A survey on localization techniques in wireless sensor networks

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Abstract

Wireless Sensor Networks (WSNs) are a kind of ad-hoc networks where the nodes in the network have sensors on board and can sense different phenomena around the sensors deployed in the field. WSNs became very popular due to its diverse nature of applications including Cyber-Physical Systems (CPS), Precision Agriculture, Disaster relief & Rescue operation, Object Tracking in terrestrial environment, Health care application to monitor the physical parameters of a human, space application etc. Most applications use the location information of a sensor node as an inherent characteristic. Location information is mandatory in order to identify in which spatial coordinate the sensor data originates. Broadly, the localization techniques are classified as: range based and range free methods. Hence study of localization techniques for Wireless Sensor Networks is highly significant today for different kind of applications. This paper gives an overview on survey of localization techniques in Wireless Sensor Networks and its current significance.

Keywords: *Wireless Sensor Networks; Localization; Range Based; Range Free; Optimization.*

1. Introduction

Wireless Sensor Networks (WSNs) [1] are a class of networks which consists of sensor nodes, densely deployed over an area. Sensor Nodes have the sensing capability to sense the physical phenomena around them. Sensing can be of several types: Nodes to sense light, object movement, Vibration, Sound etc. Sensed data of different measurements are then converted into digital signals to convey the sensed properties around them. Sensor nodes have very short radio transmission range, hence intermediate nodes act as a relay node to transmit data towards the sink node (Remote destination node or Base station- using multi hop path). Nodes in sensor network can sense in larger area remotely in an unmanned region and collaborate with each other.

Nodes in a WSN may be classified as Stationary and Mobile. In Stationary, nodes are fixed in a region where as in Mobile WSN, some or all nodes in the network move in the target region. Few applications of mobile node are as follows: Nodes deployed in Ocean are highly mobile due to wave movement, sensor fixed on vehicles, sensors embedded in human body to monitor the vital parameter of a person etc

Sensor node is generally small in size. Sensor nodes have hardware components and specific operating system. Components of a sensor node includes a Sensing Unit, Processing unit, Transceiver Unit for communication, Powering unit (battery), Storage, ADC and Application dependent unit. Architecture of a sensor node is depicted in Fig 1.

Sensor nodes may be Analog or Digital sensor. Analog Sensor would produce data in continuous form. Data is further processed to transform it into human understandable form. Examples for analog sensors are as follows: accelerometers, ultrasonic sensor, pressure sensors, light sensors, temperature sensors etc.
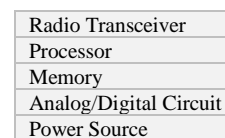
Radio Transceiver
Processor
Memory
Analog/Digital Circuit
Power Source

Fig. 1: Architecture of A Sensor Node.

a) Digital Sensor outputs the sensed data digitally. Push button is an example of digital sensor.
b) Processor: It has specific microprocessor with limited processing capability. Memory and Input-Output are integrated on same circuit. Random Access Memory (RAM) handles the sent/received data. Read Only Memory (ROM) stores operating system of the sensor. Tiny OS, Contiki OS, Nano-RK, Lite OS, Mantis OS are few examples of the operating system used in WSN [7]. Faroog et al. have examined various operating systems used in sensor nodes and explained each aspect of operating system.
c) Transceiver: It is a communication module for sending and receiving data to other nodes in the network. Several Radio Frequency Technologies [8] are available for WSNs such as Bluetooth Technology (IEEE 802.15.1), Wi-Fi Technology (IEEE 802.11.a/b/h/g), UWB technology (IEEE 802.15.3), Wavenis Technology (EN300–220 and FCC15.247—Coronis Systems), ZigBee Technology etc. Appropriate technology can be chosen based on the parameter of requirement like high data rate, long transfer range, and low power mode.
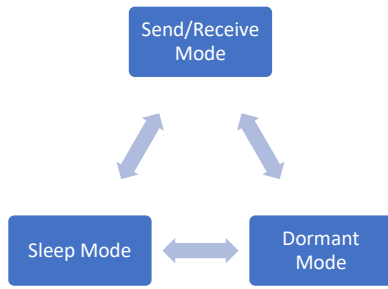
Fig. 2: State Transition of A Sensor Node.

Energy/power of a sensor node has to be efficiently used in order to increase the lifetime of the nodes in the network. Most of the energy in transceiver is used for sending and receiving data. In order to conserve the energy [9], transceiver will be in any one of the following modes: Sleep, Idle, Send and Receive. State transition of a node is depicted as shown in Fig 2.

- In Sleep Mode, the nodes turn off their communication module and become inactive. In this mode the node is involved in time synchronization activity.
- In Send/Receive mode, the nodes would be actively participating in transmission /reception of data.
- In Dormant Mode, the node goes to the low power mode for an agreed period of time t. After the time period t, it rediscovers the network and initiates the communication.

Wireless Sensor networks became attractive due to its variety of applications that includes Cyber Physical Systems, Precision Agriculture, Disaster relief & Rescue operation, Object tracking in terrestrial environment, Health care application to monitor the physical parameters of human, space application etc. Most of the applications use location information of a sensor node as an inherent characteristic. Location information is vital to identify in which spatial coordinate the sensor data originates. Hence study on localization in Wireless sensor network is more significant today for different kind of applications.

Paper organization is done as follows: Section 2 presents the Overview of Localization problem, Section 3 briefs about the classification of localization techniques and highlights in detail the range based as well as range free schemes. Section 4 gives the conclusion and future work.

2. Overview of localization problem

Localization refers to the collection of mechanisms to find the spatial location of a node. For some applications, raw data sent by the sensor should be combined with spatial information to analysis and draw conclusions about the scenario.

Consider a WSN consists of sensor nodes in a two-dimensional squared field of size x * y, with the communication range of q,

with the assumption that the nodes in the network have symmetric communication. We denote the WSN by the graph as

G = {V, E} where V represents nodes in the network and E represents virtual link for nodes to communicate wirelessly. Vertices/Nodes in a network may categorize as Unknown node (U), Settled Node(S) and Beacon Nodes or Reference Nodes (R) [8].

- Unknown Node (U): These nodes do not know their spatial coordinates in the environment. Main Objective of localization problem is to find the spatial coordinate of this unknown node.
- Settled Node (S): Initially most of the nodes are unknown nodes, these unknown nodes estimate their position through the localization system. This estimation may produce the spatial coordinates with some positional error.
- Reference Nodes (R): These nodes get their spatial location through Global Positioning System (GPS) or manual placement. These nodes are referred with different names such as Anchor nodes, Beacon nodes, Reference nodes Landmarks etc. And this serves as a base for localization system for WSNs.

Localization problem can be formulated as follows:

Localization Problem Definition: Given a Multihop Network G ={V,E},with set of nodes with edges forming wireless communication between the nodes, a set of Reference nodes with their known spatial location (X_r,Y_r) and set of Unknown node(U). Main objective of the localization problem is to estimate / find the spatial position of unknown nodes (X_u,Y_u). This process would convert Unknown nodes to settled nodes. Pictorially the localization problem can be represented as in Fig 3.
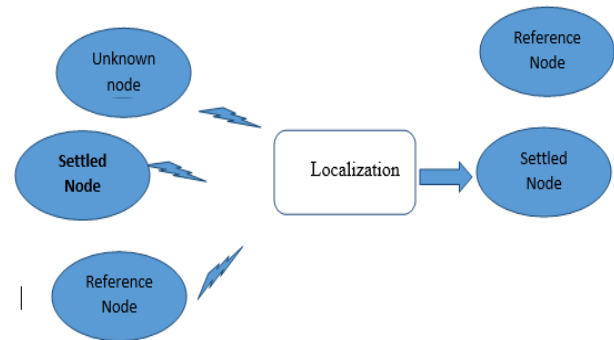

Fig. 3: Localization System Problem.

3. Classification of localization techniques

Mechanisms for estimating the node's physical location can be classified into two categories: Range based and Range –free approach as depicted in Fig 4.
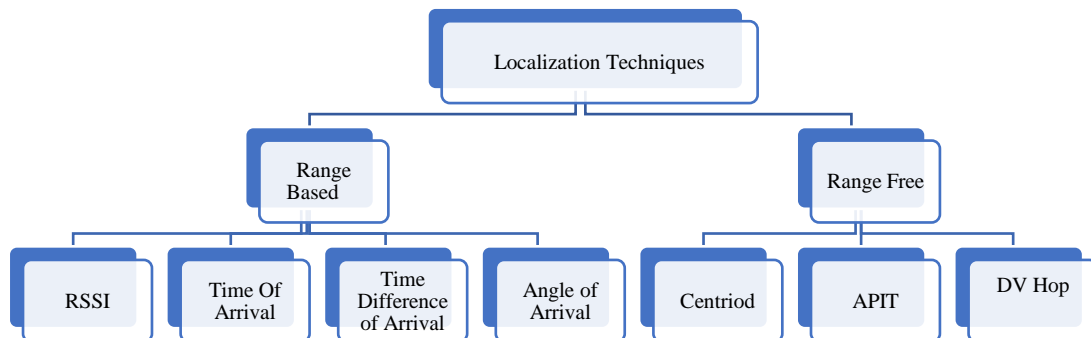

Fig. 4: Classification of Localization Techniques.

3.1. Range based approach

Range based approach uses the distance measurement to estimate the node's physical location. Some of the approaches are: Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA)[22]. Except RSSI, all the approaches need extra hardware in terms of Antenna for transmitting and receiving the RF signals.

Received Signal Strength Indicator (RSSI)

In RSSI, received signal information is used to calculate the location information. It is a simple approach, but less accurate. All these algorithms, uses Anchor node or Reference node which is provisioned with GPS device. With reference to Anchor node, remaining node's location can be estimated.

Using Received signal strength, the distance between the transmitter and receiver can be estimated as follows:

$$RSSI = -10n \log_{10} d + A \tag{1}$$

In Equation (1), A is RSSI value, n is the path loss exponent (value -2.7 to 4.3, varies for indoor and outdoor environments) and d is the distance.

RSSI is one of the commonly used methods for the indoor localization. Received Signal Strength (RSS) is the approximate signal power strength received at the receiver power. It is measured in terms of decibel-milliwatts (dBm). The RSS is used to compute the distance between Transmitter and Receiver. RSSI is an indicator of relative measurement of received signal strength which has arbitrary value typically defined by the vendor of the node.

A Radio module from Digi International, XBee has RSSI indicator in the form of LED, whose light intensity signifies the signal strength .RSSI for XBee would be in the range of -40dBm to -100 dBm. Greater negative value signifies a weaker signal [20]. Atheros WiFi chipset uses RSSI values between 0 and 60 Cisco uses a range between 0 and 100. Measured signal strength in indoor environments would be varying due environment interference. Elnahrawy et al. [21], have discussed the basic limitations of using signal strength in indoor environment was discussed.

In [20], the authors have employed a hybrid target localization scheme for cooperative 3D wireless sensor networks. Their proposed work combines distance (RSSI information) and angle measurements (Angle of Arrival information). Based on angle and distance measurement they have derived a novel non-convex estimator.

Time of Arrival (TOA) and Time Difference of Arrival (TDOA)

These methods estimate the distance based on the arrival time of radio signal at the receiver side. Calculated ToA is multiplied with a known propagation speed gives the measured distance between source and receivers. For this approach, both sender and receiver need to be synchronized. Time Difference of Arrival estimates the distance by measuring the signal's arrival time difference between unknown and beacon node.

Angle of Arrival (AOA)

This approach requires antenna array to estimate the angle at which the signal transmitted signal reaches the receiver and calculates the time difference of arrival. AOA provides accurate estimation if the transmitter and receiver distance is small, it needs complex hardware and careful calibrations. If the distance between the transmitter and receiver increases, small accuracy error would lead to larger error in actual position estimation.

3.2. Range free localization

Bulusu et al stated that embedding GPS service to each node in sensor network is not a preferred approach for the following reasons [12]: (i) Cost-Sensor networks consists of larger number of nodes deployed in a region. In such scenario, facilitating each node with GPS unit would be a costlier solution. (ii) Limited battery power. (iii) For some applications, nodes may be deployed in indoors; reception of signals from satellite would be affected by climatic condition. (iv) Inaccurate- GPS does not give very accu-

rate spatial coordinate, approximately 10-20 m of erroneous spatial data would be reported [2], which is not desirable for applications which need exact geographic position.

Requirements of a localization scheme are:
1) Distributed –Nodes in the network compute their positions on their own with the help of anchor nodes and immediate neighbouring nodes.
2) Reduce the number of node to node communication.
3) Handle intermittent network conditions.

Classification of Range free localization algorithms are given below:

APIT: He et al [5] have made significant contributions to the localization algorithms. They have proposed area based range free localization algorithm referred as APIT (Anchor based Point in Triangulation). This scheme has high powered transmitters and GPS. Node whose location information obtained through GPS is termed as Anchor node. This scheme divides the target environment into triangular regions between beacon nodes.

APIT algorithm works based on the following procedure: a) Beacon exchange- Exchanging location information from Anchors b) PIT Testing (Point in Triangulation) -Node chooses three anchors from which a beacon was received and checks whether it is inside the triangle formed by connecting these three anchor nodes. c) APIT Aggregation-This test is iteratively carried out until all nodes are covered for testing or the required accuracy is attained. d) Centre of Gravity Computation: APIT calculates the Centre of Gravity of the intersection of all of the triangles in which a node resides to determine its estimated position.

APIT algorithm works well even during irregular radio patterns and random placement of nodes.

Adhoc Positioning System (APS)

APS is a distributed, uses hop by hop method. It is a combination of GPS and Distance Vector Method to provide the approximate spatial location. At least 3nodes (referred as landmark nodes) are GPs enabled. Node exchanges their position information with its immediate neighbors and its available landmarks position estimate as well. Two methods of hop by hop distance propagation are explored:
1) DV-Hop Propagation Method
2) DV-Distance Propagation Method

DV-Hop method: This method is similar to Distance Vector (DV) routing where each node maintains a table and exchanges its information. Example of DV Hop is depicted in Fig 5. Assume that node A, B and C are anchor nodes and X is unknown node.
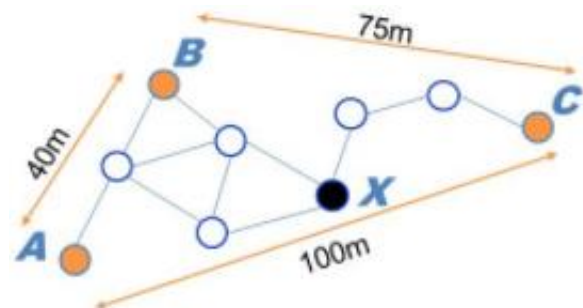

Fig. 5: Example of DV-Hop Method.

Assume that node X gets its average hop distance form B. Average Hop distance can be calculated as follows:

Average distance =

$$\sum(\text{Dist to landmark nodes} / \sum(\text{Number of nodes}) \tag{2}$$

From Eqn. (2), the node X can estimate its position.

Centroid Algorithm

A Distributed, coarse grained localization algorithm [11], that uses anchor beacons, which has spatial information (X_i, Y_i) to estimate nodes location. This scheme is known as Anchor Positioning System which estimates the position based on beacons from land-

marks/anchors nodes. Upon receiving beacons, a node estimates its location using the following centroid formula:

$$Xest, Yest = \left(\frac{xi1+\cdots+xk}{k}, \frac{yi1+\cdots+yik}{k}\right) \tag{3}$$

Where Xest,Yest are the estimated position of unknown node, k is the number of nodes. The advantage of this method is very simple and easy to implement.

Chan et al classified the localization method into target /source localization and node self-localization [12]. Node self-localization is classified in to two categories: Range based localization and range free localization. Authors presented localization in special condition and introduced the evaluation criteria for localization in wireless sensor networks. Their study was helpful in identifying the challenges and methods in the following:

1) Localization for binary sensor data
2) Localization in special scenarios
3) Evaluation criteria for localization methods

Wireless Binary Sensor Network

Binary sensor reports the presence of an event if the measured signal strength is above the threshold. Due to the limited energy of the sensor nodes, it is very vital to limit the communication within the network. Niu et al. claimed that some WSN have limited energy and bandwidth constraints [5]. Hence it is required to limit the communication within the network. Binary sensors (Acoustic, infrared, light etc.) becomes active by sending the signal if the strength of the signal is above the threshold. These sensors make only Boolean decisions (Detection /Non-Detection). Hence binary data are transmitted from the local sensors to the base station. They have proposed an energy based Maximum Likelihood target location estimation using binary data.

Cheng et al have proposed a low complexity based and energy efficient localization and tracking method for binary sensors in noisy environments. This approach is based on known spatial topology [13].

SNAP (Subtract Negative Add Positive) algorithm [14] which is fault tolerant; quickly identify the event location using binary data received from sensor nodes. They divide the area in to k x k grid cells and for each cell they calculate the likelihood of a source occurring in the middle of the cell based received signal strength. Maximum likelihood matrix points to the estimated event location. Authors uses distributed range –based localization algorithm [16] with added three new features and claimed that the proposed work gives better performance and highly scalable. Firstly, backbone is constructed based on the intermediate nodes between the multiple beacon nodes. These nodes on the backbone would helpful to localize/guide the other non-beacon nodes. Second feature of their work is to use heuristic function to push the optimization of the marginal to provide better sample value of individuals. Thirdly,2 hop-neighboring distance approximation is used to obtain better distance approximation and eludes the rigidity problem

GUI et al contributed Check –out DV hop and selective 3-Anchor DV hop algorithms and explored the existing DDV hop [16], Self-Adaptive DV-hop and Robust DV hop. These algorithms were with different scenarios. Moreover, they have proposed localization protocol which can be used with synchronized and unsynchronized networks. They have simulated in the DV based algorithms and their contributions on WSNet and simulation results are analyzed in terms of mobility, synchronization and accuracy.

4. Conclusion

In this paper, some fundamental research on localization techniques was discussed and their applications are investigated. It is understood that different localization solutions are required for diverse range of applications of WSNs. It has greatly encouraged the study on localization techniques and it is understood that despite the significant research developments in WSNs, there exists quite unsolved issues in localization as WSNs has constraints on number of unknown nodes, battery power and cost. These con-straints are the motivating factors to carry out research in localization techniques to compute the spatial positions of unknown nodes with accuracy. This paper will serve as a road map for the researchers working in this field. The future work could be applying optimization and meta-heuristic techniques for localization. Also energy optimization may be considered while performing localization.

References

[1] I.F.Akyildiz, W.Su, Y. Sankarasubramanium and E. Cayirci, "Wireless Sensor Networks: A Survey", IEEE Communications Magazine, vol. 40, no. 8, pp. 102-114, Aug. 2002. https://doi.org/10.1109/MCOM.2002.1024422.

[2] Niculescu, D., Nath, B.: Ad hoc positioning system (APS). In: IEEE GLOBECOM. (2001),2926–2931

[3] Savarese, C., Rabaey, J., Langendoen, K.: Robust positioning algorithms for distributedad-hoc wireless sensor networks. In: Proceedings of the General Track: USENIX AnnualTechnical Conference. (2002) 317–327

[4] Savvides, A., Han, C., Srivastava, M.B.: Dynamic fine grained localization in ad-hoc sensornetworks. In: Proceedings of MobiCom. (2001) 166–179

[5] He, T., Huang, C., Blum, B., Stankovic, J.A., Abdelzaher, T.: Range-free localizationschemes for large scale sensor networks. In: Proceedings of MobiCom. (2003) 81–95

[6] R. Niu and P. Varshney, "Target location estimation in wireless sensor networks using binary data," in Proceedings of the 38th International Conference on Information Sciences and Systems, pp. 17–19, Princeton, NJ, USA, March 2004.

[7] Muhammad Omer Farooq and Thomas Kunz," Operating Systems for Wireless Sensor Networks: A Survey",Sensor 2011, Open Access

[8] Radio-Frequency Technologies for WSNs,Chapter 2, Springer

[9] Boukerche, A., Oliveira, H. A. B. F., Nakamura, E. F. and Loureiro, A. A. F. (2008) Localization Systems for Wireless Sensor Networks",IEEE Wireless Communication ,December 2007 https://doi.org/10.1002/9780470396360.ch11.

[10] L. E.W. Van Hoesel, L. Dal Pont, and P. J.M. Havinga, Design of an Autonomous DecentralizedMAC Protocol forWireless Sensor Networks, Centre for Telematics and Information Technology,University of Twente, Enschede, The Netherlands.

[11] Alrajeh,Bashir, Shams, "Localization Techniques in Wireless Sensor Networks", International Journal of Distributed Sensor Networks,Volume 2013, Article ID 304628

[12] N Bulusu, J Heidemann, D Estrin,"GPS-less Low Cost Outdoor Localization for Very Small Devices", IEEE Personal Communications, Vol 7. No.5, pp. 27-34, Oct 2000. https://doi.org/10.1109/98.878533.

[13] Cheng, Wu,Zhang, Wu,Mengxin Li,Carsten Maple,A Review Article A Survey of Localization in Wireless Sensor Network, Hindawi Publishing Corporation International Journal of Distributed Sensor Networks,2012 https://doi.org/10.1155/2012/962523.

[14] X. Liu, G. Zhao, and X. Ma, "Target localization and tracking in noisy binary sensor networks with known spatial topology," Wireless Communications and Mobile Computing, vol. 9, no. 8, pp. 1028–1039, 2009. https://doi.org/10.1002/wcm.652.

[15] M. P. Michaelides and C. G. Panayiotou, "Fault tolerant event location estimation in sensor networks using binary data," IEEE Transactions on Computers, vol. 58, no. 9, pp. 1185– 1197, 2009. https://doi.org/10.1109/TC.2009.60.

[16] Linqing Gui , Thierry Val , Anne Wei , Réjane Dalce,"Improvement of range-free localization technology by a novel DV-hop protocol in wireless sensor networks"", Elsevier, Adhoc Networks,2016

[17] Stanoeva,SonjaFiliposkac,VisarathInd,LjupcoKocarev," cooperative method for wireless sensor network localization" Elsevier, Adhoc Networks,2016

[18] L. Chelouah et al., Localization protocols for mobile wireless sensor networks: A survey, Computers and Electrical Engineering (2017). https://doi.org/10.1016/j.compeleceng.2017.03.024.

[19] Niewiadomsk,ASzynkiewicz, "Localization In Wireless Sensor Networks: Classification And Evaluation Of Techniques", Int. J. Appl. Math. Comput. Sci., 2012, Vol. 22, No. 2

[20] S Tomic,, M Beko, R Dinis , P Montezuma "Distributed algorithm for target localization in wireless sensor networks using RSS and AoA measurements", Elsevier,Pervasive and Mobile Computing 2017

[21] https://www.digi.com/xbee

[22] Faheem Zafari, A Gkelias, "A Survey of Indoor Localization Systems and Technologies ",arXiv:1709.01015 ,Sep 2017

[23] D. Niculescu and B. Nath, Ad Hoc Positioning System (APS) using AoA, INFOCOM' 03, San Francisco, CA,2003

[24] Elnahrawy, Eiman, Li, Xiaoyan, Martin, Richard P.: The Limits of Localization using Signal Strength: A Comparative Study. In: Proceedings of IEEE SECON, pp.406—414, California, USA, 2004. https://doi.org/10.1109/SAHCN.2004.1381942.

[25] Afzal, Samira: A Review of Localization Techniques for Wireless Sensor Networks. J.Basic Appl.Sci.Res 2(8):7795---7801, 2012.

[26] Youssef, A., Youssef, M.: A Taxonomy of Localization Schemes for Wireless Sensor Networks. In: Proceeding of International Conference on Wireless Networks (ICWN), Las Vegas, USA, 2007

[27] R. Nagpal, Organizing a Global Coordinate System from Local Information on an Amorphous Computer, A.I. Memo1666, MIT A.I. Laboratory, August 1999.