A Review on Localization Algorithms in Wireless Sensor Networks

Priya
Computer Science and Engineering
Deenbandhu Chhotu Ram University of Science and Engineering
Haryana, India

Amita Malik
Computer Science and Engineering
Deenbandhu Chhotu Ram University of Science and Engineering
Haryana, India

Abstract: In wireless sensor networks (WSNs), nodes are deployed in sensor fields for monitoring and controlling the physical environments. Node localization is fundamental challenge in wireless sensor networks as without knowing the location of nodes sensed information will have no value. Therefore, it is vital that nodes must know their location. This paper provides a review of basic techniques for localization. The localization algorithms are classified into GPS based or GPS free, Anchor based or Anchor free, Centralized or Distributed and Range based or range free. Paper further discusses limitations of each of the algorithms.

Keywords- Wireless sensor networks, Global positioning system, Localization, Range-based, Range free.

1. INTRODUCTION

Most of the daily life activities depend on sensor technology with great advancement in wireless sensor network (WSN). WSN is a technique that trace nearby environment activities and behavior for monitoring and controlling activities [1] [5]. It has large number of areas where it is used appreciably as in military for battle field surveillance, environmental monitoring (like temperature, pressure, humidity etc.), health care, industrial controlling, inventory system, household, habitat monitoring, traffic control monitoring, under water monitoring, target tracking, wildfire detection, in rescuing other emergency situations etc[2]. WSN consists of large number of sensor nodes which performs computation or processing on received/collected information and do communication means send processed information over the network. Sensor nodes are low powered, low mobility, low cost devices. WSN has many design and technical challenges as Adhoc deployment, production cost, limited battery, complex calculations, fault tolerance, scalability, hardware constraints, and network topology.

Sensor nodes are deployed in an ad hoc manner and the nodes have to identify themselves in some spatial co-ordinate system. This problem is referred to as localization [3]. Localization is one of the technical challenge in Wireless sensor network due to adhoc deployment i.e. sensor nodes are deployed in regions which have no infrastructure like forest. Localization is an active area of research. It means to determine the location of the sensor node, which sense the happening of event and collect the data. Then sensor sends that data to the base station, this information will be irrelevant if we do not know the location from where it come or position of the event where it occurred. Localization refers to find the location of an event where it actually occurs.

One more easy solution is manual configuration but this is impractical in large scale or when sensors are deployed in inaccessible areas such as dense forest, volcanoes or when sensors are mobile. Another easy solution is to equip all the sensor nodes with GPS [4] (Global positioning system) system which provide exact location of the event over the network. As a sensor network consist of large number of sensor nodes to cover a region and equipping each node with GPS is too costly, power consuming and increase the size of the sensor node which is not suitable in construction of cheap small sensor nodes. GPS can work only outdoors. GPS requires line of sight between the receiver and satellites; but big buildings, heavy trees obstruct signals thereby reducing signal strength. So it has low accuracy due to poor signal reception. These are some reasons due to which equipping all the nodes with GPS is not desirable, so only some nodes are equipped with GPS, which are known as Anchor node/ Beacon node/ landmark node who know their position. These nodes are used further for position estimation of other unknown nodes. For this purpose many localization algorithms introduced to solve localization problem.

The rest of paper is organized as follows: Section II give a brief overview of the localization process. In Section III, some of the localization algorithms are discussed. Section IV concludes the paper.

II. LOCALIZATION PROCESS

Localization discovers spatial relationships between objects. Sensor nodes determine their location by localization. It is estimated through communication distance between localized and unlocalized node and the angle at which they receive the signal. Localization process consist of mainly two stages: in first stage, nodes computes distance or angle to the anchor nodes in its proximity or vicinity using different methods. In second stage, sensor nodes use all the distance estimates to compute its actual location using the method that deployed on the basis of the methods used in first stage.

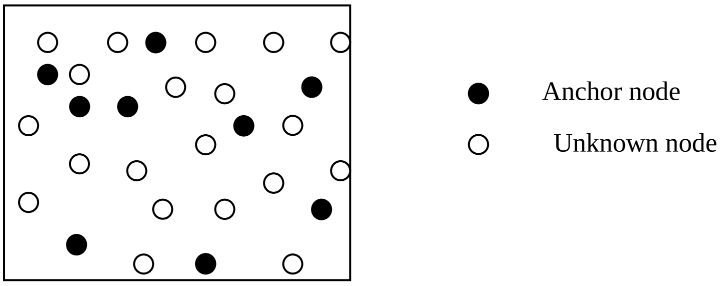

Figure 1: A network with sensor and anchor nodes.

Location measurement techniques [5] can be categorised into 3 main groups as follows.

1. Triangulation
2. Trilateration[6]
3. Multilateration

In triangulation [7] initially AoA measurements are gathered at the sensor node from at least three anchor nodes and to localize the node geometric operations and properties are applied on the measurements.

Trilateration [7] uses distance measurements of three anchor nodes to the unknown node in its near vicinity receive tuples in the form (x, y, d). In this tuple, (x, y) are the coordinates of that anchor node and d is the distance to the anchor node. Then simple geometric operations are applied to find the location of the node where all the three anchor nodes intersect each other.

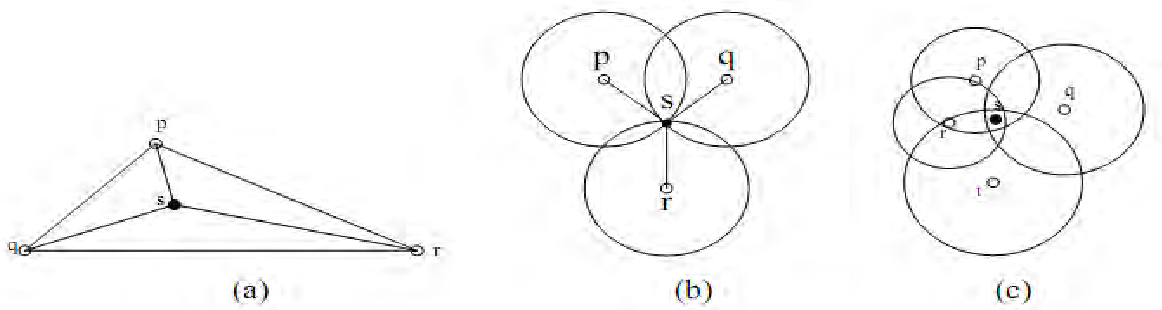

Figure 2: a) Triangulation b) Trilateration c) Multilateration [5]

In Multilateration [7] more than three anchor nodes are used to compute the location of the node by the mathematical intersection of many hyperbolas based on the time at which the receive signal or on the basis of distance from more than three anchor nodes.

III. LOCALIZATION ALGORITHMS

Localization algorithms [8] are basically classified as

- GPS based or GPS free
- Anchor based or Anchor free[3]
- Centralized or Distributed
- Range based or range free

In GPS based network all the nodes are equipped with GPS system which gives accurate location to all the nodes but equipping all the nodes with GPS not the best solution as it cannot work in indoor or dense foliage due to obstruction in line of sight. Its localization accuracy is too high but from economic point it too costly and sensor nodes are required to be small but the size of GPS and its antenna increases the sensor node form factor whereas GPS free algorithms do not use GPS systems to localize node only some nodes are equipped with GPS system which are known as Anchor or Beacon nodes which initiates localization process and they use connectivity information to measure distance between the nodes relative to local network and as it does not use GPS systems it is less costly as compared to GPS based algorithms[9].

In anchor based network some nodes are deployed manually or some nodes are equipped with GPS systems which gives accurate locations of sensor nodes [3][9][10]. Anchor nodes initiates' localization process to localize unknown nodes by these known nodes positions. Localization accuracy of unknown nodes is highly dependent on the number of anchor nodes in the network. And if we use GPS receivers, these are expensive and it uses line of sight communication so it cannot be used in indoors for localization and one alternative is that we can deploy nodes manually but it is not feasible if we have to deploy 10,000 sensor node field with 500 anchor nodes manually localized. Anchor-free algorithms estimate relative positions of nodes instead of computing absolute node positions and anchor free algorithms are used for indoor localization.

In centralized algorithms [9] [11], as shown in figure 3a no computations need to be performed by the nodes since they communicate through the sink node, which does the computations for them. Centralized algorithms find a solution to the computational limitation of nodes and communication consumes more energy as compared to computation. Also, the locations obtained are more precise. But, this leads to an increase in pressure on the sink node and once the sink node fails, the complete network collapses. Also, as the number of nodes increase, the energy efficiency decreases, the time delay increases and the traffic congestion also increases.

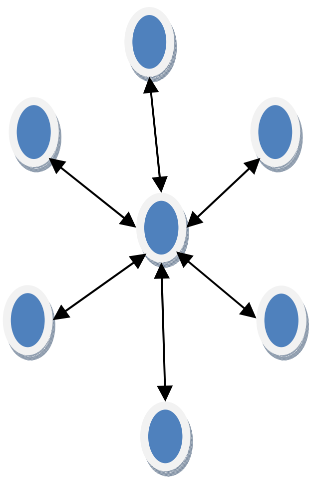

Figure 3a: Centralized localization

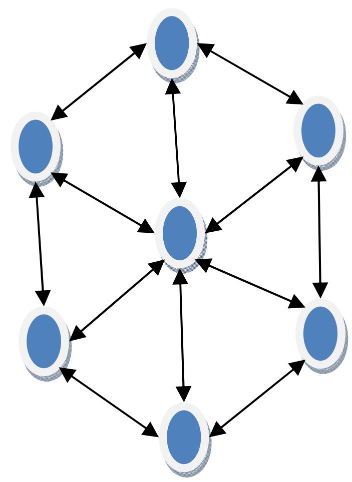

Figure 3b: Distributed Localization

Distributed algorithms [9] [11] (figure 3b), on the other hand, reduces the traffic congestion, has good scalability and has less storage requirements shown in figure. The computational burden is distributed equally among all the nodes and communication cost reduces as compared to centralized algorithms. But, there is no concept of using shortest-path for the inter-node communication, which leads to a decrease in throughput.

Range based [7] approaches make full use of range information and derive specific parameters from this to estimate location. The basic key of this technique is to measure the range of wireless signal transmission. This approach depends on distance or angle between nodes to obtain unknown node's location. The three approaches based on distance measurement are RSSI (Received signal strength), TDOA (time Difference of Arrival) and TOA (Time of Arrival) and based on angle measurement is AOA(Angel of Arrival).

RSSI(Received signal strength indicator)[7][8][12], in this technique distance between two nodes transmitter and receiver is calculated by the signal strength received at the receiver end as all the nodes are equipped with radios to do communication. There are three parameters which are used to calculate distance between transmitter and receiver: 1) Strength of the signal, 2) Information about transmitted strength and 3) The path-loss model. As the strength of a signal diminishes with the square of the distance between transmitter and receiver is increased. With the help of this equation we calculate the distance:

$$P_r = \frac{p_t G_t G_r \lambda_2}{(4\lambda)^2 d^2} \quad (1)$$

Where P_t = transmitted signal strength, G_t = transmitter antenna gain, G_r = received antenna gain, and λ = wavelength of the transmitter signal in meters.

This approach has low hardware cost, because most receivers are capable of calculating the received signal strength and less computational cost to compute location. And the main drawback of this technique is that it is more vulnerable to noise and interference in between communication which results in limited accuracy of localized node. This technique is firstly used in RADAR systems.

Time Difference of Arrival is distance based estimation technique. In this scheme, we measure radio and ultrasound signals arrival time difference between anchor node and unknown node. Each node is equipped with a microphone and a speaker.

In TDoA [13], the transmitter first sends a radio message. It waits some fixed interval of time, t_{delay} (which might be zero), and then produces a fixed pattern of "chirps" on its speaker. When listening nodes hear the radio signal, they note the current time, t_{radio}, and then turn on their microphones. When their microphones detect the chirp pattern, they again note the current time, t_{sound}. Once they have t_{radio}, t_{sound}, and t_{delay}, the listeners measures the distance d between themselves and the transmitter as we know, radio waves travel significantly faster than sound in air.

$$d = (s_{radio} - s_{sound}) * (t_{sound} - t_{radio} - t_{delay}) \qquad (2)$$

TDoA methods are fairly accurate under line-of-sight conditions; however, they perform accurate in areas that are free of echoes, and when the speakers and microphones are synchronized to each other.

The limitation of TDoA systems is that they require special hardware to be built into sensor nodes, specially a speaker and a microphone. TDoA systems perform almost accurately when they are synchronized properly, since speakers and microphones never have same transmission and reception properties. Further, the speed of sound in air varies with the temperature and humidity which increases the chances of error into equation 2, resulting difficulty in the line-of-sight constraint to meet in some environments.

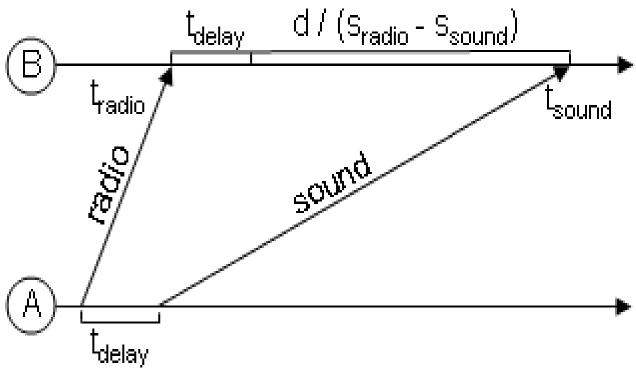

Figure 4: Time Difference of Arrival (TDoA). Sensor A transmits a radio pulse and then an acoustic pulse. By calculating the time difference of arrival between the two pulses, sensor B can measure its distance from A.

Time of Arrival (TOA) [13]: In TOA, speed of wavelength and time of radio signals travelling between anchor node and unlocalized node is measured to estimate the location of unlocalized node. GPS uses TOA, and it is a highly accurate technique; however, it requires high processing capability.

Angle of Arrival (AOA): [14] [15]. Unlocalized node location can be estimated using angle of two anchors signals. These are the angles at which the anchors signals are received by the unlocalized nodes. Unlocalized nodes use triangulation method to estimate their locations.

In this algorithm data is collected using radio or microphone arrays, which allow a listening node to measure the direction of a transmitting node. It can also collect AoA data from optical communication methods. In these methods, several (3-4) microphones hear a single transmitted signal. To measure the angle of arrival of the signal it determines the time difference between the signal's arrivals at different microphones.

In a few degrees these methods obtains accurate results. The angle-of-arrival hardware becomes heavier and more costly then TDoA ranging hardware, as each node must have one speaker and several microphones. Further, the need for spatial separation between speakers it is difficult to reside as the form factor of sensors shrinks. Angle of Arrival hardware is sometimes increases with digital compasses. A digital compass simply shows the global orientation of its node, which can be quite useful in addition with AoA information.

Range free techniques use connectivity and topology information to find location of a node. These techniques are simple and cost effective as compared to range based techniques. Connectivity localization algorithm, centroid localization algorithm are range free techniques.

Centroid Localization

Bulusu and Heidmann [4] [16] [17] proposed a range free, proximity based, coarse-grained centroid localization algorithm. This algorithm execution has three steps.

a) All anchors broadcast their location to all sensor nodes within their transmission range.

b) Each unknown node hears for a fixed amount of time t and collects all the beacon signals it receives from various reference points.

c) All unknown sensor nodes measure their own positions by a centroid determination formula from all n positions of the anchors in range.

$$(X\text{est},\text{Yest}) = \left[\frac{X1 + \cdots + Xn}{n}, \frac{Y1 + \cdots + Yn}{n}\right] \qquad (3)$$

Where X_{est} and Y_{est} are the estimated coordinates of the sensor node and $X_{1:n}$,$Y_{1:n}$ are the coordinates of all n anchor nodes listened by the unknown sensor node. In this algorithm the location error is high due to centroid formula and it focuses on node self localization for 2d networks.

DV-Hop Localization

Niculescu and Nath [18] have proposed DV-Hop localization algorithm which is a mechanism that is similar to traditional distance vector routing. The core idea of DV-Hop implementation is divided into three steps. This method employs a distance vector based packets exchange so that all nodes have the minimum hops and the coordinates of all the anchor nodes. Then, anchor nodes calculate the average HopSize and broadcast it with data packets. When the unknown node receives the average hop size, it calculates the distance d to each anchor according to the recorded hop information. Then it uses trilateration to estimate unknown node position.

$$HopSizei = \frac{\sum \sqrt{(Xi - Xj)^2 + (Yi - Yj)^2}}{\sum hi}, i \neq j, all\ anchors\ j. \qquad (4)$$

Junguo Zhang et. al[19] and Jianning Ding et. al[20] proposed some improvement over basic DV-Hop algorithm.

Amorphous localization [17]

R.Nagpal [21] has proposed independently from DV-Hop, which uses a similar algorithm for calculating position. First, like DV-Hop each node estimate hop distance in number of hops to each anchor node through beacon packet propagation. Once anchor nodes calculate average hop distance then each node collects neighboring nodes hop distance estimates and computes an average of all its neighbours' values.

The Amorphous localization algorithm applies different method from the DV-Hop algorithm to calculate the average distance of a single hop. This assumes that the density of the network n_{local} is known already, so that it can calculate offline HopSize in accordance with the Klien rock and Slivester formula:

$$Hopsize = r\left[1 + e^{-nlocal} - \int_{-1}^{1} e^{\frac{nlocal}{\pi}\left(arccost - t\sqrt{1-t^2}\right)} dt\right] \qquad (5)$$

After obtaining the estimated distances from three anchors, triangulation is used to calculate a node's location.

Gradient localization [8][21][22]

In this algorithm, Multilateration is performed by unknown nodes to get its location. Gradient starts by anchor nodes and helps unlocalized nodes to estimate their positions from three anchor nodes by using Multilateration. Hop count value which is initially set to 0, incremented when it propagates to other neighboring nodes. Every sensor node takes information of the shortest path from anchor nodes. Gradient algorithm follows these steps such as the following: Firstly, anchor node broadcasts beacon packets which contain its coordinate and hop count value. In second step, unknown nodes calculate shortest path between itself and the anchor node from which it receives beacon message using this mathematical equation:

$$D_{ji} = h_{j,A_i} d_{hop} \qquad (6)$$

Where d_{hop} is calculated distance covered by one hop. In third step, error equation is used to get minimum error in which node calculates its coordinate by using Multilateration as follows:

$$E_{j=} \sum_{i=1}^{n} \left(d_{ji} - d^{ji}\right), \qquad (7)$$

Where d_{ji} is the caculated distance computed through gradient propagation.

IV. SUMMARY

In this paper we presented a review on node localization techniques in WSNs and a brief idea of application areas. Localization algorithms are classified into four categories: (1) GPS based and GPS free, (2) Anchor based and Anchor free (3) Centralized and distributed and (4) Range based and Range free. All the algorithms discussed have their own advantages and limitations. GPS based algorithms have very high accuracy but computation and hardware cost increases as compared to GPS free. Decentralized algorithms are better than centralized algorithms. Range based and Range free techniques are thoroughly analyzed, range based techniques have high hardware and computation cost as compared to range free. Range free techniques are easy to implement and is applicable in large networks. Most of the localization algorithms have been proposed in 2D sensor network, comparatively few localization algorithms for 3D environment, so work can be done in this direction.

REFERENCES

[1] I.F. Akyildiz, Weilian Su, Y. Sankarasubramaniam, and E. Cayirci." A survey on sensor networks".IEEE Communications Magazine, Aug. 2002.

[2] Andreas Savvides, Mani Srivastava, Lewis Girod and Deborah Estrin. "Localization In Sensor Networks" In: Book 'Wireless sensor network' pages 327-349, 2004.

[3] Jing WANG, R. K. GHOSH, Sajal K. DAS, "A survey on sensor localization" J Control Theory Appl 2010 8 (1) 2–11

[4] Nirupama Bulusu, John Heidemann, and Deborah Estrin "GPS-less Low-Cost Outdoor Localization for Very Small Devices", IEEE Personal Communications, October 2000.

[5] Avinash Srinivasan and Jie Wu, "A Survey on Secure Localization in Wireless sensor Networks," Florida Atlantic University, Boca Raton, FL, USA, 2007.

[6] Oguejiofor O.S, Aniedu A.N, Ejiofor H.C, Okolibe A.U "Trilateration Based localization Algorithm for Wireless Sensor Network" International Journal of Science and Modern Engineering (IJISME) ISSN: 2319-6386, Volume-1, Issue-10, September 2013

[7] Francisco Santos, Instituto Superior Tecnico," Localization in Wireless Sensor Networks", ACM Journal Name, Vol. V, No. N, November 2008

[8] Nabil Ali Alrajeh, Maryam Bashir, and Bilal Shams, "Localization Techniques in Wireless Sensor Networks," Hindawi Publishing Corporation, International Journal of Distributed Sensor Networks, Volume 2013, Article ID 304628, 9 pages, 15 June 2013.

[9] A. Youssef and M. Youssef, "A taxonomy of localization schemes for wireless sensor networks," in Proceedings of the International Conference onWireless Networks (ICWN '07), pp. 444–450, Las Vegas, Nev, USA, 2007.

[10] Ewa Niewiadomska-Szynkiewicz," Localization Inwireless Sensor Networks: Classification And Evaluation Of Techniques" Int. J. Appl. Math. Comput. Sci., 2012, Vol. 22, No. 2, 281–297.

[11] Kavita Sharma, Mukesh Chawla, Jyoti Ahlawat, "Localization in Wireless Sensor Networks", International Journal of Computer Science and Communication Engineering Volume 1 Issue 1 October 2012.

[12] Amitangshu Pal, "Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges", Network Protocols and Algorithms ISSN 1943-3581 2010, Vol. 2, No. 1.

[13] J. Bachrach, C. Taylor. Localization in sensor networks [M]//Handbook of Sensor Networks: Algorithms and Architectures. Hoboken: John Wiley & Sons, 2005: 277 – 310.

[14] D. Niculescu and B. Nath, "Ad hoc positioning system (APS) using AOA," Proc. IEEE INFOCOM, pp. 1734–1743, Mar.-Apr.2003.

[15] Guoqiang Mao, Barıs¸ Fidan and Brian D.O. Anderson, "Wireless Sensor Network Localization Techniques", In ACM JULY 2007.

[16] Hongyang Chen, Pei Huang, Marcelo Martins, Hing Cheung So, and Kaoru Sezaki, "Novel Centroid Localization Algorithm for Three-Dimensional Wireless Sensor Networks", In Proc. of the 4th international conference on IEEE wireless communications2008 (pp. 1–4).

[17] Shuang Gu, Yong Yue, Carsten Maple, Chengdong Wu, "Localisation Algorithm in Wireless Sensor Networks", Proceedings of the 17th International Conference on Automation & Computing, University of Huddersfield, Huddersfield, UK, 10 September 2011.

[18] D. Niculescu, and B.Nath. "DV based positioning in ad hoc networks". Journal of Telecommunication Systems, 22(14), 267–280, 2003.

[19] Junguo Zhang Beijing Forestry Univ.,Beijing, China Wenbin Li ; DongxuCui ; Xiaoming Sun ; Feng Zhou. "Study on Improved DV-Hop Node Localization Algorithm in Wireless Sensor Network". In: Industrial Electronics and Applications (ICIEA), 2010 the 5th IEEE Conference on , 2010, pg 1855 – 1858.

[20] Jianning Ding, Li Zhang, Guanggui Cheng, Zhiyong Ling, Zhongqiang Zhang, Yi Lei. "Study on DV-Hop Algorithm Based on Modifying Hop Count for Wireless SensorNetworks," IJCSET, October 2012 , Vol 2, Issue 10, 1452-1456.

[21] Radhika Nagpal, "Organizing a Global Coordinate System from Local Information on an Amorphous Computer", A.I. Memo No. 1666, August 12, 1999.

[22] A. R. Kulaib, R. M. Shubair, M. A. Al-Qutayri, Jason W. P. Ng, "An Overview of Localization Techniques for Wireless Sensor Networks", International Conference on Innovations in Information Technology (IIT), 2011