Localization in Wireless Sensor Networks: A review

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Abstract-- Various advancement in wireless communication and electronics technologies have enabled the development of low cost, low-power, multifunctional sensor nodes that are small in size and are able to sense, process data and communicate with each other in short distances wirelessly. A continuous growth in both applications and interests of wireless sensor network have witnessed recent years. A brief introduction of Wireless sensor network (WSN) and its localization techniques is provided. WSN have been considered as promising tools for many location dependent applications such as area surveillance, search and rescue, mobile tracking and navigation, etc. In addition, the geographic information of sensor nodes can be critical for improving network management, topology planning, packet routing and security. In this review paper, we present the comprehensive study of WSN and its localization techniques.

***Keywords**– Wireless Sensor Network, Ad Hoc Network, Anchor Node, GPS, Localization Techniques*

I. INTRODUCTION

Wireless sensor network (WSN) represents a result of recent advances in low power systems and highly integrated digital electronics caused by the development of micro-sensors[1]. The WSN consists of a large number of sensors aiming at performing a common task (Figure1). A wide range of applications are carried out by such networks, like environment monitoring, robotic exploration, metering, biology and security.

Wireless sensor network is a large number of static or mobile sensors nodes which form the wireless network using self-organization and multi-hop method, its purpose is to collaborate detection, processing and transmitting the object monitoring information in areas where the network coverage. The sensor node, sink node, the user node constitute the three elements of sensor networks. Sensor node is the foundation of the whole network, they are responsible for the perception of data, processing data, store data and transmit data.

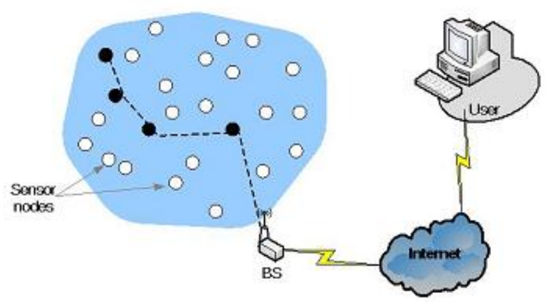

Figure 1: Architecture of a Wireless Sensor Network

The sensor nodes are usually scattered in a sensor field as shown in above figure .Each of these scattered sensor nodes has the capabilities to collect data and route data back to the sink or base station(BS) and the end user .Data are routed back to the end user by a multihop infrastructure less architecture through the base station. The BS may communicate with the end user via internet.

Wireless sensor network nodes are generally battery-powered; a deployment of lifetime use, the battery charging and replacement is difficult.[2] Therefore, in the design of wireless sensor networks, we should work for the efficient use of energy node in the completion of the requirements under the premise, as far as possible to extend the life of the entire network.The main issue in the WSN is its limited energy. Many techniques ,algorithm and protocols have been developed for conservation of node energy. In many applications the nodes are unattended in the sensor field for a long time ,so it should be necessary to retain the power of the node for a long time to work properly. Most of the power is consumed in transmission and reception of the data . Power consumption is and will be the primary metric to design a sensor node. Multihop communication in sensor networks is expected to consume less power than the traditional single hop communication, The transmission power level s can be kept low ,which is highly desired in covert operations. Multihop communication can also effectively overcome some of the signal propagation effects experienced in long distance wireless communication.

Wireless sensor network is a little bit different from the wireless ad hoc network in sense that there are a number of sensor nodes in sensor network can be several orders of magnitude higher than the nodes in an ad hoc network, sensor nodes are densely deployed , sensor nodes are prone to failure, the topology of a sensor network changes very frequently, sensor nodes are limited in power, computational capacities and memory, sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based o point to point communications.[2] Localization in wireless sensor networks is the process of determining the geographical positions of sensors. Only some of the sensors (anchors) in the networks have prior knowledge about their geographical positions. Localization algorithms use the location information of anchors and estimates of distances between neighbouring nodes to determine the positions of the rest of the sensors. So the localization is also the main factor which has to be studied .We will discuss some of localization techniques in further sections.

II. CHARACTERISTICS OF WSN

In this section we discuss the requirements and the characteristics of the sensor node that should be necessary to have for the network QoS and life span of it.

A. Energy Efficiency

Sensor node must be energy efficient. Sensor nodes have a limit amount of energy resource that determines their lifetime. Since it is unfeasible to recharge thousands of nodes, each node should be as energy efficient as possible. The power consumption can be divided into three domains- sensing, communication and data processing. The main task of a sensor node in a sensor field is to detect events, perform quick local data processing, and then transmit the data. In some application scenarios, replenishment of power resources might be impossible. Sensor node lifetime, therefore, shows a strong dependence on battery lifetime. So the energy conservation is the main issue for the network life.

B. Communication Media

In a sensor network, communicating nodes are linked by a wireless medium. These links can be formed by radio, infrared or optical media. One option for radio links is the use of industrial, scientific and medical (ISM) bands, which offer license-free communication in most countries. Much of the current hardware for sensor nodes is based upon RF circuit design. The wireless sensor node, uses a Bluetooth- compatible 2.4 GHz transceiver with an integrated frequency synthesizer. Another possible mode of inter node communication in sensor networks is by infrared. The main drawback though, is the requirement of a line of sight between sender and receiver. Hence, the choice of transmission medium must be supported by robust coding and modulation schemes.

C. Fault Tolerance

Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures. If the environment where the sensor nodes are deployed has little interference, then the protocols can be more relaxed. The failure of sensor nodes should not affect the overall task of the sensor network.

D. Distributed processing

Each sensor node should be able to process local data, data fusion algorithms to collect data from environment and aggregate this data, transforming it to information.

E. Distributed sensing

Using a wireless sensor network, many more data can be collected compared to just one sensor. Even deploying a sensor with great line of sight, it could have obstructions. Thus, distributed sensing provides robustness to environmental obstacles.

F. Low-cost

Sensor node should be cheap. Since this network will have hundreds or thousands of sensor nodes, these devices should be low cost in spite of compromising the quality of service of the sensor network.

G. Scalability

The number of sensor nodes deployed in the sensor field for studying a phenomenon may be in the order of hundreds or thousands. Depending on the application, the number may reach an extreme value of millions. The new schemes must be able to work with this number of nodes. They must also utilize the high density nature of the sensor networks.

H. Network Topology

A numbers of inaccessible and unattended sensor nodes, which are prone to frequent failures, make topology maintenance a challenging task. Deploying high number of nodes densely requires careful handling of topology maintenance.

III. APPLICATIONS OF WSN

WSN applications can be classified into two categories: monitoring and tracking. Monitoring applications include indoor or outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring. Tracking applications include tracking objects, animals, humans, and vehicles. While there are many different applications, below we describe a few example applications that have been deployed and tested in the real environment [3].

A. Home Applications

Sensor network can be used in home automation applications such as such as vacuum cleaners, micro-wave ovens, refrigerators, and VCRs [2]. These sensor nodes inside the domestic devices can interact with each other and with the external network via the Internet or Satellite. They allow end users to manage home devices locally and remotely more easily. The sensor nodes can be embedded into furniture and appliances, and they can communicate with each other and the room server. The room server can also communicate with other room servers to learn about the services they offered, e.g., printing, scanning, and faxing. These room servers and sensor nodes can be integrated with existing embedded devices to become self-organizing, self-regulated.

B. Environmental Applications

Some environmental applications of sensor networks include tracking the movements of birds, small animals, and insects; monitoring environmental conditions that affect crops and livestock. Sensor network can be used to detect of fire of forest. Since sensor nodes may be strategically, randomly, and densely deployed in a forest, sensor nodes can relay the exact origin of the fire to the end users before the fire is spread uncontrollable.

This can be used to detect the flood. Some of the benefits is the ability to monitor the pesticides level in the drinking water, the level of soil erosion, and the level of air pollution in real-time scenario.

C. Military Applications

Wireless sensor network has to be deployed quickly, self-organization, strong concealment and high fault tolerance characteristics, so the wireless sensor network has become an essential part of the military C4ISRT (Command, Control, Communication, Computing, Intelligence, Surveillance, Reconnaissance and Targeting) system[3]. So the military departments pay much attention to it and many countries have invested a lot of manpower and financial resources for research. “Smart dust” is a very representative of the military application research project.

Targeting: Sensor networks can be incorporated into guidance systems of the intelligent ammunition.

Battle damage assessment: Just before or after attacks, sensor networks can be deployed in the target area to gather the battle damage assessment data.

Commanders can constantly monitor the status of troops, the condition and the availability of the equipment and the ammunition in a battlefield by the use of sensor networks. The network can monitor the surrounding environment temperature, brightness, and vibration. It even can detect the existence of radiation or toxic chemicals of the surroundings. Critical terrains, approach routes, paths and straits can be rapidly covered with sensor networks and closely watched for the activities of the opposing forces. As the operations evolve and new operational plans are prepared, new sensor networks can be deployed anytime for battlefield surveillance[2].

D. Health Applications

In the medical field, because of the small size of the wireless sensor network nodes and wireless communication technology, and they are portability, real-time monitoring, low power consumption, location compared with fixed medical equipment. So they can provide new solutions and techniques for telemonitoring, first aid, etiological diagnosis, and medical equipment tracing and medication management [3]. If sensor nodes can be attached to medications, the chance of getting and prescribing the wrong medication to patients can be minimized. Because, patients will have sensor nodes that identify their allergies and required medications.

E. Other Applications

Some of the commercial applications are monitoring material fatigue; building virtual keyboards; managing inventory; monitoring product quality; constructing smart office spaces; environmental control in office buildings; robot control and guidance in automatic manufacturing environments; interactive toys; interactive museums; factory process control and automation; monitoring disaster area; smart structures with sensor nodes embedded inside; machine diagnosis; transportation; factory instrumentation; local control of actuators; detecting and monitoring car thefts; vehicle tracking and detection; and instrumentation of semiconductor processing chambers, rotating machinery, wind tunnels, and anechoic chambers.[2] The air conditioning and heat of most buildings are centrally controlled. Therefore, the temperature inside a room can vary by few degrees; one side might be warmer than the other because there is only one control in the room and the air flow from the central system is not evenly distributed. A distributed wireless sensor network system can be installed to control the air flow and temperature in different parts of the room.

There are two approaches to track and detect the vehicle: first, the line of bearing of the vehicle is determined locally within the clusters and then it is forwarded to the base station, and second, the raw data collected by the sensor nodes are forwarded to the base station to determine the location of the vehicle. [2]Sensor nodes are being deployed to detect and identify threats within a geographic region and report these threats to remote end users by the Internet for analysis.WSN has so many other applications in commercial use and due to its advancements it will become the most useful technology in future.

IV. LOCALIZATION IN WSN

Localization in wireless sensor networks is to determine the geographical positions of sensors in a wireless sensor network.

In many applications of wireless sensor networks, precise location information of sensor nodes is critical to the success of the applications.[5][4] Most data collected from sensors are only meaningful when they are coupled with the location information of the corresponding sensors. Consider an application of habitat monitoring. Thousands of sensors are dropped in the targeted region of a tropical rain-forest by an aeroplane. Nodes are equipped with sensing devices to monitor the changes of temperature and humidity of the environment. To make every measurement useful to scientists, the location where measurements are taken has to be known.

The most trivial solution is manual configuration. The location of each sensor is predetermined before deployment. Sensors are installed to the assigned locations by human. Obviously, this solution is in scalable as much labour is required for the installation.[10]Furthermore, it is sometimes infeasible to have manual configuration as the location information of sensors is unknown before actual deployment. Recalled the previous example of habitat monitoring, sensors are dropped from an aeroplane which exact locations are only known when sensors land on the forest.

Another solution for localization is equipping every sensor with a GPS receiver.[5] Sensors can locate themselves individually using the GPS signals. However, installing a GPS receiver for every sensor node greatly increase the total cost of the sensor network. In addition, the introduction of GPS receiver increases the energy consumption of a node and hence shortens its life time. Lastly, the location obtained from GPS-receiver may not be precise enough for certain applications and the accuracy of GPS is affected by various environmental factors. Accuracy can be of tenths of meters for general GPS.

In view of the inadequacy of manual configuration and employment of GPS-receiver, researchers propose a framework for localization in wireless sensor networks. In a sensor network, some of the sensor nodes have prior knowledge about their locations, either through GPS or manual configuration. They are called anchors or beacons. Other nodes that do not have location information infer their positions by making use of the location information of anchors and other information available in the network, e.g. measured distance between neighbours, connectivity, etc[9].

To measure the distance between neighbouring nodes, each sensor has to be equipped with a ranging device.[10] There are several ways to measure the distance between two sensors. Since each sensor is equipped with wireless communication capability in a wireless sensor network, the strength of received signals from neighbours can be used to estimate the corresponding distances. Localization algorithms can be roughly classified into three categories based on the mathematical background. The most prevalent method is trilateration or multilateration.

V. CLASSIFICATION OF LOCALIZATION TECHNIQUES

In this section, a classification of localization techniques in WSNs is provided. It can be classified mainly into four parts as follows:

1. Centralized and Distributed Algorithms
2. Range free and Range based Algorithms
3. Anchor free and Anchor based Algorithms
4. Mobile and Stationary Node Localization

A. Centralized versus Distributed Localization Algorithms

Localization algorithms can be categorized as centralized [4] or distributed [5] algorithms based on their computational organization. In centralized algorithms, nodes send data to a central location where computation is performed and the location of each node is determined and sent back to the nodes. The drawbacks of centralized algorithms are their high communication costs and intrinsic delay. In most cases, the intrinsic delay of centralized algorithms increases as the number of nodes in the network increases, thus making centralized algorithms inefficient for large networks.

As a result, distributed algorithms that distribute the computational load across the network to decrease delay and to minimize the amount of inter-sensor communication have been introduced [6]. In distributed algorithms, each node determines its location by communication with its neighboring nodes. Generally, distributed algorithms are more robust and energy efficient since each node determines its location locally with the help of its neighbors, without the need to send and receive location information to and from a central server. Distributed algorithms however can be more complex to implement and at times may not be possible due to the limited computational capabilities of sensor nodes.

B. Range-Free versus Range-Based Localization Techniques

For determining the location of a sensor node, two types of techniques exist: range-free [4] and range-based [5]-[6]. Range-free techniques use connectivity information between neighboring nodes to estimate the nodes" position, range-based techniques however require ranging information that can be used to estimate the distance between two neighboring nodes. On the one hand, range-free techniques do not require any additional hardware and use proximity information to estimate the location of the nodes in a WSN, and thus have limited precision. On the other hand, range-based techniques use range measurements such as time of arrival (ToA), angle of arrival (AoA), received signal strength indicator (RSSI), and time difference of arrival (TDoA) to measure the distances between the nodes in order to estimate the location of the nodes. These different ranging techniques are described as follows[9].

a. Time of Arrival

In the Time of Arrival (ToA) technique, all sensors transmit a signal with a predefined velocity to their neighbors. Then, the nodes each send a signal back to their neighbors and by using the transmission and received times each node estimates its distance to its neighbor[6].

b. Received Signal Strength Indicator

Received Signal Strength Indicator (RSSI) is defined as the amount of power present in a received radio signal. Due to radio-propagation path loss, received signal strength (RSS) decreases as the distance of the radio propagation increases. Therefore, the distance between two sensor nodes can be compared using the RSS value at the receiver, assuming that the transmission power at the sender is either fixed or known.[5][6].

An advantage of this technique is that no additional hardware is required as it uses a standard feature found in most wireless devices, namely the received signal strength indicator. Also it does not significantly impact local power consumption or sensor size and thus cost.[7] The disadvantage of this technique is its inaccuracy. For example, if the sensor network is deployed indoors, walls and other obstacles would severely reduce the precision of the method due to nonlinearities, noise, interference, and absorption.

c. Time Difference of Arrival

The Time Difference of Arrival (TDoA) technique requires the nodes to transmit two signals that travel at different speeds. In this technique, each node is equipped with a microphone and a speaker. Most systems use ultrasound while some use audible frequencies. In TDoA, a radio message is sent by the transmitter, which then waits some fixed interval of time and then produces a fixed pattern of chirps on its speaker. In listening mode, the nodes hear the radio signal and note the current time, and then they turn on their microphones to detect the chirp pattern and again note the current time. Once they have the different times, the nodes can compute the distance between themselves and the transmitter using the fact that radio waves travel much faster than sound in air [8].

If line-of-sight conditions are met and the environment is echo-free, TDoA techniques perform extremely accurately. The disadvantage of such systems is that they require special hardware which must be built into the sensor nodes. Also, the speed of sound in air varies with air temperature and humidity, which can introduce inaccuracies. Lastly, it is very difficult to meet line-of-sight conditions in many environments such as inside buildings or in mountainous terrains [5]-[6].

d. Angle of Arrival

Angle of Arrival (AoA) techniques gather data using either radio or microphone arrays. These arrays allow a receiving node determine the direction of a transmitting node. Optical communication techniques can also be used to gather AoA data. In these techniques, a single transmitted signal is heard by several spatially separated microphones. The phase or time difference between the signal"s arrival at different microphones is calculated and thus the AoA of the signal is found.

This technique is accurate to within a few degrees but the downside is that AoA hardware is bigger and more expensive than TDoA ranging hardware, since each node must have one speaker and several microphones. Another important factor is the need for spatial separation between speakers which will be difficult to accommodate as the size of sensor nodes decreases.

In conclusion, range-based techniques can provide very accurate results but require expensive hardware, such as ultrasound devices for TDoA and antenna arrays for AoA. A disadvantage of range-based techniques is that distance information can be difficult to obtain in practice due to issues such as lack of omni-directional ranging and presence of obstacles which prevent line-of-sight.

C. Anchor-Based versus Anchor-Free Localization Techniques

Another classification of localization algorithms for WSNs is based on whether or not external reference nodes are needed. These nodes, called anchor nodes (or simply anchors for short), usually either have a GPS receiver installed on them or know their position by manual configuration. They are used by other nodes as reference nodes in order to provide coordinates in the absolute reference system being used.

Anchor-based algorithms [7]-[8] use anchor nodes to rotate, translate and sometimes scale a relative coordinate system so that it coincides with an absolute coordinate system. In such algorithms, a fraction of the nodes must be anchor nodes or at least a minimum number of anchor nodes are required for adequate results. For 2-dimensional spaces, at least three non collinear anchor nodes and for 3-dimensional spaces, at least four non coplanar anchor nodes are required. The final coordinate assignments of the sensor nodes are valid with respect to a global coordinate system or any other coordinate system being used. A drawback to anchor-based algorithms is that another positioning system is required to determine the anchor node positions. Therefore, if the other positioning system is unavailable, for instance, for GPS-based anchors located in areas where there is no clear view of the sky, the algorithm may not function properly. Another drawback to anchor-based algorithms is that anchor nodes are expensive as they usually require a GPS receiver to be mounted on them. Therefore, algorithms that require many anchor nodes are not very cost-effective. Location information can also be hard-coded into anchor nodes, however, in this case careful deployment of anchor nodes is required, which may be very expensive or even impossible in inaccessible terrains.

In contrast, anchor-free localization algorithms [8] do not require anchor nodes. These algorithms provide only relative node locations, i.e., node locations that reflect the position of the sensor nodes relative to each other. For some applications, such relative coordinates are sufficient, however. For example, in geographic routing protocols, the next forwarding node is usually chosen based on a distance metric that requires the next hop to be physically closer to the destination, which can be perfectly expressed with relative coordinates.

D. Mobile versus Stationary Node Localization

The problem of mobility in WSNs has recently gained much interest as the number of applications that require mobile sensor nodes has increased. Studies conducted on introducing mobility in WSNs have resulted in an overall improvement in the network by not only increasing the overall network lifetime, but also by improving the data capacity of the network as well as addressing delay and latency problems. Some authors have proposed algorithms in which mobile anchor nodes are used in order to aid with the localization of stationary sensor nodes [7]; inventory management is an example of an application that takes advantage of such an approach. In other scenarios however, some or all of the sensor nodes are mobile [5][6] this is where “mobility creates the problem of locating and tracking moving sensors in real time”.

VI. RESEARCH GAP

We studied localization in WSN in 2-D format, we can extend and study this for 3-D localization in which the localization is anchor free, range free and having distributed algorithms. We studied this mainly for static nodes, mobile nodes can also be used for localization and efficient cluster formations and designs of the routing protocols which are very easily implemented in localization and may have energy efficient for increment of network life time.

CONCLUSION

WSNs present fascinate challenges for the application of distributed signal processing and distributed control. These systems will challenge us to apply appropriate techniques to construct cheap processing units with sensing nodes considering energy constraints .In the future, this wide range of application areas will make sensor networks an integral part of our lives.

However, realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, hardware, topology change, environment and power consumption. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking techniques are required.

In this paper we classify various localization algorithms under the categorization of Range Based, Range Free, Anchor Based, Anchor Free, Centralized or Distributed Localization Algorithm. The localization technique, with a focus on low hardware cost and high accuracy, is Distributed RSSI based technique; It does not require any extra hardware and give much accurate results. By using this technique we also found the location of mobile node in harsh environment**.**

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