# Widespread Easy and Subtle Tracking with Wireless Identification Networkless Devices -- WEST WIND: an Environmental Tracking System

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## Abstract

*In this paper we introduce and describe a radio frequency-based system for location identification and tracking. The basic design of the system consists of transmitters in the environment, transceivers on the person or object for which location information is desired, and a receiver in the environment. Each of these three pieces of hardware and their associated software are discussed in this paper. We also talk about system design considerations, privacy concerns, and current and future applications of the system.*

## Background

This system was initially designed as a person tracking and location system in the Aware Home Residential Laboratory [1]. In that paper we discuss the need for a system that allows us to determine where in the home a person or object is located. The West Wind system is designed to meet that need.

The Aware Home is a two-story house plus a basement and attic. Each floor is approximately 1,400 square feet, giving a total finished size of over 5,000 square feet. We wanted a system that would allow us to track people and objects in at least the two main floors. The construction of the house is a normal wood frame, allowing radio frequency signals to easily pass between floors and rooms.

The design for this system was inspired by the work done on the Locust system [4]. This system uses infrared (IR) beacons in the environment to transmit unique IDs. Each beacon has a limited transmit range creating a small cell. A receiver could then pick up the IR signal when in that cell and interpret the ID as location information. The basic idea is the same for our system only using RF transmitters. The transmitters placed in the environment send out unique IDs. A badge worn by the person then interprets the ID as location information. This part of the system was originally developed for the location system in the augmented-audio game Guided by Voices [2]. We have further extended the system in West Wind so that the badge on the person can selectively retransmit the position information back to the environment to be used by other applications.

## Design Considerations

One of the key design considerations for West Wind is that of privacy. We wanted to explicitly support the privacy of the users of the system. Like the Locust system, West Wind handles privacy concerns very well because of the basic model used in the system design. The system is inherently private because the transmitters are in the environment and the receiver is on the person; this is similar to the design of the Global Positioning System. With this model people control their own location information through their badge. If the situation were reversed and the transmitter was on the person and the receivers form the cells in the environment then the environment would have to be trusted to handle the sensitive location information correctly. We believe that a system allowing user control is inherently more privacy-conscious compared to one that has the user trusting the environment.

Although giving the user control over revealing their identity is critical we also need to allow other systems in the Aware Home the ability to get the location information of the person. West Wind extends the ability provided in the Locust system and the positioning system of Guided by Voices by providing the ability to rebroadcast the person's position information back to the environment using the infrastructure. Although this is a privacy concern, we have several mechanisms to allow the user to select between various levels of privacy that in turn would enable different levels of functionality in the end applications.

First, even though the badge is transmitting, the environment can not use just that information to reveal identity. This is because there are very few receivers for the retransmitted position information (as compared to a large number of beacons). The small number of receivers limits the ability to localize a badge in a similar fashion as to how the badge localizes itself among the small environment cells. Furthermore, because we have a

microcontroller on the badge, in can relay different types of information to the environment providing different levels of privacy. In the simplest mode it can simply act as a repeater, retransmitting any information it receives. The badge could further enable greater privacy by selectively broadcasting the location information in a variety of ways. It could only retransmit in certain areas – i.e. only send out my position information if I get beacon numbers 1, 7, or 42. Or it could change the precision to which it reported the user's location. For example, it could report only the presence of the user in the house, the general area the user is in, or the exact location of the user.

Another dimension of privacy the system enables is that of anonymity. In the situations above, the badge retransmits the location information as well as an identifier specifying which badge is where and therefore the location of each person. The badge could also send this information without a person ID. This would inform the house that there is a person at the given location, but the system would not reveal who that person is. Another possibility is to just reveal an ID that maps to a group of people and not to an individual.

Using the transmitter/receiver configuration of West Wind also has logistical advantages. By having the transmitter on the person and the cell receivers in the environment all of the receivers would need to be networked together. With our system, the transmitters in the environment are independent; all they need is power. This makes the system simple to deploy. One could go into a new area and distribute beacons, only recording where they where left for future use.

## System Design

As mentioned above there are three components that make up the location tracking system West Wind. These pieces are the transmitters in the environment, a transceiver in a badge on a person or object to be located, and a receiver in the environment. The following figure shows the relation of each component within the environment:

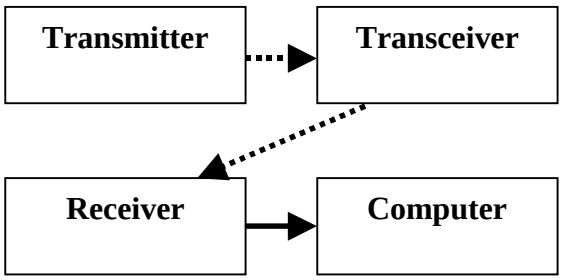


Figure 1. System diagram

Here, the dotted lines indicate a wireless connection, and the solid line is a wired connection.

Figure 2 shows the layout in the Aware Home. The circles represent the area covered by the transmitters in the environment.

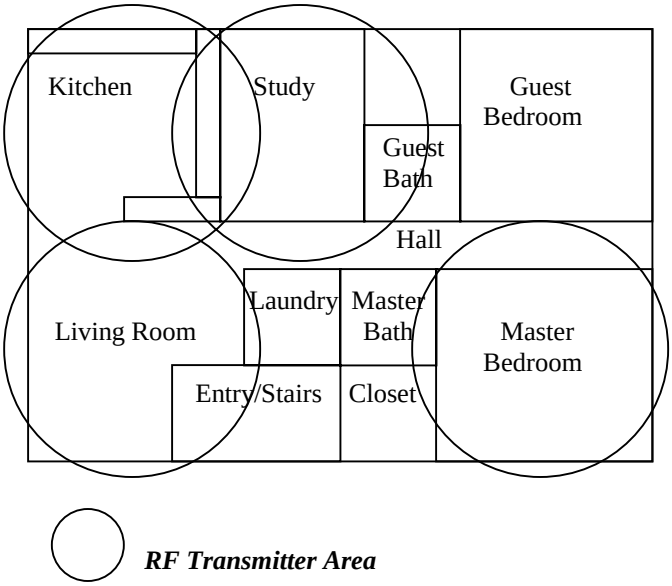


Figure 2. Aware Home RF layout

West Wind employs multiple transmitters in the environment. Each one creates a small cell providing a separate zone of identification. In our preliminary setup we have one transmitter per room. Each of these transmitters broadcasts a unique identification number approximately once per second. The transceiver in a badge on the person receives the ID number from any nearby transmitters in the environment. The badge then attaches its own identity, and transmits the new data packet on another frequency to the environmental receiver. This receiver is listening to a large area (currently the whole house) for any badge broadcasts. The receiver passes the information through a serial connection to a computer where it can then be used by interested applications.

## Implementation

West Wind was developed using commercial components. This enables a low cost designed and allowed for rapid implementation.

The Microchip PIC16F84 microcontroller [3] is used throughout the components of the system. The flash memory of the device allows programs be re-written easily enabling rapid prototyping. The PIC16F84 also operates over a large range of voltages and uses little power, typically running at less than 2mA at 5V and 4MHz. In addition, it includes a watchdog timer that allows the microcontroller to enter a lower power sleep

mode when inactive and then to automatically wake up after a period of time. In this mode it typically operates at 7uA at 4V.

The radio transmitters used for West Wind are from Abacom. These transmitters operate over a large range of voltages (2-14V) and are low power (typically 4mA). The transmitters can send data at up to 4 kHz and are small, measuring only 10.16mm by 17.78mm. The Abacom receivers run from a 5V supply and typically consume about 2.5mA and can receive data up to a rate of 2kHz. The receiver is only 13.7mm by 38.1mm.

The transmitters placed in the in the environment for West Wind are designed to be small and low powered. They consists of a PIC microcontroller and support electronics, an Abacom 418MHz AM transmitter, a voltage regulator, and a battery. The software on the transmitter is responsible for sending a unique ID approximately once a second. During one cycle, the transmitter wakes up, powers up the RF transmitter, sends the ID, powers down the RF transmitter, and finally goes back to sleep.

The out going ID is encoded for error detection/correction because the raw RF channel is quite noisy. We are currently using Manchester Encoding. Although this is not really an error correction code it can easily detect if the incoming data is properly formatted and allows us to throw out data that is obviously bad. For example, the system often receives noise that is composed of mostly 0's or mostly 1's. The Manchester Code balances the number of 0's and 1's easily detecting this type of common error. The Manchester Encoding also keeps the data DC-balanced which aids in the radio reception. The next type of error detection we wish to try is Hamming Encoding. This will allow us to detect 2-bit errors and correct 1-bit errors in an 8-bit byte.

The next piece of the West Wind system is the transceiver badge worn by the person to be tracked. It is also a very straightforward design consisting of a PIC and support electronics, an Abacom 418MHz AM receiver and an Abacom 433Mhz AM transmitter. The badge software can vary in complexity. Our current implementation just retransmits each id received from a cell and attaches a badge ID. The software on the badge is in control of the retransmission of the user's location. The program on the badge could be configured based on the user's preferences to allow for the various levels of privacy desired.

The receiver, or base station, located in the house consists of an Abacom 433MHz AM receiver and MAX 232 serial line driver. This base station is attached to a PC through a serial communications port. The software running on the PC decodes the information coming from the receiver. It processes this information using the badge ID to determine the person this data is for, and the cell ID to infer the person's location. This information is currently fed into an application that shows the user's location on a map of the house. Future applications would get their location data from this PC.

The way we accommodate two types of transmissions (those from the environment to the receivers on the badge and those from the badge back to the house) is by using two different frequencies. The environment-to-person communication operates on 418 MHz and the communication between the person and the house is on 433 MHz. This frees us from trying to synchronize the two types of communication and reduces the amount of contention for each channel. The retransmission of identity could also occur on any other wireless data network such as wireless Ethernet or Bluetooth. We provide the second radio channel for a fully self-contained solution.

One type of contention that we are aware of is the possibility that two overlapping zones are broadcasting their number at the same time. If a transceiver is simultaneously located in both zones and this occurs, there will be a collision and the beacon information would be lost. This is mediated by having each transmitter sleep for 1-second +/- a small random wait time between transmissions of its ID number. This prevents transmitters from continuously sending at the same time.

## Applications

We are currently working on integrating this system into the Aware Home infrastructure. We are using several systems to obtain location information on individuals in the home including this system, a location system from PinPoint Corporation, and a computer vision tracking system. One of our goals with tracking is to combine several systems' data to give more accurate information on where someone is in the home or to allow us to use one system in an area or situation where another system may not work.

One application that we have implemented is a baby monitor that follows the user. This is designed so that there is a microphone in the room with the baby and speakers throughout the house. A parent or caregiver can then start the baby monitor application and then walk throughout the house and have the sound of the infant follow them without having to carry a wireless speaker.

Another application that we are building that will use this system is an intelligent intercom that automatically routes between two locations that are endpoints for a conversation. The West Wind infrastructure will allow us to know the location of the individuals who are using the system for conversations.

## Future Work

Future work on the system will focus on three areas: privacy, usability, and reliability. We want to implement a software system that will allow the user of the system a greater deal of control over what information the house can know about them. If we combine the transceiver with a wearable computer, it will give a greater range of options for the software that can be run and the user interface that can be presented. We will look into both combining the transceiver with a wearable and possibilities for expanding the interface on the physical transceiver.

Usability and reliability are to issues that must be addressed in order to use the system on a regular basis in the home environment. Usability includes the interface discussed above and also the form factor of the device. The transceiver is currently a small soldered breadboard that will be put in an enclosure to be worn on a person. This relates to other issue, reliability, in that the physical board is now easy to break. Before the West Wind system can go into continuous use it needs to be made more durable.

A final improvement that we are working towards is drawing power from the environment to run the transmitters. We plan to calculate the amount of power available from ambient RF in the environment and then work to decrease the power consumption of the transmitters to see if we can power them from this source.

## Conclusions

We have found that the West Wind system is a feasible solution for providing location information in the home environment for which it was initially constructed. The ability to deploy as few or as many beacons throughout the environment has allowed us to add more as other projects necessitate. We plan to continue using and improving this system for our needs.

This system handles privacy in a way that we have found to be advantageous. We believe that the ability for the individual to control the amount of information that is known about them is an important aspect of an environment that is gathering information on the individual. This is another area of this system that merits our attention when using this system in other applications.

## References

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