Localization System for Wireless Sensor Network

Prabhat Kumar, M. P. Singh, U. S. Triar, and Raj Anwit

Abstract— Ever-growing needs of ubiquitous environment has further increased our dependence on sensors and sensor networks. 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 provide us with meaningful information only if we know the position of the sensor node. However, 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. This work, attempts to review most promising localization methods proposed so far in a comparative manner. The paper classifies the localization methods and discusses the localization system components.

Keywords--- Localization, Multilateration, Trilateration, WSN

I. Introduction

A SENSOR Node [1] (SN) is the result of multidisciplinary technological success of human beings. It is small, lightweight and portable and has the capability of communication, computation, and sensing the physical world. A sensor node may capture various physical properties, such as temperature, pressure, humidity, motion, illumination, vibration, sound, chemical concentrations, pollutant levels, vital body functions etc. It is equipped with a transducer, microcontroller, transceiver and power source. The transducer generates electrical signal based on sensed physical effects and phenomena. The microcomputer processes and stores the sensor output. The transceiver receives commands from a Base Station (BS) and transmits data to it. Sensors receives power from a battery and its replacement is not possible in most real time uses. Sensor nodes resource constraints in terms of computation & communication as compared with other computing & communicating devices [2] [3] making the network lifetime an important area of research.

The type of sensor depends on specific application. Micro-electromechanical system (MEMS) [1]. 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 coordinator of the system in the network system.

A Wireless Sensor Network (WSN) [4, 6] is a group of sensor nodes, which execute some monitoring task in a collaborative and autonomous manner. 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 vice- versa.

Localization is the process of determining the location information of a node in the sensor network Location information of node becomes a necessity in lots of WSN applications for node addressing, node density determination, object tracking, node management, management of correlated data, etc. This location estimation helps in optimal path selection in routing as well as locating changes or event occurring in the environment of interests. Thus, localization becomes a key technology for WSN development and operation.

II. Classification of Localization System

Localization approaches are broadly 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-Global Positioning System (GPS), Reduced Signal Strength Indicator(RSSI),Angle of Arrival (AOA),Time Difference of Arrival (TDOA),Active Echo, Time of Arrival (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

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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, Approximate Point in Triangulation(APIT), centroid etc.
   B) Beacon node not required- MDS-MAP, Relaxation based, co-ordinate stitching
2. Based on connectivity-
   A) Proximity information – APIT, convex, centroid.
   B) Network connectivity-Dv-hop, MDS-MAP, Amorphous

WSN Localization methods can be classified as per Fig. 1.

In **Direct localization** anchor nodes are placed manually by known location or implementation of GPS device to each and every sensor node having known location information whereas in **indirect scheme** the sensor node are deployed randomly and based on certain ranging information like RSS, AoA etc. or adjacent node information position of the node is computed. Anchor Based have sensor node having pre-defined position information which are deployed with other nodes. The anchor node may have some greater computation capabilities. Two subdivisions are possible,

- **Fixed anchor node**: Anchor nodes having pre-defined location information are fixed in their position and other node uses its coordinate as reference point to compute its position
- **Mobile anchor node**: They are granted extra functionalities so that it can change its position and individual node computes its position relative to two or more signals obtained from at different time and different location.

In **Anchor Free** no anchor or beacon nodes are required for the computation of position. Node communicates with the neighboring nodes and only connectivity information is required to set-up the network. In **Centralized**, all computation/ processing is done at the central node or sink node in the central scheme. Other nodes just calculate the ranging information only and send it to central base station which compute the location information and send it back to the individual nodes. In the **distributed** approach the computation of position is done at the node itself and the result is send to the central base station. This scheme is further classified in the following categories

- **Beacon-based distributed algorithms**: Nodes determine its position with distance measurement from some specific reference node, called beacon node, having predefined position information.
- **Relaxation-based distributed algorithms**: A coarse algorithm is used to roughly localize nodes in the network. This is followed by a refinement step, which typically involves each node adjusting its position to approximate the optimal solution. .
- **Coordinate system stitching based distributed algorithms**: The network is divided into small overlapping sub-regions, each of which creates an optimal local map followed by merger of local maps into a single global map.
- **Hybrid localization algorithms**: These schemes use two different localization techniques such as: multidimensional scaling (MDS) and proximity based map (PDM) or MDS and Ad-hoc Positioning System (APS) to reduce communication and computation cost.

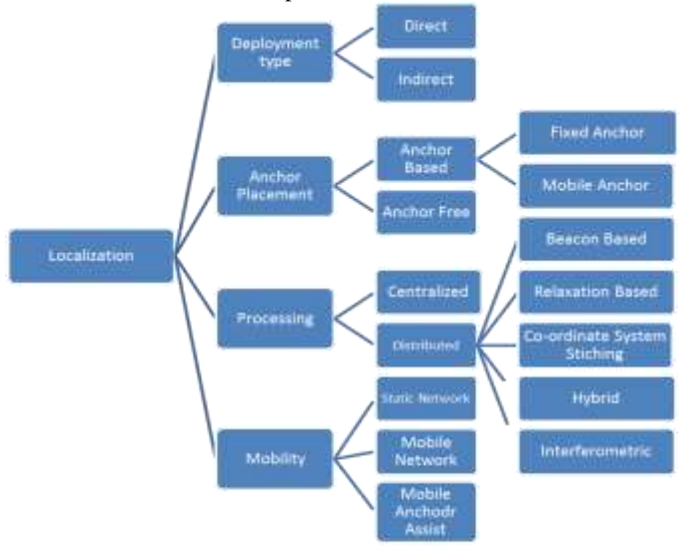

Fig. 1 Taxonomy of WSN Localization

- **Interferometric ranging based localization**: Radio interferometric positioning exploits interfering radio waves emitted from two locations at different frequencies to obtain the necessary ranging information for localization.

III. Localization System Components

Localization systems can be divided into four distinct components: **Distance/angle estimation**: This component is responsible for estimating information about the distances and/or angles between two nodes which will be used by the other components of the localization system. **Position computation**: It is responsible for computing a node's position based on available information concerning distances/angles and positions of reference nodes. **Localization algorithm**: It determines how the available information will be manipulated in order to allow most or all of the nodes of a WSN to estimate their positions. **Mapping**: This is the process of linking the computed location of the node to some real world locations.

Distance /Angle Estimation

It consists of estimation of distance and angle between two nodes which are adjacent or in communication range of nodes. This is further used to compute position and localization algorithms. The main methods used are:-

RSSI: The distance between two nodes is taken as collected signal strength. It is inversely proportional to the square of the distance it propagates and a known radio propagation model can be used to obtain the distance between the nodes using it. RSSI offers low cost but signals are vulnerable to noise and interference. For correct result it is common to make a system calibration [2], where values of RSSI and distances are evaluated ahead of time in a controlled environment.

TOA [6]: The separation between two nodes is calculated as the product of speed of signal and propagation time of signal from one node to another. This requires synchronized nodes and inclusion of packets leaving time in the packet itself

TDOA [7]: Signals with contrasting propagation speed are sent at the same time 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- $d = (v_1 - v_2)*(t_2 - t_1)$, where v_1 and v_2 are the propagation speed of the radio and ultrasound signals, and t_1 and t_2 are the times instant when radio and ultrasound signals arrive respectively. DSSS modulation technique is also used to compute the distance between two nodes using TDoA.

Active Echo [22]: Nikolaj Anderson introduced this method based on round trip time of RF signal from one node to other. The nodes are termed as master and slave. The difference between the times 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. Accuracy of this technique is very high but it requires dedicated hardware to implement this proposal.

AOA [7, 10]: The AOA (Angle of Arrival) of the signal can also be used by localization systems. This angle can be related to the node itself, or an electronic compass, or to a second signal received by the node. The estimation of the AoA is done by using directive antennas or an array of receivers - usually three or more - that are uniformly separated. In the last case, based on the arrival times of the signal at each of the receivers, it becomes possible to estimate the AoA of this signal. Experiments show that this method has an inaccuracy of some degrees (about 5° [7]). The need for extra hardware and a minimum distance between the receivers incurs some disadvantages in terms of the cost and size of nodes.

Radio Hop Count: Hop count explains the local connectivity information of the nodes. RSSI measurements are inaccurate, but they are used to determine the local connectivity information of nodes. Two nodes are said to be in communication range or can communicate using radio signals if distance between them is less than r, where r is maximum range of their radio signal. Local connectivity information results the network as an unweight graph where vertices are nodes and the edges represents the direct radio link between the nodes. Hope count h_{ij} between two nodes i and j is defined as the length of shorted path between the node v_i and v_j.

Position Computation

When a node has enough information about distances and/or angles and positions, it can compute its own position using one of the methods studied in this section. Methods include trilateration, multilateration, triangulation, probabilistic approaches, bounding box, and the central position. The choice of methods to use also impacts the final performance of the localization system. Such a choice depends on the information available and the processor's limitations.

Lateration: It is used to calculate the position of the unknown node when position of two reference nodes and distance of unknown node from these reference nodes is known. We use simple cosine rule to obtain the position of the unknown node. If the position of A and B and the two sides a and b are known in Fig 3. The angle α can be found by using cosine rule with the following equations:

$$a^2 = b^2 + c^2 - 2bc\cos\alpha$$

$$\Rightarrow \quad \cos\alpha = \frac{b^2+c^2-a^2}{2bc}$$

$$\Rightarrow \quad \alpha = \cos^{-1}\left(\frac{b^2+c^2-a^2}{2bc}\right)$$

Further, we can calculate the position of C using the following formulae-

$x_i = a\cos\alpha$

$y_i = a\sin\alpha$

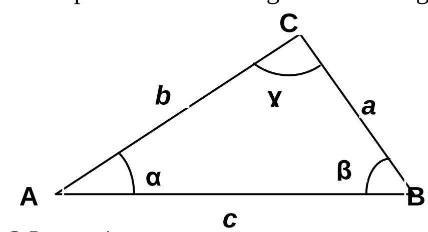

Fig. 2 Lateration process

This yields two values for position of C in 2D and a circle in 3D. So to calculate the exact position of C we need one more reference point or this approach can be used in only known scenario where there is only one known acceptable position of C is predetermined. Using three reference points there are two known approaches trilateration and multilateration to compute the position of unknown node.

Trilateration and Multilateration

Trilateration is the main technique to calculate 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 (x_1,y_1), (x_2,y_2) and (x_3,y_3) and corresponding distances from unknown node be d_1,d_2 and d_3, 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 number of reference node is available, multilateration is used to compute the position of the node. This technique uses TDoA measurement. The main difference between trilateration and multilateration is that the former uses three references while the later can use three or more.

Bounding Box [12]: This method uses squares in place of circles in trilateration. A bounding box is defined for each node i as square with center of the node at x_i, y_i and the side equal to 2d where d is the estimated distance. This method is free from floating point computation as intersection of bounding boxes can be easily done by taking minimum of high coordinates and maximum of low coordinates of all bounding boxes. The final position of node is computed as intersection point of all the bounding boxes. Despite some error in this method, it is computationally simpler than trilateration.

Triangulation [7][10]: This method uses angle measurement as input instead of distance and position computation is done by node itself. Three reference nodes are required and the unknown node computes its position using simple trigonometric relation with estimated angle to each reference node and position of the reference node.

Centroid: The 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(x_1, y_1), (x_2, y_2)……(x_n, y_n) the position of node will be $x_0=(x_1+x_2+\ldots x_n)$ / n and $y_0=(y_1+y_2+\ldots y_n)$ / n.

Probabilistic Approach: The uncertainty in the distance estimation led to development of probabilistic approach. In this method the error in the distance estimate are modeled as random variables. When an unknown node receives a packet from a reference node, it can be in any place around the reference node with equal probabilities. When another packet is received from another reference node, the unknown node computes its position again. When new position information is received from other nodes, it becomes possible to identify the probable location of the unknown node [11]. The main drawbacks of this approach are the high computational cost and the space required to store the information.

Localization Algorithms

The localization algorithm is the main component of a localization system. This component determines how the information concerning distances and positions is manipulated in order to allow most or all of the nodes of a WSN to estimate their positions.

Ad Hoc Positioning System (APS) [17]: In APS, three or more beacon nodes are deployed with the unknown nodes. Each node estimates its distance to the beacon node in multi-hop way and computes its position using trilateration. Dv-Hop, Dv-Distance, and Euclidean are three methods proposed for hop-by-hope distance propagation. In Dv-Hop the beacon nodes start sending their position information to the other nodes. All the nodes receive the position information of beacon nodes and distance from it in terms of hope count. Beacon nodes compute the average hope size based on information about distance from the other beacon and hope-count from it. This value is flooded in the network and the individual node computes its distance from beacon node as multiplication of this value with the hope-count from the beacon node. An advantage of the APS is that its localization algorithm requires a low number of beacon nodes in order to work. However, the way distances are propagated, especially in Dv-Hop and Dv-Distance, as well as the way these distances are converted from hops to meters in Dv-Hop, result in erroneous position computation, which increases the final localization error of the system.

Recursive Position Estimation (RPE) [16]: In RPE initially some reference node (generally 5% of total nodes) with known position are deployed with the unknown nodes. RPE algorithm has been divided in four phases-

1) Node determines its beacon node.
2) Estimate distance from beacon node using distance estimation methods, like RSSI.
3) Node computes its position using trilateration.
4) Node becomes a beacon node by broad-casting its newly computed position.

When a node becomes a reference, it can assist other nodes in computing their positions as well. An advantage of this algorithm is that the number of reference nodes increases quickly, in such a way that the majority of the nodes can compute their position. This technique has the disadvantage of propagating localization errors. Inaccurate position estimation of one node can be used by other nodes to estimate their positions, increasing this inaccuracy. Furthermore, a node must have at least three reference neighbors in order to compute its position.

Semi definite Programming (SDP) [14]: It represents the geometric constraints between nodes by linear matrix inequalities (LMIs). All the LMIs of the network are combined to form a single semi definite program which produces a bounding region for each node as solution. This bounded region is the area where node exists. Only the geometrical constructs which form a convex region can be represented as LMIs. 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 [15]: It is a 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 represented as sparse matrix R where r_{ij} 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.
5) 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), MDS Hybrid Range Q-MDS. Non-metric MDS: The algorithm developed by Vo, Challa and Lee; [23]. Weighted MDS: The algorithm developed by Costa, Patwari and Hero [24]

Localization with a Mobile Beacon

Some of the recent research works have used mobile beacon [21] in localization. Mobile beacon knows its position and usually have capacity to travel in some predefined direction or path. Mobile node moves in the sensor field and broadcast its current position. When sufficient number of location message (generally three or more) is received by unknown nodes, it computes its position relative to positions of anchor node using probabilistic approach, received co-ordinate and distance estimate obtained by RSSI measurements.

This method has advantage that communication cost is low and less error than classical approaches but there are some disadvantages like nodes have to wait till the beacon node moves nearby them to compute position, also some nodes never get beacon nodes close to them forever.

Several localization algorithms focus on different aspects such as errors, number of beacons, number of settled nodes, or GPS usage, among other things. The choice of which algorithm to use depends on the resources available, the scenario, the requirements of the application, and the mean localization error acceptable to the nodes.

GPS - It is the most basic range based localization method which uses a constellation of 24 satellites as reference node with the ground station to provide positioning services for the ground nodes. However it increases cost & size of nodes and also has positioning error.

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. 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.

IV. Conclusion

WSN are a necessity now and are proving to be an essential supplement to wireless networks. This paper has briefly explained the most important Localization methods and algorithms developed so far including a discussion on the merits and demerits. There is not any general rule or general method of localization which suits in all scenarios. Algorithms using neural networks are now a day used for localization in wireless sensor networks, rendering noticeable results [25]. Localization for Mobile node is difficult and requires suitable algorithms .Wang et. Al. [26] has put forward a suiting algorithm. Cheng et. al. [27] focuses more on energy based methods for localization. In [28] authors states time delay based localization methods are better than energy based. Localization inside water requires different algorithms compared to normal scenario [29]. Obstacles present can cause problem in localization, so this needs to be tackled. ODLS [30] is an acceptable method which fits in the scenario.

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