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Issues and Challenges in RSSI based Target Localization and Tracking in Wireless Sensor Networks

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Abstract— **Moving target localization & tracking has been currently widely addressed area of research because of its lot of significance in broad varying applications. The major approaches for target localization & tracking in a defined WSN are Range Based, Range Free, Prediction Filter based Approaches aimed at achieving either Localization & Tracking accuracy or Energy Efficiency or Security or combination of these depending upon application at hand. Besides other range based techniques (TOA, TDOA, AOA) aimed at localization/tracking, RSSI-based approach is most widely used in spite of various challenges associated with it. The most important reason is that it does not need the extra hardware as most of electronic gadgets have built-in RSSI Circuitry to read RSS. By exploiting this RSSI measurement, one can find distance between transmitter & receiver using a suitable mathematical model of signal attenuation. However due to high dynamicity of wireless environment, the RSSI measurements are notoriously unpredictable. This paper discusses the RSSI based localization & tracking problem in detail & also surveys various other solutions proposed by the research community in the domain. Recent strategies to improve localization accuracy & tracking accuracy in RSSI based systems especially for dynamic environments & open research issues are also discussed as well.**

Keywords— Received Signal Strength Indication (RSSI), Time of Arrival (TOA), Time Difference of Arrival (TDOA), Wireless Sensor Network (WSN)

I. INTRODUCTION

WSN is basically a collection of number of small, low cost & randomly deployed heterogeneous embedded nodes communicating with each other in a wireless manner using suitable wireless technology such as Zigbee, Bluetooth, Wi-Fi, Infrared,..etc., aimed at monitoring a specific parameter of interest in a area under test as shown in fig.1. Besides its origin in military purposes, WSN are currently being successfully used in a variety of real world applications ranging from battlefield surveillance, habitat monitoring, environmental monitoring, health application, target tracking etc. The Node Localization & Tracking is one of the fundamental research area of WSN. Its typical applications include tracking intruders in battlefield, locating objects in building, determining their number, positions, and movements, emergency response applications, industrial and environmental monitoring [1],[2]. Obviously success of such applications depends on the accuracy in locating the target of interest as well as in predicting its future path in monitoring area. Consequently, many efforts have been taken recently to raise accuracy in localization & tracking.

Moving target can be a person or animal or object or a vehicle. Several aspects are considered before developing algorithms for moving target tracking. Based on such aspects several classification are possible such as Active / Passive[1], Range Based / Range Free , Indoor / Outdoor, Single target / Multiple target ,Centralized/ Distributed, 2-D / 3-D [5] & Static WSN based / Mobile WSN (MSN) [7] based. For instance if the target cooperates itself in localization & tracking, then it is Active (also called as Collaborative/Cooperative) target tracking , otherwise it is Passive target (Non Cooperative) tracking. In active case target is equipped with a specific transmitting device, so that given WSN nodes can detect, localize & track it. While in passive case target is "Device-Free" wherein the target do not carry any sensor node to help localization & tracking. If the target tracking algorithm relies on distance (range) calculation, then it is termed as Range Based [2]. Though coupled with higher accuracy, Range Based techniques require additional hardware. The dominant techniques are RSSI ,TOA, AOA, TDOA Whereas if the algorithm exploits connectivity of nodes rather than distance calculation, then it is Range Free in which the most common techniques are Hop Count, APIT, Centroid (CL) and DV-Hop [1], [2],[8]. If the area D is inside building , then it is Indoor problem while if it is an open space, then it is simply an Outdoor problem. Number of moving targets decides whether the problem at hand is Single or Multiple target tracking problem whereas the place of computation of sensed data decides whether the problem is Centralized or Distributed (dominantly use of Clustering) [3],[4],[6]. Also many researchers have developed target tracking algorithm considering 2-D surrounding, while very less efforts have been reported for 3-D environmental scenario. In majority of research work all the nodes in given WSN are static while some research work exploited few mobile nodes in WSN for tracking problem. Additionally all above mentioned categories centers around specific performance parameter depending upon application demand.

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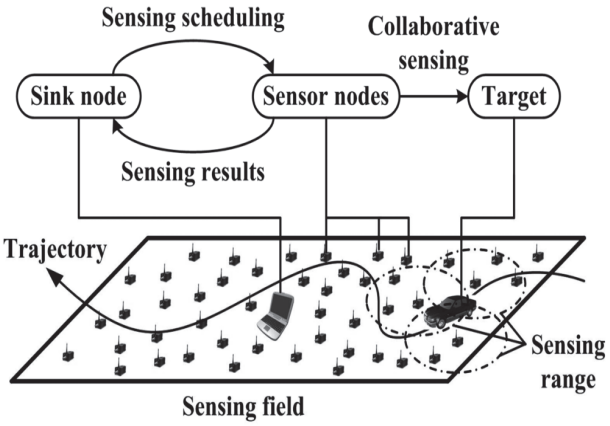

Fig.1 Typical scenario of moving target tracking using WSN

The prime objective of localization and tracking is to position the target (localization problem) and estimating its trajectory (tracking problem) by exploiting the field measurements at successive time intervals. Basically localization problem mainly focus on the positioning accuracy, while the tracking problem aims at tracking target in a timely manner to suit the application need [1]. Basically the accuracy & reliability of target tracking algorithm heavily depends on target localization accuracy which in turn depends on localization technique employed, dynamic nature of environment. Although localization can be done by using GPS with the help of satellites. However the major limitation of GPS is that it can not be implemented in dense forests, mountains because of unavailability of line-of-sight (LOS) from GPS satellites. Additionally installing GPS to each sensor node is not a economical solution. Hence the research trend is to use few nodes with GPS installed (referred as Beacon Nodes (whose coordinates (locations) are known) in coordination with GPS-free nodes (referred as normal sensor nodes (whose coordinates (locations) are unknown)) to determine the location of moving target at a specific time interval. Therefore Collaboration among nodes is highly essential in localization & tracking problem.

Capability of Radio Frequency (RF) (compared infrared, acoustic , or ultra-wideband) to penetrate smoke, nonmetallic obstacles and walls makes them suitable for target localization & tracking applications. The RSSI is readily available at the physical layer of each wireless node without requiring any additional hardware. Besides simplicity in RSSI measurements & lower power consumption compared to other methods, RSSI values are generally corrupted by environmental noise (due to dynamicity of wireless medium causing reflections, refractions & multipath propagation), target localization & in turn its tracking purely based on RSSI is highly unreliable. Additionally environment dependant parameters in signal path loss model (discussed in sect III) may vary in between, causing inaccurate conversion of RSSI-distance estimation during tracking. Another important challenge is as distance between transmitting & receiving nodes is very large (in range of a few meters), the distance estimation between them suffers with interference. Therefore in order to design & develop a better target tracking algorithm, one must understand issues & challenges in RSSI based localization & tracking in the context of specific application scenario. Our main focus in this paper is to thoroughly discuss various issues, challenges & approaches in RSSI based active localization & tracking along with open research issues. This survey also discusses recent trends in this context. The paper is outlined as follows. After a detail discussion of localization/tracking problem along with all possible categories (section I), the principal of RSSI based Localization/tracking, path loss models, issues & challenges in the RSSI based methods are summarized in section II. Section III presents active RSSI based localization/ tracking is addressed & corresponding state of art techniques. Section IV presents recent trends in RSSI based localization/tracking domain while section V concludes the survey with future research directions.

II. RSSI-BASED LOCALIZATION AND TRACKING

The RSSI based target localization basically applies a appropriate path loss model to estimate the distance between the target & signal receiving nodes (beacon nodes). Once distances of target & sensor nodes are obtained, then using trilateration (incase of three anchor nodes) or multilateration (incase of four/more anchor nodes) method [5],[6] the target location is estimated in D. Currently the research on RSSI based Localization revolves mainly around three aspects. One, Improve the path loss model to suit the dynamicity of operating environment for correcting RSSI measurements. Two, Inputting measurements from other sources to RSSI based system to reduce the localization & tracking error. Third, Apply a suitable Bayesian framework such as KF or PF or their variants depending upon application requirement.

A. RSSI Path Loss Models

The RSSI path loss models helps to find out distance between transmitting & receiving nodes, which then can be further used to locate target of interest. It is basically a set of mathematical expressions used to represent the radio characteristics of a given wireless environment. It can be classified as theoretical models (which deal with the fundamental principles of radio wave propagation) and empirical models (which are based on actual measurements of medium parameters). Taking into account wide range of applicative area, a correct understanding and modeling of the path loss model is thus most important aspect in improving the localization/tracking accuracy. Although the dominant theoretical RSSI path loss models generally used are Free Space propagation model, Two-ray ground Model and Log Normal Shadowing Model, some research work has also developed new models to suit the given medium. The first two models do not describe for the application environment while the third model is a more general signal propagation model. Log Normal Shadowing Model [5] is suitable for indoor and outdoor environments. This model provides a number of parameters which can be configured according to different environment (indoor and outdoor) Thus The accuracy in distance calculation & tracking heavily depends upon the accuracy of the path loss model

used. Therefore selecting the appropriate model for the target localization & tracking is the key to success.

B. Performance Evaluation of RSSI Based Localization

Many research efforts either aim at pursuing better Energy Efficiency at the cost of Tracking accuracy or aim to achieve the Tracking Accuracy with less attention on Energy Efficiency [3],[11]. While some applications tries to attain a good balance between these two parameters in order to suit given application. However especially for mission critical applications such as battlefield surveillance, intruder detection, tracking accuracy is of prime importance than other performance issues.

Localization Accuracy & Tracking Accuracy : At present the trend is to attain the tracking accuracy to scale of few centimeters [14]. Basically localization accuracy is estimated by comparing actual target location & calculated location. The important metric to measure these parameters are mean square error, root mean square error, variance or average localization error [5],[8].

Energy Efficiency : Higher number of active sensor nodes for localization & tracking task at a time, more will be the tracking accuracy attained, off course at the cost of additional power consumption [3],[11]. As WSN is generally energy constrained, the algorithm must be energy efficient enough to avoid redundant communication between nodes so as to raise energy efficiency & prolong network lifetime [6]. One way to resolve this issue is to employ selective activation of sensor nodes (or clustering) & collaboration among them. Additionally one must not ignore the computational complexity of algorithm to improve energy efficiency.

Density of beacon nodes: The localization accuracy is highly dependant on the density of beacon nodes. Higher the density, more better the localization & tracking accuracy is. However higher density of beacon nodes is associated with additional system cost. Therefore research trend is to lower beacon density as low as possible without degrading the quality of localization.

III. ACTIVE RANGE BASED LOCALIZATION AND TRACKING

In the active target tracking case, the target is itself equipped with a node or a RF / IR (Infrared)/ Acoustic source that transmits/receives signals so as to take active part in the localization process. Further if process involves distance estimation to locate & track moving target, then it is referred as Active Range Based Localization & Tracking. In this framework if the sensor field D contains total N nodes, then the target can be localized by remaining $N - 1$ nodes. Different technological solutions have been proposed under this scenario. Following subsections describes proposed solutions and architectures in the domain so far.

A. IR Based Systems

In IR based system the target wears a IR source that periodically or on demand transmits a unique identifier. A set of beacon nodes are positioned at known locations to collect the signals from target. This information is then sent to a central server for further processing to estimate the locations of the target at successive time intervals within WSN. Besides low costs offered by IR based solutions, its use is quite limited due to its small transmission range & its inability to penetrate other obstacles in line of sight (LOS) between target & beacon nodes.

B. AOA Based Systems

In these systems the receiving nodes (equipped with arrays of at least two receiving antennas) estimate the AOA (direction) of the signal emitted from an active target. The target is then located & tracked by exploiting these angles with the help of few mathematical equations. These solutions successfully overcome the limitations of IR based approach at the cost of requirement for arrays of directional antennas & associated system cost & complexity WSN infrastructure.

C. TOA Based Systems

Rather than measuring the direction as in AOA based system, TOA based system exploits the TOA or the TDOA information for localization & tracking by employing RF signals or acoustics waves. In the former case, the transmission instance and the signal propagation delay from the active target to the receiving node are taken into account. While for the TDOA case either the difference in time at which a single signal from the target arrives at three or more receiving nodes or the time difference of arrival of two different signals (e.g., ultrasound and radio frequency) generated at the same time instant at the same receiving node, are exploited. This technique though ensures good performances in outdoor environments without obstacles, the localization/tracking accuracy drastically reduces in indoor environments due to the multiple reflections of RF signals, & therefore need appropriate signal processing techniques for mitigating the multipath fading. Although it is more accurate than RSSI and is not affected by channel fading but major limitation is to achieve accurate time synchronization between nodes.

D. Received Signal Strength Indicator (RSSI) Based Systems

Out of all active range based active localization & tracking techniques , RSSI based systems do not require any additional hardware as almost all electronic transceivers have inbuilt RSSI circuit. The idea of this technique is to measure RSS value transmitted by active target at specified receiving nodes (generally beacon nodes) & then transforming it to get distance (range) between target & receiving nodes using suitable path loss model. The position of target of interest is then obtained using Trilateration or Multilateration technique or some other suitable technique. Despite of fact that RSSI based solution is cost effective solution especially for large

scale WSN system, it has several limitations as described in section 1.

IV. Recent Trends in RSSI based Localization & Tracking

A. Use of Fingerprinting

A lot of research efforts based on pattern recognition have been reported in the literature to deal target localization [13],[14]. The idea is to generate fingerprints (also called radio map) during an offline training phase wherein RSSI data emitted by target is collected at a set of few or all known locations in WSN area. Then the real time target RSSI values are matched with established radio map to solve localization problem at hand. However, the RSSI radio map establishment phase takes a lot of time, both for RSSI sampling and for computing which may affect system latency & thereby localization accuracy.

B. Use of probabilistic Bayesian Inference

As the distance-RSSI relationship is highly unreliable due to various reasons as mentioned earlier, therefore RSSI propagation may not be adequately captured by a fixed invariant model [4],[13]. A number of variants on probabilistic Bayesian inference approaches have appeared in the literature in the context of target localization/tracking. Bayesian inference is a probabilistic framework which sequentially estimates the unknown state from noisy observations using a dynamic predictive model and an observation likelihood. Bayesian methods can estimate a target's velocity and acceleration in addition to position, and can also provide an uncertainty measure of the estimates. The dominant Bayesian methods employed for RSSI based active target tracking are KF, PF or one of their variants [8], [9],[10].

C. Modifying new RSSI based Model

The authors in [12] have developed a new RSSI-based model, called Exponential-Rayleigh (ER) model, to mitigate the unpredictability in RSSI-Distance releation and offer superior tracking performance in both outdoor and indoor environment. The proposed ER model specifically involves focus on the large-scale exponential attenuation part and the small scale Rayleigh enhancement part. The novelty of this model is the Rayleigh part which mitigate the target induced multipath components. This research work stimulates to modify existing RSSI based models, concentrating on one one of the error prone aspects in wireless medium (such as fast fading, multipath propagation,..etc), to reduce the ranging error associated with RSSI based distance estimation techniques.

D. Adjusting Transmission Power Levels

Prior knowledge about the target state or surrounding environment can be exploited to improve localization/tracking accuracy [14]. For instance, knowledge of environment dimensions or possible velocities can be utilized to decide an optimum transmission power level of the nodes to reduce interference level. Existing RSSI-based tracking systems usually do not exploit such a knowledge.

E. Use of Mobility :

There are two critical problems associated with traditional localization/tracking algorithms due to use of fixed sensor nodes. One, high energy consumption due to frequent switching between sensor states during tracking moving target. Second, target miss due to communication holes due to static nature of nodes, especially if target moves in the holes. The mobility of sensor nodes with static nodes can be exploited to eliminate these two issues [16]. That means through cooperation between mobile nodes and fixed nodes, the tracking quality can be improved largely as well as tracking performance can be fairly improved.

The concept of mobile beacon is also exploited successfully in [8]. Few researchers have also addressed the target tracking problem with mobile sinks successfully [10],[19].

V. CONCLUSION

Target localization/tracking using wireless sensor networks is of prime importance in various applications. A lot of efforts have been made by many researchers and a variety of algorithm also have been proposed. In this paper, a survey of RSSI based techniques as applied to the localization & tracking of targets in WSN has been reported. Representative state of the art techniques for localization and tracking have been described with due focus on Active (Cooperative/Collaborative) target. As time varying environmental conditions deeply influence the reliability of the systems and therefore great care must be exercised in defining localization/ tracking algorithm.

There are still several open research issues in RSSI based target localization & tracking problem : (1) to mitigate the effects of highly dynamic wireless environment (proper modeling of multipath signals & shadowing), (2) to detect sharp changes in target direction & varying speed of the target, (3) to raise prediction accuracy of target trajectory, missing target recovery, (4) to accurately calibrate environment dependant parameters in path loss models & (5) to further work on the concepts such as mobile sink, mobile beacon, transmission power can greatly enhance accuracy of target localization & tracking problem.

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