Is RSSI a Reliable Parameter in Sensor Localization Algorithms – An Experimental Study

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Abstract

Wireless sensor networks are becoming ubiquitous and their application areas are widening by the day. Localization algorithms play an important role in enhancing the utility of data collected by enabling sensors to determine the location from which each data packet is obtained. Localization can be done by implementing beacon based algorithms or signature based algorithms. Much of the research work in this area assumes received signal strength indicator (RSSI) as a parameter in their localization algorithms. Since RSSI is the key parameter, we conducted practical experiments to assess whether RSSI could indeed be used by localization algorithms to determine distances between sensors. In our experiments, we tried to calibrate and map RSSI to distance under various conditions and concluded that despite promising hypothetical advantages of RSSI, even under ideal conditions it cannot be used to determine inter nodal distances in wireless sensor networks.

Keywords: Distance measurements, ESN, Localization Algorithms, LQI, Motes, RSSI, Wireless Sensor Networks

1. INTRODUCTION

Wireless Sensor Networks (WSN) are becoming more common in use and extensive research is currently underway to expand the application areas of WSN [1]. Some of the most important application areas of sensor networks include hurricane areas, volcano areas, forest fire areas, etc. and these networks are usually known as emergency sensor networks (ESN) [2]. In most of the applications related to ESN the data collected will become useless unless the location information can be discerned from it. Thus localization algorithms [3, 6] play a significant role in the domain of wireless sensor networks. Mainly these algorithms are categorized into two – signature based and beacon based. RSSI (Received Signal Strength Indicator) [7] and LQI (Link Quality Indicator) [4] are considered as two parameters which play a pivotal role in the beacon based localization of sensor nodes. Typically RSSI is a measure of dBm, which is ten times the logarithm of the ratio of the power (P) at the receiving end and the reference power (P_{ref}). Power at the receiving end is inversely proportional to the square of distance. Hence RSSI could potentially be used as an indicator of the distance at which the sending mote is located from the receiving mote. When data from many such neighboring motes are combined, the location of the sending mote can be judged with reasonable accuracy.

The literature study about RSSI shows that RSSI is not a good candidate for localization experiments [5]. Despite this, many papers assume the use of RSSI in distance measurements. Therefore, it is necessary to test whether this hypothesis is correct or not by creating a practical experimental setup on a more basic level than those used in previous studies.

The organization of this paper is as follows: The next section presents the background information related to RSSI and localization.

Section 3 presents experimental setup for performing RSSI related measurements. Section 4 contains the results of our experiments. Section 5 discusses the implications and interprets the results we obtained. Finally, in Section 6, we conclude this paper with plans of future work.

2. BACKGROUND

RSSI and distance have a relationship which is derived as follows.

As mentioned previously, RSSI is defined as ten times the logarithm of the ratio of power of the received signal and a reference power (e.g., 1mW). i.e., RSSI α 10 log $P/P_{ref.}$ This would mean that RSSI α log P. It is known that power dissipates from a point source as it moves further out and the relationship between power and distance is that power is inversely proportional to the square of the distance travelled. In other words, RSSI α $\log(1/distance^2)$.Simplifying this relationship further we can conclude that RSSI α –log distance. Thus if we were to plot the RSSI measured and plot it against log of distance we should be able to obtain an inverse linear relationship and a graph thus generated would serve as a standard curve that can then be employed by a receiving mote to estimate the distance at which a sending mote would be located. It would also be possible to estimate the degree of confidence with which the receiving mote can make this estimation from the variance at each data point. Thus in this paper we attempt to generate a standard curve between RSSI and sensor motes' distances and test whether this curve can be used to estimate the distance between motes by randomly placing motes and measuring the RSSI values. Such a curve if proven successful would provide a cheap, easy and invaluable tool to map the motes in a WSN making the data obtained from such network useful.

To put this mathematically, consider the standard graph given in Figure 1.

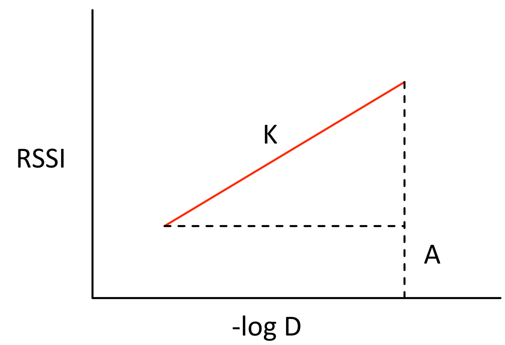

Figure 1 Standard graph showing expected relationship between RSSI and [-log (distance)].

K is the slope of the standard plot. K can be obtained by performing a linear regression analysis on the data points used to generate the standard curve. This analysis could also provide the estimate of the constant parameter 'A' in the equation that fits the data the best. Further this linear regression fit plot can be used to estimate the distance between two motes for a given RSSI value based on the formula as shown below.

$$RSSI = -K \log D + A$$

$$D = 10^{[(A-RSSI)/K]}$$

3. MATERIALS AND METHODS

We have conducted practical experiments to see whether RSSI can be used as a candidate in localization algorithms regardless of the hypothetical assumptions that have been revolving around RSSI. The aim of the experiments was to prove or disprove that RSSI can be used as an indicator of distance between motes in a sensor network. The development kit we used is Crossbow® Imote2 from Intel which integrates 802.15.4 radio (CC2420) with a built-in 2.4GHz antenna. We have tried to create an ideal environment to conduct these experiments by avoiding confounding factors that would spuriously alter RSSI. The precautions taken include, 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 experimental set up consisted of two crossbow motes programmed with `count_send` and `count_receive` programs written using visual C#. `count_receive` program was also designed to read the RSSI value from the mote's memory and display it in command prompt. The motes were arranged in a two dimensional plane and the receiver mote is connected to a laptop through a USB cable. The raw data was collected and the RSSI value was extracted from memory. We have taken 30 measurements at each location. The mean of RSSI value obtained at a given distance was calculated and variance and standard error of mean were determined. The whole process is repeated by positioning the mote in a different location in the same direction. The mean values were plotted against distance and a non linear relationship was verified. Subsequently the RSSI value was plotted against the log of distance and linear regression was applied to generate a standard curve for the given motes. Further experiments were conducted, RSSI values were obtained and the distance was calculated from the standard curve in order to verify its validity.

4. RESULTS

From the data we got we have plotted a graph between distance and RSSI. From multiple experiments conducted in different directions we obtained the graphs shown below.

(a) Direction - North

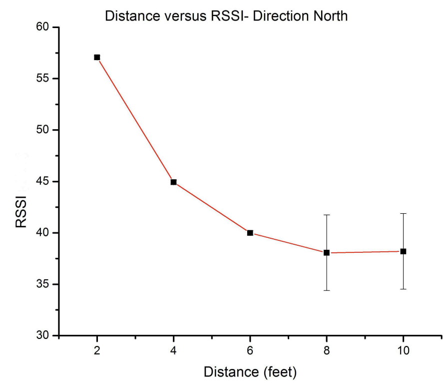

Figure 2 Distance versus RSSI plot showing inverse non-linear relationship.

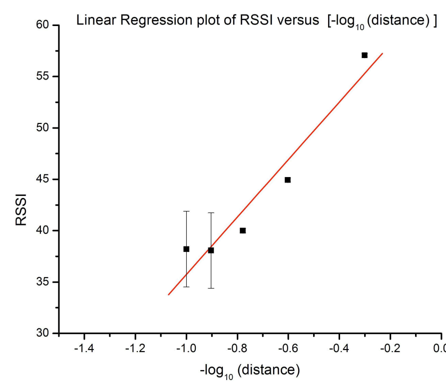

Figure 3 Linear regression analysis showing predicted relationship between RSSI and [-log (distance)] in direction north.

Just as predicted, distance and RSSI show a non linear relationship such that the RSSI value decreases with increase in distance. To further elucidate the nature of this, data was re-plotted with –log (d). This data was then subjected to linear regression analysis and it can be seen that the RSSI values follow a linear relationship. It can also be seen that as the distance increases (negative logarithm decreases), the error in RSSI value increases thereby decreasing its reliability at extremes of the range of its radio transmission radius. RSSI is measured as an integer value and can be converted into its corresponding dBm value by subtracting a constant. This would mean that RSSI cannot have decimals/fractions, hence it does not offer enough resolution to distinguish subtle changes in distances. But it theoretically offers resolution to distinguish between distances that are large enough to cause at least a unit change in dBm power ratio at the receiving mote. Hence we avoided using small increments of distances in our experiments. We further looked at RSSI in other directions to see if the behavior seen in Figure 1 can be replicated in other directions as well. Even though the initial result was promising, through this multi direction experiments it became clear that even under ideal conditions with weather and interference controlled, the RSSI data could not be relied upon. At times the data showed the expected inverse square relation with distance and at times it didn't.

(b) Direction – West

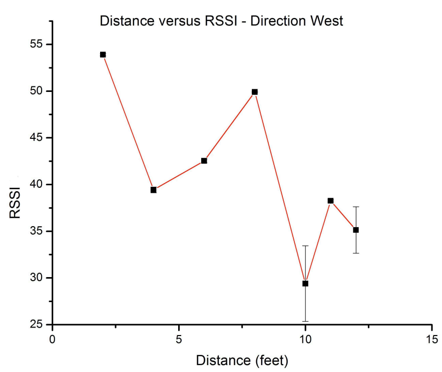

Figure 4 Distance versus RSSI plot showing lack of reliability when tested in a different direction.

(c) Direction - East

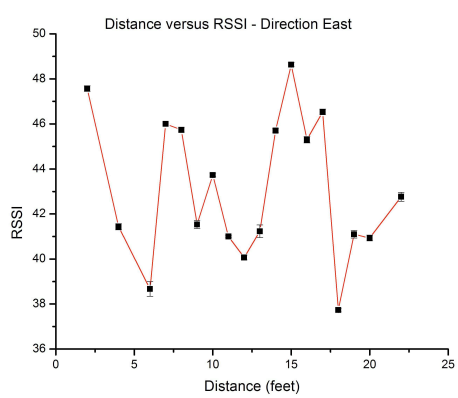

Figure 5 Distance versus RSSI plot showing lack of reliability when tested in a different direction.

The above graphs (Figure 4 and Figure 5) exposed the problems with using RSSI in determining the distance at which the sending node is located.

5. DISCUSSION

RSSI was considered as a metric in most of the distance measurement algorithms. Even though the ineffectiveness of RSSI is mentioned in the literature, not many attempts were made to implement it in a practical environment and verity it. Elnahrawy et al have explored the idea of using RSSI in localization algorithms conducted in indoor environments and determined that more complex models and algorithms are required to improve accuracy of RSSI based methods when used indoors [5]. However on a more basic level the reliability and accuracy of using RSSI to determine distance has not been extensively tested in a simple environment (e.g., outdoors), where interference by structures and stray wireless signals of frequencies similar to that of the mote being tested (2.4GHz) are not present. Such a simplistic experimental setup would establish, on a more fundamental level, whether RSSI can be used for distance measurements and localization. The initial experiments gave some promising results and it was thought that RSSI can be used at least to some set of WSN application areas. The main attraction to RSSI as a metric is that the measurement and calculations involved with RSSI are very simple and less complicated than other localization metrics. But later on, after conducting a number of experiments repeatedly in a maximum possible ideal environment, we came to the conclusion that RSSI cannot be used as a reliable metric in localization algorithms because of the following reasons:

Firstly, from the above graphs it is evident that even in the ideal scenarios RSSI doesn't give a consistent behavior. So in an actual deployment area the performance of RSSI can be much more unreliable because of the presence of confounding factors like interference from other objects, attenuation caused due to barriers, malfunctioning of the motes due to less secure environment, power failures etc.

Secondly, it is evident from the graphs that as the distance increase the error in measured RSSI value increases (Figure 2). So RSSI gives very unreliable results at the extremes of its range. The chances for this to happen are more in an emergency wireless sensor network because motes can be destroyed in natural calamities, effectively increasing the distance between two available motes thereby making RSSI unreliable.

6. CONCLUSION AND FUTURE WORK

Because of the reasons cited above, we come to the conclusion that RSSI cannot be used as a metric for distance measurements in localization algorithms. Hence it is extremely difficult to develop a graph between RSSI and distance which can be used as a standard reference for getting the distance value for a given RSSI value.

In future we would also like to measure RSSI with respect to multiple reference points to see if doing so would improve localization accuracy. Further we would like to conduct experiments in the same environment and measure a different parameter called LQI (Link Quality Indicator). We plan to explore the relationship between LQI and distance and see if LQI would be a strong and reliable candidate to be used in localization algorithms.

ACKNOWLEDGMENTS

This research is supported in part by U.S. Department of Defense Grant No. H98230-08-1-0333.

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