A Cooperative Trilateration Technique for Object Localization

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Abstract—**Wireless Sensor Networks (WSN) exhibit enormous potential in the realization of Cyber-Physical System (CPS) and Internet of Things (IoT) because of their suitability for a large number of applications in healthcare, agriculture, education, aviation, weather forecast, military, smart homes, manufacturing and many other domains. One of the established applications of WSN is localization of moving objects, which is integral part of monitoring, surveillance, intrusion detection and target tracking. For localizing a moving object in WSNs, generally, a set of location-aware static WSN nodes are used to localize the mobile nodes or moving target using a specific localization algorithm. RSSI and Trilateration based location identification is a well-known traditional method which needs distance calculation prior to localization. Many researchers have modified the traditional trilateration method to better suit their application or in general. In this paper we present, a modified trilateration method, which uses our application specific cooperative technique with better choice of beacon node placement to improve distance calculation method. The distance values are then used to expedite the trilateration process. The proposed technique has been simulated and compared with the traditional method. The results show that our proposed technique consumes less energy and ensures faster and complete localization through the deployed sensor nodes.**

Keywords— **Localization, Trilateration, RSSI, Grid deployment, cooperative technique**

I. Introduction

A Wireless Sensor Network (WSN) is a collection of resource constrained sensor nodes, working together, to monitor and control a physical or environmental phenomenon. WSN exhibit enormous potential in the realization of Cyber-Physical System (CPS) and Internet of Things (IoT) because of their suitability for a large number of applications in healthcare, agriculture, education, aviation, weather forecast, military, smart homes, manufacturing and many other domains. One of the well-known and established applications of WSN is localization of moving objects, which is integral part of monitoring, surveillance, intrusion detection and target tracking.

Localization is a fundamental task in a number of scenarios, where data is tightly coupled with the environment and the location where it is generated. Especially in movement and activity monitoring systems where events and/or devices are moving around in the environment, it is essential to continuously track the position of the targets over time rather than just finding and report the location only once.

For localizing a moving object in WSNs, generally, a set of location-aware static WSN nodes are used to localize the mobile nodes or moving target using a specific localization algorithm [1]. The target is classified as active or passive. An active target is where the target cooperates and can communicate to the network, whereas, in passive case the target is not responsive. There exist a number of localization schemes, which can be categorized into two main classes, i.e. range-free and range-based schemes. The range-free techniques use connectivity and proximity information for localization. The range-free techniques include but are not limited to scene analysis, pattern matching, hop-count and proximity based approaches [2]. Range-based schemes are used to estimate the distance between the nodes using Angle of Arrival (AoA), Received Signal Strength Indicator (RSSI, and Time of Arrival (TOA), etc.

Apart from GPS location system, the RSSI and trilateration based [3], reference beacon nodes based [4] are some of the suitable range-based technologies for WSN outdoor localization. The convex-hull [8][10] based algorithms [7] like Jarvis March and Graham's scan [5][9] are newly implemented range-based techniques for WSN localization. Approximate Point in Triangulation (APIT), Centroid, Bounding Box and DV-Hop (Ad-hoc positioning) are some of the range-free localization algorithms [6].

The RSSI technique is based on the received signal strength indicator to estimate the distance between neighbouring nodes. In free-space, the RSSI value is inversely proportional to the squared distance between the transmitter and the receiver. The radio signals attenuate with the increase of the distance. The propagation of the radio signals may be affected by reflection, diffraction, and scattering. Especially in indoor environments, such effects may impact the measurement accuracy. Therefore, this technique is more suitable for outdoor, rather than indoor applications. This technique has the advantage of requiring no additional hardware since the RSSI feature exists in most wireless devices, and there is no significant impact on the local power consumption [11]. RSSI is affected by environmental and device errors that cause localization errors and reduce accuracy. Environmental errors are caused due to wireless communication channel. The causes are usually multi path, shadowing effect, and interference from other RF sources. Device errors are usually caused due to calibration errors, and the important issue here is to keep constant transmit power even under the circumstances of device differences and depleting batteries. Signal samples, even with the same transmit power, show some standard deviations due to atmospheric conditions. Temperature, for example, has a little effect on a signal. However, rain can affect the signal considerably. Especially, in localization based on the received signal strength method, this will cause less accuracy and reliability [19].

The general idea of using trilateration method for outdoor localization is that it is one of the simplest methods for localization and cheaper but it provides less accuracy and propagates error. The downsides of the trilateration have led many researchers to optimize the trilateration algorithm and its related positioning methods with suitable techniques which produce better throughput in the specific application regions [23].

In this paper, we make use of the trilateration based localization techniques especially for our planned localized scenarios for monitoring of trucks at the port of Salalah container terminal. The localization technique is a well-known and established concept, but we have customized the distance calculation algorithm for our scenario by introducing a cooperative technique. We have further compared the proposed customized algorithm with the traditional trilateration and the results show the proposed technique consumes less energy and ensures faster and complete localization of the deployed sensor nodes.

The remaining paper is organized in such a way that the next section discusses the related work, followed by scenario description, algorithm explanation and simulation results.

II. RELATED WORK

A huge number of WSN localization methodologies based on different metrics and measures have been proposed and implemented by many researchers and WSN developers especially for outdoor localization. GPS is the best positioning system, but it is not cost-effective when the application is large. Many of the researchers have proposed the localization based on RSSI and trilateration especially for outdoor WSN. The performance of the algorithm is application dependent.

Oguejiofor et.al, [12] have proposed a trilateration based localization in a testbed area containing anchor and blind nodes to characterize the pathloss exponent and to determine the localization error of the algorithm. They computed the pathloss exponent to be 2.2 and localization error to be 0.74m. Laybad Asmaa et.al, [13] have proved the performance of trilateration and multilateration techniques for localization and the number of beacon nodes' role in localization accuracy.

Yang and Liu [20] have proposed a Quality of Trilateration to improve the accuracy of localization, with Confidence based Iterative localization scheme, where each node carries a confidence value to indicate the location accuracy. Though the scheme consumes more complexity, the accuracy improves and the error propagation reduces when compared to the traditional method.

Aiqing Zhang et.al, [21] set forth a novel trilateration based on Point In Triangle testing Localization (TPITL) algorithm, which selects three special neighbour anchors to construct the smallest anchor triangle around an unknown node. The choice of optimized anchors is done by Point In Triangle testing based on Distance (PITD) method, which reduces errors and improves accuracy compared to the approximation PIT.

A novel fuzzy based algorithm to solve the trilateration problem of node located in the overlapping region of circles has been proposed by Rekha Yadav, Neha Singh [22]. The simulation results have shown that the fuzzy optimization and centroid technique to implement the modified trilateration has brought lesser error propagation compared to the simple weighted centroid technique.

III. SCENARIO DESCRIPTION

Seaports are the main transport hubs for exports and imports of a country. A container terminal is the vastly functioning part of a port where the containers are temporarily piled up in the container yard. Trucks are used to move the containers between ships and the yard, which is typically a no-pedestrian zone. However, sometimes there are workers on the yard due to unavoidable situations. To improve the workers' safety and efficiency of work at the port, localization of truck in the yard is a major requirement. Localizing trucks helps generate alerts for workers in the area. Also, in order to minimize the round-trip time for trucks it is important that trucks are not stopped leisurely. Real-time localization helps track the trucks to improve safety and throughput.

We have considered the container terminal of the port of Salalah, [16] Sultanate of Oman for localization of trucks in the yard. The port container yard is 2.3 Km in length and 270 meters wide.

Figure 1: Port of Salalah Terminal Scenario

Long range infra-red sensors [14-15] are preferred which have maximum sensing range of 5.5m. All the nodes are in neighbor communication range, which follow multi-hop communication to the sink. One mobile node has been used for validating the truck localization. The trilateration based customized localization method has been simulated for the fixed sensor nodes and the mobile node and compared with the traditional trilateration algorithm for the performance. The port container yard scenario is shown in Figure 1. It is assumed that truck is a cooperative target equipped with sensor node, which enables radio link to the fixed sensors and through which we can calculate the distance to the target using the obtained RSS value. Additionally, since the tracks are pre-defined in the Region of Interest (RoI), obstacle error is insignificant. RSSI is more useful in this scenario, whereas the range-free techniques are often lack in accuracy.

IV. CUSTOMIZED TRILATERATION ALGORITHM

Most of the peer-to-peer capable networks are undergoing multi-hop localization, WSN is one among them. The multi-hop localization often suffers with high computational complexity and large propagation errors when the number of deployed nodes is more than few hundreds. In case of one-hop localization, the sensor nodes completely depend on multiple anchor nodes for their location information and no peer-to-peer communication to the neighbour nodes regarding localization. But this increases the cost of more beacon nodes and the power of the beacon nodes reduces drastically. The concept of reference nodes [24] is one of the suitable solutions to reduce the complexities, in which the unknown nodes after getting their location information act as beacon nodes (reference nodes) to localize the one-hop neighbour nodes if three of them are non-collinear. The process continues until all the nodes get localized and get their location details. The reference node initiative is distributed in nature thus reduces the number of beacon nodes, dependency on manually localized beacon nodes and the traffic to the sink nodes.

Here, we start with the explanation of the proposed algorithm and the suitability to the chosen Region of Interest (RoI), the port container terminal. Here the Received Signal Strength Indicator* (RSSI) and range based trilateration method* in grid deployment of WSN are followed.

The beacon nodes (x, y and z) are placed in such a way that they could form the vertices of an equilateral triangle, in the middle of the RoI. When a node j gets RSSI from the three beacon nodes in 1 hop, the position is identified with minimal error and localization* is performed. The newly localized node j acts as a reference node which starts localizing other nodes (provided three beacons or three reference nodes cooperate). If three reference nodes or beacon nodes are collinear, for instance x, j and y are the nodes, a and b are two neighbor nodes in the communication range of any two beacon nodes (xj or jz), a and b nodes get two RSSI values as shown in Figure 2. They cooperate and with respect to each other, they get the distance.

Let d1 is distance from x to a, d2 is distance from j to a, similarly, d3 is from x to b and d4 is from j to b. If (d1 ~ d3) and (d2 ~ d4) || (d1~d4) and (d2 ~d3), Calculate distance dist from a to b dist= d22-d42 or dist = d32-d12. If d1, d2, dist are known, localize a and b consecutively. The process is continued until all nodes are localized. Figure 3 depicts the localization flowchart.

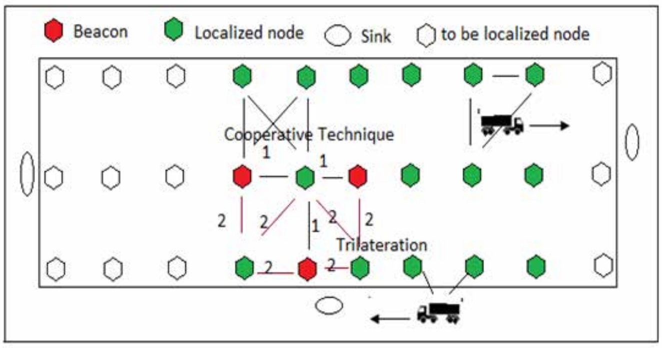

Figure 2: Scenario description

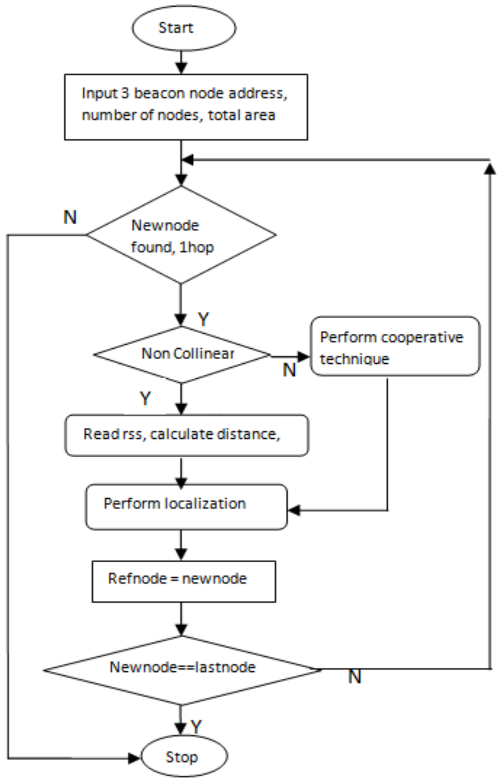

Figure 3: Localization Flowchart

If x1,y1; x2,y2; x3,y3 are the known location coordinates of three beacon nodes and d1, d2 and d3 are the distances calculated to a non-localized node, the location of that node (xn, yn) is calculated as below:

$$2\begin{pmatrix} x_3-x_1 & y_3-y_1 \\ x_3-x_2 & y_3-y_2 \end{pmatrix}\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{pmatrix} (d_1^2-d_3^2)-(x_1^2-x_3^2)-(y_1^2-y_3^2) \\ (d_2^2-d_3^2)-(x_2^2-x_3^2)-(y_2^2-y_3^2) \end{pmatrix}$$

For instance, (x1, y1) = (45, 45) (x2, y2) = (135, 45) (x3, y3) = (90, 0) and the distance in meters d1 = 5, d2 = 7 and d3 = 4, the (xn, yn) is (80.9, 40.3). Figure 4 describes the localization algorithm while cooperative algorithm is shown in Figure 5.

1. Start
2. Assume grid deployment, sensing range constant, homogeneous network
3. Initialize n as number of nodes, x, y, z beacon nodes, Loc=0
4. Read j (new node), read rss_j ,
5. If N(rss) ==3 and hop==1, Calculate distance, perform localization*; n=n-1
6. Reference node==New node; Loc++
7. If N(Beacon nodes || reference nodes) ==3, Repeat through step 3 until n=0
8. Else if N(rss)==2 and hop==1, perform cooperative technique*
9. Else if N(rss)<2, wait
10. If Loc==Prev(Loc), goto sleep
11. Else repeat through step 3
12. Stop

Figure 4: Localization Algorithms

1. Start
2. Initialize beacons or reference node x, y; newnodes a & b
3. If (x & y) collinear, read rss(x) and rss(y) to a & rss1(x) & rss1(y) to b
4. Calculate distance d_x, d_y from rss(x), rss(y) to a and d_{x1}, d_{y1} to b
5. If ($d_x \sim d_y$) and ($d_{x1} \sim d_{y1}$) || ($d_x \sim d_{y1}$) and ($d_{x1} \sim d_y$) {
6. Calculate distance dist from a to b dist= $d_{x1}^2 - d_{y1}^2$ or dist = $d_y^2 - d_x^2$}
7. Localize a with three distances d_x, d_y and dist
8. Localize b with d_{x1} d_{y1} and dist
9. Stop

Figure 5: Cooperative Technique

A. Sink to Node Communication

When there is one sink, multi-hop communication to the sink (sink MAC address stored in all nodes) is followed. The problem with one sink is that the traffic increases towards the sink. Here we use multi- sink scenario. When there are multiple sinks, same sensor node may connect to more than one sink, if it is located in the transmission range of the sinks and minimum delay in receiving signals. We consider minimal hop, so when a sensor node takes multiple hop to the sink which exceeds the threshold, then the sink–to-node connection can be forbidden [17-19]. Even with minimal hop a sensor node may connect to more than one sink, this problem is handled by the smart sensors by comparing the RSSI from the sinks and connect to the better RSSI sink and ignore the others. When the same RSSI is noted from more than one sink, then the node may select the sink based on probability. Another issue is when many nodes connect to the same sink as the previous criteria are satisfied. In that case, the sinks are observed for the amount of energy consumed; the sinks with more energy consumptions are considered to be victims and the nodes connected to those sinks are identified. The nodes are compared for minimum delay and those have comparatively maximum delay in receiving signals are released from the current victim sink and made to connect with next nearby sink. This process repeats until all the sinks have energy consumption less than the maximum allowable threshold value [18] and all the sensor nodes are connected. Since the sensors are stationary except those fixed on the vehicles, the frequent shifting of nodes among sinks is negligible.

B. Truck Localization

When the truck is inside the RoI there are no much complications in localization. The trucks may move in the outer boundary of the RoI where the sensor coverage still exists (Figure: 4). But localization cannot be performed, if it is done, the error rate will be more. This is because only two or three nodes can sense the movement at a time which are collinear. To alleviate the problem, the following procedure is followed.

i. *Let x1, x2, x3 …. are the boundary nodes in any one side of the RoI. Let the target node m moves. [When a sensor node has not more than five 1-hop neighbor nodes, it assumes to be a boundary node]*

ii. *Let RSS1 is from m to x1, RSS2 is from m to x2 and so on.*

iii. *While RSS1 gradually decreases relative to the speed of m, RSS2 increases and vice versa is also true.*

iv. *The x1 communicates to x2 with an event sensed, if x2, x3 … senses the same, the movement is recognized.*

v. *If m moves out of RoI range, the event is sensed till the last node.*

vi. *If m moves inside the RoI, proper localization starts.*

vii. *If m stops moving, the event is not reported by the further nodes.*

viii. *The two nodes nearer to m, say x4 and x5 are reporting to the sink about the id of the newly identified node. The id says the details of the truck.*

ix. *If m starts moving, process continues from step c with further nodes.*

The flowchart for the truck localization is shown in figure 6.

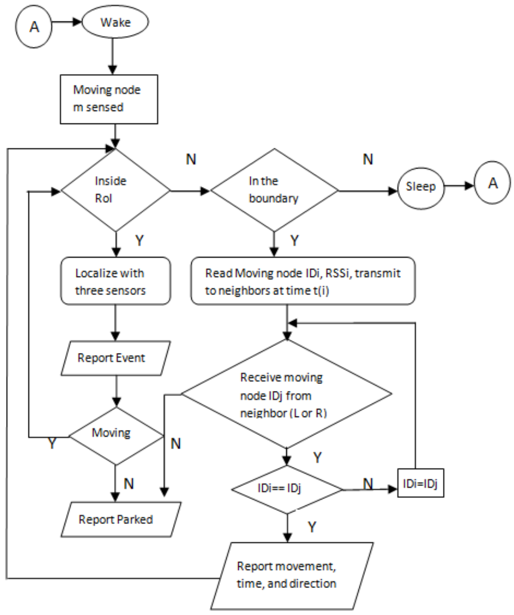

Figure 6: Flowchart for truck localization

V. SIMULATION RESULTS

Simulation of the proposed algorithm with cooperative technique has been performed in NS2 simulator.

The initial setup of the simulation includes the number of nodes (30 – 27 + 3 beacons), one mobile node, straight line motion, initial energy 0.6 and simulation time 10.0 s. During the simulation of the traditional trilateration, (Figure: 5) random placement of three beacons was chosen, but care was taken not to be collinear. At the end of 10.0 s, three nodes were not localized. The moving node also was not localized.

But while simulating the proposed trilateration with cooperative technique, all the nodes were localized before 10.0 s of simulation time including the moving node. The average residual energy has been calculated with the Automated Post Processing tool [25] which is also high compared to the traditional method as shown in figures 7a and 7b. The time complexity of the algorithm is O (N) as there are N-3 nodes localized. When one or more moving targets are to be localized, all the N sensors are not involved, but based on movement the positions are calculated which leads to additional complexity than O (N). So the computational complexity is O (N Log N), [5] which is less or equal compared to other popular localization algorithms.

The distance calculation of both traditional and proposed techniques varies when the beacon nodes are located in collinear positions as explained in the section IV.

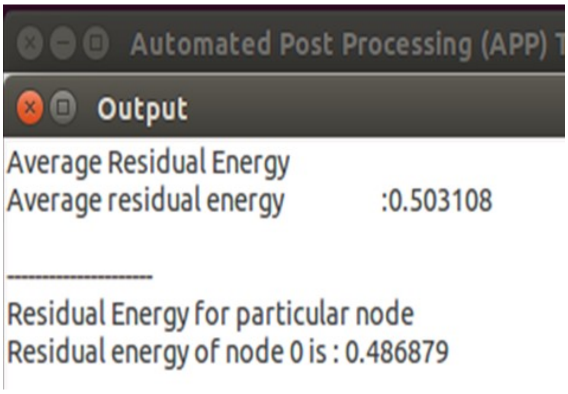

Figure 7a: Residual energy of Cooperative Technique

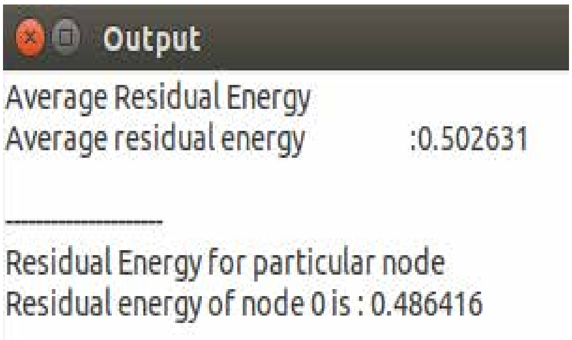

Figure 7b: Residual Energy Traditional trilateration

The movement graph with actual path and traditional trilateration and cooperative technique localization is shown in Figure 8. The localization error, as shown in Figure 9, has been calculated with the deviation from the actual location of the node while localizing with both the techniques. The error rate of the localization varies in accordance with the standard deviation and the mean of normal distribution. The standard deviation is directly proportional to the error rate.

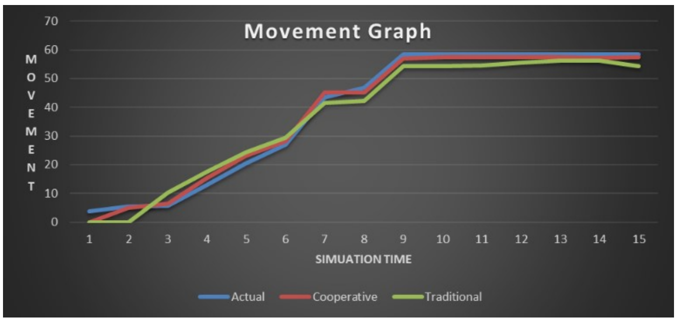

Figure 8: Comparison graph of the movement.

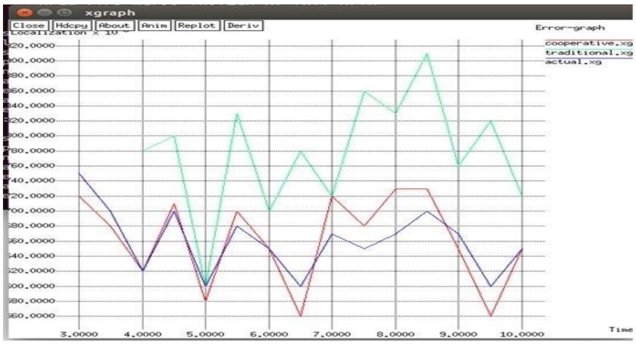

Figure 8: Localization error graph of the actual movement, traditional trilateration and the cooperative technique.

VI. CONCLUSION

A lot of localization algorithms have been proposed for WSN outdoor and indoor localizations, among which the RSSI and trilateration method is traditionally followed. But due to the lack of accuracy of the trilateration method in outdoor localization, there are several revisions made in distance calculation, positioning and localization algorithm. In this paper, we have revised the distance calculation which is application specific and chosen the apt beacon node position. We simulated the proposed cooperative algorithm and compared with the traditional method. The average residual energy is more in the proposed algorithm, fixed node as well as mobile node localization took lesser time and produced comparatively less localization error for the mobile node.

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