

# Experiences with Location Sensing Systems at the University of Michigan\*

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## 1 Introduction

Over the last decade, a great deal of research has been done in location-aware computing. Making a user's location available to them, their computing devices, and optionally to other people creates many interesting research opportunities in areas such as mobile computing, ubiquitous computing, user interface design, and database design.

Many projects using location-aware computing begin by designing a location sensing system, then create projects and experiments based around that system. We decided to provide the location sensing system as infrastructure, so our various research groups could spend their time thinking about the “next step”—that is, what you can *do* with location information, rather than how to collect and process it.

To provide this infrastructure, we began work on a new project with the following goals:

- Developing a building-wide location sensing infrastructure using commercial, off-the-shelf technology.
- Keeping costs low enough for a large-scale installation, eventually spanning multiple buildings, and with many participants.
- Creating an interface to this system which is scalable, powerful, and respectful of users' privacy.

In the process of creating this infrastructure, we have evaluated a number of location sensing technologies, commercial and otherwise. We found that although information was available about research systems[10], there was little information about using commercial systems in research. We further found that the properties

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and costs of these systems varied greatly, and require trade-offs between infrastructure cost, client costs, and accuracy.

We'd like to share some of our experiences with these different technologies, as a starting point for others interested in creating similar systems. The basic information about each system we tried is summarized in Table 1.

## 2 Technologies Tried

When we began working on this project, we expected to take a look at a variety of working systems, then select the one that best met our requirements for cost, accuracy, and other factors. We instead found a wide variety of systems in a wide variety of places down the path towards “working.”

While we were searching for the perfect system, we tried out a number of different technologies, each of which had a different set of trade-offs.

### 2.1 RFID

Passive RFID is a technology for detecting the location of small tags within the antenna field of a reader device. We experimented with systems from Alien Technologies[2] and Matrics[4] based on the EPC standards[9]. We mounted the systems above the drop ceilings near doorways and hallways, and used tags mounted on 1/4 inch of foam backing then clipped onto the front of users' shirts.[12] The infrastructure costs for this system ranged from moderate to high, depending on whether readers were placed at all doorways or only at hallway intersections. The per-client costs were very low.

The chief advantage of this system is the very low client cost. The biggest disadvantages are the require-

ments for tags to be readable: we found that in order to operate correctly, tags must be fairly large ( $\frac{1}{2}$  inch x 3 inches to  $3\frac{5}{8}$  inch square), remain at least  $\frac{1}{4}$  inch away from the body to avoid interference, have a direct path to the antenna, and be oriented approximately parallel to the antenna. While these requirements are easily implemented for packaging, for a wearable tag they are a significant burden.

We also tried some experiments with active RFID, which uses more costly battery powered tags to give a longer range. We expected the longer range to help relax some of the strict requirements for tag readability. The range was longer and the orientation for the tags was more flexible, but the tags still needed to be kept away from the body and required a direct path to the antenna. We felt that these requirements remained a significant burden to a person wearing these tags.

## 2.2 Ultra-Wideband

Ultra wideband is a technology for transmitting very short pulses of information over a very large bandwidth. The book *An Introduction to Ultra Wideband Communication Systems* describes its most distinguishing feature: its “large instantaneous bandwidth enables fine time resolution for network time distribution, precision location capability, or use as a radar.” [7]. This property makes it a suitable technology for creating a robust location sensing system.

We used a Ultra Wideband system from UbiSense, [6] which is marketed to research institutions as a location sensing solution. The cost of the infrastructure for the system was moderate, and the tag costs were high. Tag lifetimes were advertised as 1 year, though we did not try to verify this.

In our initial tests, the results from this system were very good: with a few hours of calibration and setup, we were able to get accuracy within a few centimeters in a single 15 x 20 foot room. Unfortunately, when we tried to expand our tests to a larger area, we ran into problems, probably caused by interference from the metal building materials used in our cement walls. The sensors were not able to see the tags at all in most cases, and the system didn’t work. We plan on trying this system again in our new building, which was not built using metal grids in the wall.

## 2.3 802.11 Timing

802.11 is an interesting technology for location sensing because of its ubiquity. Since many users already have it in their laptops and PDAs, in many cases the cost to the client is zero, and there’s no additional hassle since they’re already carrying around the devices. As more and more 802.11 chipsets are sold, we expect prices to

continue falling. Additionally, there are already many people working on reducing 802.11’s power consumption, which is likely to improve tag lifetimes. We tried several systems which use 802.11 clients as devices to be tracked.

The first of these systems was from AeroScout. [1] It uses 802.11 “sniffers” mounted on the ceilings. These sniffers keep precisely coordinated clocks, and every time they see a signal from an 802.11 client, they record the time when the signal arrived. They then send this information to a central server, which uses a time difference of arrival (TDOA) algorithm to estimate the device’s location, assuming that the signal traveled in a straight line from the client to the AeroScout device. The infrastructure costs are high, and the tag costs are moderate, though in many cases there is no cost to the tags since they are already contained in laptops and PDAs. The battery lifetime of the tags is advertised as 3 months, and we did not try to verify that.

We tried this system in a square area of the building, by placing AeroScout receivers in hallway intersections at 4 corners of the square. We found that the accuracy was poor; AeroScout’s engineer suspected this was caused by the metal building materials in our walls. We plan to try this system again in our new building.

## 2.4 802.11 Signal Strength

Signal strength is another indicator of the distance between an access point and an 802.11 client. Although it varies too much to be used directly to calculate distance, the signal strength between a client and base station seem to remain fairly stable in the same room. We tried a system from Ekahau [3] that takes advantage of this situation: we provide their system with signal strength measurements to all of the “visible” access points in precise locations throughout the building, and it uses that data to create a statistical model. Their software then uses Bayesian techniques to give a location estimate based on signal strength readings.

Ekahau is primarily a software solution, which uses existing 802.11 hardware to gather most of its real-world data. Their server is Java-based, and runs on Windows or any flavor of Unix with a working Java virtual machine. Their client can run on any Windows-based laptop, or Windows CE-based PDA. It uses a proprietary protocol to communicate signal strength readings to the server. Tags are also available at a moderate cost, though the battery lifetimes are very short (approximately 1 day with location updates every second). Most of the costs for the system are licensing, and the per-client licensing cost is moderate in sufficient volume. There is no cost for the server apart from the client licenses, but the infrastructure requires a fairly

dense 802.11 network, and a great deal of labor to provide the sample points. In our case, the network was sufficiently dense that no additional infrastructure was required.

In our experiments, we found our laptop had a median error of 2.0 meters, and was able to locate the device in the correct room 86% of the time, and our PDA had a median error of 3.2 meters and was placed in the correct room 72% of the time.

## 2.5 Many Low-power 802.11 Access Points

A very simple way of detecting whether a device is near a location is by placing an access point there, then testing whether the device can detect the access point. We found that the signal can be blocked by a copper screen, which we used to stop it from bleeding into hallways or nearby rooms. This system is privacy-preserving, as all location sensing is done by the client.

We built a very simple system to test this idea; a real deployment would probably use something like PlaceLab.[5] The infrastructure costs are very high, and the clients are required to be a PDA or laptop that can do its own processing.

We found that, at least on a small scale, this system basically worked as we expected; however the costs were too high for large-scale deployment.

## 2.6 Many Low-power Bluetooth sensors

Similar to using proximity to 802.11 access points to detect whether a device is near a physical location, we can place a Bluetooth device in a known location, then see whether a Bluetooth scan[8] from a stationary “beacon” detects this device[11]; or have the beacon device scan for nearby mobile devices. By placing many of these devices throughout the building, we can determine a device’s location with some accuracy. The infrastructure cost of this system is moderate, and the client is required to be a PDA, laptop, or cellphone that can do its own processing.

On a small scale, this scheme seemed to work as expected. We were able to detect which of several Bluetooth devices we were closest to in a small group of rooms. We did not try it on a larger scale because of the cost and the lack of suitable Bluetooth tags.

## 3 Lessons Learned

In the process of analyzing all of these systems, we learned a number of important lessons.

First, the performance of these systems is very dependent on the environment. For example, we were

surprised how much factors like the building materials used in our building could affect some of these systems, and how much proximity to the body degraded the performance of RFID. Further, the system specifications provided by vendors often make very optimistic assumptions, and can differ greatly from real-world performance.

Second, user factors are very important. We got fairly far into designing a system based on passive RFID before determining that the tags would be inconvenient for users; we would have made faster progress if we’d considered this and rejected the system much earlier in the process, rather than after much of the technical work was done.

Finally, location sensing is still an immature industry, and there is no clear leader. We looked at a lot of systems trying to find the “best one,” but found instead a set of trade-offs to choose from.

## 4 Ongoing Work

After examining all of these systems, we have initially selected Ekahau as our primary system, though we’re still working out the details. After things are finalized, we will begin installing this in our new building, and finding areas with poor accuracy and adding supplemental access points.

We have developed a privacy system to protect users location information, and are working on integrating it into a query infrastructure. We are also working on improving the query infrastructure; currently it broadcasts all information to all subscribers, and we’ll need to refine that before we can use it on a large scale.

Table 1: Summary of commercial location sensing systems

System	Accuracy	Infrastructure Cost	Per-Client Cost	Tag form	Tag Lifetime
Passive RFID, Hallway Thresholds	Hallway	Moderate	Very Low	Thin tag + foam, on shirt	Infinite
Passive RFID, Room Thresholds	Room	High	Very Low	Thin tag foam, on shirt	Infinite
Active RFID, Hallway Thresholds	Hallway	Moderate	Moderate	Keychain-sized tag, on shirt	Unknown
Active RFID, Room Thresholds	Room	High	Moderate	Keychain-sized tag, on shirt	Unknown
UbiSense	Unknown ( $\frac{1}{2}$ meter <sup>1</sup> )	Low	High	80cm x 60cm x 20cm block	Up to 1 year
AeroScout	Unknown <sup>2</sup>	Moderate	Moderate	802.11 device, or 50cm x 30cm x 10cm block	Up to 3 months
Ekahau	Room	Very Low	Moderate to High	802.11 device, or 60cm x 60cm x 20cm block	1-10 days
Many Low-Power 802.11 APs	Room	Very High	Moderate	802.11 device	Device lifetime
Many Low-Power Bluetooth Sensors	Room	Very High	Moderate	Bluetooth device	Device lifetime

<sup>1</sup>This system worked poorly in our building, but in smaller tests had an accuracy of about half a meter.

<sup>2</sup>This system worked poorly in our building; documented accuracy is about 1 meter.

## References

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