A novel range based node localization in Wireless Sensor Networks

Ejaz Hussain, Xiong Zhang, Li Chao, and Sadique Ahmed Bugti

***Abstract*—Sensor networks are a type of communication which gives a reliable communication at a low cost. These networks have collection of components which organize themselves autonomously in the network which gives a seamless communication at low cost and in a self-organized fashion. But for achieving this goal it poses certain kinds of new concepts and optimization problems like node localization, deployment and mobility management. In this paper we are addressing one of the crucial issues namely node localization by using Token Management Vector Manipulation (TMVM). With this novel approach, we can estimate the location of deployed nodes without depending on central synchronized time reference at receivers end and at the anchors/transmitter end. Vector Manipulation (VM) gives an approach for determining the co-ordinates of unknown nodes at greater ease. Results show that this newly proposed method gives a greater accuracy in terms of average distance error on different variance of Gaussian values and performs better than synergetic localization algorithm on higher values of variance.**

***Index Terms*—TMVM, node- localization, range based localization, vector manipulation, wireless sensor networks.**

I. Introduction

It is evident from the recent years that their is an increased interest in the use of wireless sensor networks (WSNs) in numerous applications such as forest monitoring, disaster management, space exploration, factory automation, border protection and battlefield surveillance[1,2]. The burning issue in wireless sensor networks is the automatic localization of the deployed nodes. These algorithms have their range from simple to very complex, but they all only categories into two different fields namely range free methods and range based methods [3].

Range free methods can not provide the location of deployed nodes so accurate but they are cost effective and robust to noise. Niculescu and Nath proposed a typical range-free algorithm DV-HOP [4]. DV-HOP uses distance-vector forwarding technique to get the minimum hop count from a node to heard anchors. Multidimensional scaling maps (MDS-MAP) was proposed by Sheng et al. [5] and after this variance of MDS-MAP are presented as centralized MDS-MAP(C) and distributed MDS-MAP (P). There is another method Support Vector Machine (SVM) proposed by Tran and Nguyen[6]. In this method machine learning approach is used to localize the nodes.

In range-based methods, range measurements are used, such as received signal strength (RSS) [7], RSS is the voltage measured at receivers. Much of the work is being done on this topic, yet it is notoriously unpredictable [8]. Also before using this approach into a very critical application, their sources of errors must be well understood. Angle of arrival (AOA) [9] provides localization information complementary to the Time of arrival (TOA) and RSS measurements. Two popular ways are used to measure the AOA, the first one used array processing technique. In second approach, AOA estimation uses RSS ratio between two (or more) directional antennas. Time difference of arrival (TDOA) [10] measurements measure the difference between the arrival times of a transmitter signal at two receivers respectively.

The popular distance estimation method is the TOA [11] method in which the range is estimated based on the time the signal spends travelling from the transmitter to the receiver. Since it is very much obvious that, the speed of RF propagation is very well known in both free space and air, it gives a direct estimation of the distance between the transmitter and the receiver once the travel time is estimated. In a distributed environment such as wireless sensor networks there may be no central synchronized time reference that regulates the activities of each node. Instead, each node manages its own time reference. Accurate TOA estimation needs perfect synchronization between the clocks of the transmitter and the receiver. Although three anchors are necessary to obtain position, a fourth anchor will be needed for time correction.

In this paper we are addressing one of the crucial issues namely node localization by using the Token Management Vector Manipulation (TMVM). With this novel approach, we can estimate the location of deployed nodes without depending on central synchronized time reference at receivers end and at the anchors/transmitter end. Vector Manipulation (VM) gives an approach for determining the co-ordinates of unknown nodes at greater ease. Results show that this newly proposed method gives a greater accuracy in terms of average distance error on different variance of Gaussian values.

The rest of the paper is organized as follows. Section II discusses the motivation and contribution. Proposed approach is introduced in section III. Results and conclusion are presented in section IV and V respectively.

II. Motivation and Contribution

In wireless sensor networks there are many issues and one burning issue is the automatic localization of the deployed nodes. The contribution of this paper is to present a new

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approach TMVM for estimating the location of deployed nodes without depending on central synchronized time reference at receivers end and at the anchors/transmitter end. It is evident in wireless sensor networks that data has no worth if it comes from any source having no position information. So, in this paper we focus on method which gives reliable positioning information of the deployed nodes before sending the data to the destinations. For this, only information we need is, the positioning of the anchor/beacons nodes. For estimating the position of deployed nodes, three anchor nodes are required to fulfill the task. The anchor nodes transmit periodically their position information and randomly generated tokens. Distributed nodes receive this information and manipulate to estimate their positions before sending the meaningful data to the destinations. Simulation results show that, this method is excellent and at par to many of the existing algorithms for estimating the position of unknown deployed nodes and has greater accuracy in terms of average distance error on different variance of Gaussian values.

III. Proposed Approach

We used MATLAB platform environment for the simulation of proposed method. 100m^2 area is considered for the deployed infrastructure. Our model is free space propagation model which is limited to 2-dimenional space.

Fig 1 shows the layout of randomly distributed nodes in the area of concern. In this layout there are three beacon/anchor nodes which are responsible of constructing the basic communication tree for every unknown deployed node. The concept rely on the fact that position of all non localized nodes deployed in the area of concern can be determined if the position of localized/beacon nodes is available.

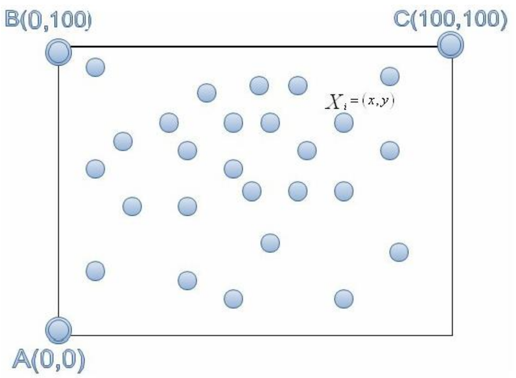

Fig. 1. Layout diagram of deployed nodes

To address the need of nodes deployment in wireless sensor network in distributed environment, we used an algorithm named as TMVM and to illustrate the feasibility of this algorithm, TMVM adopts the "general assumptions" of WSNs as follows.

- Quasi-stationary nodes are used in network.
- The nodes are left unattended after deployment.
- All nodes have similar capabilities, processing, communication and initial energy.
- The transmission ranges of nodes are adjustable.
- All N nodes at any position can hear the beacons of all anchor nodes

The network consists of three anchor nodes along with N unknown randomly distributed nodes. We placed three anchor nodes at the three corners of the square for the basic communication. Coordinates of the anchor nodes are shown in the Fig 1 which are A (0, 0), B (0, 100) and C (100, 100). The goal of this paper is to locate and estimate the position of N randomly distributed nodes in the bounded region without depending on central synchronized time reference at receivers end and at the anchors/transmitter end.

To further elaborate the algorithm we divided TMVM into two stages: Token Management (TM) and Vector Manipulation (VM). The notations used in the paper with their meanings are tabulated under Table I.

TABLE I: Notations and Their Meanings

Notation	Meaning
ΔT_1	Time difference of signal transmitted from Node A to X directly and from A to X via B
ΔT_2	Time difference of signal transmitted from Node C to X directly and from C to X via B
$T_{1(start)}$	Timer 1 at every un-known node starts upon receiving the signal from beacon node A
$T_{1(stop)}$	Timer 1 at every un-known node stops upon receiving the signal from beacon node B carrying the token of node A
$T_{2(start)}$	Timer 2 at every un-known node starts upon receiving the signal from beacon node C
$T_{2(stop)}$	Timer 2 at every un-known node stops upon receiving the signal from beacon node B carrying the token of node C
$AB_{(t)}$	Time it takes the signal to propagate from node A to Node B
$AX_{(t)}$	Time it takes the signal to propagate from node A to un-known node X
$BX_{(t)}$	Time it takes the signal to propagate from node B to un-known node X
$CX_{(t)}$	Time it takes the signal to propagate from node C to un-known node X
$CB_{(t)}$	Time it takes the signal to propagate from node C to Node B

A self explanatory flow chart for TMVM is depicted in Fig.2 below.

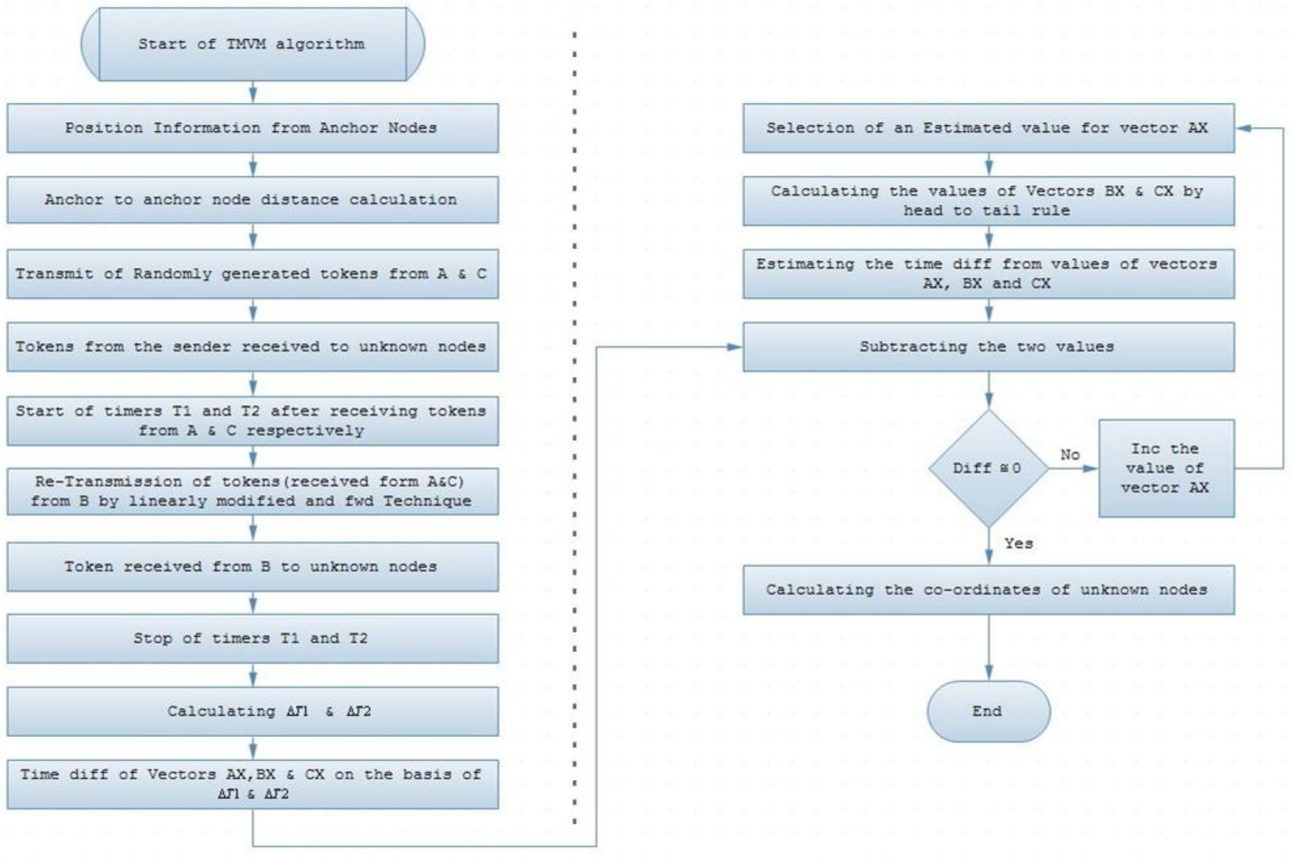

Fig. 2. Flow chart of TMVM

A. Token Management Process

All the calculations necessary for the measurement of the distance between anchor nodes and token traveling timings are covered in this stage. This stage is also responsible for the calculation of time difference values of the calculated vectors.

An estimated value of vector AX is used to determine the values of rest of vectors BX and CX by simply vectors head to tail rule. With the help of these estimated values, we can estimate the time difference values. These time difference values are then compared to the values with the calculated ones in the first stage. Co- ordinates of unknown nodes can be determined if the resultant of two values is equal to zero, otherwise a new estimated value is assigned to vector AX. The process is repeated until we get the diff nearly equal to zero.

A.1 Measuring the distance and traveling time of signal between anchor nodes Token Management Process

At the start anchor nodes periodically send their position information along with their identity. The signal disseminates to all unknown nodes and anchor nodes, but all three anchor nodes ignore the received positioning signals. The deployed nodes in the region calculate the distances between anchors nodes from the available position information. Euclidean distance between two anchor nodes is given below.

$$dt(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} \tag{1}$$

From the available value of distance between two points, signal propagation time can be calculated as under

$$t(p,q) = C / dt(p,q) \tag{2}$$

A.2 Constructing the time difference equations

In the scheme of TM, anchor nodes send periodically randomly generated tokens with their identity. In this paper, we chooses two anchor nodes A and C to send these tokens and anchor B to re-transmit the same after receiving from either A or C but with its own identity.

When Token disseminated form A, it simultaneously propagates to anchor nodes B and C as well as to all N unknown nodes. Timer T1 at unknown nodes starts upon receiving of token from A and stops on the receiving the same from B. Time duration between these arrivals of token is calculated as follows.

$$\Delta T_1 = T_{1(stop)} - T_{1(start)} \tag{3}$$

Similarly, when the token signal disseminated form C, received at all unknown nodes, T2 starts and upon receiving the same from anchor node B, it stops. Difference of this time equation is given below.

$$\Delta T_2 = T_{2(stop)} - T_{2(start)} \tag{4}$$

Equations (3) and (4) can be re-written as under

$$\Delta T_1 = AB_{(t)} + BX_{(t)} - AX_{(t)} \tag{5}$$

$$\Delta T_2 = CB_{(t)} + BX_{(t)} - CX_{(t)} \tag{6}$$

So by knowing the signal propagation time between AB and ΔT_1, we can get the equation of time difference for BX and AX.

$$BX_{(t)} - AX_{(t)} = \Delta T_1 - AB_{(t)} \quad (7)$$

Similarly knowing the signal propagation time between CB and ΔT_2, we can get the equation of time difference for BX and CX.

$$BX_{(t)} - CX_{(t)} = \Delta T_2 - CB_{(t)} \quad (8)$$

The contribution of (7) and (8) is very important for the further calculations.

B. Vector Manipulation Iteration Process

In VM stage, we determine the coordinates of unknown nodes by simple vector manipulation. We used an iterative method along with geometrical computation for getting the desired results. An iterative method is a mathematical procedure that generates a sequence of improved approximate solutions for a class of problems. An iterative process should be convergent, i.e., it should come closer to the desired result as the number of iterations increases.

We divide the Vector Manipulation iteration process into two steps to make things clear.

B.1 Step-1

Any unknown node say X_i assign a random value to vector AX with respect to anchor node A. This node has already the value of $\overrightarrow{AB}$ calculated earlier in 3(A.1). Vector AX with slope θ is shown Fig 3.

Now by knowing the values of $\overrightarrow{AB}$ and AX, length and slope of XB can be calculated by head to tail rule.

$$\overrightarrow{XB} = \overrightarrow{AB} - \overrightarrow{AX} \quad (9)$$

Similarly, the length and slope of CX can be determined by the following equation.

$$\overrightarrow{CX} = \overrightarrow{CB} - \overrightarrow{XB} \quad (10)$$

Therefore, once we have the values of AX, XB and CX, we can easily determine the signal propagation time between them as well as the signal propagation time difference between BX and AX and BC and CX.

B.2 Step-2

In this step a refinement process takes place, measured time values from equation (3) and (4) are compared with the estimated values calculated in the step-1. If the difference between all the corresponding values is equal to zero the iteration/refinement process stop and equations (11) and (12) gives the coordinates of X_i, otherwise new value is assigned to AX till we achieve the refined desired result.

$$X_{i(x-axis)} = [d / sqrt\left(n^2 + 1\right)] + A_x \quad (11)$$

$$X_{i(y-axis)} = d[sqrt(n^2) / sqrt(n^2 + 1)] + A_y \quad (12)$$

In the above equations d and n are the assigned distance and slope to vector AX.

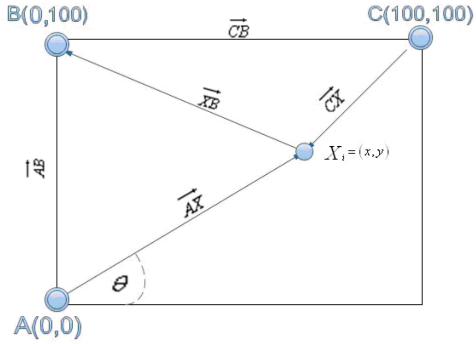

Fig. 3. Vector manipulation for node x

IV. Simulation Results

Accurate node localization mostly depends on the delay in the signal through propagation medium and time delay in the circuits. These are the major contributor of the errors. The dramatic advances in IC design with low time delay have made possible to use these circuits in wireless sensor networks. Time delays in the circuits ranging from more than 1 ns down to the picoseconds range, depending on the technology being used. Signal propagation time delay which is the most crucial part in the measurements can be modeled as Gaussian with the following equation.

$$f(T_{i,j} = t \mid \theta) = \aleph\left(t; d_{i,j} / v_p + \mu T, \sigma_T^2\right) \quad (13)$$

where μT and σ_T^2 are the mean and variance of the time delay error. UWB measurements conducted in Motorola factory showed μT =0.3 ns and σ_T =1.9 ns. This mean error μT can be estimated (as a nuisance parameter) by the localization algorithm so that it can be subtracted out [12]. But σ_T has a great influence on the estimation of values. We have observed the error at different values of variance and compared the result with the synergetic localization algorithm [13]. With the ideal situation taking variance as low as 0.2, we observed the average distance error of 0.11m as shown in the Fig 4. In Fig 5 we have taken the variance as 2.0 and on this quantity we observed the average distance error of 0.71m.

The refinement process shown in Fig 6 tells that by increasing the number of iteration we get the lowest possible average distance error at different values of variance. It is true that with the increase of variance we lose accuracy of the system but the comparison results in Fig 7 shows that our system performs better at increased variance as compared to the synergetic localization algorithm.

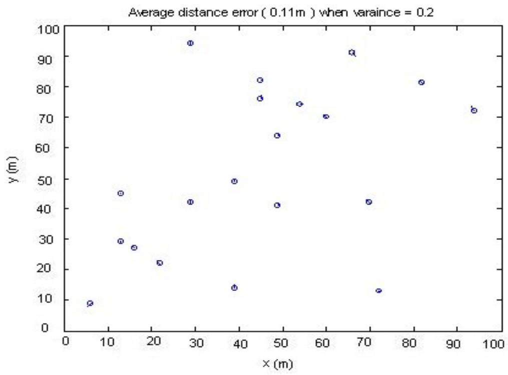

Fig. 4. Average distance error with variance of 0.2

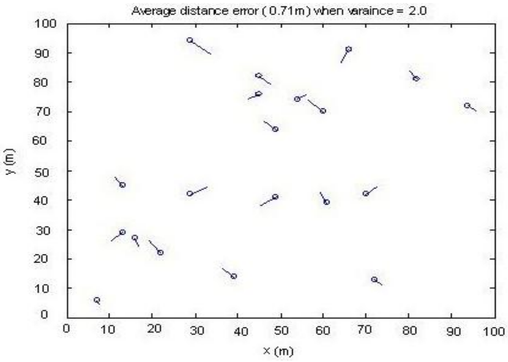

Fig. 5. Average distance error with variance of 2.0

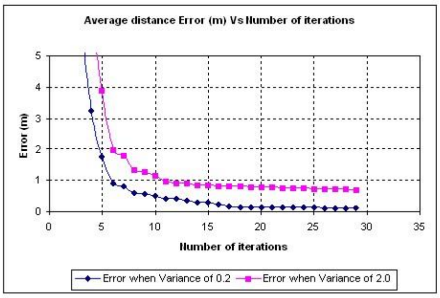

Fig. 6. Average distance error Vs number of iteration

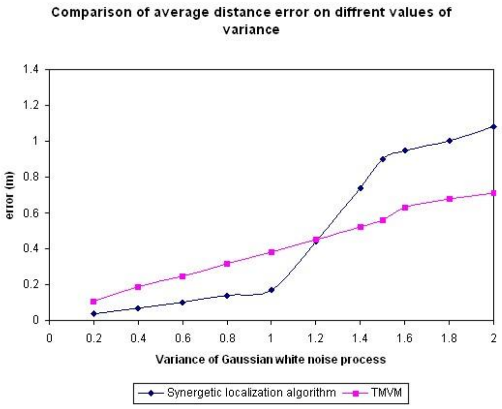

Fig. 7. Comparison at diff values of variance

V. Conclusion

Efficiency and usefulness of WSN operation mainly depends on the node location. Sensors can generally be placed in an area of interest either deterministically or randomly. The choice of the deployment scheme depends highly on the type of sensors, application and environment that the sensors will operate in. In this paper we addressed one of the crucial issues namely node localization by using the Token Management Vector Manipulation (TMVM). This scheme gives more accuracy in terms of average distance error necessary for precise node localization. We get the close enough results after a number of refinement steps. This method behaves and provides the better performance on higher values of variance. This novel approach further strengthens its existence by dropping the dependency of central synchronized time reference necessary for node localization estimation.

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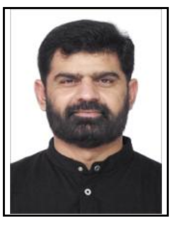

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