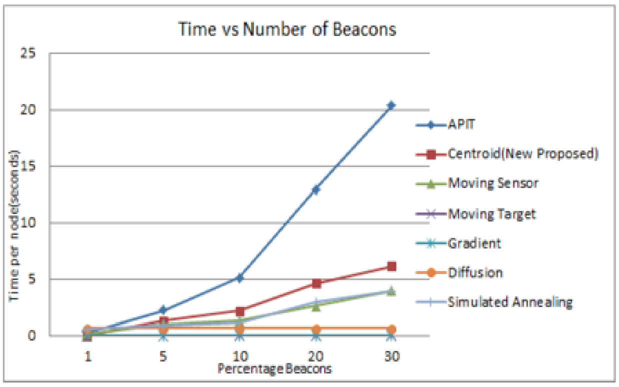

Fig. 1:

% Beacons	1	5	10	20	30
APIT	0.285	2.196	5.094	12.92	20.34
Centroid	0.002	1.267	2.139	4.591	6.029
Moving Sensor	0.158	0.958	1.313	2.583	4.268
Moving Target	0.006	0.013	0.015	0.016	0.017
Gradient	0.001	0.004	0.006	0.007	0.008
Diffusion	0.639	0.637	0.645	0.638	0.642
Annealing	0.521	0.913	1.132	2.912	3.372

Table 1: Computation Time vs % Beacons

B. Accuracy

The accuracy has been measured in Average Estimate of Error. Intuitively, as the number of beacons increases, the error of localization will increase. More the beacons, more the data collection and which will lead to better results. APIT performs very well in the process and shows very low error with even small number of beacons. (see Table II)

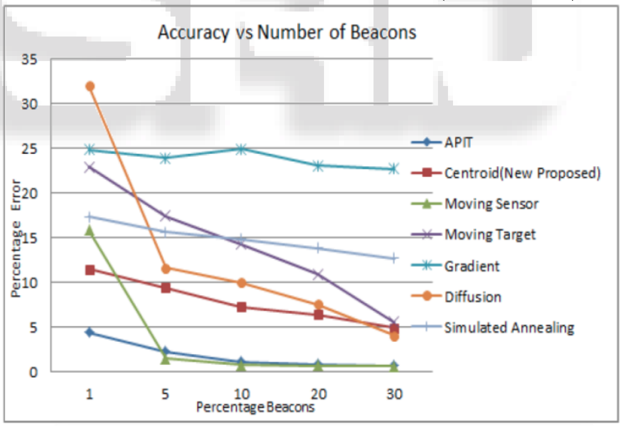

Fig. 2:

% Beacons	1	5	10	20	30
APIT	4.4	2.2	1.1	0.8	4.4
Centroid	11.4	9.4	7.2	6.4	11.4
Moving Sensor	15.8	1.5	0.7	0.7	15.8
Moving Target	22.9	17.3	14.2	10.8	22.9
Gradient	24.8	23.9	24.9	23.0	24.8
Diffusion	32.0	11.6	9.9	7.5	32.0
Annealing	17.3	15.6	14.8	13.8	17.3

Table 2: Avg Error Estimate vs % Beacons

The effect on accuracy over the percentage of obstacles is shown in Table III. As the obstacles increase the average error increases. Diffusion and Gradient are some algorithms which are cqomapritvely less affected with the obstacles distribution.

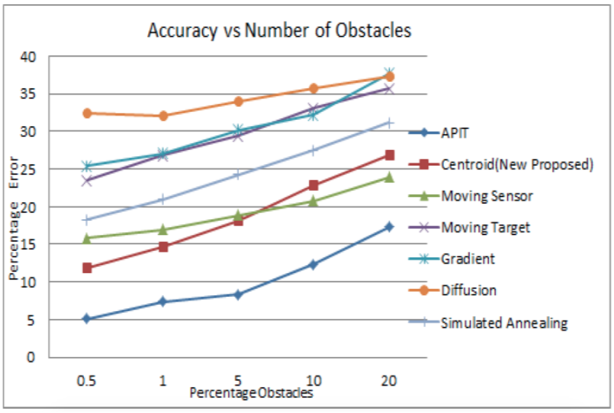

Fig. 3:

% Obstacles	0.5	1	5	10	20
APIT	5.11	7.42	8.34	12.32	17.29
Centroid	11.88	14.73	18.18	22.84	26.92
Moving Sensor	15.79	16.94	18.83	20.81	23.91
Moving Target	23.46	26.83	29.39	33.1	35.72
Gradient	25.43	27.06	30.18	32.19	37.72
Diffusion	32.47	32.1	34.06	35.74	37.36
Annealing	18.37	22.01	24.78	27.46	31.86

Table 3: Avg Error Estimate vs % Obstacles

C. Precision

The estimate of deviation of error depicts the precision of the localization of algorithm. More the deviation from absolute value lesser the precision. The diffusion algorithm has least precision and APIT performs best in case of precision. (see Table IV)

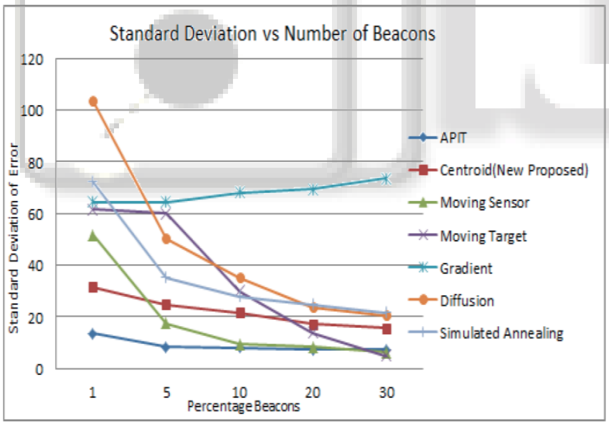

Fig. 4:

% Beacons	1	5	10	20	30
APIT	13.4	8.3	7.9	7.3	7.1
Centroid	31.6	24.8	21.5	17.2	15.6
Moving Sensor	51.6	17.4	9.4	8.3	6.1
Moving Target	61.6	60.1	30.1	13.8	4.8
Gradient	64.4	64.4	68.1	69.4	73.5
Diffusion	103.7	50.4	35.2	23.7	20.6
Simulated	72.4	35.2	28.0	24.7	21.5

Table 5: Standard Deviation of Error

VI. CONCLUSION

Given the inherent constraints of the sensor devices envisioned and the estimation accuracy desired by location-dependent applications, range-free localization schemes are regarded as a cost-effective and sufficient solution for localization in sensor networks. From our extensive comparison study, we identify preferable configurations of seven different recently proposed range-free localization schemes. In particular, we figured out that APIT scheme performs best when we simulate irregular radio patterns and random node placements. It also works well when low communication overhead is desired.

Moreover, these results show that the accuracy provided by the range-free schemes considered is sufficient to support various applications in sensor networks with only slight performance degradation.

VII. FUTURE WORKS

A cost function can be derived as function of accuracy, tolerance due to obstacles, time required for computation and variation in error etc. Based on this obtained cost function, wireless sensor algorithms can be benchmarked. For a functional requirement, an appropriate algorithm can be chosen by minimizing the cost. For example, if time is an important parameter, an algorithm with low computational time will be preferred eg. Centroid or Moving Sensor instead of algorithms with high computational time like APIT.

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