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Location Estimation in WSNs: a survey

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Abstract

Location information in WSNs is an important block in the information retrieved for the deployed sensor nodes. The sensor node's task is to sense a specific environmental effect like humidity or pressure. The information collected from the network usually contains the information regarding the sensed event and the sensor node that initiated the sensing activity in the network. The location information of the sensed phenomena is of great importance to the end user because it uncovers the behaviour of the environment being monitored and how the sensed event has an effect on that environment. Location information is important also to apprehend a source of an undesirable activity (e.g., fire protection systems).

1. Introduction

Location information can be exploited to improve the operation of other layers in the network operational stack like routing protocols [1], [2], [3], and [4]. Amongst the resource constraints the WSNs share, network lifetime is an important aspect and needs to be covered in the development of WSN operation [5], [6]. Mobility in WSNs can have an effect on the power consumption of the network in general because of the rapid change of the nodes' locations. Location estimation of the mobile nodes can become a frequent process and consumes power. Therefore, a location estimation method for mobile WSNs has to be power efficient.

2. Related Work

Location estimation methods proposed for WSNs range from additive modules to the nodes like GPS modules [6], and to the utilisation of mathematical trigonometry and distance measurements to find the location of the sensor node required (e.g., Trilateration and Triangulation). RF signals can be utilised to estimate the distances required in the localisation method through their Received Signal Strength Indicator (RSSI); because the nodes use wireless interfaces, it makes it possible to measure the RSSI of the connection signals. Other types of signals used to estimate the required distances includes but is not exclusive to: acoustic waves, light waves or any other alternatives to RF based signals.

Location estimation for WSNs is a vital area of research and has gained a major interest by researchers [7], [8], [9], and [10]. It is possible to list some of the major methods of localisation for WSNs as follows:

1. Global Positioning System (GPS): GPS receiver modules are attached to sensor nodes as a location estimation tool by utilising their satellite coordinates [11], [12], and [13]. GPS systems are currently found on many electronic appliances and are used for urban localisation purposes. The major disadvantages with attaching sensor nodes with GPS modules is that they are rather expensive and cost a high amount of energy to operate when used in WSNs. They are also not appropriate for indoor applications.

2. Time-Of-Arrival (TOA): To apply the TOA method, sensor nodes are required to be equipped with two different types of signal source transmitters (acoustic waves, RF transmitter or infrared signals). The nodes can then transmit the required signals between each other and by calculating the time differences of both signals' arrival it is then possible to estimate the required location [14], [15]. The advantage of such an approach is the relatively low cost of the equipment as opposed to GPS systems. However, the accuracy of the signal estimation is rather low as the method requires a complex calculation to estimate the location required.

3. Angle-Of-Arrival (AOA): Like the TOA operation, the receiving node would calculate its location according to the received signal's angle of arrival [16], [17]. The signal type can be RF based. The nodes need to be attached with an array of directional antennae and by that the angle of the signal's arrival can be estimated and then the location calculated. Like TOA, AOA has difficulties of accuracy when calculating the angle of arrival and requires extra equipment to be added to the node(s).

4. Trilateration: Trilateration is the method of estimating a point of intersection of three circles (or three spheres if 3D geometry is applied). Location estimation using a trilateration method requires the availability of three beacon nodes (Beacon nodes are wired or wireless nodes that know their location whether by GPS or built-in by the user) [17], [18]. These nodes are placed around the sensor node(s) to estimate the location by determining the distance of a sensor node from each beacon node. With this information it is possible to estimate the location of the requested node. Trilateration is one of the widely used GPS free location estimation methods in wireless systems as it requires the distance estimation of three beacon points using one type of signal, usually an RF signal is produced by the wireless interface modules.

5. Triangulation: Like trilateration, triangulation requires the presence of beacon nodes. However, only two can be sufficient [19], [20], [5], [8] and [10] compared to the three required by trilateration. Sensor nodes are required to have a directional antenna in their design to determine the angle of the signal's arrival and the distance of the beacon nodes from the requested sensor node. This forms a triangle and by trigonometric algebra, the location can be estimated. The directional antenna can sense the direction of the transmission unlike an Omni directional antenna which senses the signals on wide ranges of directions. With this disadvantage, the nodes are required to be equipped with an array of directional antennae (like the AOA method).

Following the trend by the methods proposed for locating a sensor node, there are three important variables to consider when implementing a location estimation method. The first is the node distance from the beacon node, the signal angle of arrival from a beacon node and the location of the beacon node [10]. The most used type of signal in estimating the distance is the RF signal because it is already available by the network interface of the wireless nodes [20]. This fact has given RF signals a great number of advocates as a distance estimation tool [18].

Usually, RF signals can be translated to their relative RSSI and from the latter it is possible to calculate the required distance. Other systems have proposed the usage of other types of signals like laser-beam signals or acoustic waves signals [12] because the equipment that produces such signals consumes less power than GPS modules. A study on joint RSS-based estimation of unknown location coordinates was performed by [11]. The results of the study show the possible errors of distance calculation if the RF value is dependent on RSSI. An extended work performed by Xinrong Li [14] investigated the usage of RSSI in a collaborative localisation method which merges the operation of two localisation algorithms called the multidimensional scaling (MDS) and maximum-likelihood estimator (MLE). The result is an algorithm of a collaborative approach that has the strength of both methods to avoid the inherent signal-modelling error in the MDS method. The method is suitable for stationary WSN deployment. Cooperative localisation examples can be followed by the following proposed methods in [15], [17] and [13].

Guoqiang et al. [12] also indicated the ease of using and implementing RSSI as a distance estimator with precautions as the error produced by the estimation is dependent on the propagation model used in the calculations. The field of RF estimation has a tremendous number of proposals because of their greater availability in implementation (e.g., the wireless interface of the node) than other types of signals [11], [10].

Acoustic waves were proposed as an alternative for RF signals and an example of using these signals was implemented by Kim and Choi [12]. They implemented an indoor localisation system that utilises acoustic waves as distance estimators of the nodes from the beacon point. The system is aided by a digital compass to determine the direction of the mobile object. Because the environment is indoors, the system implements a band-pass filter to avoid the noisy effect that the acoustic waves can produce in indoor locations.

Zheng Sun et al. [16] proposed Cortina, an indoor localisation system that utilises both RSSI and Rtof-based (Round-trip Time-of-Flight) techniques to estimate the required distances. Various algorithms have been applied to override the multi-path problem; the complex calculation can result in high power consumption for the wireless node. Indoor location estimation caught high interest in the field of indoor sensor networks because of the challenges that come with such an environment. A proposal to improve the RSS estimation by [17] implementing two methods to achieve accurate signal propagation was made. The two methods were regression-based and correlation-based. The proposed methods have been aimed at indoor environments.

SpiderBat [18] is a location estimation system proposed for a WSN which includes the information of both distance and the angle of the sensor node by using an ultrasound-based transmitter and receivers in all compass directions. The node is also equipped with a digital compass to indicate the direction of the node. By collecting the information from both sources, it is possible to calculate the location of the required node. The system requires one anchor node to operate. It also requires the nodes to be equipped with two types of modules: the ultrasound transmitters and the digital compass. The node can consume a high amount of power depending on how frequently the location information is required. Chia-Ho Ou [19] proposed a localisation method for a WSN using mobile anchor nodes. Each anchor node is equipped with four directional antennae, digital compass and a GPS module. The anchor node roams around the deployed stationary sensors and through sending beacon messages, the receiving node would be able to determine their coordinates according the sender antenna of the anchor node. The method aims to be efficient in the power consumption of the nodes and possess a low location estimation error. The directional antenna-based mobile or stationary anchor localisation scheme is highly proposed in this research area as several works have been described by [11], [12] and [13]. The number of deployed anchor nodes in the network also affects the performance of the localisation process of the network [15], [12].

Mobility in a WSN increases the problem of localisation as the nodes tend to change their location rapidly which requires the localisation process to be called every time the network topology changes, Unlike stationary WSNs where the localisation can be achieved at the initialisation process of the network.

Isaac Amundson et al. [11] proposed a localisation approach for a mobile WSN where the sensor nodes are equipped with a digital compass to maintain the position of the mobile node during mobility. The proposed method requires the anchor nodes to have an array of nodes: one is the primary node and two more assisting nodes are combined together to make one anchor node. The mobile node performs regular localisation using triangulation. The rapid change in the mobile node position increases the calling for the triangulation location estimation process which leads to high power consumption on the sensor node's behalf. The speeds of mobility in the performed simulations were between 100mm/s and 400mm/s.

Localisation systems proposed for WSNs are mainly focused on providing the location of the sensor node(s) in the network (mainly stationary nodes). The importance of the location is dependent on the application type applied. However, sensor networks are energy constrained systems. If the nodes were to be mobile in the network and the location was required rapidly, the localisation process is would be initiated rapidly. The localisation process can be computationally exhausting which would then reflected on the node's power consumption. Energy efficiency has to be a priority in designing a suitable localisation method for mobile WSNs.

3. Conclusions and future work

This paper investigated numerous works and research that has been done in the field of location estimation for wireless sensor networks. A future to this paper would investigate different combinations of methods to improve the process of localization in WSNs whether they were implemented in stationary fashion or with mobility capabilities.

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