Improved APIT Localization Algorithm In Wireless Sensor Networks

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***Abstract*— Localization is an active area of research in the field of wireless sensor networks. The best solution is provided with the help of range based localization. However, the setup cost is very high for such a system. Range free localization provides an in-budget solution but at the same time, it compromises with the accuracy and increases the localization error. This paper intends to present a cost effective yet more accurate localization solution scheme. This scheme is a range free localization with a blend of APIT, RSSI and PSO algorithm. The algorithm selects and weights the RSSI measurements of the neighboring nodes from the beacon node during beacon exchange to measure the distance based upon the strength. Further, we use PSO along with a cost function to reduce the cost of the co-ordinates by continuous iterations using position and velocity vectors of the neighboring nodes by finding the co-ordinates with the global and local least cost. Finally, we use APIT to calculate the co-ordinates of the unknown or the desired node with the help of the beacon nodes and the neighboring nodes as calculated using PSO. Since the localization is range free, hardware setup cost is minimum and the simulation results shows that the location error is dropped sharply as compared to APIT and combination of APIT with RSSI. As a result, it leads to better accuracy with low cost.**

Keywords—APIT-Approximate Point In Triangulation; RSSI-Received Signal Strength Indication; PSO- Particle Swarm Optimization

I. INTRODUCTION

Wireless sensor network is a network with spatially distributed nodes where each node is equipped with some sensor to monitor different parameters. It has a number of commercial and industrial applications and can be used in various real world applications such as search and rescue, industrial monitoring, health monitoring, disaster management, smart environments, forest fire detection, etc [1,7]. In such networks, localization is the main area of research where one has to estimate the position of unknown nodes in the network. The simplest method to identify the position of a node in the network is with the help of GPS [1]. But the cost increases as the number of nodes in the network increases and hence it increases the overall production cost. Secondly, the GPS device consumes high power and as a result the effective lifetime of the network gets reduce. A number of localization algorithms exist in the literature. However those algorithms are either application specific or cannot be applied to wide range of WSN or have high setup cost. Based upon the technique used to estimate and identify the node position, the localization schemes are broadly classified into two categories: range-based and range-free [2].

The range-based schemes mainly handle the absolute estimation of distance and angle. Some of the range based algorithms are Received Signal Strength Indication (RSSI), time of arrival (TOA), time difference of arrival (TDOA) and angle of arrival (AOA) [8]. The range free schemes use the signal strength to connectivity between two nodes and decide upon the location of the unknown node in the network. The algorithms using the concept of range-free are APIT, centroid system, distance vector (DV) hop and gradient algorithm. Moreover, it doesn't require any special hardware. As a result the production cost is very less and effective in the case of range-free scheme of localization. And hence it is preferred over range-based scheme. However, the localization error in case of range free schemes is higher as compared to the range-based algorithms [3, 4].

So, this paper presents a cost effective yet more accurate localization solution scheme. This scheme is a range free localization with a blend of APIT, RSSI and PSO algorithm. The algorithm selects and weights the RSSI measurements of the neighboring nodes from the beacon node during beacon exchange to measure the distance based upon the strength. Further, we use PSO along with a cost function to reduce the cost of the co-ordinates by continuous iterations using position and velocity vectors of the neighboring nodes by finding the co-ordinates with the global and local least cost. Finally, we use APIT to calculate the co-ordinates of the unknown or the desired node with the help of the beacon nodes and the neighboring nodes as calculated using PSO. Since the localization is range free, hardware setup cost is minimum and the simulation results shows that the location error is dropped sharply as compared to APIT and combination of APIT with RSSI. As a result, it leads to better accuracy with low cost.

II. WSN LOCALIZATION PROBLEM

A wireless sensor network is composed of n nodes where each node is having a range of communication *r*. In this paper, network with symmetric links is considered. That is, two nodes *v1* and *v2* are said to be reachable if and only if *v1* reaches *v2* with the same signal strength as *v2* reaches *v1*. There are three kinds of nodes described below:

Unknown Nodes — unknown nodes are the nodes whose localization information is not known in the network. They are represented by U. The main goal of any localization scheme is to estimate the positions of such nodes.
Settled Nodes — these are the unknown nodes who have identified their location in the network by using some localization technique. They are represented by S. The quality of any localization technique is estimated in terms of number of such settled nodes and the localization error of these nodes.
Beacon Nodes- These nodes are the predetermined nodes. Their location is either manually fed or obtained using GPS in the network. They are represented by B. These nodes are the base node to start any localization algorithm.

Formally, the problem of localization can be defined as below.
Localization Problem: Given a wireless sensor network G = (*V, E*), where V is a set of vertices and E is a set of edges and a set of beacon nodes A with their positions (x_a, y_a), for all $a \in$ A, the problem is to obtain the position of unknown nodes i.e, (x_u, y_u) s.t. $u \in U$, and converting the unknown nodes into settled nodes, *S*.

III. RELATED WORK

A. RSSI

RSSI algorithm [5] basically forms the initial phase i.e. the beacon exchange part of the simulation. To perform RSSI beacon nodes send beacons to all the neighboring nodes in the sample space and in return the neighboring nodes send back a beacon along with the information containing the signal strength. Theoretically signal strength is inversely proportional to the distance between the beacons and the neighboring nodes [10]. Path loss is assumed to be negligible here. After getting the values of signal strength the beacon nodes process the RSSI equation to gain knowledge about the distance of the unknown node to the neighboring node [11].

$$RSS = -10n\, log\, D \;\; + C \qquad (1)$$

As given in Equation (1), RSS is a linear logarithmic function of distance *D* with a constant factor *C*. The slope of the linear equation is represented using a variable *n*. We use this equation on all possible combinations of beacon nodes and neighboring nodes and store those results. Further, the distance of the beacon node can be calculated from its neighboring node. We already know the co-ordinates of beacon nodes and we now know the Euclidian distance of every neighboring node from the beacon node. We can form three equations and solve for every neighboring node to get the co-ordinates.

$$D1 = [(x_{a1} - x_n)^2 + (y_{a1} - y_n)^2]^{1/2} \qquad (2)$$
$$D2 = [(x_{a2} - x_n)^2 + (y_{a2} - y_n)^2]^{1/2} \qquad (3)$$
$$D3 = [(x_{a3} - x_n)^2 + (y_{a3} - y_n)^2]^{1/2} \qquad (4)$$

where (x_{ai},y_{ai}) represents the coordinates of i^{th} beacon node, (x_n,y_n) are the coordinate of node and D_i is the distance between i^{th} beacon node and its neighboring node as received using RSSI. We finally have the co-ordinates of neighboring nodes

B. PARTICLE SWARM OPTIMIZATION(PSO)

Particle swarm optimization (PSO) is a nature inspired optimization technique which improves the candidate solution iteratively with respect to the given parameters. It tackles an issue by considering a population of different solutions(named as particles), and allowing these particles to roam within the search-space as indicated by basic numerical formulae over the particle's position and speed[13]. Each particle's movement is impacted by its nearby best known position, but at the same time is guided toward the best known positions in the search space, which are refreshed as better positions are found by different particles. This is relied upon to push the swarm toward the best solutions. This is a meta heuristic as it makes very few assumptions about the issue being improved and can look extensive spaces of candidate solutions [14].
Due to hardware constraints there will surely exist several errors in the RSSI technique in order to overcome those we need to use an optimization scheme. We use PSO to make our results robust. Here initially the local minimum cost and the global minimum cost are considered to be tending to infinity.
For every unknown node, new co-ordinates are generated using velocity and position vector equation and the corresponding local cost is generated using cost function. This cost is compared to the previously generated cost and if this cost is lesser than the iteration is repeated until we get a fixed least cost. This may go up to 500-600 iterations and maybe more. At last we get optimized co-ordinate for the neighboring node. Repeat this algorithm over every neighboring node so as to get optimized co-ordinates.

$$Vel(t+1) = s \times Vel(t) + \alpha\big(r(t) - y(t)\big) + \beta\big(l(t) - y(t)\big) \qquad (5)$$
$$y(t+1) = y(t) + Vel(t+1) \qquad (6)$$

Where α =1, β=1 ,*r(t)*= local least cost ,*l(t)* = global least cost, *y(t)*= co-ordinates at time t and $Vel(t)$= velocity at time t.
Using these equations we get new co-ordinates and cost function generates new cost which can be compared to the previously obtained cost and updated accordingly.

C. APPROXIMATE POINT IN TRIANGULATION(APIT)

APIT is a novel approach of finding the location of an unknown node by restricting the possible area to a triangular region created by connected three beacon nodes. Depending upon whether the node is lying inside or outside the defined triangular region, possible area is further reduced. Repeated application of same method with different combinations of beacon nodes lead to more accurate results.
Theoretically the approximate localization can be done using the Point-In-Triangulation Test (PIT) which can further be refined to get more accurate results [6]. In this test, three

beacon nodes are selected form the given set of all audible nodes and it is checked whether the unknown node lies inside the triangle that can be formed by connecting the selected beacon nodes. This PIT test is repeated by APIT with different combinations of audible beacon nodes. The process goes on until either the desired accuracy is achieved or all combinations are tried.

APIT Algorithm is illustrated using Fig 1 [2]. According to the algorithm, three beacon nodes say: A, B, C are selected and it is determined whether the unknown node point M resides inside triangle ΔABC or not.

Theorem I: If point M lies inside the triangle ΔABC, the area of ΔABC is some of area of all three triangles created due to point M. i.e.

area ΔABM +area ΔACM +area ΔBCM=area ΔABC

Theorem II: If point M lies outside the triangle ΔABC, then

area ΔABM +area ΔACM +area ΔBCM >area ΔABC .

If the point lies inside the triangle then the centroid of the triangle is stored. This process is repeated for every possible triangle. At the end we get a list of centroids.

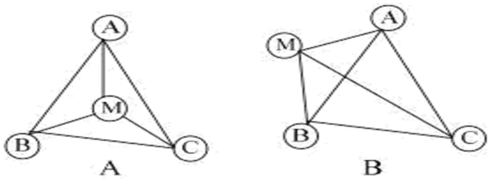

Fig 1. Example of APIT

At this point, the triangles having that node inside are picked and the center of gravity (COG) of the intersection of all those triangles is computed to determine the approximate position of the unknown node.

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$$X = \frac{\sum x_i}{n} \quad (7)$$

$$Y = \frac{\sum y_i}{n} \quad (8)$$

where n is the number of centroids obtained and x_i and y_i are corresponding co-ordinates.

IV. THE PROPOSED APPROACH

The proposed approach is explained using Fig 2.

In this paper we begin with the complete information of the beacon nodes along with the co-ordinates. Our first job is to identify the estimation of position of the neighboring nodes.

For that the beacon exchange occurs where the neighboring nodes sends the signal strength to each and every beacon node.

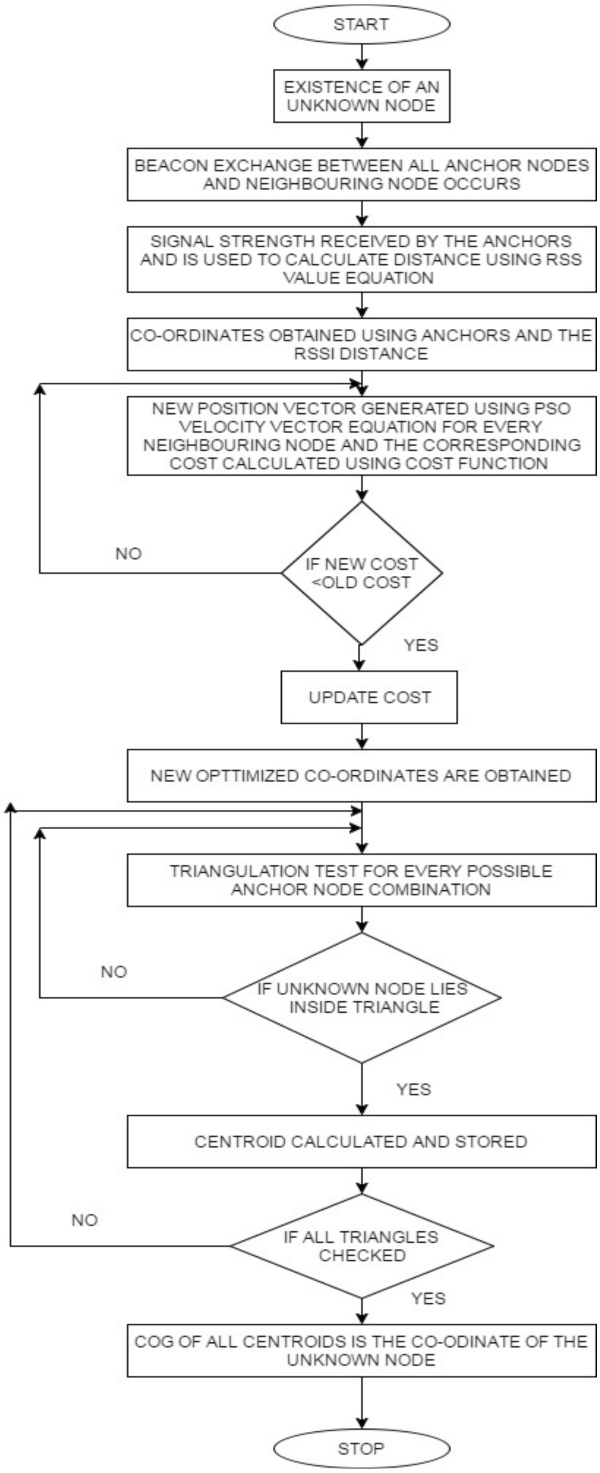

Fig 2. Flowchart depicting proposed approach

We use Equation (1) on all possible combinations of beacon nodes and neighboring nodes and store those results. Hence, using the RSSI equation, we get a rough estimate of the distance of the neighboring node using beacons. Now we already have the position of beacons and also the distance of a neighboring node from all the beacons. Using any three beacons we create three Euclidian distance equations and solve them to get the neighboring node co-ordinate. This process is repeated for all the co-ordinates.

But still the position of the neighboring nodes may not be accurate and robust because of the hardware constraints. As a result there is a need for an optimization algorithm. We use particle swarm optimization. The cost function(fitness) for this problem is taken as:

$$cost = \sum_{j=1}^{m} \sqrt{(x_n - x_j)^2 + (y_n - y_j)^2} - d_j$$

where (x_n, y_n) are co-ordinates of unknown nodes, (x_a, y_a) are beacon node co-ordinates which is closest to the neighbouring node, d_j is the RSSI distance between beacon node j and unknown node, m are the total number of beacon nodes.

For every neighboring node new co-ordinates are generated using velocity and position vector equation and the corresponding local cost is generated using cost function. This cost is compared to the previously generated cost and if this cost is lesser than the iteration is repeated until we get a fixed least cost. This may go up to 500-600 iterations and maybe more. At last we get optimized co-ordinate for the neighboring node. Repeat this algorithm over every neighboring node so as to get optimized co-ordinates.

Using these equations we get new co-ordinates and cost function generates new cost which can be compared to the previously obtained cost and updated accordingly. Finally we have all the optimized neighboring node co-ordinates.

Now we need to find out the position of the unknown node. For that, APIT scheme is used and the triangulation test is performed. In this test, three beacon nodes are selected form the given set of all audible nodes and it is checked whether the unknown node lies inside the triangle that can be formed by connecting the selected beacon nodes. This PIT test is repeated by APIT with different combinations of audible beacon nodes. The process goes on until either the desired accuracy is achieved or all combinations are tried.

Then the triangles having that node inside are picked and the center of gravity (COG) of the intersection of all those triangles is computed to determine the approximate position of the unknown node.

This algorithm gives the final co-ordinates of the unknown node.

The beacon nodes are marked black while beacon nodes are marked red as shown in Fig 3. 10 beacon nodes are randomly placed on the grid. The location of these nodes is known to all the nodes. 5 neighboring nodes are placed randomly on the grid but within a fixed section of the grid such that the selected nodes lies within the specified range of the unknown node APIT Test is performed for each of the possible triplets of the beacon nodes. For each test performed, only if all the neighboring nodes are inside the triangle, the unknown node assumes itself to be inside the triangle as well.

V. RESULTS

The proposed approach is simulated in Matlab[17] and compared with APIT algorithm and APIT with RSSI algorithm on the basis of localization error[16] .

The algorithm is tested by creating a 16×16 WSN network as shown in Fig 3. Fig 3 shows all the combinations of triangles formed in the network.

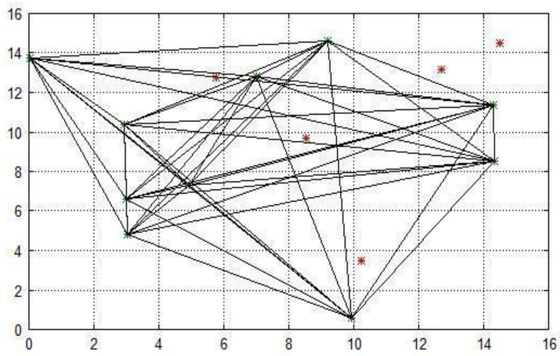

Fig 3. WSN area showing APIT algorithm

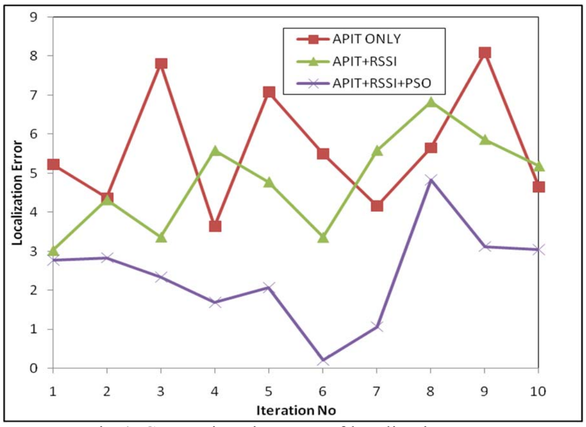

Fig 4. Comparison in terms of localization error

Fig 4 shows the simulation results. From the Fig 4, it is observed that the proposed schemes outperform the existing algorithms.

VI. CONCLUSION

Localization of a node in a wireless sensor network has a number of applications in real world. Recently, research is going on optimization of localization schemes. APIT is one of the most widely used algorithms to solve this problem. In this paper, we have combined the APIT algorithm with RSSI and then PSO is applied for the optimization. It has been observed that ccombining the algorithms have provided better results in the calculation of the position of the unknown node. We have used MATLAB simulation and the results have proved that use of RSSI and PSO have given lesser localization error.

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