Volume 5, Issue 1, January 2015 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Localization System for Wireless Sensor Networks

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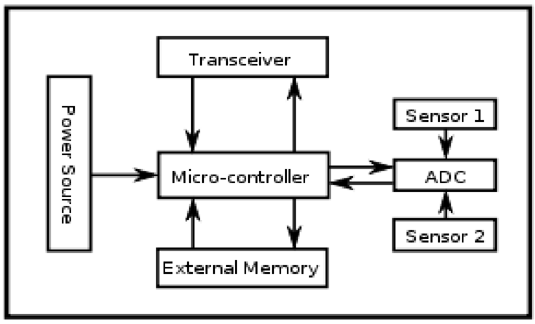
Abstract— Sensors are frequently being used for monitoring different phenomena of environment, Military, Health, Industry, Automobiles etc., and the information derived from sensed data are being used for making important decisions which directly affects humans and at times human life. This sensed data can only be of use if we know the exact position of the sensor node. This is not always easy as in many real life scenario, the deployment is random and in hostile conditions. Further, replacing a dead or damaged node is not an option in many circumstances. Many different approaches have been proposed by research community for localization information of a node deployed in a target area. In this work, an attempt has been made to review most promising localization methods proposed so far in comparative manner.

Keywords— Localization, Mobility, Sensor Networks, Beacon node, Trilateration, Multilateration

I. INTRODUCTION

. Sensors, also called detectors are small devices which can measure a physical quantity and convert it into a signal which can be measured by an observer mostly an electronic device. A **sensor node** is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. The basic structure of sensor node having communication capabilities consists of –a power system usually a battery, processing unit, antenna and sensor/actuator. The type of actuator depends on specific application. Microelectromechanical

Architecture of wireless sensor node



system(MEMS)[1] sensors are used to measure temperature, pressure, humidity, acceleration and chemical changes.
IEEE802.15.4 defines two types of sensor nodes-a) full functional device(FDD) which uses the complete protocol set and b) reduced functional device(RFD) which uses reduced or minimum protocol set.
Generally the FDD nodes act as co-coordinator of the system in the network system. Wireless sensor network is thought to be composed of n sensor nodes with some predefined communication capabilities distributed over two dimensional area. Each node has communication range r. For simplicity we consider symmetric communication link i.e. for two nodes say, u and v, u is in communication range of v if and only if v is in communication range of u. With this regard the WSN network can be represented as Euclidean graph G=(V,E), where:
1. V = {v1, v2, ..., vn} is the set of sensor node,s.
2.< Vi, Vj> ∈ E if v i reaches v j; that is, the distance between vi and vj is less than r.
w(e) ≤ r is the weight of edge e =w 〈i, j, the distance between vi and vj.
Localization is the process of determining the location information of a node in the network system. . In lots of WSN application requirements like node addressing, geographical routing, node density determination, object tracking, node management, management of correlated data location information of node becomes a crucial point. Thus localization becomes a key technology for WSN development and operation.
Some terms can be used to designate the state of a node:
Definition 1 (Unknown Nodes — U): These are the free nodes which do not have their location information. The main goal of the localization system is to find out the position information of Unknown nodes.
Definition 2 (Settled Nodes — S): These are the nodes which were previously unknown nodes and after computing localization algorithms have got their position information. The error and inaccuracy in measurement are the key parameters which determine the quality of the localization system.

Definition 3 (Beacon Nodes — B): These are also known as anchor node-having pre-determined position information either by manual placement or by use of GPS device.

The localization problem can then be defined as follows.

Definition 4 (Localization Problem): A system of sensor node deployed randomly having some nodes with known position Bi(xi,yi) and unknown node u1,u2,……un. To find out position of node ui and transforming it to settled node S or making them beacon node for further computations

II. CLASSIFICATION OF LOCALIZATION SYSTEM

Localization approaches are classified into two groups- Range based and Range free approaches.

Range based approaches- This system depends on calculation of point to point range measurement. These methods aim to calculate the exact position of the sensor nodes. The devices used by these methods are expensive and more energy consuming. The most promising methods are- GPS, RSSI, AoA, TODA, Active Echo, TOA etc.

Range free approaches- These methods compute relative or approximate position of sensor nodes. It does not require expensive hardware support for localization hence it is cost effective and low energy consuming but less accurate. Range free methods are classified into following groups depending upon basis of classification-

1. Based on anchor node-
   A) Beacon node required- diffusion, bounding box, gradient, APIT, centroid etc.
   B) Beacon node not required- MDS-MAP, Relaxation based, co-ordinate stiching
2. Based on connectivity-
   A) Proximity information – APIT, convex, centroid.
   B) Network connectivity- Dv-hop, MDS-MAP, Amorphous

III. LOCALIZATION ALGORITHMS

GPS

It is the most basic range based localization method which uses a constellation of 24 satellites as reference node in conjunction with the ground station to provide positioning services for the ground nodes. [] However it is not possible to attach GPS receiver to each and every node as it increases cost factor. Also the positioning error in GPS system is 10-20 m , which is much greater than the size of the nodes. In addition, the size constraints of the sensor nodes such as Rene board make it difficult to attach with GPS.

RSSI

The received signal strength is a measure of distance between two nodes. The received signal strength varies inversely proportional to the squire of the distance it propagates and a known radio propagation model can be used to determine the distance between the nodes using it[2]. The bigger is the distance between the nodes the less is the strength of signal received. However this system suffers from different problems like noise, obstacles and type of antenna. The main advantages of this method is its low cost and dis-advantage is signals are often susceptible to noise and interference.

Some experiments [3] show errors from 2 to 3 m in scenarios where all nodes are placed in a plane field 1.5 m from the ground with a communication range of 10 m. In simulations and experiments RSSI provide excellent result but in real world scenario it fails to obtain correct result.[4].

TOA

The distance between two nodes is calculated as the multiplication of speed of signal and propagation time of signal from one node to another. In this way, if a signal is sent at time t 1 and reaches the receiver node at time t 2, the distance between sender and receiver is calculated as-

D=s(t2-t1), where d= distance between the nodes, s =speed of the signal, (t2-t1)=time difference.

This requires synchronized nodes and time measure when the packets leave the node to be attached with packet itself.

TDoA (Time Difference of Arrival)

In this approach multiple signals with different propagation speed are sent simultaneously from one node. The difference in the times is calculated at another node when signal arrive. Generally packet sent is treated as first signal while the second signal used is usually sound due to its slower speed which makes computation in time difference suitable. The distance can now be computed by the formula

$d = (v1 – v2)*(t 2 – t 1)$,

Where v1 and v2 are the propagation speed of the radio and ultrasound signals, and t1 and t2 are time instants when radio and ultrasound signals arrive, respectively. DSSS modulation [8] technique is also used to compute the distance between two nodes using TDoA.

The experimental result shows that an error of 2or 3cm were obtained using ultrasound [3] with nodes 3m apart while 23 cm with node distance 2m using acoustic sound[9]. Despite the greater accuracy in computation, this method requires extra hardware with powerful transmitter to send second signal.

Active Echo

This method was proposed by Nikolaj and Anderson and is based on round trip time of RF signal from one node to other. Actually the nodes are termed as master and slave. The difference between time instants when signal are sent from master node and the reply signal received by it are calculated and termed as time of flight. It requires the continuous processing at the slave node for accurate measurements. It does not require node synchronization and all the computation is done at the master node only. Accuracy of this technique is very high but it requires dedicated hardware to implement this proposal.

AOA

The AoA is also used in localization system. The angle of arrival of signal [7,10] is measured with respect to node itself or electronic compass or some other incident signal. Directive antennas or uniformly separated array of receivers (three or more) are used to calculate angle of arrival. In [7] it has been shown that the inaccuracy in measurement is usually about 5° and the measurement require extra hardware for computation. The inaccuracy increased as the separation between nodes increases.

The choice of which method to use to estimate the distance between nodes in a localization system is an important factor that influences the final performance of the system. Usually, as shown in the next section, to estimate a position, a node uses at least three distance estimations, each with an associated error. On the other hand, if only the accuracy of these methods was important, we could just use TDoA since it has fewer errors. However, factors including the size and cost (in terms of hardware, processor, and energy) of the nodes must also be taken into consideration. Thus, the method chosen for estimating distances depends on the application requirements as well as available resources. After computing the range measurement trilateration or multilateration is used to compute the position of the nodes.

Trilateration and Multilateration

Trilateration is the most important technique to compute the position of nodes. The unknown node determines its distance from any three non-collinear reference nodes using one of distance estimation method and computes its position as the intersection point of three circles drown taking reference nodes as centers and the distance between reference nodes. If the position of the reference nodes be (x1,y1), (x2,y2) and (x3,y3) and corresponding distances from unknown node be d1,d2 and d3, we can compute position(x, y) of unknown node with the equations $(x - x_i)^2 + (y - y_i)^2 = d_i^2$, for i=1,2,3... However in real world scenario the distance estimation suffers from errors and the computed position result in infinite set of solution instead of only one point.

In case, where large numbers of reference nodes are available, multilateration is used to compute the position of the node. However if the distance estimation suffers from error the corresponding position estimation do not produce a single point solution but In this case an over- determined system of equations must be solved. These systems of equations do not produce a single solution. With n reference point and also taking error in consideration, which makes $d_i = d_i - \varepsilon$, and corresponding equation becomes $(x - x_i)^2 + (y - y_i)^2 = d^2 - e$, where ε is an independent normal random variable with zero mean. By subtracting last equation the system can be linearized into $Ax \approx b$. This linear system can easily be solved using standard methods.

Ad Hoc Positioning System

It require small number of beacon nodes (e.g., three or more)[17] to be deployed with the unknown nodes. The distance from the beacon node is estimated by the unknown nodes by multihop way. After that each node computes its position using multilateration. The methods proposed on the basis of hop-by-hop distance propagation are: Dv-Hop, Dv-Distance, and Euclidean.

In Dv-Hop APS the beacon nodes starts broadcasting its position information throughout the network and the sensor nodes keep record of hop count of each of beacon nodes. This procedure works same as distance vector algorithm and all the nodes get information of position of all the beacon nodes and distance from it in hop count measure. When one node get position information of other beacon node, it computes the average size of one hop by dividing the distance between them with the hop count between them. The value of average hop distance is broadcasted in the network. And unknown node transforms the data in the form of hop count to distances in meter. The complexity of this proposal is given by $O(n*(m + 1))$, where n is the number of nodes and m is the number of beacon nodes.

This proposal requires small number of beacon nodes but the accuracy of the proposed solution is not good and it provides erroneous results.

SDP

Semidefinite Programming (SDP)- This approach (proposed by Doherty) represents the geometric constraints between nodes by linear matrix inequalities(LMIs) and all the LMIs of the network are combined to form a single semidefinite program, which produce a bounding region for each node as solution, when solved. This bounded region is the area where node, exists. All geometrical constraint can't be represented as an LMIs, but which form a convex region. Hope count can be represented as circle; angle of arrival can be represented as triangle. But radio range data cannot be represented as convex constraint. However this is an elegant method as it provides the position of the node as intersection of the given convex constraints.

MDS-MAP

MDS-MAP is centralized algorithm which uses multidimensional scaling (MDS) technique for localization. For n points suspended in some volume having information of distance between each pair of points, Multidimensional scaling uses law of cosine and linear algebra to construct the relative position of the points based on pair-wise distances. MDS-MAP is direct application of multidimensional scaling. This algorithm has following steps-

1. Information from network is gathered and data are represented as sparse matrix R where rij is the range between the nodes I and j, and zero if no data is collected or nodes are too far.
2. Standard all pair shortest path algorithm (Dijkstra,Floyd) is run on R to produce a complete matrix of inter-node distances D.
3. Classical MDS is run on D to find the estimated node position X.
4. Obtained position X is transformed into global coordinate using some fixed anchor nodes.

Based on types of MDS and inter-node distance estimation different types of MDS techniques have been proposed-
Metric MDS : MDS-MAP(C), MDS-MAP (P), MDSHybrid Range Q-MDS
Non-metric MDS : The algorithm developed by Vo, Challa and Lee;
Weighted MDS : The algorithm developed by Costa, Patwari and Hero;

LLE [22]

In this algorithm the local connectivity information is assumed to be high-dimensional data at each node in such a way that it resembles that each node obtain a snap-shot of the map (where each node occupies one dimension). After getting high dimensional data from each node a search algorithm is run to find the neighbourhood of all nodes. After that a LS fitting problem is solved by eigenvalue decomposition [23] to find location of all nodes. Considering local estimates this algorithm is less complex than MDS but for regular shapes it is inferior to that.

Bounding Box

The bounding box [12] method uses squares -instead of circles as in trilateration to bound the possible positions of a node. An example of this method is depicted in Fig. For each reference node i, a bounding box is defined as a square with its centre at the position of this node (xi , y i), with sides of size 2d i (where d is the estimated distance) and with coordinates (x i -d i , y i - d i) and (x i + d i , y i + di). The intersection of all bounding boxes can be easily computed without any need for floating point operations by taking the maximum of the low coordinates and the minimum of the high coordinates of all bounding boxes. This is the shaded rectangle in Fig.. The final position of the unknown node is then computed as the center of the intersection of all bounding boxes.
Despite the final error of this method, which is greater than trilateration, computing the intersection of squares uses fewer processor resources than computing the intersection of circles.

Centroid

In this method position of node is computed as the centroid of its neighbor position. It only requires the radio connectivity between the node and averaging the position of the neighboring nodes position of unknown node is computed. Let the position of the neighboring n nodes are(x1,y1),(x2,y2)……(xn,yn) the position of node will be X0=(x1+x2+…..xn)/n and y0=(y1+y2+…..yn)/n. Centroid localization algorithm uses the centroid coordinate of the selected beacon nodes as the estimated coordinates of the unknown nodes. This algorithm requires a small amount of computation cost. However, it is bad in localization accuracy.

Recursive Position Estimation

In this approach [16] a set of beacon nodes (usually 5 percent of total nodes) are deployed with other nodes. The unknown nodes estimate their position using beacon nodes and become reference nodes. In this way the number of reference node or beacon node increases significantly and soon all unknown nodes find their position information. This algorithm is divided into four phases- 1. A node determines its reference nodes. 2. Node estimates its distance from reference node using any of distance estimation methods like AoA, TDOA, and RSSI etc. 3. Node computes its position using trilateration or multilateration. 4. Node broadcasts its estimated position information and becomes a reference node.

As soon as a node becomes reference node, it assists other nodes to find their position. In this way the number of reference node increases rapidly and hence all nodes estimate their position quickly. But there is a drawback of this method, that once error in encountered in the measurements it propagates throughout the network causing more inaccuracy in localization of the system

Localization with a Mobile Beacon

Some of the recent research works in literature proposed solution based on mobile beacon [21] to assist the nodes to estimate their location information. Mobile beacon knows its position and able to move in certain known direction and up to some distances. This beacon can be robot, some vehicle or human beings. The unknown nodes get three or more signals from the same source from different places and compute its position using simple trilateration or multilateration.

The communication cost is small as there is not much communication overheads since only one beacon node broad-cast its position information. And rest of nodes estimate its position based on packet it receive from the mobile beacon.

This method is elegant in the sense that error propagation is low but there is overhead of time in localization procedure as unless mobile beacon passes nearby an unknown node it cannot estimate its position.

IV. FINAL REMARK AND FUTURE PROSPECTS

The Localization strategy depends on the application type and the environmental condition of the area. In most of the cases we require only the approximation in measurements and some cases we need exact position of the sensor node. The application where only approximate result is required we follow range free localization methods while for exactness we follow range based calculation. There is no any method has been developed till date which can be applicable in all scenarios. Different methods have been devised for different application condition like indoor, outdoor, undersea and space etc. Localization system for extreme space, device setup for RSSI based calculation and calibrations, prolonging the battery life , smart dust, smart home, indoor localization, undersea localization are the open research issues on which most of the work is going on these days.

V. CONCLUSION

In this paper we have briefly provided the introduction to wireless sensor networks. We have briefly explained the most important algorithms developed so far providing their merits and demerits. There is not any general rule or general method of localization which suits in all scenarios. In this paper we have provided different algorithms with proper specification of its usefulness in certain scenario. The necessity of different solution for different environment and also higher number of possible application of WSNs motivated the research and study of new solution for localization system.

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