A Review of Simulation Framework for Wireless Sensor Networks Localization

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***Abstract*—Wireless sensor networks have the capability to deliver the environmental data to the user. Among the significant data is the location of the node either in static or mobile. A number of network simulators were extensively reviewed specifically for the development of wireless sensor networks protocol. However, there is little work done in assessing the framework for localization simulation. This paper addresses the lack of the previous surveys by giving the guidelines for localization developer to select the suitable network simulator or programming language. It includes a comparative description on importance features in evaluating the localization algorithm. In addition, it discusses the general performance evaluation metric use for localization. Finally, it list several open issues which help in developing and analyzing the localization algorithm.**

Keywords*—*localization; range-based; range-free; survey; simulation.

I. Introduction

Wireless sensor networks (WSN) are excellent choice in bridging the physical data that correlate with the environment via its ability in sensing, communicating and computing the data. Sensor nodes are capable of illustrating the actual phenomenon or event happened when the measured data associate with location information. Yunhou et al. [1]emphasized the localizability of node offers tremendous advantages to the network procedure and administration specifically in executing the node deployment, topology control, power scheduling and mobility management. A massive of survey papers [2-4] on localization techniques for WSN were produced and most of the papers focused on classifying the methods based on WSN's limitation. In general the localization technique is classified into two which are range-based and range-free. Range- based use ranging measurements to estimate the distance between nodes. The distance measurement can be accurately retrieved by using special ranging hardware. The ranging hardware exploits the physical property of RF and acoustic signal. Range-free techniques rely on the connectivity among nodes in the network. The connectivity benefits from the information retrieved from other nodes. The information may contain the number of hop and proximity information like neighboring node and received strength signal indicator (RSSI) [5].

However, to date there is not much discussion on the framework to evaluate the localization algorithm using simulation specifically for WSN. Therefore, the purpose of this work is to review the essential framework for localization simulation in assessing the algorithm. Section II briefs about the general simulators used to evaluate the proposed localization algorithm. Next section details the localization framework. Section IV explains the performance evaluation use in localization. The final section summarizes the findings and highlights the open issue for localization simulation framework.

II. Common Simulators in Localization

According to Michael Allen et al. [6], the development of localization algorithm comprises of three cycles which are simulation, emulation and experimentation. In testing the localization algorithm, both emulation and experimentation methods are excellent choice since these platforms provide network setting similar to the real environment. Nevertheless, experimentation method incur high expenses since the algorithm testing would involve large volume of sensor hardwares. Apart from that, even the emulation has its own the disadvantages, whereby the emulator is unable to integrate with other wireless communication infrastructure since it is specifically designed to imitate the WSN system only. Simulation represent an economical and fastest technique to evaluate the localization algorithm. There are a number of simulators used to evaluate the performance of the localization algorithm. Nonetheless, this paper will not cover all WSN simulators currently available for academia and industry. It only selects several simulators and programming languages which are frequently used in the development of the localization algorithm. The simulators and languages used in the past to test the localization algorithm are; NS- 2, NS- 3, Omnet++, C , C++, Java and Matlab.

A. NS- 2 and NS -3

NS-2 and NS-3 are the most common open-source software used by the localization developer. Both simulators can incorporate WSN with other wireless communication such as wireless local area network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE). Another advantage of using this simulator, is that it provides a library of mobility pattern. These two features provide opportunity for WSN localization algorithm implementation.

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B. OMNET++

OMNeT++ simulator comes complete with GUI and mobility pattern library. It is capable of integrating WSN with other wireless communication like NS-2 and NS-3 simulator. The localization developer can further evaluate the algorithm under different environment namely Body Area Network (BAN), Vehicular Ad Hoc Network (VANET) [7] with road traffic model called Simulation of Urban Mobility (SUMO) [8], and Multimedia Wireless Sensor Networks (MWSN) using camera vision [9]. Nevertheless, there is no localization algorithm library available in OMNeT++.

C. C, C++ and JAVA

C, C++ and Java are the fundamental programming languages used to investigate the feasibility of the localization algorithm. In fact, most network simulators [10] used these same programming languages as the basis. The objective of this paper is to show that these languages can be used as a tool to perform localization evaluation. The localization developer needs to start from a scratch thus the development and validation of localization algorithm process become longer. The attempt to compare the new proposed localization algorithm with the previous algorithm would fail if the old algorithm is unavailable and difficult to implement.

D. MATLAB

The simplicity of the MATLAB's programming syntax and the availability of built-in complex mathematical expression made the development and assessment of the localization algorithm effortless. For instance, a majority of range-based localization implemented in MATLAB since the validation of the localization algorithm uses the statistical approach or digital signal processing technique. In fact the complicated modeling process of ranging signals either radio frequency (RF) or acoustic signal is possible. There are some limitation using the algorithm in custom-built simulator like Silhouette [11], Senelex [12] and SNLSDP [13]. The network setting is simplify and might be obsolete. Therefore, it is crucial to ensure the custom-built component is up to date and the network model is similar to the real deployment.

TABLE I summarizes the important features supported by the current simulation's environment for the development of the localization algorithm. The table shows which simulator is suitable for range-based or range-free localization. It also highlights the availability of built-in library within the simulation tools. Some network simulator has mobility pattern library that could be used for depth analysis of a localization algorithm. However, to the best of the author's knowledge none of the current network simulators offer a complete localization algorithm library. In addition, the network simulators have a simpler version of channel modeling. It did not include the component library for instance geometrical function and anisotropic network. Both features are critical in the assessment of a localization algorithm since it reflects the real environment and process the information into estimated location. Apart from that, Raghavendra et al. [14] reported there are a number of attempts in using computational intelligence (CI) techniques to improve the localization accuracy. Nevertheless, there are no built-in CI libraries in these network simulators. The most interesting features that benefit the localization developer when using the network simulator is the opportunity to integrate the algorithm with other wireless communication system.

On the other hand, any localization algorithm which is evaluated using programming language C, C++, Java and MATLAB has limitation to incorporate other wireless communication devices since the previous localization algorithm were stand alone coding and were tested without the detailed WSN model. Nevertheless, C, C++, Java and MATLAB have other advantages whereby it offers built-in CI toolbox, for example, fuzzy logic, Monte Carlo and Markov Model. It depends on how the localization developer designs and executes the localization algorithms.

III. FRAMEWORK FOR LOCALIZATION SIMULATION

With respect to the constraint mentioned in the previous section, this paper proposed a framework for localization simulation. Fig. 1 illustrates the essential facet in simulation for development of the localization algorithm. Firstly, the localization developer needs to determine the role of the node. There are three entities namely sensor, sink, anchor and any of them is responsible for performing localization algorithm in the network. Generally both anchor and sink are considered to have larger transmission range compared to sensor node in the network. Moreover only anchor equips with Global Positioning System (GPS) that provides the location information.

TABLE I. IMPORTANT FEATURES IN LOCALIZATION ALGORITHM SUPPORT BY NETWORK SIMULATOR AND PROGRAMING LANGUAGE

Important features	**Localization Simulators and Programming Language**			
	NS-2 / NS-3	***OMNeT++***	***C,C++and Java***	***MATLAB***
Type of localization	Range-free	Range-free	Both[a]	Both[a]
Mobility Library	Yes	Yes	Depend[b]	Depend[b]
Localization Library	No	No	Depend[b]	Depend[b]
Channel Modeling	Both[a]	Both[a]	Both[a]	Range-based
Anisotropic Network	No	No	Depend[b]	Depend[b]
Geometrical Formulation	No	No	Depend[b]	Depend[b]
Integration with other wireless communication	Yes	Yes	Limited	Limited
Computational Intelligence Technique Library	No	No	Yes	Yes

a. *Cover for both Range-free and Range-based Localization*

b. *The availability of the features is depend on the localization algorithm*

Fig. 1. Framework for localization simulation.

Apart from that, some localization algorithm requires the mobility pattern implemented on any of those three entities. Among the well known, mobile pattern implemented in localization algorithm are Random Way Point, Random Walk [15], Snake-Like [16], and Perpendicular Intersection [17]. Another important feature in evaluating the localization algorithm is the energy model. To date, both sink and anchor so far, are assumed to have less energy limitation compared to sensor node. The energy model is crucial from the sensor node view point. To the best of author's knowledge, the analysis of energy consumption in localization was done by using the big O notation or signaling cost.

The second essential facet in WSN localization simulation is the environment profile. The environment profile in localization is referring to channel modeling and anisotropic network. A proper channel modeling is very important in localization since it reflects the real environment. According to Seyed [18] the channel modeling can be categorize into two which are large-scale and small-scale. Large-scale channel modeling concern characteristic of the path- loss, shadowing, radio power and antenna element [19]. These characteristics are fundamental for range-based and range-free localization. In contrast, the small-scale channel modeling emphasize on spatial, temporal, spectral and angular statistics. This statistic information is important particularly in evaluating the range-based localization.

Another important environment profile is the anisotropic network. This environment profile thoroughly studied in evaluating the range-free localization. Anisotropic is defined as the property of adjacent length between nodes are different in all direction [20]. Xuan Liu et al [21] claimed anisotropic network could happened from two perspectives: scattered node deployment and irregular radio pattern. Scattered node deployment could happen if the localization developer takes consideration the geographical obstacles and uneven terrain condition in testing the localization algorithm. Among notable anisotropic network studied for localization is the irregular radio pattern. Gang Zhou et al [22] developed the Radio Irregularity Model (RIM) to approximate the anisotropic network via extensive study. In addition, some localization developer studied different type of holes namely S, C and H holes in anisotropic network. The hole may result from unbalanced energy consumption and communication failure due to external interference during localization phase [23].

The final component in the framework for localization simulation is the algorithm library. Range-based and range-free algorithm has totally different way of execution. The fundamental range-based technique is the distance measurement. The ranging hardware derives the distance measurement between node by using the time of arrival and angle of the radio frequency (RF) and acoustic signals. Among renowned algorithm used in range-based localization are maximum likelyhood, phase interferometry, Kalman filter and cross-correlation [2]. On the other hand, range-free localization use the information inside the packet delivered by the other nodes namely sensor node, anchor and sink. Therefore the connectivity among the nodes within network during localization phase is crucial. Depend on the proposed algorithm, either of the three elements namely anchor, sensor and sink are required to perform either transmit only, received only or both operations.

Interestingly, both range-free and range-based exploit the geometrical theory in retrieving the location of the node. The geometrical theories that commonly implemented in the previous localization algorithm are; Lateration, Triangulation and Sweep.

A. Lateration

Basically there are two type lateration use in localization namely trilateration and multilateration. Trilateration is a method of deriving the Euclidean distance with three known locations. The idea is using the circular or sphere formula as the radio range of the nodes. Meanwhile, multilateration involve more than three nodes who know its location. The unknown node uses the arrival of signals from other node to discover its location [24]. Both trilateration and multilateration utilized the linear equation. The location of the unknown node supposedly is the intersection of the radio range and then from that the linear equation is developed. By solving the linear equation, the estimated location is obtained.

B. Triangulation

Unlike lateration, triangulation enables the node to determine its location by including the angle measurement [25]. Furthermore triangulations compliment lateration weakness, in which it is unable to detect the node's location when the unknown node deviates from the nodes' overlapping radio range. By extending the angle from at least two priori nodes and using the Pythagorean Theorem the unknown node's location is retrieved.

C. Sweep

Goldenberg et al. and Fang et al. [26, 27] claimed that the sweep method is able to reduce the localization error due to flip configuration. Sweep method requires at least two nodes that

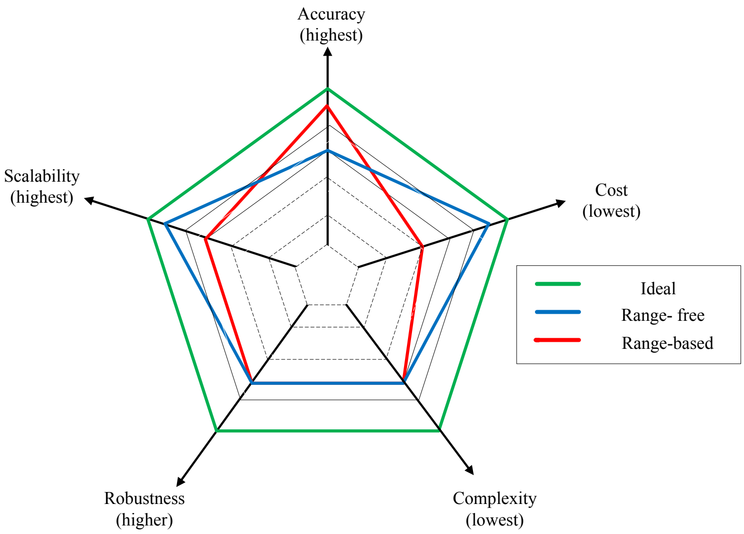

Fig. 2. Comparison performance evaluation for localization algorithm.

have ground true location. In sweep method each unknown node has two possible locations. Eventually these two locations would have another two estimated locations like tree diagram. For instance, let n as the location of the node and the possible locations is derive by using the tree diagram. Therefore with sweep method the node has a set of estimated location. This method has a drawback where the estimated location may increase as the number of node increase.

The framework in localization simulation compromises of three aspects which are node, environmental profile and localization algorithms. The next section would explain the performance metric studied in evaluating the proposed localization algorithm.

IV. Performance Evaluation

This paper focuses only on the performance metrics that are used by range-based and range-free technique in WSN. The assessment parameters are developed depending on the execution method of localization algorithm. There are five major and important performance metrics in assessing the WSN localization algorithm which are; Accuracy, Scalability, Cost, Robustness and Complexity.

A. Accuracy

It is the principle metric in evaluating a localization algorithm. The fundamental of accuracy term is to compare the estimated location with the ground truth location. The common term use to describe the accuracy level is mean absolute error (MAE) and Cramer- Rao Bound (CRB). MAE [6]determines the accuracy by averaging the localization error from each node in the network. Meanwhile CRB assume the range measured are line-of-sight (LOS) and give the lower bound on the variance of the localization algorithm [28].

B. Cost

There are two aspects in evaluating the cost of localization algorithm which are from hardware cost and human cost perspective. Human cost is referring to the human intervention during localization process. This may involve maintaining the sensor platform individually. The evaluation criteria purely during the practical implementation phase. On the other hand, the hardware cost is related with the additional module on sensor platform and number of node in the network. Similar to the previous cost, the additional module criteria is measures based on field operation phase.

C. Scalability

Sensor node has limited transmission range and energy source therefore the WSN consist myriad of sensor nodes. Some localization algorithm depends on information from other node in the network. When the sensors in the network reduce due to energy depletion, missing or broken, the quality of localization algorithm may severely affect.

D. Robustness

Robustness of localization algorithm is purposely to evaluate its ability in dynamic topology. Dynamic topology may refer as the nodes' topology keeps changing during localization phase. The feasibility of localization algorithm is tested under the condition of inconsistent distance among nodes. In nodes' deployment the topology may become random rather than deterministic. This is due to uneven terrain and obstacles. Moreover the mobility pattern and speed of the node may contribute the dynamic of nodes' topology as well.

E. Complexity

When complicated localization is implemented on WSN platform it requires the node to have intensive computational capability. Therefore a metric called convergence time is use to evaluate the period of time taken to ensure all the node in network has completed the localization phase. The complexity of the localization algorithm is evaluated specifically when the topology of node change as the state mobile.

As in Fig. 2, the spider chart illustrates the requirement for all performance metric. The diagram shows the comparison between the ideal case, range-based and range-free localization. It also highlights the tradeoff using both localization methods.

V. LOCALIZATION IN WSN APPLICATION

Localization and tracking algorithm play a vital role in various WSN applications. The knowledge of node's location either at specific time or speed enables the WSN application to be autonomous, economical and efficient. Among the application benefits with the localization algorithm are summarized in the following paragraphs.

A. Forestry Conservation

WSN facilitate a numbers of activities in conserving the forest namely wild fire risk evaluation, illegal logging surveillance, climate observation and tree canopy estimation. Common method to place the sensor is by using the electronic distance measurement. However, this effort is labor demanding and time consuming especially in complex and uneven geographical terrain. Another option is using the GPS to determine the sensor's location. Problem with GPS, it does not working because of the RF propagation. The implication of previous methods has made in-network localization is preferable in foliage area [29-31].

B. Livestock Management

The dairy livestock management compromise of various tasks such as animal's inventory record, pasture scheduling, grazing area control, health and behavior inspection. The traditional management is challenging since it involves animals like cow or sheep randomly spread in the rural, wide and open grazing field. Several studies have revealed that localization and physical readings of these animals can be done by using the WSN [32-34]. An interesting attempt using the kinetic energy to power up the sensors for localization purpose is done by Gutierrez et al [35].Overall, these past studies suggest several courses of action for reducing the localization error and the number of anchors.

C. Coal Mining

Coal mining is an underground tunnels explored by human. The wireless sensor networks are able to detect the geographical structure of the underground tunnel. In situ interactions between the wall and sensors provide a real-time tunnel condition and location of the miners or the mining entrance. Although GPS and accelerometer are the best devices in locating the miner nevertheless, the radio signal is change dynamically which give negative impact to the quality of accuracy [36, 37].

D. Emergency Responders

Flood, earthquake, tsunami, fire and landslide are among hazardous situation can happen at any time with extreme speed rate. When nature disasters happen, the technology like mobile phone or WLAN could get disconnected. It is really important for emergency responder system to find the rescue team or victim location and identify high risk disaster area. Both Fischer et al and Filippoupolitis et al [38, 39] use WSN to trace the victim's without the pre-existing infrastructure. These findings suggest that in general the localization algorithm for emergency responders should able to obtain a high accuracy in limited period of time.

VI. OPEN ISSUES AND CONCLUSIONS

The following are the important open issue in evaluating localization algorithm. There is several interesting open issue that allow the localization algorithm be study in depth which are:

A. Framework of Localization Application

WSN applications are diverse in term of its Quality of Service (QoS) and method of its implementation. Furthermore, in some applications the sensor platform may have different data type namely text, audio and video. Thus a framework of localization technique that specify according to the application's environment and network parameters is vital.

B. Integration of WSN Localization with other wireless communication systems

WSN offer a great correlation between data retrieved and environment. Nevertheless, such data including the location of the nodes requires a high speed and sophisticated wireless communication namely ultra-wideband (UWB), WLAN and LTE as the gateway to the end user. A magnificent technology called Internet of Thing (IoT) envisioned the integration of these wireless technologies with WSN. Therefore the integration effort between different wireless standard may impact the localizability of the nodes and require a thorough investigation.

C. Framework for 3D Localization

The above review only concerns the framework for localization algorithm in 2D. In recent years, the research of 3D localization algorithm attracts other localization developer. For instance, the localization of WSN in forest monitoring and underwater environment requires the height or depth of the node's location. Hence the analysis of localization algorithm in 3D localization can improve the modeling network process as real implementation.

In a nut shell, this paper reviews thoroughly the pivotal part in executing the localization algorithm via simulation. It discuss in detail the fundamental elements in the node, environment profile and localization algorithm. The paper emphasizes the crucial criteria that could help the developers assess the algorithm. The evaluation of localization algorithm still requires the emulator and experimental for further validation since the problem of clock drift of sensor node platform is not available in simulation. Nevertheless, evaluating the localization algorithm via simulation, it would be effortless and economical since the algorithm would be easy to replicate for improvement purpose.

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