Experimental Analysis of RSSI for Distance and Position Estimation

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***Abstract*— In wireless sensor network (WSN), position awareness (localization) of the sensor nodes is necessary to exploit the communication and to provide the meaningful information about their surroundings. Here Received Signal Strength Indicator (RSSI) technique is used as it requires no extra hardware and can be used for both indoor and outdoor environment. RSSI is having limitations such as high randomness due to fading and shadowing. This makes difficulties in establishing exact relationship between RSSI value and distance. In this paper we propose the method of creating database by using Split Range Technique (SRT) to estimate the approximate distance between two nodes. Using this database, position estimation has been done. For this Adaptive n-Triangle algorithm is implemented. Present results of RSSI shows the approximate positioning of the sensor node with the error estimation of about 5 -10%. The experiment can be extended to show the predicted path of a moving object which is being identified by sensors.**

***Keywords*— WSN, RSSI, distance estimation, position estimation, AT86RF230.**

I. Introduction

Similar to many technological developments, wireless sensor network has emerged from military needs and found its way into civil applications. The massive advances of micro-electromechanical systems (MEMS), computing and communication technology have helped the emergence of massively distributed wireless sensor networks consisting of hundreds and thousands of nodes. They are extensively being used in different environments to perform various monitoring tasks such as data collection, rescue, disaster-relief, target tracking etc. Most of the out-door deployments of the sensor network are being done by scattering the nodes throughout the region of interest. This provides a random mesh topology for the network and there is a clear uncertainty of the location of nodes. The data collected will not be useful unless the location information can be discerned from it. In such scenarios, localization and position estimation play a major role.

There are many algorithms and techniques available for localization of wireless sensor nodes. Among them, the basic and fundamental technique is to use the received signal strength for identifying the position. If the radio signal through which we are establishing network can be used in position estimation of a node, than it is the most cost effective solution. This solution can be applied to both indoor and outdoor environments by introducing additional features in the software, without any hardware modification. RSSI (Received Signal Strength Indicator) and LQI (Link Quality Indicator) are considered as two parameters which play a pivotal role in most of the localization algorithms of sensor networks. RSSI indicators and its associated registers are generally inbuilt in radio chips. Many experiments of localization using RSSI has been performed with radio CC2420 [1], [2], [5], CC1000 [3], [4]. In our work we have used IRIS motes [6] which comprises of AT86RF230 radio chip.

In this work, repeated measurements of RSSI between two nodes at varying distance have been done for different scenarios both indoor and outdoor. Distance estimation database has been prepared considering the attenuation factor of obstacles, power levels of nodes and antenna orientation. Further using this database, position estimation of Mobile node in a plane is done using Adaptive n-Triangle method.

The presentation of this paper is organized as follows: In Section 2, we present the related work discussing various range based localization techniques. In Section 3 the issues related to RSSI and the methods of RSSI measurement are explained. Section 4 describes the experimental setup used for distance and position estimation. Section 5 includes the results obtained and the analysis followed by conclusion in section 6.

II. RELATED WORK

Over the past few years many solutions have been proposed for localization in wireless ad-hoc and sensor networks which can be broadly classified into two main categories – *range based* and *range free*. Range based techniques estimate distances (range) from RSS measurements between the unknown node and the reference nodes and uses them to triangulate the location of the unknown node [1], [3], [4], [5], [11]. On the other hand range free techniques estimate the location of the unknown node without determining the range like GPS, Cricket, and Ultrasonic sensor based techniques. For our work, we have studied some range based localization techniques and previous analysis done on utilizing RSSI for localization, which are discussed in this section.

The work described in [4] does experimental analysis on RSSI using MICA2 motes with CC1000 radio. They have done distance estimation through empirical quantification of error metrics of RSSI model. Further, on this basis k- nearest signal space neighbor match algorithm localization has been done. As they use MICA2 motes, in which RSSI value generation is from 10 bit ADC of microcontroller, which gives poor resolution. Also the shadowing and signal contention effects have not been taken care.

Ecolocation [3] algorithm employ a constraint- based approach that provides for robust location decoding even in the presence of random RSS fluctuations due to multi-path

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fading and shadowing. MICA2 motes have been used for this experimentation also.

Work in [5] develops algorithm based on RSSI to be utilized for both indoor and outdoor environment. It does calibration of RSSI coefficients and by applying iterative trilateration, distance and position estimation has been done. Here the approach applied is less complex but probabilistic in nature. Radio used here is CC2420.

Experimental study done on utilization of RSSI in embedded nodes [11] and how reliable is RSSI in [1] gives the practical idea about the random nature of RSSI, conveys that other than distance RSSI value also depend on type of Radio, power level and antenna orientation.

In our work, IRIS motes with radio AT86RF230 have been used. During the experimentation power level of the nodes and antenna orientation has been taken care. Our technique has been generalized for indoor and outdoor environment.

III. RESEARCH METHODOLOGY

A. RSSI Model and Issues

Theoretically, the energy of a radio signal attenuates with the square of the distance from the signal's source. As a result, a node listening to a radio transmission should be able to use the strength of the received signal to calculate its distance from the transmitter. Since all the nodes are having radios, RSSI can be used to compute ranges for localization.

Assuming that the transmission power P_{tx}, the path loss model, and the path loss coefficient α are known, the receiver can use the received signal strength P_{rcvd} to solve for the distance d in a path loss equation like

$$P_{rcvd} = c * P_{tx} \;/\; (d \wedge \alpha) \qquad \text{... eq (1)}$$

This is appealing since no additional hardware is necessary and distance estimates can even be derived without additional overhead from communication that is taking place anyway. [1]

RSSI has certain known issues which have to be considered:

- RSSI values are not constant but can heavily oscillate, even if there is no movement in sender and receiver. This effect can be counteracted by repeated measurements and filtering out incorrect values by statistical techniques.
- If calibration of device is not been done then the same actual signal strength can result in different RSSI value on different devices. Similarly, the actual transmission power of such a transceiver shows discrepancies with multi-path fading.
- Presence of obstacles in combination with multi-path fading. In such case the signal attenuation along an indirect path is higher than the direct path, can lead to incorrectly assuming a longer distance than what is actually the case.
- For an indoor application, RSSI will have an even more important effect, as the radio signal can be affected by the surrounding environment, and the reflections will create a multi-path solution. The walls and the furniture will work as obstacles for the radio signal, but those are permanent obstacles, whose effects have to taken care in the programming.
- In a working environment such as a lab, office or corridor, the movement of people acts as extra obstacles for the radio signals. They are mobile, and are not always present. So the radio propagation profile will have a different shape if computed at daytime or at night.

Still RSSI is preferred for simple location estimation algorithm because: (i) No extra hardware is needed. (ii) It can be used for both indoor and outdoor applications just with the change of path loss coefficient α in eq (1).

B. RSSI Measurement

The wireless sensor nodes used in the practical experiments conducted for measuring RSSI are IRIS motes [6]. The RF transceiver used is AT86RF230 [7] which is a high performance RF-CMOS 2.4 GHz radio transceiver targeted for IEEE 802.15.4 and ZigBee Applications.

AT86RF230 radio has RSSI indicator with the sensitivity of -91dBm. The chip has two main registers related to receive signal strength.

a. RSSI_VAL register which stores a 5 bit RSSI value. The RSSI value obtained from this register is an integer value which needs to be converted to dBm using following relation:

$$P_{rf} = \text{RSSI\_BASE\_VAL} + 3(\text{RSSI}) \qquad \text{... eq (2)}$$

Where, Prf is the input RF power in dBm, RSSI_BASE_VAL = -91dBm and RSSI is value read from the registers between 1 to 28.

b. Energy Detection, ED register stores the average RSSI value over eight symbols (128us). Its range is between 0 to 84 which needs to be converted to dBm using following relation:

$$P_{rf} \text{ in dBm} = \text{ED} - 91 \qquad \text{... eq (3)}$$

Thus by reading the values of the RSSI related registers, signal strength is calculated. In our work ED value has been read for calculating RSSI and distance relation. As RSSI value varies with change of battery power, so battery voltage was also transmitted with every packet. Nes C [9] coding in TinyOS [8], has been done for IRIS motes for the experiment.

IV. EXPERIMENTAL SETUP

Our experimentation consists of two phases: Distance Estimation & Position Estimation. Distance estimation is to develop database for calculating distance from RSSI value. Position Estimation has been done to test the effectiveness of the database developed. Assumption has been made, that no interference source in 2.4GHz range is present in the indoor and outdoor experimental area.

A. Distance Estimation

For this setup two numbers of IRIS motes and one Base Station (BS) were used. One has been assigned as *reference node*, while other as *mobile node*. *Mobile node* has been moved towards the *reference node* at the rate of $\Delta R/sec$. and passes a packet with *node id & Battery voltage* to the *reference node* at every increment of ΔR. The measurements have been taken for the distance of 2 meters with ΔR of 5cm. Thus in one direction *reference node* collects 40 packets and measures 40 RSSI values at 40 points. It forwards the RSSI values with battery voltages received for every packet to BS connected to PC, where all data logging is done. With one setup, experiment is performed for 60 times in forward and backward direction. Such experiments have been done in the following environments:

a) Indoor without obstacles
b) Indoor with obstacles.
c) Outdoor

Mean value of RSSI *vs* distance graph has been plotted for all experiments and curve fitting is done. Database is prepared by analyzing the split linear segments of the fitted curves. This technique is referred in the paper as Split Range Technique (SRT).

B. *Position Estimation*

For the position estimation of the mobile wireless sensor node in a plane, the database generated by distance estimation is used. *Reference nodes* have been placed in a symmetric way at known positions. The centralized localization approach is being adapted for estimation of position [4]. In the initialization process, all of the *reference nodes* forward their coordinates to *mobile node* when it is in its range. The *mobile node* deduces the RSSI values of the signal received and forwards them along with the coordinates, to the Base Station (BS). The coordinates of the *mobile node* is calculated using the following Adaptive n-Triangle algorithm:

1. N *reference nodes* are placed in a symmetric pattern over a plane with each one assigned the coordinates x_1,y_1 from the set $\{(x_i, y_i)……….(x_N,y_N)\}$
2. Let the *mobile node* ***m*** with unknown coordinates (x,y) be present in range of M *reference nodes*. Collect M number of coordinates, *Battery Voltage* ,B_{vM} and RSSI values, R_M from these M *reference nodes* and forwards to BS.
3. if B_{vM} <2.3 : filter that RSSI value
4. BS computes D_M distances of mobile node to the M *reference nodes* using R_M from distance estimation database.
5. M triangles are formed with ***m*** as vertex of all triangles.
6. First M_i -M_j distance computed.
7. D_{Mi} and D_{Mj} computed in step 3 is used in triangle theorem to compute (x,y) coordinates of mobile node.
8. M coordinates of mth *mobile nodes* are obtained.
9. Mean of all final M coordinates gives the final coordinate(x,y) of *mobile node*.
10. As *reference node* placing is predetermined so database should be selected according to the category in which Mi node falls.
11. Sample 10 RSSI values for each *reference node* and repeat step 3-10 for 4 iterations.

For our experimentation, four IRIS nodes were placed in rectangular plane as shown in Fig.1 and the position of the mobile node was calculated at different points.

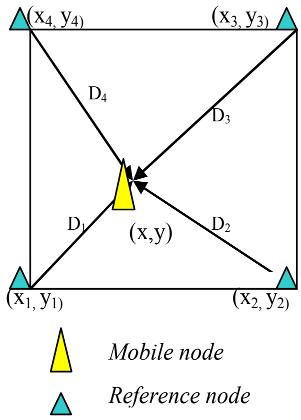


Fig. 1 Experimental plane

In this setup N =4 , M =4 and as per above algorithm, the value of x and y are calculated.

Here the accuracy of position estimation depends on the accuracy of the distance estimation. As there will be inaccuracy in distance estimation, so the error gets included in the above mentioned mathematical formulation hence results in more error in position estimation. Error has been reduced to some extent by applying windowing technique for averaging.

V. RESULTS & ANALYSIS

In this section, we present an analysis of the results which we obtained in the two stages of our experimentation. For both stages, indoor observations were taken in WSN Lab of Computer Division, IGCAR and outdoor experiments were performed outside the building along the road where the vehicle movement is less.

A. *Distance Estimation*

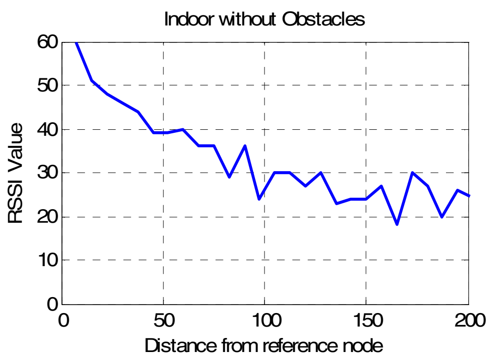


Fig. 2 Single Observation plot

In general, RSSI varies with distance, type of obstacles, antenna orientation and change in transmitted power. Hence in our experiments, repeated observations were taken with same antenna orientation. Obviously, the battery power will drop during the experimentation and that will leave to change in transmitted power. To take care of this *Battery Voltage* is also been transmitted in every packet to the *mobile node*.

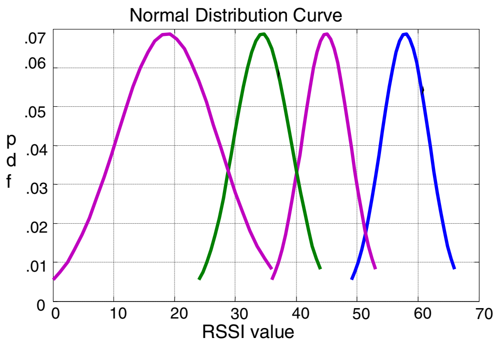
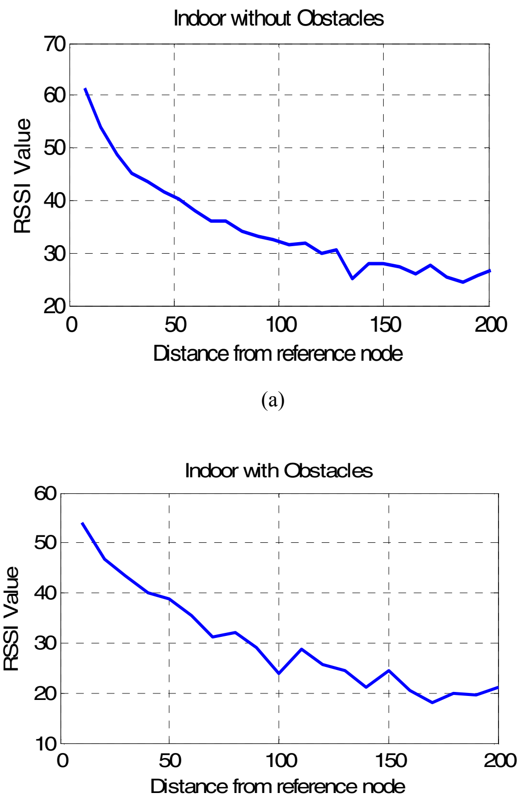


Fig. 3 Normal Distribution of RSSI value shown at four different points

A single observation plot for RSSI value is shown in Fig. 2, which shows that there is too much fluctuation in RSSI value. As per analysis[1], RSSI is random in nature. This random nature is overcome by repetition of experiments. Normal distribution curve shown in Fig. 3 for indoor observations also justifies this.



(a)

(b)

Fig. 4 Mean value plot

For indoor environment, the first 60 sets of observations were obtained without any obstacles close to the experimental area and other 60 sets were taken in the presence of static and movable obstacles. Fig. 4 shows the mean value curve for both the setups. From these curves it is verified that, with presence of obstacles the value of RSSI drops. In both cases variation of RSSI value with battery voltage variation was also studied. IRIS nodes operate on 2AA cells and the maximum voltage at the most which a node will receive will be around 2.8volts. The minimum voltage required for node operation is 2.0volts. Analysis was done for voltage ranges between 2.8 to 2.0. Significant drop is seen in RSSI value when the battery voltage drops below 2.3 volts. Such RSSI values are filtered in database.

As mean value curve is also showing fluctuations and non uniformity, curve fitting is done by applying constraint on limit in RSSI variation. The equations relating RSSI and distance for each segment obtained after applying SRT is stored in database.

Same experiments were done for outdoor environment also. The mean value plot for 60 observations is shown in Fig. 5 along with segmentation. Observation for outdoor environment was extended up to 45m, which showed fluctuation in RSSI value, as in Fig. 6

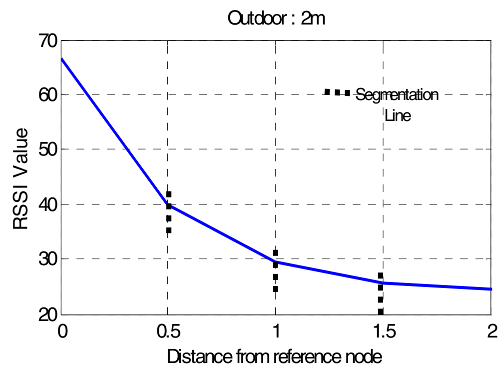


Fig. 5 Segmented Mean value plot

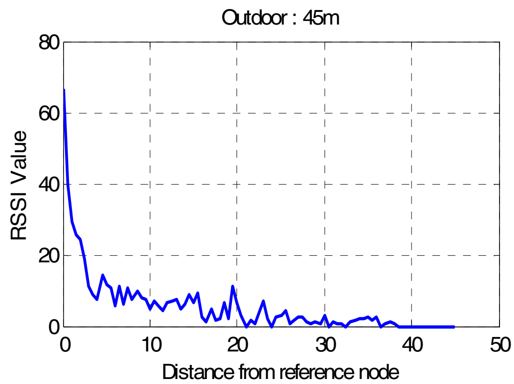


Fig. 6 Outdoor 45m observation

From indoor and outdoor observations it is easily interpreted that fluctuation are less in outdoor environment, as multi –path fading and shadowing effects are less due to less number of obstacles.

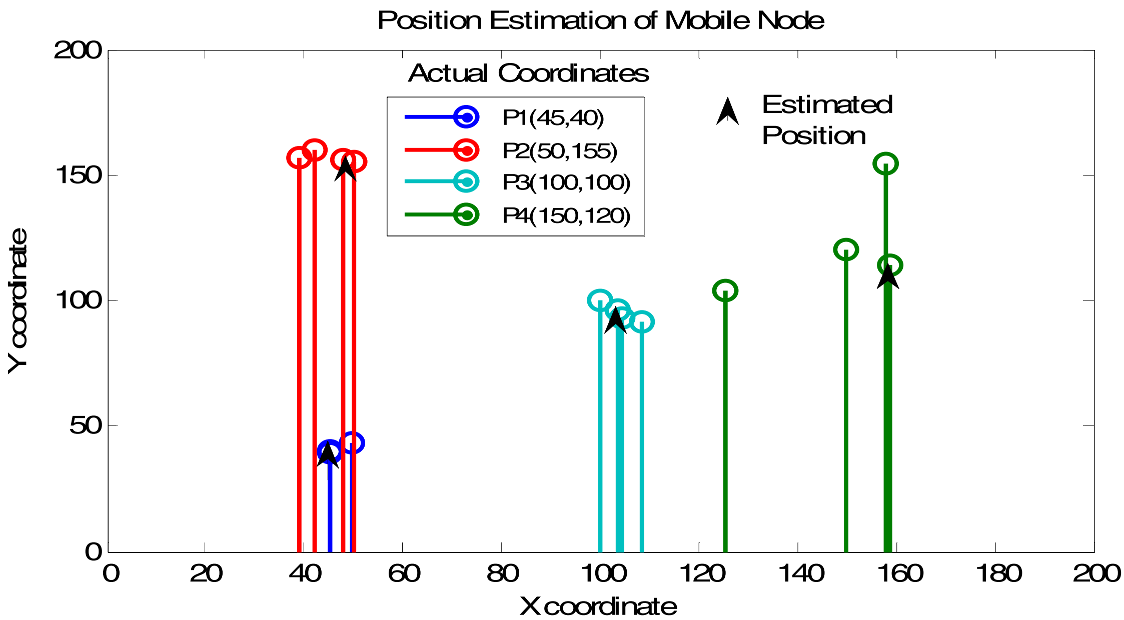


Fig. 7 Position Estimation of mobile node at 4 different points P1, P2, P3 and P4

B. *Position Estimation*

As explained in Section 4, the position estimation experiment has been done with four reference nodes located in the corners of 200x200 square plane [node 1 at (0,0); node 2 at (200,0); node 3 at (200,200) ; node 4 at (0,200)]. Following the Adaptive n- Triangle algorithm, here 4 triangles will be formed as all *reference nodes* are in range of mobile node. By iterative process in algorithm, three position coordinates are obtained for mobile node at one particular position. The final iteration is the estimated position shown by black arrow in Fig.7. From figure we can also interpret that final position is more close to the actual coordinate. *Mobile node* position estimation done at four different points in the experiment is shown in above figure.

From these experiments, it is observed that, more the number of times the RSSI value is sampled, the position of node can be calculated accurately. This signifies that as soon as the node is placed at a point, there are fluctuations in RSSI value. But when the node remains stable at that point its RSSI value corresponding to reference nodes is also getting stabilized. Sampling of RSSI value for 10 seconds has been done considering trade off position estimation accuracy and acceptable delay in tracking.

VI. Conclusions

Position estimation by using Adaptive n-Triangle method does estimation of position with 5-10% error. This method can easily be deployed for indoor and outdoor environment as database switching as per the position of reference node need to be done. The drawback of this method is that before applying to a environment, complete knowledge of the area is needed, otherwise error percentage will increase.

RSSI value is very much susceptible to interference and fading effects, results can be improved by reducing the error limit in Distance Estimation by increasing the number of experiments of observations, calibrating the system with different types of interfering sources and using refining algorithms like predictive algorithms with SRT.

In Position Estimation results can be improved if the error in Distance Estimation is less. Further improvement can be done by using adaptive filtering for RSSI vale, considering the attenuation factor of various obstacles in database. For much better position estimation or tracking some parameter like LQI (Link Quality Indication) can be used along with RSSI.

The experiment was performed over a lab model. However, the code can be adapted for any size plane, with changes in database for distance estimation.

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