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Wireless Location Determination: Using Existing 802.11 Wireless Networks to Determine a Users Location

Travis Calvert
Minnesota State University, Mankato

WIRELESS LOCATION DETERMINATION: USING EXISTING 802.11 WIRELESS NETWORKS TO DETERMINE A USER'S LOCATION

Travis Calvert (Computer Science)
Dr. Steven Case, Faculty Mentor (Computer Science)

The ability to determine a user's location through an existing 802.11 wireless network has vast implications in the area of context-aware and pervasive computing. Such abilities have been developed mainly in the Linux environment to date. To maximize its usefulness, a location determination system was developed for the more dominant Windows operation system. While being able to operate outdoors as well as indoors, this system succeeds where traditional GPS (Global Positioning Systems) fail, namely indoor environments. This system could benefit the large number of existing wireless networks and requires no additional hardware; only a few simple software downloads. The ability of a user to determine his/her location with the click of a button and begin using the services in the immediate vicinity or be shown a map leading to the desired area/item (a book in a library for example), are but two illustrations of the benefits that a wireless location determination system serve.

1 Introduction

With the introduction of the MavNet [12] to the campus of Minnesota State University, Mankato in the summer of 1998, the promise of greater electronic services offered to students and faculty was made. The fulfillment of that aim is continuing to be realized in ways that expand the possibilities of what technology can do to further education. Currently the campus of MSU is covered by a large number of Cisco 1200 Access Points and wireless connection to the MavNet is available in most all buildings on the campus.

The ability of a user to determine their location with a few software downloads and the click of a button, using existing 802.11 networks, can lead to new and expanded services for mobile computer users. Such services might include; being able to send documents to a printer in the users near vicinity, creation of an active map that included the users location (could be extremely helpful when locating resources in the library or for introduction of new students to campus), asset tracking (location of a device such as PDA's on loan for example), and as an aid in locating other students and faculty on campus. These services have yet to be implemented, as first the ability to determine location must be established.

Global Positioning Systems (GPS) make use of 24 satellites orbiting the earth in geosynchronous orbit that transmit their position and time of day to any device on the Earth's surface that happen to be listening[1]. A GPS device, through triangulation of multiple signals received and determination of propagation (how long it took the signal to go from the satellite to the GPS device), is able to accurately determine a users location to within a meter. The problem with GPS is that the device must have a clear line of sight between itself and the satellite. This means the technology is unusable in heavily forested areas, urban environments with tall buildings and indoor environments.

The popularity of wireless 802.11 networks over the past few years has grown significantly and provides an excellent opportunity to include location based services in indoor environments, where GPS fails. With the wireless networks in place, a user with a laptop or PDA and an 802.11b network card needs no further hardware. A few simple software downloads are all that is required to begin using location determination.

There has been a great deal of research done on this topic and therefore the aim of this paper is not to illustrate any new techniques in location determination. Rather, the intent is to demonstrate how one can access and utilize the data necessary for location determination as performed on a Windows machine, as most research this author has read deals with Linux environments. As Windows continues to be the dominate operating system for laptops and some PDAs, most users would benefit from a having location determination system designed for that platform.

2. Related Work

A recent search on WiFiPlanet.com [9] revealed an article that detailed several commercial organizations who manufacture and sell wireless location determination software. Ekahau, being the first of these, provides a "positioning engine" that on average can determine a users location within 1 meter, for which retail prices begin at $2995. Another commercial developer of wireless product and services, WhereNet, does not list prices on their website. However WhereNet's location determination services are dependent upon using WhereNet's proprietary access points, a costly investment to be sure.

Turning away from commercial vendors and instead looking toward academic research it became clear that the methods of determining user location through wireless networks have already been documented in several journals. The most notable of these, "RADAR: An In-Building RF-based User Location and Tracking System" [2], comes from a Microsoft Research team consisting of P. Bahl and V.N.Padmanabahn. Ironically enough in the course of their paper they disclose the fact that they were using a system running FreeBSD rather than Windows. Nonetheless, the paper explains how they were able to determine a user's location with a median error of 2 to 3 meters. Their basic approach was to take sample of radio signals and correlate them to known physical locations during what they called the offline phase. Once these samples were taken and stored, a linear search, in what was dubbed the real time phase, of all recorded samples was performed and the closest (in terms of radio signals) match was determined to be the user's location (this is what is known as a nearest neighbor search). Additional gains in accuracy were made by averaging the three closest locations found during the search; what is referred to as triangulation. Means of determining location via formulating radio propagation models were discussed, but proved to be less accurate. This study appears to be the gold standard of wireless location determination research, as most other research articles dealing with wireless location determination refer to this study.

Another study conducted at Carnegie-Mellon University [13], applied much the same technique as the RADAR study, with some additional gains in accuracy. Here again the basic technique was triangulation, with the main difference being implemented in a "table-based lookup." The improvement in accuracy was due mainly to a larger number of samples being taken during the off-line phase and averaged, and also the fact that this study was conducted in an environment that allowed for clear line of sight. Also of note in regards to this study was the mention of the large number of samples that would be required to map out an entire campus, an extremely important consideration when thinking ahead to PDA and cell phone applications. The possible remedy mentioned in this study is to divide the radio samples into smaller maps based upon the Access point the user is currently connected to. This study, while making significant contributions to accuracy and size of radio map concerns, does not stray far from the original RADAR study.

A University of Maryland [14] paper published last year, formally proves that the accuracy of wireless location determination will be greater when using probabilistic rather than strictly deterministic techniques. The two studies mentioned previously both rely upon deterministic techniques. The idea behind a probabilistic technique is that a search to find location is based upon which location in the stored radio map "has the maximum probability given the received signal strength vector."[14] Even though this study proves the superiority of probabilistic approaches, the implementation of a wireless location determination must be done one step at a time.

3. Methodology

All mention thus far has been on the location determination algorithms and techniques, with no mention made of how one extracts the necessary data from the network adapter card. In order to communicate with the network adapter, a Windows specification known as NDIS (Network Driver Interface Specification) [5] can be used via a device driver and Protocol Manager to "bind" to the adapter and issue commands or make queries to the network adapter. The task of writing a device driver is not easily achieved, however after several Internet searches a universal application programming interface(API) known as RawEther was found to suit the needs of this particular project. RawEther is " … a framework for development of Windows products that 'directly' access NDIS network interface (NIC) drivers from Win32 applications." [7] Downloading and installing the RawEther sample executables launches an installation wizard that: selects and installs the appropriate version of NDIS protocol driver for your version of Windows, installs a Direct Link Library (DLL) that is used to hide platform dependencies, and a several sample applications. Once these files are in place development of applications that extend the functionality of the original RawEther executables can begin.

After having contacted Thomas F. Divine, the creator of RawEther, at PCAUSA; he was kind enough to grant MSU usage of the source code of RawEther for academic use. All of the executables found in RawEther were written in Visual C++ 6.0. Thanks to the MSDNAA partnership between MSU and Microsoft, a download of Microsoft Visual Studio allowed for editing and extension of the RawEther samples.

The RawEther sample that was found to be the most useful in developing a location determination system was one called WLANDetect. This application simply searches through all network adapters on a users system and queries them to determine if they are 802.11 capable (wireless), if so a simple little dialog box pops up and displays information regarding the adapter such as: adapter name, connection status, the cards'

MAC address, signal strength (of the AP to which it is connected), MAC address of the AP, etc. This application was chosen to base a wireless location determination application from because of the automatic detection and binding to the user's wireless card which makes for easy queries to the card.

A Microsoft document entitled "IEEE 802.11 Network Adapter Design Guidelines for Windows XP" [10] explains the structures that are used in making NDIS requests (set) and queries of a wireless NIC. The two most important Object Identifiers (OID)s used for a location determination system are called OID_802_11_BSSID_LIST_SCAN and OID_802_11_BSSID_LIST. The first of these is a request to the NIC to perform a background scan for any Access Points (APs) that might be able to communicate with the NIC. The second is a query to the NIC that returns a list of all APs detected and their attributes. These two operations form the basis of extracting the necessary data to determine a user's location. There was one other OID that became necessary to use when it was determined that the list returned by the NIC was not removing or updating information from APs that were no longer within range of the NIC. The solution to this problem was to issue a request called OID_802_11_DISASSOCIATE. Issuing this request to the NIC forces the radio to turn off. The automatic configuration of Windows would then re-start the adapter, and then a List Scan and List query could be called which would no longer contain outdated information from APs that could no longer communicate with the NIC. The rest of the application consists of data manipulation and displaying that data to the user.

In building the application another interesting consideration arose. The previous work that has been done on this subject was simpler in certain respects of the testing environment. The Carnegie-Mellon study [13] for example was only conducted along a one dimensional linear path. Both the RADAR [2] and Carnegie-Mellon [13] studies were conducted in an environment in which the number of APs "audible" throughout the entire test bed were of a fixed and constant number. Also of note is the limited size of the physical space being measured in those studies (980 sq. meters and 200 ft., respectively.)

The most troubling of these aspects in the complexity of the testing environment is the varying number of APs that one would encounter in a real world environment. The formula given in the RADAR [2] example for finding the nearest neighbor (of radio signals) is identical to that of Euclidean distance measures: $\text{sqrt}((ss_1-ss_1')^2+(ss_2-ss_2')^2+(ss_3-ss_3')^2)$, where there is a constant of three APs audible at all points in the test bed. Obviously, this would cause problems in a nearest neighbor search in which the number of APs was varying (the more APs on record that matched the real-time samples' data would increase the radio distance given by the Euclidean function.) The approach that was discovered for this project was to reward or give credence to an AP that matched the real-time sample to each of those on file. When comparing the real-time sample with those records on file a score of 100 points was given to an AP record that matched that of the current real-time sample, which was then decremented by the absolute value of the difference between the signal strengths. Writing this a formula in a more formal fashion could be described as follows:

? (100-(abs(ss-ss'))), for all matching APs.

While there may exist better methods of location determination, this one suffices to produce results roughly equivalent to that of the original RADAR study as explained in the next section

4. Test Results

For this study the Minnesota State University, Mankato Memorial Library was chosen as the test-bed, due to its rectangular shape that is oriented perpendicular with a North-South line, and its considerable hours of availability. The southwest corner of the library was chosen as the origin so that all locations plotted in the library could be described as positive integers. According to Minnesota State University, Mankato grad student James Beal [3], the MSU library measures approximately 100 by 55 meters, as determined by aerial photography. Comparing this building dimension with the online library map [11], it can be determined that every vertical column is approx. 6.66 meters apart and therefore every third column that can be found in the library is roughly 20 meters away from each other.

Radio samples were taken at the origin, every 20 meters (in both the X and Y dimension), and along the North wall (which was estimated to be 55 meters from the south wall) as shown below in Fig 1.

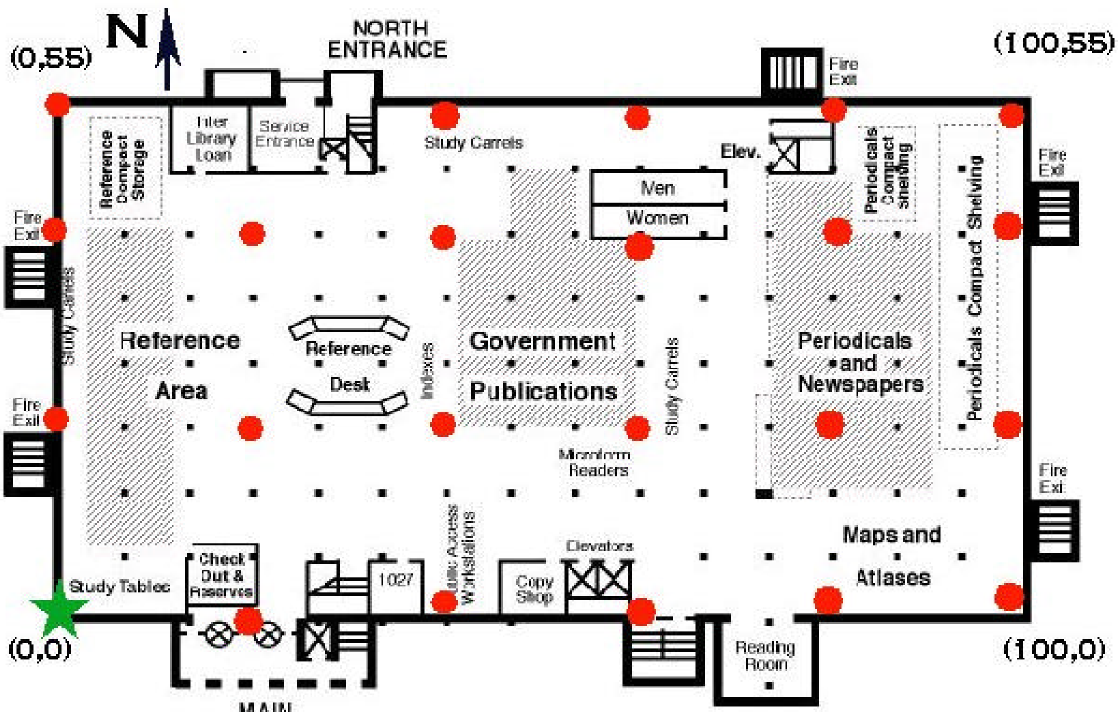

Figure 1: Library Map (First floor)

***Note (Samples could not be taken at location (20,55))**
**** Map is altered version of map found at: http://www.lib.mnsu.edu/lib/libmap1.html**

In all 23 samples were taken on the first floor, in addition to 23 samples of the second floor (6 meters above the first floor), for a grand total of 46 locations sampled.

Additional functionality was then written in to the software application that would allow a location that had previously mapped to be re-visited and the radio signal data for that location to be given a weighted average according to the number of times that location had been sampled. The reason this was done was to accommodate for natural fluctuations that occur when measuring signal strengths. The first floor was then re-sampled at all locations an additional four times.

Once all this radio signal data had been gathered, attempts at determining user location began. Over five separate days and at varying times of day, 71 attempts at determining location were made (nearly all of which being one of the 46 locations mapped) . Just over half (52%) of all trials, returned the exact location. The mean distance error was calculated to be 12.16 meters.

These results follow closely with the RADAR [2] study when one considers the physical space and number of samples taken. In the RADAR study the physical space being mapped was a mere 998 sq. meters versus the 5500 sq meters that comprise one floor of the MSU library. The distance error reported in the RADAR study was claimed to be achievable in the 2-3 meter range, given that at least 40 samples were taken. In this paper the distance error of 12 meters, while seemingly large (4 to 6 times as large), is comparable due to the eleven fold increase in the size of the physical space being mapped versus the nearly identical number of samples being taken.

5. Future Work

In order to verify that the results achieved herein are indeed comparable to previous work, more samples need to be taken on a tighter gradient. Measurements could be taken at every vertical column in the MSU library (every 6.66 meters). Additional gains in accuracy could be gained through means of triangulating the three closest neighbors and implementing additional statistical methods as described in the University of Maryland study [14].

Other advances that could be made on this project, while not necessarily dealing with the location determination techniques, could include porting the application to a Pocket PC, including a graphical display of coordinates onto a live map, and updating the radio map file(averaging radio signals) after a search is performed and can be trusted to have provided accurate results.

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Author biography:

Travis Calvert is a senior at Minnesota State University, Mankato majoring in computer science. He is the proud recipient of a 2002-2003 National Science Foundation scholarship and a 2003-2004 Department of Computer Science scholarship. His primary research interest has been in using pre-existing 802.11 wireless networks for location determination techniques. After graduating from North Iowa Area Community College in1993, he has worked as an Electronics Technician, and is currently employed as a Robotics Maintenance Technician.

Faculty mentor biography:

Dr. Steven Case is Assistant Professor in the Department of Computer and Information Sciences at Minnesota State University, Mankato. He also serves as the Director of the Center for Pervasive Computing and Communication. Dr. Case received is doctorate from Nova Southeastern University.

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