International Journal of Computer and Information Technology (ISSN: 2279 – 0764)
Volume 07– Issue 05, September 2018

Location Estimation of Unknown Nodes using RSSI Measurement in Wireless Sensor Networks

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Abstract---- **In wireless sensor networks (WSN), sensor node localization is an important issue because of the dynamic nature of sensor deployment. The main idea of this work is to estimate the location of the unknown node(s) using the received signal strength indicator (RSSI) measurements and the positions of a set of beacons. The mobile node sends message(s) at intervals of time and the base station will calculate the RSSI and estimates approximately the distance based on the signal strength. A feasibility study is used to show the positioning accuracy of the designed method with stationery and mobile sensor nodes. For RSSI based methods, large collection of training RSSI samples is needed to calibrate the positioning system and to achieve a high positioning quality. The quality of these samples is directly related to the position of sensors in wireless sensor networks. The implementation, testing and calculation of the distance using the RSSI values were successfully performed and the results were recorded. Though the work was successfully performed and the location of a mobile node was estimated but it was not accurate. The results show the relation between the RSSI measurements and the propagation distance and these are approximately equal for practical and theoretical measurements.**

Keywords* – *Wireless Sensor Network; Localization; RSSI;

I. INTRODUCTION

In wireless sensor networks (WSN) the manufacturing of small and low cost sensors became technically and economically more feasible. The function of sensors is in the measurement of ambient conditions related to the environment surrounding the sensor and transforms them into electric signals [1-4]. Through this process some properties of object located and events happening in the surrounding can be revealed. WSN contain hundreds to thousands of sensor nodes. These nodes have the capability to communicate with each other, or to the external base-station (BS) directly. In order to sense a vast geographical area with a great accuracy there should be a large number of sensor nodes [3]. The two major challenging issues include: the location tracking accuracy of the mobile node using received signal strength in wireless sensor networks, and a better method for tracking mobile nodes when compared with the latest and most sophisticated technology like global positioning system (GPS) [5].

The main components of sensor node hardware are the: Controller for processing all the appropriate data that is competent to execute the program code; Memory for storing programming codes and useful data; Communication devices that send/receive the data in wireless sensor networks; Sensors that can control or observe the physical parameters of the environment; and Power supply that provides the energy to the nodes' power supply. This power supply is necessary, and is supplied in the form of double-A batteries.

Basically, the location tracking system consists of two separate hardware components that include the measuring unit that carries the major part of the system intelligence and the signal transmitter /receiver [6-7]. On the whole, the sensor nodes consist of sensing, transmitting/receiving, processing, position finding system and the power unit. Sensor nodes are scattered in sensor field, it is the particular place where the sensors are deployed [8-10]. They communicate between themselves or with a base station in order to produce high quality information about the physical environment. Each of these distributed sensors has the ability to collect and route the data.

A base station allows the collection of sensor network data onto the personal computer. Irrespective of any MICAZ mode can act as a base station when connected to computer interface or to any gateway board. A serial/universal serial bus (USB) interface supplied with MIB510 or MIB520 can be used for programming and data communications in WSN.

Mica2 sensor nodes run TinyOS, an event-driven operating system for networked applications in wireless embedded systems. The memory footprint of TinyOS is small, with the core components requiring only 400 bytes of data and instruction memory. TinyOS supports other hardware platforms as well. [5]. Each of these elements has to be operated by balancing the trade-off between as small and power consumption as possible on the one side and the need to fulfil their tasks on the other side. In even more moderate visions, the nodes are sometimes claimed to have to be decreased to the size of grains of dust. In more sensible applications, the size of a node is not so important; rather, convenience, simple power supply, and cost are more important.

This system is gainfully useful in many military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions such as temperature, movement, sound, light, or the presence of certain objects, inventory control, and disaster management [7]. The deployment of sensor nodes is very fast in these applications. It can also be used in a range of applications wherever it is necessary to monitor an environment or the subjects within, such as habitat monitoring, healthcare applications, home automation, and traffic control [8]. Other areas may include pipeline monitoring, battlefield surveillance [11], industrial process control, environmental monitoring and control, national defense and military affairs [4]

The rest of this paper is organized as follows. In Section II, the previous works by other authors is presented. Section III will give the different hardware and software tools for this work. Section IV will dwell on the different experiments conducted and their Results. Section V provides Discussion and Evaluation while Conclusions are presented in Section VI.

II. PREVIOUS WORK

Several researches of this kind have been conducted by different researchers to provide basic background for this work. In [4], Squarical Model, the referenced distances and already known APs location can be used to calculate the location of mobile nodes. With the relation between RSSI levels and reference distances known, the distance between a mobile node and the reference nodes can be estimated by collecting the RSSI levels of packets transmitted by the target node and received at each reference node. Accordingly, from the result of this work, though using RSSI for tracking the location of mobile node in WSN provides less accurate initial estimate for distance with slightly greater computational overhead, it is proven to be cheap, has low-overhead in terms of hardware costs, better localization error, less storage and communication overhead when compared with others. [11] has also proposed a Fuzzy logic-based multilateration scheme localization (FLMSL) for estimating the position of the sensor nodes that is randomly deployed over a 1000 * 1000 m^2 sensor area. The FLMSL operate by calculating the Received Signal Strength of the signal send from the sensor node to the sink node, define the fuzzy input and output linguistic variables after which the Fuzzy Rule is formed. Fuzzification and defuzzification is carried out. The Jacobi equation may now be used to find the fuzzified location of nodes (x, y) with the help of Dk value and the value of X = {x, y} obtained is converged obtain the location of the sensor node. The result shows that this method (FLMSL) enhances better localization accuracy by minimizing the positional errors while reducing energy consumption and control overhead.

At the department of Computer Science and Information Engineering at National Chiao-Tung University, Taiwan, a narrative protocol based on the mobile agent concept was proposed. Here, once a new node is spotted, the mobile agent will begin to track the travelling path of the node. The node is mobile since it will choose the sensor closest to the object. This will be performing the tri-late-ration algorithm and estimates the coordinates of the node. The object is assumed to be moving with a constant speed of 1-3m/s and if the speed is increased to 5m/s then the sensors are not able to detect the moving object. [2].

Here, this paper will be based on the radio wave propagation to calculate the location of a node using the received signal strength. Their technique basically speaks about selecting a set of points and then based on the RF connectivity between these points; the transmitting sensors are placed only on a subset of these points. Since the transmission range is limited, the outsider can receive the packets unique ID at any place in the region. In view of the fact that every node is served similar transmitters by which the location point can be estimated. There is no guarantee of coverage in this technique, when the readings are included in the graph.

III. SOFTWARE AND HARDWARE TOOLS

A. *Software Tool*

TINYOS is an open source operating system especially designed for wireless sensor networks. The important feature of the TINYOS is the component based architecture which allows it a speedy growth of innovation and implementation of sensor networks at the same time code size can be minimised according to the severe memory constraints in the network. [5]. TinyOS is a superfluous attraction; since wireless nodes can be kept running for a long time energetically scaling down power consumption when the processor is not in use. TinyOS is runtime environment for nesC programs running on Mote hardware. [6]. A typical declaration of sending mote is shown below in Figure 1

```
#include "RssiDemoMessages.h"

configuration SendingMoteAppC {
} implementation {
  components ActiveMessageC, MainC, LedsC;
  components new AMSenderC(AM_RSSIMSG) as RssiMsgSender;
  components new AMReceiverC(AM_RSSIMSG);
  components new TimerMilliC() as SendTimer;
  components CC2420PacketC;
  components SendingMoteC as App;

  App.Boot -> MainC;
  App.SendTimer -> SendTimer;
  App.Receive -> AMReceiverC;
  App.Leds -> LedsC;
  App.RssiMsgSend -> RssiMsgSender;
  App.RadioControl -> ActiveMessageC;
  App.CC2420Packet -> CC2420PacketC;

}
```

Figure 1: Declaration of sending mote

B. Hardware Tool

The Micaz Mote hardware component and its different specifications are shown in Figures 2 and 3, and Table 1

TABLE 1. MICAZ MOTE SPECIFICATION

Processor/ Radio Board	MPR2400CA	Remarks
Processor Performance	128k bytes	
Measurement Serial Flash	512k bytes	< 100,000 measurements
Configuration EEPROM	4 k bytes	
Serial Communication	UART	0 - 3V transmission lines
Analog to Digital Communication	10bit ADC	8 V, 0 – 3V input
Other Interfaces	Digital I/O, I2C, SPI	-
Current Draw	8 mA	Active mode
	< 15 µA	Sleep mode
RF Transceiver		
Frequency band	2400 to 2483.5 MHz	ISB band, programmable in 1MHz steps
Transmit (TX) Data Rate	250 kbps	-
RF Power	-24 to 0 dBm	-
Receive sensitivity	-90dBm(min), -94dbm (typical)	
Adjacent channel reduction	47 dBm	+5 MHz Channel Spacing
	38 dBm	-5 MHz Channel Spacing
Outdoor Range	75 to 100 m	1/2 wave dipole antenna, LoS
Indoor Range	20 to 30 m	1/2 wave dipole antenna
Current Draw	19.7 mA	Receive mode
	11 mA	TX, -10 dBm
	14 µA	TX, -5 dBm
	17.4 mA	TX, 0 dBm
	20 µA	Idle mode, voltage regular on
	1 µA	Sleep mode, voltage reg off
Battery	2×AA batteries	Attached pack
User Interface	3 LEDs	Red, green, and yellow

Figure 2: Micaz Mote

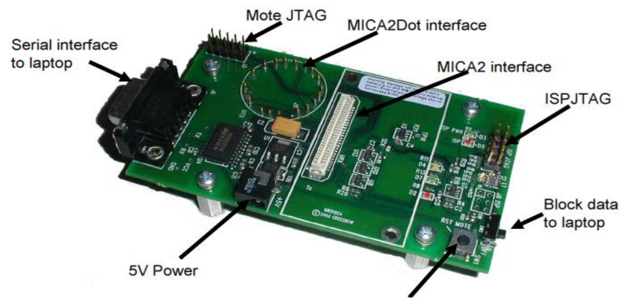


Figure 3: Micaz Mote Programming Board

IV. EXPERIMENTS AND RESULTS

This experiment was conducted using three sensor motes as stationery motes and one receiving motes. The position of the receiving and sending motes was kept constant, whereas the mobile position of mobile node has been changed for every experiment. All the Experiments are conducted in Pandon Basement and all the precautions have been taken such as, ensuring that the surface on which the experiments were conducted on was level and verifying that the motes operated in full battery power at the beginning and end of each experiment. It was also ensured that there were no obstacles in the communication path between the motes causing attenuation of the signals and that any electronic equipment that could potentially cause interference were not present in the vicinity of the experiment area. The power used for this experiment was 31. Figure 4 gives an idea about the arrangement of the sensor motes.

As the three nodes have a fixed position in the XY plane, the coordinates have been taken as (0, 0) for the node N1, (30, 0) for the node N2, and (15, 30) for the third node N3. In order to find the location of the mobile node MN, the coordinates given to it are (Xm, Ym). We now know the coordinates of all the three fixed nodes and the RSSI values from the mobile node; it will be easy to calculate the distance between the fixed node and the mobile node by using the Equation 1:

$$D = 10^{\left[\frac{A-RSSI}{K}\right]} \tag{1}$$

Using simple linear regression, the values of A and K was obtained by which the value of D is calculated from. Trilateration method can now be applied for finding the exact position of the mobile node. The value of (Xm, Ym) can be calculated as shown below in Equations 2 and 3.

$$Xm = \frac{r_1^2 - r_2^2 + A^2}{2A} \tag{2}$$

$$Ym = \mp\sqrt{r_1^2 - \left[\frac{r_1^2 - r_2^2 + A^2}{2A}\right]^2} \tag{3}$$

Where r_1, r_2 *and* r_3 are the respective distances between the mobile node and the stationary nodes.

TABLE 2. RSSI AND DISTANCE MEASUREMENTS

RSSI (dBm)	Measured r_1 (cm)	Distance r_2 (cm)	r_3 (cm)	Actual r'_1 (cm)	Distance r'_2 (cm)	r'_3 (cm)
-46, -45, -43	24.22	19.31	15.12	22	24.6	13.63
-46, -47, -43	24.01	26.18	13.49	22.36	28.28	11.18
-42, -45, -44	10.91	17.14	15.32	14.32	21.67	18.68
-43, -46, -45	12.91	24.62	19.24	17.6	28.4	16.14
-46, -44, -40	21.78	15.31	7.08	25.4	19	10.63
-46, -47, -40	20.67	28.52	6.98	25	25	10
-45, -45, -44	18.34	20.41	16.91	19.2	19.2	18
-45, -47, -43	18.09	30.19	12.68	20.6	32	14
-40, -45, -46	8.13	20.65	22.06	13	22.7	23

A. Experiment I

In the first experiment the maximum power was kept at 31. The RSSI values were extracted from the stationary node and the mobile node. Now a graph is drawn between RSSI values obtained and log D. Linear regression has been performed on these RSSI, log D and the equation is compared with the RSSI-distance equation to find the constants A and K. These values will be the same for all other experiments. The arrangement of sensor motes in the first experiment is also shown below in Figure 4. The values of A and K are 29.861 and 11.981. The graph showing simple linear regression is drawn below as shown in Figure 5.

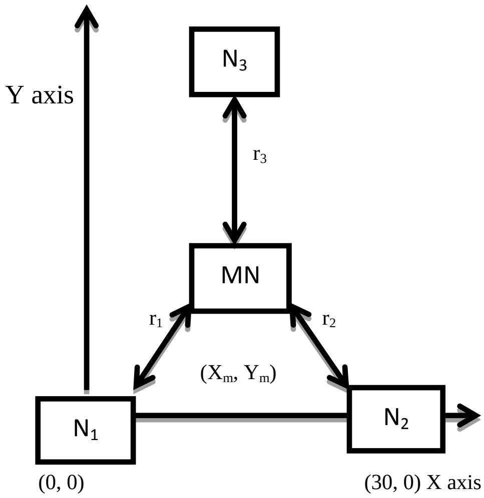


Figure 4 Arrangement of the Sensor Motes in the Experiment

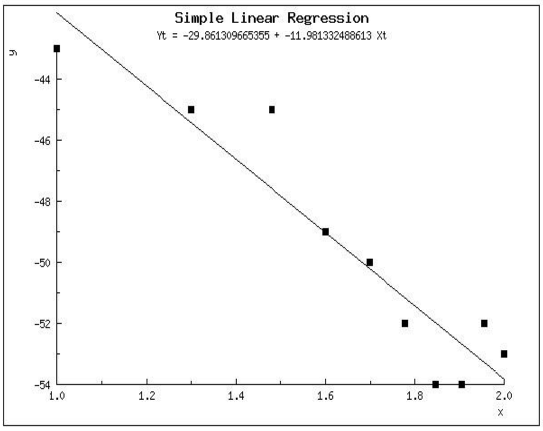


Figure 5 Simple Linear Regression for RSSI value to calculate the A and K constants

B. Experiment II

In this experiment, the location of mobile node started moving. The first attempt was moving mobile node to east about 5cms and then calculating the exact location using RSSI values. From the table it is observed that the RSSI values are -45, -45, and -44, the experimentally obtained measured distance value is 18.34, 20.41 and 16.91 cm and the theoretically obtained observed distance value is 19.2cm, 19.2cm, and 18cm which are the distances of the mobile node from the base station. By using the (Xm, Ym) equation for these values it will be possible to get the approximate position of mobile nodes. This means that the values are correct.

C. Experiment III

Here, the location of mobile node was moved to the west about 5cms and then calculating the exact location using RSSI values. From the Table 2 it is observed that the RSSI values are -46, -47, and -43, while the respective experimentally obtained distance values are 24.01, 26.18 and 13.49 cm, and the respective theoretically obtained distance values are 22.36cm, 28.28cm, and 11.18cm. These are the distances of the mobile node from the base station. Similar to experiment II, the (Xm, Ym) Equations 2 and 3 are used to estimate these values.

D. Experiment IV

Furthermore, the location of mobile node was moved to the north about 5cm and then calculating the exact location using RSSI values. From the Table 2, it is observed that the RSSI values are -45, -45, and -44, the experimentally obtained distance value is 18.34, 20.41 and 16.91 cm and the theoretically obtained distance value is 19.2cm, 19.2cm, and 18cm which are the distances of the mobile node from the base station. When graph is plotted for both, it looks similar. This implies the values are correct.

E. Experiment V

In this case, the location of mobile node was moved to south about 5cms and then calculating the exact location using RSSI values. From the table it is observed that the RSSI values are -43, -46, and -45, the experimentally obtained distance value is 12.91, 24.62 and 19.24 cm and the theoretically obtained distance value is 17.6cm, 28.4cm, and 16.14cm which are the distances of the mobile node from the base station. A similar method to experiment II is used to extract an approximate position of mobile nodes. This means that the values are correct.

F. Experiment VI

In this experiment, the location of mobile node was moved to the northeast about 5cms and then calculating the exact location using RSSI values. From the table it is observed that the RSSI values are -43, -46, and -45, the experimentally obtained distance value is 12.91, 24.62 and 19.24 cm and the theoretically obtained distance value is 17.6cm, 28.4cm and 16.14cm which are the distances of the mobile node from the base station. Also by using the (Xm, Ym) equation for these values it will be possible to get the approximate position of mobile nodes. This means that the values are correct.

G. Experiment VII

Finally, the location of mobile node was moved to the southeast about 5cms and then calculating the exact location

TABLE 3. ERROR DISTANCE

Measured Distance (cm)			Actual Distance (cm)			Error Distance (cm)		
24.22	19.31	15.12	22	24.6	13.63	2.2	4.19	1.49
24.01	26.18	13.49	22.36	28.28	11.18	1.65	2.1	2.31
10.91	17.14	15.32	14.32	21.67	18.68	3.41	4.53	3.36
12.91	24.62	19.24	17.6	28.4	16.14	4.69	4.2	3.10
21.78	15.31	7.08	25.4	19	10.63	4.3	4.3	3.23
20.67	28.52	6.98	25	25	10	4.3	3.52	4.02
18.34	20.41	16.91	19.2	19.2	18	0.86	1.21	1.9
18.09	30.19	12.68	20.6	32	14	2.51	1.81	1.32
8.13	20.65	22.06	13	22.7	23	3.97	2.05	1.06

using RSSI values. From the table it is observed that the RSSI values are -43, -46, and -45, the experimentally obtained distance value is 12.91, 24.62 and 19.24 cm and the theoretically obtained distance value is 17.6cm, 28.4cm, and 16.14cm which are the distances of the mobile node from the base station. By using the (Xm, Ym) equation for these values it will be possible to get the approximate position of mobile nodes. This means that the values are correct.

The error distance which is calculated Distance (error) = Actual Distance – Measured Distance is provided in Table 3 below.

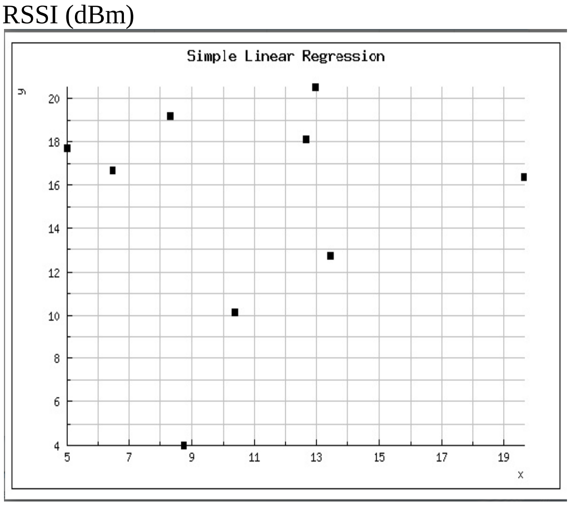
V. EVALUATION AND DISCUSSION

This work has presented a radio frequency-based (RF-based) location tracking system, which can be used in a Wireless Sensor Network (WSN) with known coordinates of the stationary nodes. Its performance of several real systems has been verified through different kinds of experiments. The location accuracy of this algorithm for a triangular, placed node structure is 80%. According to the experiments conducted, the algorithm is relatively high for precision, low cost and uses a small amount of the energy.

To prove the accuracy of the results a graph models are provided below to compare the theoretical and practical values of RSSI as a function of distance. The results show that there was not much difference between the assumed and achieved results of some experiments and was similar for some other experiments.

Some of the several things observed that hindered the RSSI values by which the accuracy of the location estimation depended include the influences of metal reflection, the polarization of the electromagnetic fields due to the diffraction at the edges.

RSSI (dBm)



Distance (cm)

Figure 6 Theoretical Values of the estimated mobile nodes position

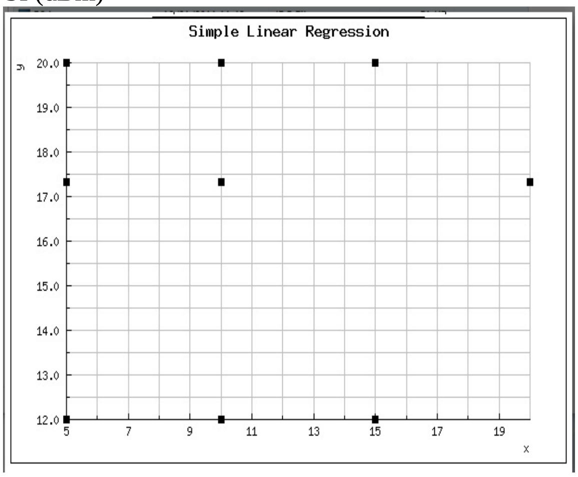


Figure 7 Experimental values of the estimated mobile nodes position

VI. CONCLUSION

In this work the experimental and theoretical results and the performance study of tracking the location of a mobile node using the RSSI measurements have been presented. Analytical models that can be utilized as a framework for designing the location system have also been provided.

The results prove that the RSSI received was random in measurement. It is possible to a certain extent that the location tracking based on RSSI measurements is accurate. But due to different types of influences such as the presence of programmer or programmer's orientation, the nature of experimental environment, variation in AA battery power level and so on, the RSSI values were not very accurate. Among all the experiments conducted, the most accurate values were obtained from experiments which were conducted on the floor and were approximately matching with the theoretical measurements. It is believed that if the amount of beacon nodes are increased then the accuracy of tracking the location of the mobile node will increase too.

ACKNOWLEDGMENT

The authours of this work which to acknowledge laboratory technologist and student who aided in carrying out some of the measurements involved in this research work.

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