# A Localization System using Wireless Network Sensors: A Comparison of Two Techniques

Mark Terwilliger, Ajay Gupta, Vijay Bhuse, Zille Huma Kamal, and Mohammad Ali Salahuddin

Western Michigan University, Kalamazoo, MI 49008, USA
{mgterwil, gupta, vsbhuse, zkamal, masalahu}@cs.wmich.edu

***Abstract* - Locating objects, such as keys, office equipment, people, or even an enemy vehicle, is an application that has received a lot of attention over recent years. With the emergence of wireless networks and mobile computing devices, providing location-aware technology and services to new applications has become important for developers. Recent advances in sensor technology have allowed wireless sensor networks to provide location services. Many applications of wireless sensor networks assume that the devices are location-aware. In this paper, we discuss the Ferret localization system. Using only the radio features of the sensors, the Ferret system provides two techniques for locating an object. The system provides good results, but several extensions are discussed to make it more scalable and reliable.**

## 1 Overview

Advancements in low-power electronic devices integrated with wireless communication capabilities and sensors have opened up an exciting new field in computer science. **Wireless sensor networks (WSN)** can be developed at a relatively low-cost and can be deployed in a variety of different settings. A WSN is typically formed by deploying many sensor nodes in an ad hoc manner. These nodes sense physical characteristics of the world. The sensors could be measuring a variety of properties, including temperature, acoustics, light, and pollution. Base stations are responsible for sending queries to and collecting data from the sensor nodes. Some of the main characteristics of a networked sensor include: (1) small physical size, (2) low power consumption, (3) limited processing power, (4) short-range communications, and (5) a small amount of storage.

Localization is an area that has attracted much attention in recent years [2-7,9]. With the constrained resources of network sensors, as well as their high failure rate, many challenges exist in using them to locate objects. In addition to looking at the cost of a system, calibration and fault tolerance are issues that must be addressed. The type of localization problem that the Ferret system initially set out to solve was one in an office environment. Given a building with many offices, hallways, closets, etc., the system's goal was to locate some piece of equipment, such as a laptop or video projector. More precise accuracy is always ideal, but if our system could pinpoint the object to the correct room, we consider this a success. The rest of this paper will be divided into sections covering related work, the Ferret localization system, the potentiometer technique, the RSSI technique, results, conclusions, and future work.

## 2 Related Work

The current landscape of location sensing systems is filled with a variety of technologies. The most popular system, GPS [1], uses radio time-of-flight lateration via satellites, but has the limitation of only working outdoors. Most of the location systems, such as Active Badges [2], AT&T's Active Bats [3], Microsoft's Radar [4], and MIT's Cricket [5], use known positions or distances in the location or calibration process. These systems are reliant on an a priori *infrastructure*. This leads to two problems: (1) The system will not scale well to a large topology, and (2) It is very difficult to do location sensing in an ad-hoc manner.

The UC Berkeley Calamari project [6] is working on ad-hoc localization by fusing results from RF received signal strength information (RSSI) and acoustic time of flight (TOF). Combining technologies provides more accurate distance estimates, but uses more power and requires special hardware. The SpotOn system [7] used only RSSI to provide ad-hoc location sensing in small-scale environments. Although this project is now completed and SpotON hardware is no longer available, the authors gave several suggestions for future research that is relevant to our location system. One area of research examines transmitting at multiple power levels and trying to obtain more accurate distance estimates based on the received RSSI. One of the techniques that the Ferret system uses is to gauge the distance between nodes by adjusting the potentiometer that controls the transmission power level.

## 3 The Ferret Localization System

We have developed Ferret, a localization system that uses wireless networked sensors. The system consists of a known infrastructure of nodes that responds to beacons from an object to be located. All of the nodes used in the Ferret system are Mica motes, the second-generation wireless smart sensors developed at the University of California Berkeley.

The Mica mote, marketed by Crossbow Technology, is pictured in Figure 1. The mote consists of an ATMEL 4 MHz processor and a 916 MHz radio transceiver. With limited storage space and powered by two AA batteries, programmers of the motes must be conscious of the resource constraints. The motes have a 51-pin connector that allows for interface with a variety of sensors. For operating system support, the motes use TinyOS, a small, open-source, energy-efficient system also developed by researchers at UC Berkeley [8].

**Figure 1: The Mica mote.**

The software aspect of the Ferret system consists of three components:

1. The potentiometer localization sub-system
2. The RSSI localization sub-system
3. An environment calibration tool

Figure 2 illustrates the graphical user interface of the system. The user inputs the ID of the node to be located, as well as the localization technique to be used (potentiometer or RSSI). In the diagram, the numbered nodes (e.g., 7, 8,…) are the IDs of the infrastructure nodes. These nodes are aware of their IDs and the system is aware of their locations. The actual coordinates of the node to be located can be entered when localization errors are being computed during the testing phase. In order for the localization to work, the system must be able to establish a relationship between the distance nodes are separated and the radio property of interest (potentiometer setting or RSSI). This relationship varies among different environments (interference from machinery, indoor versus outdoors, etc.). When the Ferret system is moved from one environment to another, the calibration tool is used to establish the distance relationship for that particular environment.

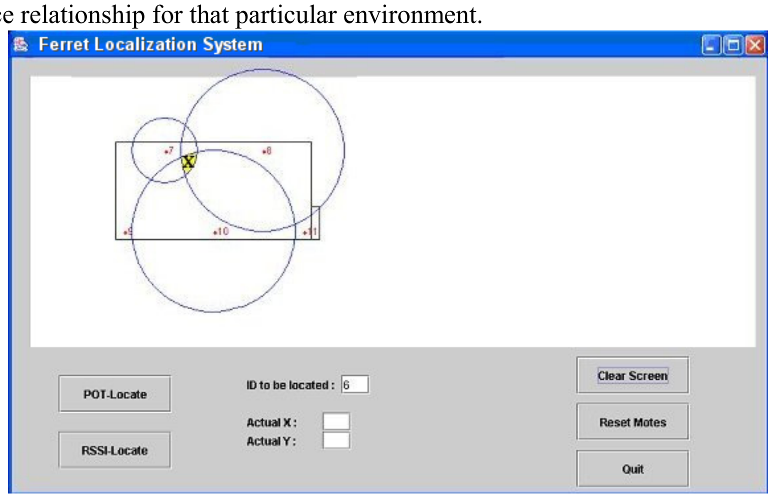


**Figure 2: The FERRET interface.**

For the potentiometer sub-system, for example, the calibration tool is responsible for developing the communication ranges for given transmission power levels. The output from the calibration tool is a table that looks like the following:

| Potentiometer | 99 | 95 | 90 | 85 | 80 | 75 | 70 | 65 | 60 |
|---|---|---|---|---|---|---|---|---|---|
| Distance (ft) | 2 | 5 | 8 | 10 | 12 | 15 | 18 | 24 | 30 |

The table is created dynamically by running the calibration tool each time the system is moved to a new environment. The algorithm used by the calibration tool is shown below in Figure 3.

```
Set distance to 1 and place MoteS and MoteR one foot apart
Set potentiometer to MIN_POWER
Repeat
     MoteS sends 10 messages
     MoteR responds to all messages that it "hears"
     If number_heard_messages < threshold
          output potentiometer and (distance – 1) to table
          decrease potentiometer by step
     else
          move MoteR one foot further from MoteS
Until potentiometer = MAX_POWER
```

**Figure 3: The calibration tool algorithm.**

In the two subsequent sections, a detailed description of the potentiometer and RSSI localization sub-systems will be given.

# 4 The Potentiometer Technique

In both techniques, a query is routed from the base station to the object to be located via the infrastructure nodes. In the potentiometer technique, the object to be located (mobile node) begins by transmitting the beacon at the lowest power level and listens for replies from the infrastructure nodes. Increasing the power level with each transmission, once the mobile node gets three replies, it forwards its data to the base station for computation of position based on triangulation.

This technique is illustrated by the output of the Ferret system, as shown in Figure 2. The circles represent the infrastructure nodes that responded and are centered at the infrastructure node ID. The radius of the circle is obtained from the table corresponding to the power level used when the message was sent. For example, if node with ID #7 received a message when potentiometer value 95 was being used, it would know that node to be tracked was within 5 feet. The Ferret system concentrates on the intersection of the circles that are formed (shaded region in Figure 2) when three nodes reply. It calculates the center of mass of this region and uses this position as the location predictor (indicated with an X by the system).

# 5 The RSSI Technique

Knowing that distance and RSSI (Received Signal Strength Indicator) are related, the first step in implementing this technique was to perform some experiments. A relationship needed to be established so that a function could estimate distances based on RSSI values. Figure 4 shows the results of these experiments in which a 5-sample mean of RSSI values is plotted versus varying distances. In the small range of distances that we were interested, a linear relationship was found with a correlation of 0.796.

In the RSSI method, the mobile node sends out a series of five signals using full transmission power. The infrastructure nodes reply to all beacons that they hear from. The mobile node records the identification number and the RSSI value for all received packets. It computes the average RSSI for each neighbor that it heard from and identifies the three "closest" neighbors by looking for the largest averages. As with the potentiometer technique, it forwards its data to the base station for computation of position.

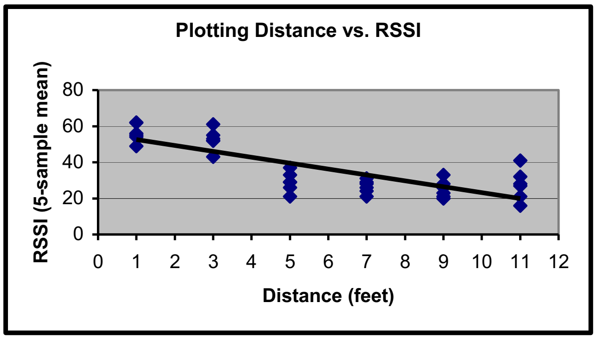


**Figure 4: Results plotting distance versus RSSI.**

To compute the location for prediction, consider a point $(x_a,y_a)$. For any of the three neighbor points $(x_i,y_i)$, an error, $E_i$ can be calculated ($A_i$ is the actual distance and $D_i$ is the distance estimated given $RSSI_i$).

$$E_i = | A_i - D_i |$$

$$E_i = | \sqrt{(y_i - y_a)^2 + (x_i - x_a)^2} - D_i |$$

The RSSI technique estimates the location by examining the state space and determining the point with the minimum sum of errors. The sum of the errors can be calculated by combining the errors from the three neighbor points: $$E_{sum} = \sum_{i=1}^{3} E_i$$

## 6 Results

An experiment was set up in the Western Michigan University Wireless Sensor Network Laboratory. The dimensions of the room are 22 by 9 feet, which is 198 square feet. The initial test used five infrastructure nodes (as illustrated in Figure 2). Fifteen uniformly distributed points (3 x 5 mesh) were used for objects to be located. The results are shown in Figures 5-8. In Figure 5, the minimum, maximum and mean errors are plotted for the potentiometer technique. A comparable graph is shown in Figure 6 for the RSSI technique. Figure 7 expresses the variability of the two techniques by plotting the standard deviations of the errors. The average time to locate for each technique is shown if Figure 8. We next discuss these results.

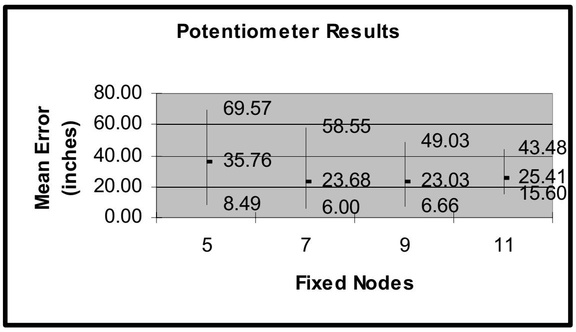


**Figure 5: Accuracy of potentiometer technique.**

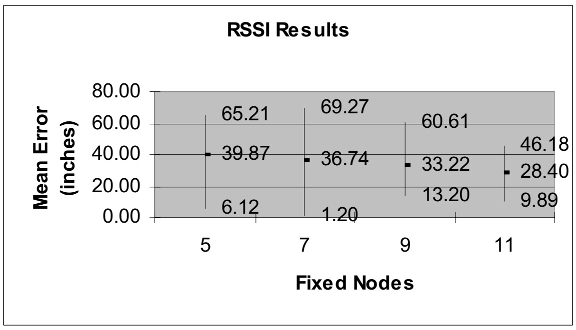


**Figure 6: Accuracy of RSSI technique.**

One way to improve both the accuracy of the system, as well as the time to locate, is to increase the density of the fixed nodes. Trials of both the potentiometer test and the RSSI test were run so that the system could be compared using five, seven, nine and eleven fixed nodes. As seen, increasing the density of the fixed nodes will improve the accuracy of the system. The accuracy of the RSSI sub-system continued to improve as the density increased, but the accuracy of the potentiometer sub-system reached a plateau when the number of fixed nodes in the lab was seven. By increasing the number of fixed nodes, the overall cost of the system is greater. The user must decide what level of accuracy is desired or needed in order to determine the appropriate density for the fixed nodes.

As seen in Figure 8, the time to locate in the potentiometer technique decreased as the density of the fixed nodes increased. Since the RSSI technique always takes five samples, the time to locate using this sub-system was constant, about nine seconds. The amount of variability in the localization decreased for both techniques as the fixed node density increased. Figure 8 shows the standard deviation of each system dropping from about 20 inches with five fixed nodes to about 10 inches with eleven fixed nodes.

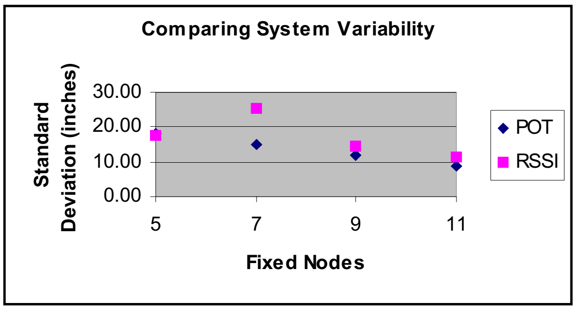


**Figure 7: Variability of the two techniques.**

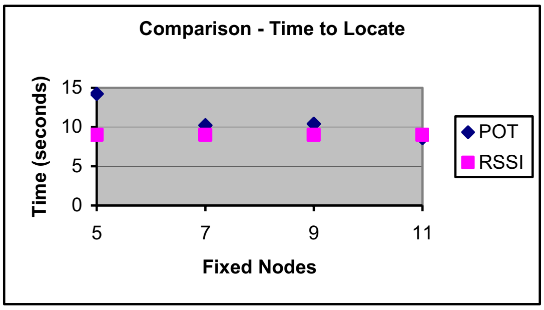


**Figure 8: Time to locate for the two techniques.**

# 7 Conclusions

Ferret, a low-cost localization system using wireless network sensors, was developed. This system gave decent results for locating objects, with a mean error of approximately 2 to 3 feet. Many improvements, however, are still necessary. First, using the third generation Mica2 motes should help improve the accuracy of the system. The Mica2 sensors have a higher quality radio than the Mica counterpart. Second, the calibration of the system is important. In a recent demo, the system behaved in a very different manner in a lab crowded with students than in a quiet, controlled environment. The system needs to be able to auto-calibrate quickly and seamlessly.

One strategy for calibration that might be used takes advantage of the fact that the positions of the infrastructure nodes are known. When calibration is needed, the infrastructure nodes that are neighbors of each other exchange a series of messages and examine the RSSI values. This strength should give an indication of the noise level for the current environment. Finally, the systems needs to be able to adapt when infrastructure nodes completely fail or begin to give faulty values. The most obvious strategy is to use redundancy. The questions then become "What density of infrastructure nodes is necessary?" and "When nodes start to fail, how is the accuracy of localization affected?"

# 8 Future Work

Our plan is to extend the current work so that we can develop an accurate, low-cost, low-energy, scalable ad-hoc location tracking system. To make this feasible, we need to provide the following:

1. **Accuracy**: As pointed out in [9], comparing the accuracy and precision of different location sensing tasks can be a difficult task. We propose to develop a metric for a location tracking system based on cost, space, and error margins. We plan to provide accuracy by fusing data from many nodes, instead of using only three data points as done by most systems.
2. **Low-cost**: Planning for larger-scale deployments, cost of individual elements becomes a crucial factor. We plan on using RF RSSI provided by network sensors. As technology continues to improve, these nodes will be mass-produced at a very cheap price.
3. **Low-energy**: When sensors are involved, power conservation is always an issue. With a large-scale deployment, this is even more the case. To preserve energy, our network of sensors will be in a sleep mode most of the time. Routing strategies that we use will also be energy conscious.

4. **Scalable**: Most research done in larger-scale location systems has been using simulations only. We would like to deploy a large network of sensors so that the unpredictable nature of indoor radio signal propagation can be analyzed.

5. **Ad hoc**: For a system to be truly ad hoc, the locations and distances between most of the nodes in the system cannot be known in advance. For large-scale location systems, fixing the location of nodes is nearly impossible. In order for our system to work, however, the locations of all infrastructure nodes must be known. To deal with this, we have begun work on developing a distributed topology discovery algorithm. RoyChoudhury,et al. [10] provide a distributed mechanism for finding a connectivity graph in an ad hoc network. In our topology discovery system, we use the RSSI from pairs of neighboring nodes to identify the 2-D coordinates of all nodes.

## Acknowledgements

Research is supported in part by the National Science Foundation under grants ACI-0000442, ACI-0203776, and MRI- 0215356, by the Western Michigan University (WMU), by the Department of Education grant R215K020362, and a Congressional Award, administered by the US Department of Education, Fund for the Improvement of Education. The authors would like to acknowledge WMU for its support and contributions to the Wireless Sensor Network Laboratory, Computational Science Center and Information Technology and Image Analysis (ITIA) Center. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the funding agencies or institutions. We would also like to acknowledge Junaith A. Shahabdeen for his initial work on the localization system.

## References

[1] Per Enge, Pretap Misra, *Special Issue on GPS: The Global Positioning System*, Proceedings of the IEEE, Volume 87, Number 1, pp. 3-172, January 1999.

[2] Roy Want, Andy Hopper, Veronica Falcao, Jon Gibbons, *The Active Badge Location System*, ACM Transactions on Information Systems, Vol. 40, No. 1, pp. 91-102, January 1992.

[3] Andy Harter, Andy Hopper, Pete Steggles, Andy Ward, Paul Webster, *The Anatomy of a Context-Aware Application*, Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom '99), Seattle, Washington, USA, August 15 - 20 1999.

[4] Paramvir Bahl, Venkata N. Padmanabhan, *RADAR: An In-Building RF-based User Location and Tracking System*, INFOCOM (2) (March 2000) pp. 775-784.

[5] Nissanka B. Priyantha, Anit Chakraborty, Hari Balakrishnan, *The Cricket Location-Support System*, 6th ACM International Conference on Mobile Computing and Networking (ACM MOBICOM), Boston, MA, August 2000.

[6] Kamin Whitehouse, David Culler, *Macro-Calibration in Sensor/Actuator Networks*, Mobile Networks and Applications, Kluwer Academic Publishers 2003.

[7] Jeffrey Hightower, Chris Vakili, Gaetano Borriello, and Roy Want, *Design and Calibration of the SpotON Ad-Hoc Location Sensing System*, August 2001.

[8] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, and K. Pister, "System Architecture Directions for Networked Sensors," *Proceedings of the 9th International Conference on Architectural Support for Programming Languages and Operating Systems*, November 2000.

[9] Jeffrey Hightower, Gaetano Borriello, *Location Systems for Ubiquitous Computing*, IEEE Computer, August 2001.

[10] Romit RoyChoudhury, S. Bandyopadhyay, Krishna Paul, *A Distributed Mechanism for Topology Discovery in Ad Hoc Wireless Networks Using Mobile Agents*, Proceedings of the 1st ACM international symposium on Mobile ad hoc networking & computing, Boston, Massachusetts pp. 145 – 146 2000.