Locating Emergency Responders in Disaster Area Using Wireless Sensor Network

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Abstract. A worldwide increase in number of natural hazards is causing heavy loss of human life and infrastructure. An effective disaster management system is required to reduce the impacts of natural hazards on common life. The first hand responders play a major role in effective and efficient disaster management. Locating and tracking the first hand responders are necessary to organize and manage real-time delivery of medical and food supplies for disaster hit people. This requires effective communication and information processing between various groups of emergency responders in harsh and remote environments. Locating, tracking, and communicating with emergency responders can be achieved by devising a body sensor system for the emergency responders. In phase 1 of this research work, we have developed an enhanced trilateration algorithm for static and mobile wireless sensor nodes. This work discusses an algorithm and its implementation for localization of emergency responders in a disaster hit area. The indoor and outdoor experimentation results are also presented.

Keywords: Wireless sensor networks, Localization, Disaster area, Emergency Responders.

1 Introduction

The advent of Wireless Sensor Network (WSN) has marked an era in the sensing and monitoring field. The technology has made possible to monitor otherwise remote and inaccessible areas such as active volcanoes, avalanches and so on. WSN is widely being used in various areas, such as, environmental monitoring, medical care, and disaster prevention and mitigation. This paper details yet another application of WSN in the post disaster scenario and comes up with an algorithm for localization.

When a disaster has struck an area, it is important to act immediately to rescue and give first line help in the form of medical aid, food and so on to the people in that area. Thus the role of first line emergency responders becomes a vital part of the post disaster scenario. In a disaster scenario, locating and tracking the first hand responders is essential to organize and manage real-time delivery of medicine and food to disaster hit people. This requires effective communication and information

P. Sénac, M. Ott, and A. Seneviratne (Eds.): ICWCA 2011, LNICST 72, pp. 1–10, 2012.

processing between various groups of emergency responders in harsh and remote environments.

Locating, tracking, and communicating with emergency responders can be achieved by devising a body sensor system for the emergency responders. This project aims to locate the emergency responders in different locations. In a disaster hit area whole communication networks may get damaged and the communication between responders is not possible. So localization of responders is very difficult with other technologies other than WSN.

This research project is an application of Wireless Sensor Network in disaster management. The paper addresses the development of an algorithm that can perform precise localization and tracking of the responders with indirect line-of-sight. Responders will be randomly located in the area so an ad-hoc network will be formed between the sensor nodes. The following sections briefs the role of responders and the location tracking algorithms used.

2 Related Work

A lot of indoor localization algorithm has been developed using Received Signal Strength Indicator (RSSI). A method for distance measurement using RSSI has been discussed in [7]. The accuracy of RSSI method can be very much influenced by multi-path, fading, non-line of sight (NLoS) conditions and other sources of interference [11]. In a disaster prone area these effects are more pronounced and as such RSSI method cannot be used in our study. Coordinate estimation method of localization using the principle of GPS has been suggested in [1]. Since the GPS modules could be costly, it has been discarded for our study.

In this project work we focused on a category of localization methods which estimate coordinate based on distance measurement. Instead of considering signal strength, time of arrival of each packet is considered which increases the accuracy of location. The algorithm is based on the Time Difference of Arrival (TDOA) method the accuracy of which is much higher when compared to the RSSI and we also present optimization methods to decrease the error of estimating the location using TDOA.

3 System Architecture

As suggested in [13], creating a common operating picture for all responders in an emergency situation is essential to take appropriate action in the disaster hit area and the safety of the responders. Protective suits used by the responders to be safe from hazardous materials create unique problems for response teams because their protective suits often make it difficult to read instrument screens, and if subject-matter experts aren't on scene, responders must find ways to relay the information back to them.

The aim is to develop an algorithm that can perform precise localization of sensor nodes with indirect line-of-sight by utilizing location information and distance measurements over multiple hops. To achieve this goal, nodes use their ranging sensors to measure distance to their neighbors and share their measurement and location information with their neighbors to collectively estimate their locations. Multilateration is a suitable method for localization in outdoor navigation. As described in [10], when the receiver sends the signal to locate itself, it finds out at least three nearest anchor nodes which know their positions. The receiver then calculates the distance between one satellite and the receiver. If the distance is "X", then it draws an imaginary sphere with "X" as the radius from the receiver to the satellite and also the node as the centre [13]. The same process is repeated for the next two nodes. Thus three spheres are drawn with just two possible positions. Out of these one point will be in space and the other will be the location of the receiver. Thus the exact position of the receiver is found out. Usually the receivers try to locate more than four satellites so as to increase the accuracy of the location. The Earth is made as the fourth sphere so that two points converge with the imaginary spheres of the other three satellites. This method is commonly called 3-D Trilateration method. Here in this paper we have tried to implement a modified version of the above mentioned method.

Fig: 1 shows the entire architecture of the system. The entire wireless sensor network is formed by required number of MicaZ mote. MicaZ mote includes the program for Localization, tracking and monitoring the position of unknown node. Also it includes the program for time synchronization.

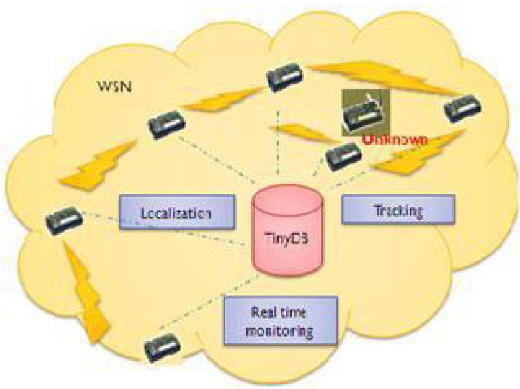

Fig. 1. System architecture

The TinyDB plays an important role here. Tiny database extract query information from a network of motes. TinyDB provides a simple Java API for writing PC applications that query and extract data from the network; it also comes with a simple graphical query-builder and result display that uses the API.

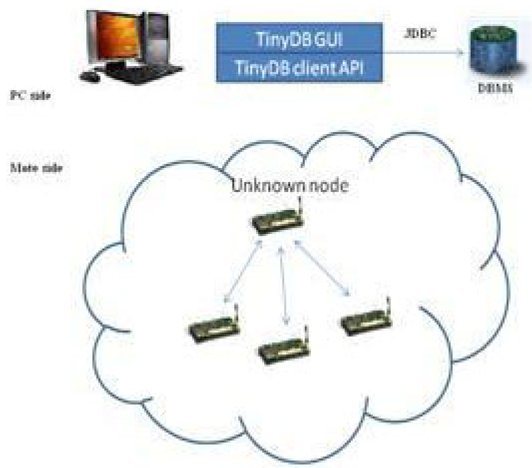

Fig. 2. TinyDB Architecture

4 Algorithm Design

The algorithm used here is a trilateration algorithm, and is implemented using TinyOS in the NesC language. This is the first step for responder's localization.

Localization algorithm

Trilateration is the method of using relative position of the nearby objects to calculate the exact location of the object of interest. Instead of using a known distance and an angle measurement as in normal triangulation methods, we used three known distances to perform the calculation. Here we use a GPS receiver to find out the coordinate points of three nodes.

The algorithm works as follows:

Step1: Set N numbers of nodes in the field and synchronize all the nodes.

Step2: Each of them continuously sent RF signals with packet containing a field for time stamp, i.e. whenever RF signal is sent by an unknown node, unknown node add the time of sending RF signal to the packet it broadcasts.

Step3: In addition there are B beacon nodes.

Step4: Each node n_i,1<=i<=N estimate its distance d_{ij} from each beacon $_j$, 1<=j<=M where M is the no: of beacon nodes in its transmission range(assume M as 3 nodes)

Step5: Each beacon node will calculate the distance from node Distance=speed × time

Step6: Making this distance as radius each beacon create a circle.

Step7: The intersecting point of these 3 circles will be the position of unknown node.

Step8: Go to Step5 if the unknown node is moving and track its position at regular instance of time.

Step9: Stop

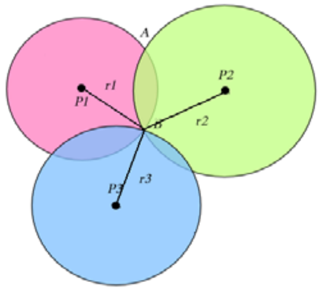

Fig. 3. Graphical Representation of Trilateration

For example (see Figure 2), point B is where the object of interest is located. The distances to the nearby objects *P1* and *P2* are known. From geometry, it can be concluded that only two possible locations, A and B, can satisfy the criteria. To avoid ambiguity, the distance of the third nearby object is introduced and now there is only one point B that could possibly exist [14].

If we apply the concept of 2-D trilateration to a GPS application which exists in 3-D space, the circles in Figure 2 become spheres.

In order for the receiver to calculate the distance from B, B send RF signals with time stamping. We know the speed of RF signal as 3x10^8m/s and we know the time of sending from the time stamping value. From this distance can be measured using equation 1.

$$\text{Distance}=\text{speed} \times \text{time} \tag{1}$$

Using this calculated distance as radius and p_1 as center, draw a circle. Repeat the same steps for p_2 and p_3. We will get three circles. Solving the three equations of the circle we get one intersecting point.

Consider three circles with positions as (x_1,y_1, z_1); (x_2,y_2, z_2) (x_3,y_3, z_3);

$$X = (4k_1+3k_2-2k_1)/6; \tag{2}$$

$$Y = (2k_1+3k_2-k_3)/6; \tag{3}$$

$$Z = (k_1+k_2-k_3)/2 \tag{4}$$

X, Y, Z are the co-ordinates of unknown node.

5 Implementation

With the entire setup field testing is also find out. The readings from the mote is calculated from the outdoor and find out the readings and they are tabulated which is shown in the table.

Table 1. The reading got from the field testing

Range(LOS)	Without delay	22m
	With delay	41m
Range(NLOS)	Obstacle human	3.5m
	Obstacle Wall	15m
Range(Environment with Vegetation)		30m

The setup includes one unknown node and three beacon nodes. The beacon nodes calculate the distance of the unknown node from them and calculate the intersection point of the three circles formed by calculated distances. The actual distance, the time stamp and speed of the wave is tabulated in table1.

Table 2. Distance Information

Receiver Nodes	Value of time stamp(s)	RF signal speed(m/s)	Radius' distance(m)
p_1	4	$3x10^8$	$12x10^8$
P_2	6	$3x10^8$	$18x10^8$
P_3	2	$3x10^8$	$6x10^8$
P_4	10	$3x10^8$	$30x10^8$
P_5	40	$3x10^8$	$120x10^8$
P_6	8	$3x10^8$	$24x10^8$
P_7	2	$3x10^8$	$6x10^8$
P_8	4	$3x10^8$	$12x10^8$

The beacon node uses the time stamp to calculate the time of arrival. Knowing the speed of the RF waves the distance could be computed as discussed in section 3.1.1. This distance is calculated in beacon node which localizes the unknown node. The data from beacon node is viewed using XSniffer (figure 4).

A second method was tried out where the unknown node itself will act as a sink node. The beacon nodes calculate the distance and send it to the unknown node which does the localization calculations. This will avoid the use of more number of nodes. It was found that the accuracy of the calculation increases. The XSniffer output is as shown in figure 5.

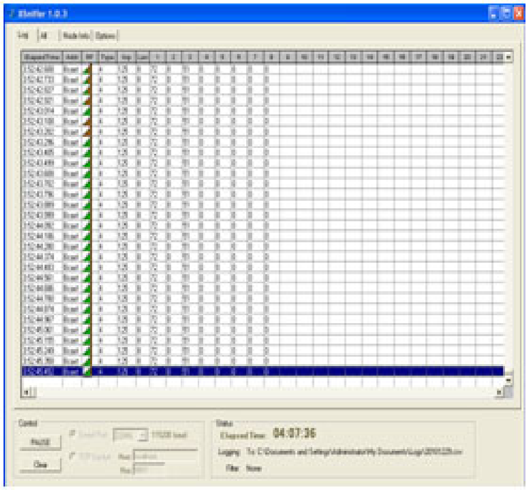

Fig. 4. Distance measurement as viewed using XSniffer

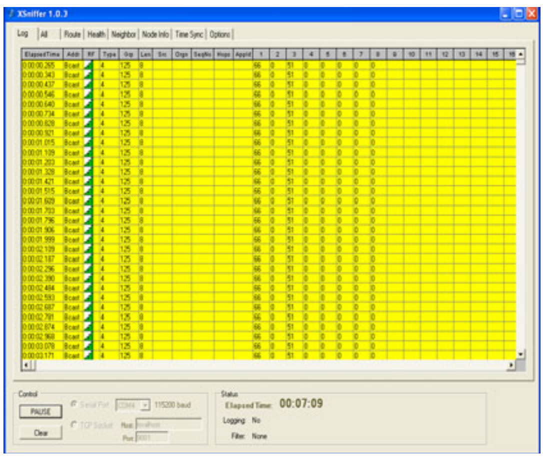

Fig. 5. Distance measurement

While experimenting, the actual distance was also calculated to find the percentage of the error. Figure 4 shows the error of the calculated distance from the actual values. The error occurs due to the dependency of distance calculations based on the time of arrival. If there is a delay introduced due to interference then there will be an error introduced.

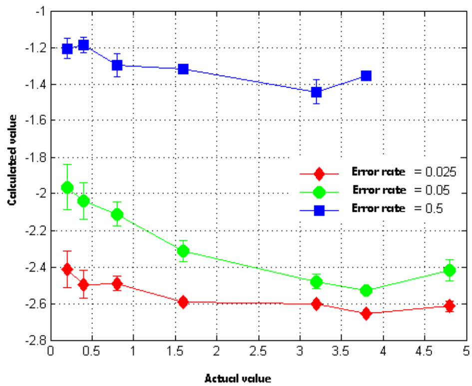

Fig. 6. Error Rate

Actual distance is measured using the measuring instruments. Using the micaz mote we calculated the distance and viewed the result using XSniffer. We did an analysis on actual distance and calculated distance which has been plotted in Figure 6 and came up with following three conclusions:

1. There are small differences in actual value and calculated values.
2. Error rate always remains in the range of 0.025%-0.5%.
3. The error rate is minimum when the unknown node and the beacon node are closer. When they are far from each other, error rate increases due to interference and delay.

Multilateration with a number of beacon nodes is a good method to reduce error in calculations. Multilateration, also known as hyperbolic positioning, is the process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from that object to three or more receivers. It also refers to the case of locating a receiver by measuring the TDOA of a signal transmitted from three or more synchronized transmitters. In practice, errors in the measurement of the time of arrival of pulses means that enhanced accuracy can be obtained with more than four receivers. In general, N receivers provide $N - 1$ hyperboloids. When there are $N > 4$ receivers, the $N - 1$ hyperboloids should, assuming a perfect model and measurements, intersect on a single point. In reality, the surfaces rarely intersect, because of various errors. In this case, the location problem can be posed as an optimization problem and solved using, for example, least squares method or an extended Kalman filter. Additionally, the TDOA of multiple transmitted pulses from the emitter can be averaged to improve accuracy.

6 Advantages

Main advantage of the system is the use of distance measurements when compared to RSSI method which is based on the measurement of signal strength. The signal strength fluctuates every time as such accurate localization of the object in the plane may not be possible. In the above said algorithm the relationship between speed and time is used for measuring the distance. The time Stamping interface is used to keep track of the time. By knowing the speed of RF signal it is possible to calculate the distance.

7 Conclusion and Future Work

This project tries to develop a proper localization of first responders. Algorithm is implemented and tested; trilateration algorithm is used for localization and extracts the value of time from Time stamping. From this distance is measured. So there is no ranging problem. When we measure distance using strength of radio signal there is a problem like reducing signal strength due to different factors. Took the relationship between time and speed and calculated the distance. This method helps to locate the real coordinate of object in the plane.

This work could be extended by implementing the algorithm in a tag which has the capability to perform the functions of GPS receiver. So that exact location can be identified with great accuracy in an outdoor environment.

The developed algorithm could be extended to Mulilateration with minor changes. When the number of nodes increases the accuracy increases. Also the unknown node can act as a sink node and reduce the complexity of the network.

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