Predictive activation for localization using minimal data-fusion in MANETs

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Abstract—We propose a unique localization algorithm for MANETs: the mobile infrastructure-less networks with support of static underlying wireless sensor network nodes. The algorithm has been designed with two stages for localizing the MANET. The first stage is the *naive activation stage* which acts as the bootstrap for the *prediction stage*. The predictive minimal energy consumption algorithm incorporates the information from the measured TOA (Time Of Arrival) to locate the mobile nodes. The experimental results and comparative analysis show that our system provides accurate localization of linearly moving MANET's using low power consumption of the underlying wireless sensor networks.

I. INTRODUCTION

Wireless sensor network are low powered, low cost sensor nodes which are capable of performing multiple functions often in adverse stochastic environment. They are small in size but still capable of communicating via radio link in short distances. Major components of such nodes include sensing components, data processing components and communicating components. A general configuration of sensor network includes a large number of sensor nodes which are deployed densely in the area where a physical phenomenon has to be measured.

Most of the critical wireless sensor network application that include operations like surveillance and tracking heavily rely upon the position of the corresponding sensor nodes. In many wireless applications localization is a critical process in MANETs. The devices need to know their absolute location or their relative location in reference to the rest of network elements/neighbors. Localization is a key issue as all of the routing decisions are ultimately based on the location of the nodes within the network. The most important characteristic of MANET is the dynamic topology which is a direct consequence of the mobility of the nodes, hence the MANET localization needs to be both accurate and robust. Furthermore, issues such as energy constraints and mobility make the localization process even more challenging.

Location tracking mechanisms are classified into various categories depending upon the measurement techniques employed. In MANETs, generally four types of systems are used for localization [5]. The performance of these systems depend upon the environment affecting the propagation characteristics which in turn effects the transmission throughput of the system. The four systems include

- lateration
- angulation
- nearest cell
- location patterning

The *nearest cell* (cell of origin) technique is cost effective and widely used in WLAN's and other cellular based RF system. They don't require much complicated algorithms and the localization performance is fast. Its not cost effective in a network where nodes have limited energy and are operating under low range of communication characteristics. In *location patterning* system, the initial phase is to calibrate the database using unique signatures of RF devices with assumptions that no two floors, buildings etc can have same propagation characteristics. In the operational phase, the location patterning uses machine learning algorithms to train the system on those calibrated reading and may also incorporate the lateration and angulation techniques. The *lateration* (distance-based) techniques require relative or absolute time measurements from different devices or may also use the RSSI (received signal strength) indicators to perform localization. Similarly, *Angulation* (angle based) techniques locate the mobile node by determining the angle of incident at which signals arrive at the receiving end of the sensor node.

Major contribution of this paper is a robust localization technique which is more energy efficient in MANET and WSNs. The basic working of our proposed system includes an intelligent linear predictive algorithm within the framework that controls duty cycles of the nodes that need to be active at a particular time for localization.

We obtain results of localization quality and energy efficiency for naive network operation. These results define our base line and we compare these results with textitPredictive Activation. We show that predictive activation with a good prediction algorithm can be a very good energy saving strategy which can result in marked difference in energy consumption with negligible difference in quality of tracking.

The rest of the paper is organized as follows: The related work in the domain of localization using wireless sensor network with time of arrival approach is discussed in Section II. Section III discusses in detail the least squares method deployed using TOA for localization. Details of simulations are given in Section IV and results obtained are discussed in Section V. Finally, we present our conclusion in Section VI.

II. RELATED WORK

Time Of Arrival (TOA) requires a minimum of two sensor nodes for calculating the location of the node. Generally there are three different approaches for measuring the time of arrival. The first one is the active process in which the time of emission is embedded in the data packet. The second approach is passive and is composed of the structure of communication signals, the emitter and its emitting time. The third approach requires the knowledge of structure of the signal but does not dependent upon the information of emitter and time of emission [12].

For localization in wireless sensor networks, some of the range based methods include the DV distance [1] ad-hoc positioning system [2]. The difference between different algorithms using “time of arrival” and “time difference of arrival” has been discussed in [11]. Another comparison between the earlier localization methods invoking both static and mobile networks using schemes such as multilateration is discussed in [4].

III. LOCALIZATION USING TIME OF ARRIVAL (TOA)

The localization problem can be formulated in terms of a graph network $G(V, E)$ where V is the subset of nodes consisting of both mobile and static nodes. The anchor nodes V_{gps} are the location aware nodes which are termed as beacons, such that $|V_{gps}| \leq |V|$. The objective of the localization is to find the mobile nodes: that is the non-anchor nodes $\{V\} - \{V_{gps}\}$ [6].

The basic phenomenon of the anchors *time of arrival* operation is to listen to all the communications of the non-anchor nodes (with assumption that the MANET and the Wireless Sensor Network operate on the same RF Channel) and also that whenever a signal is heard the controlling sensor prompts the node to respond to an initial signal. Total time is measured from the point when an initial signal is transmitted from the anchor node to the time when a response from non-anchor node is received by the anchor node. This time consist not only of the round trip time but also of the transmitting time, receiving time, and processing time on both the anchor and the non-anchor node. When these readings are subtracted from total time, it gives us the round trip time. Half of the *round trip time (RTT)* signifies the time signal takes to travel from sensor to MANET node. This time factor (when incorporated with speed of electromagnetic waves) gives the speed of light and corresponds to the distance between the sensor node to MANET node. Similar reading are taken by two other sensor nodes at the same time and data from three or more sensor nodes is passed on to control unit for fusion. Consider the example of localizing the MANET node as illustrated in the Figure 1.

In Figure 1 an unknown MANET m sends signals to other stationary nodes in the sensor network $s_i \in SN$. Mathematically, the time of arrival can be expressed as;

$$\begin{aligned} SN &= \{s_1, s_2, \dots, s_n\} \\ \text{Time of Arrival} &= t_e + \|\mathbf{x} - \mathbf{s}_i\| / c \end{aligned} \quad (1)$$

Fig. 1. Localization using time of arrival (TOA)

where c is the speed of light. The time of arrival depends upon the emitting time t_e and the time required for the signal to propagate the distance from the manet to the sensor node s_i .

The amount of time required by packets to arrive at the receiving sensors s_1, s_2 and s_3 are measured as t_1, t_2 and t_3 . In Equation 1 using the propagation velocity (c), the mobile distance from each of these sensor nodes can be calculated. As seen in Figure 1, each evaluated distance constructs a region of interest (spheres) around the respective sensor node. The accuracy of localization is affected by various environmental characteristics such as noise, therefore the spheres will not necessarily intersect at the single point. We use least square algorithm [10] for performing localization using TOA. In the above case as shown in Figure 1 the equation for region of interest is given as;

$$(m_x - x_i)^2 + (m_y - y_i)^2 + (m_z - z_i)^2 = d_i^2 \quad (2)$$

where d_i is the distance between reference node and mobile node.

$$2 \begin{pmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \end{pmatrix} \begin{pmatrix} m_x \\ m_y \\ m_z \end{pmatrix} = \begin{pmatrix} d_1^2 - d_2^2 + c_2 + c_1 \\ d_1^2 - d_3^2 + c_3 + c_1 \end{pmatrix}$$

where $c_i = x_1^2 + x_2^2 + x_3^2$ and $i = 1, 2, 3$. Therefore, the matrix can be written as;

$$\begin{aligned} 2B\mathbf{m} &= \mathbf{c} \\ \mathbf{m} &= \frac{1}{2}(B^T B)^{-1} B^T \mathbf{c} \end{aligned} \quad (3)$$

where $\mathbf{m} = [m_x \ m_y \ m_z]^T$

In our work we use the active approach of measuring the time of arrival (TOA) which further assists us with localizing the MANET. Our linear predictive framework provides an energy cost effective solution for localizing the mobile nodes in linear motion. The predictions help us to minimize the

energy consumption by controlling the duty cycle of the sensor nodes in the network.

IV. SIMULATION SETUP

A. Mica node energy profiling

For energy profiling of our system, we consider our sensor network to be based on small, low-power sensors such as the Mica2 sensor, developed by UC Berkeley. Basic feature of Mica2 sensor includes 38.4kbps transmission capability with transmission range of 300 meters. Also it has a 7.3MHz ATmega128L processor to carry out the basic tasks. This processor comes with 128KB of code memory and 512KB EEPROM. It also has 4KB of data memory. It is a very small device physically with measures as $5.7\text{cm} \times 3.1\text{cm} \times 1.8\text{cm}$. For power, it generally uses 2 AA batteries. Expected lifetime can vary a lot depending on the applications that it is used for and application duty cycle and can range from days to months [8], [7].

Operation	Time	Current
Radio initialization	350 μs	6 mA
Turning on the radio	1.5 ms	1 mA
Switch to RX/TX	250 μs	15 mA
Time to sample radio	350 μs	15 mA
Evaluate radio sample	100 μs	6 mA
To receive one byte	416 μs	15 mA
To transmit one byte	416 μs	20 mA
Sample sensors	1.1s	20 mA
Standby		216 μA
Power-save		110 μA

TABLE I
MEASURED CURRENT CONSUMPTION FOR MICA2 MODEL [3]

For the modeling of our system and for simulation purposes we used the platform of MATLAB. The sensor nodes were deployed randomly using uniform distribution over an area of 100 x 100 meters. This range is easily covered by the omni-directional operating mica2 node.

B. The basic setup for localization using multilateration TOA)

For the basic setup, we consider ideal environmental conditions: a noise free environment and an active state of all the sensor nodes during the localization process. The number of deployed static nodes are 121 and the number of mobile nodes are five. The sensor nodes are deployed in the grid formation using uniform distribution as shown in Figure 2.

Figure 2 shows the output of triangulation using TOA in ideal conditions. The yellow dots represent the sensor nodes and the red dots are the MANET nodes which can be at any random position in the 100 x 100m deployment area. Each of the subfigure in Figure 2 is a snapshot of the network at a particular time and as we move within Figure 2 from Figure 2(a) to Figure 2(b) there is a movement of the MANET nodes with a particular velocity in a random direction.

Within each of the subfigure Figure 2(a) to Figure 2(b), there are duplicated network snapshots. The top one is the actual MANET positions and the lower ones are the localized positions of the MANET. Also upper part of each subfigure

Fig. 2. Baseline simulation results using ideal conditions for Multilateration TOA

shows some blue dots, which are connected via dotted lines to the MANET. These blue dots are the ordinary sensors and the only difference is that they have detected a node in their vicinity and are activated (and are thus highlighted). For a particular mobile node, the detecting sensors maintain a link via the dotted lines, and thus for this particular mobile node these sensors measurements are used for TOA calculations.

C. Naive activation simulations for localization using multilateration TOA)

For the stochastic modeling of the system we by incorporate noise into the TOA readings as white gaussian noise with standard deviation σ_{TOA}^2 . Therefore, *time of arrival* is given as

$$\text{Time of arrival} = t_e + \| \mathbf{x} - \mathbf{s}_i \| / c + n, \quad n \sim \mathcal{N}(0, \sigma_{TOA}^2) \quad (4)$$

For this scenario the sensor nodes are deployed using normal distribution as shown in Figure 3. For naive activation, all of the nodes in the underlying sensor network are active and are sensing the MANET nodes at every instant. The Figure 3 are taken as screenshots from the simulation in which this naive activation strategy has been adapted. There are 500 sensors and 5 MANET nodes in the system, both of which

are randomly distributed. From Figure 3(a) to Figure 3(c), the nodes are moving with a particular velocity and are localized at each instant.

Fig. 3. Naive simulation results using multilateration TDOA

The naive activation acts as a bootstrap process for our linear predictive algorithm as discussed in Section IV-D. We can observe from Figure 3(a) to Figure 3(c) that during the process of localization all the sensor nodes are active and those in vicinity of each MANET contribute to the multilateration TOA. The nodes effecting the TOA calculations are highlighted in blue color and the localized MANET are highlighted red in the lower part of each of the subfigure.

D. Predictive activation simulations for localization

Our proposed scheme using the predictive activation is a two-fold process. During the initial phase the sensor nodes localize the mobile node up to two next locations: that is the first step is exactly the same as naive activation, in the sense that all the sensors are active and localize all the mobile nodes upto their two initial locations. After the network obtains two positions for each of the mobile nodes, the whole system switches to the next phase, i.e., *Predictive Activation mode*. Thus, the Naive Activation process serves as a bootstrap process (see Figure 4).

Fig. 4. Bootstrap Process for Predictive Activation

In the second step, once the system has switched to predictive activation mode, the mobile nodes' next position is calculated using only one node. In our proposed system all other nodes go into standby mode while one node in the radius keeps track of mobile node. Now if we see Figure 5, the nodes have moved with a particular velocity in reference to Figure 4. If we look closely at nodes 2 and 3, they move from their first positions, as shown by the green arrows in Figure 4. Now at this point we have the two positions of each node and we switch to the Predictive Activation as shown in Figure 5.

In Figure 5 it can be seen that all the nodes are in the standby modes except the ones which were in the vicinity of the predicted position (see Figure 4, Figure 5). Now if we again see, nodes 2 and 3, they were moving towards right with a velocity, and thus the sensors towards the right were activated. In Figure 5, the tail end of the first light green arrow shows the initial position of the node and the tail end of the dark green arrow shows the position after the movement. By looking at these positions, it is fairly easy to predict the next position in the same direction.

If the process continues, our simplest prediction algorithm would predict that these two nodes would probably move again towards the right with the same velocity and thus the nodes at the right end of the system are activated.

Fig. 5. First Predictive Activation Result

V. RESULTS AND PERFORMANCE ANALYSIS

Power consumption comparison is done for both Naive & Predictive activation with increasing number of nodes to find the boundary case as to where predictive activation becomes either equal or more expensive than the naive activation.

We see from the results (from Figure 6 to Figure 8) that as the number of mobile nodes is increased (keeping the same number of static sensors) the energy expenditure graph for the two strategies closes in until to a point where we have 100 MANETs.

Fig. 6. Energy efficiency comparison between naive and predictive activation (10 mobile node and 500 static sensors nodes)

Fig. 7. Energy efficiency comparison between naive and predictive activation (20 mobile node and 500 static sensors nodes)

Fig. 8. Energy efficiency comparison between naive and predictive activation (40 mobile node and 500 static sensors nodes)

A. Comparative Analysis with GPS localization system

As the MANET nodes are normally small devices with limited battery power, so we had to choose a GPS receiver which can easily fit along one of these nodes and in energy efficient. One of the GPS receivers which fitted into these characteristics was the Copernicus GPS Receiver. The characteristics from its datasheet [13] define it as a thumbnail sized GPS Receiver which is advisable for small handheld battery powered applications. This GPS receiver consumes typically 93.9mW at full power with continuous tracking.

We used the power specification [9] to calculate the en-

Fig. 9. Comparative analysis of energy with increasing number of nodes (naive vs predictive activation)

Fig. 10. Energy consumption comparative analysis using WSN (naive and predictive activation) vs GPS localization

energy expenditure with increasing number of MANET nodes. Figure 9 shows the comparison between the two systems. Although it becomes very clear from the steep GPS energy curve that the sensor network justifies its energy efficiency but an important fact suffices that when we have less than 5 MANET nodes, using GPS receivers for localization might be a better approach both in terms of energy (its evident from Figure 10) and also in terms of cost.

VI. CONCLUSION

Wireless Sensor Network has been used successfully in many applications for tracking mobile objects. Localization

for MANET is a very decisive operation, as all the rest of the communication between the nodes is relying on this information. Current technologies like GPS do offer a very reliable localization solution for the MANET but at a high cost of energy consumption, and this energy is scarce in wireless sensor networks. This paper provides a network assisted MANET localization system. The sensors network helps in the formation of a tracking system that localizes the MANET's during their detour through the network.

In a wireless sensor network, power consumption is of paramount importance. So our aim was to show that these low cost and low power consuming devices can be effectively used in MANET localization using a well designed predictive algorithm. By using simple data fusion techniques like TOA, which can easily be processed by the sensors, we showed that these achieve a high quality of localization, and this becomes especially important in scenarios where other localization system like GPS cannot be employed. We integrated a Predictive Movement algorithm for the MANET nodes in our localization operation, and our results showed that we can achieve a magnitude of better performance in comparison to other activations and with mobile nodes embedded with GPS systems.

REFERENCES

- [1] A. Boukerche, H. Oliveira, E. Nakamura, and A. Loureiro. Localization systems for wireless sensor networks. *wireless Communications, IEEE*, 14(6):6–12, 2007.
- [2] A. Boukerche, H. Oliveira, E. Nakamura, and A. Loureiro. Vehicular ad hoc networks: A new challenge for localization-based systems. *Computer Communications*, 31(12):2838–2849, 2008.
- [3] M. Calle and J. Kabara. Measuring energy consumption in wireless sensor networks using gps. In *Personal, Indoor and Mobile Radio Communications, 2006 IEEE 17th International Symposium on*, pages 1–5. IEEE, 2006.
- [4] W. Gao, G. Kamath, K. Veeramachaneni, and L. Osadciw. A particle swarm optimization based multilateration algorithm for uwb sensor network. In *Electrical and Computer Engineering, 2009. CCECE'09. Canadian Conference on*, pages 950–953. IEEE, 2009.
- [5] I. Guvenc and C. Chong. A survey on toa based wireless localization and nlos mitigation techniques. *Communications Surveys & Tutorials, IEEE*, 11(3):107–124, 2009.
- [6] R. Huang and G. Záruha. Monte carlo localization of wireless sensor networks with a single mobile beacon. *Wireless Networks*, 15(8):978–990, 2009.
- [7] S. A. Khan, H. Aziz, S. Maqsood, and S. Faisal. Clustered home area network: A beacon enabled ieee 802.15. 4 approach. In *Emerging Technologies, 2008. ICET 2008. 4th International Conference on*, pages 193–198. IEEE, 2008.
- [8] S. A. Khan and F. A. Khan. Performance analysis of a zigbee beacon enabled cluster tree network. In *Electrical Engineering, 2009. ICEE'09. Third International Conference on*, pages 1–6. IEEE, 2009.
- [9] O. Landsiedel, K. Wehrle, and S. Götz. Accurate prediction of power consumption in sensor networks. In *Proc. of the Second Workshop on Embedded Networked Sensors*. Citeseer, 2005.
- [10] G. Shen, R. Zetik, and R. Thoma. Performance comparison of toa and tdoa based location estimation algorithms in los environment. In *Positioning, Navigation and Communication, 2008. WPNC 2008. 5th Workshop on*, pages 71–78. Ieee, 2008.
- [11] D. Shin and T. Sung. Comparisons of error characteristics between toa and tdoa positioning. *Aerospace and Electronic Systems, IEEE Transactions on*, 38(1):307–311, 2002.
- [12] C. Steffes, R. Kaune, and S. Rau. Determining times of arrival of transponder signals in a sensor network using gps time synchronization. In *Society for computer science (Annual Meeting)*. INFORMATIK, 2011.
- [13] U. Trimble Navigation Limited, CA. Copernicus gps receiver datasheet.