Building models of Wireless Local Area Network coverage

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Abstract

Wireless LANs are becoming more and more popular because they can provide high data rate network access to computer users without the tradition cable. Additionally mobile devices allow people to have connectivity, even when moving from place to place, additionally they are small in size and light in weight. While such devices only offer some of the capabilities of PC they are more convenient to use than a desktop PC when traveling. Cellular phone and smart phones have more function than before, with some newer models phone having an embedded GPS receiver. This GPS receiver can provide user with new services, in addition to location information. Many of these handheld devices include wireless LAN functionality, enabling people to walk from one place to another with a continuous network access, via either the WLAN or the cellular network. By using voice over IP, a wireless enabled hand device becomes a Virtual Cell Phone enabling low cost calls via the WLAN when the user is within coverage of an access point which will give them access, or via the normal cellular phone network (when with in coverage).

Because the WLAN coverage is not ubiquitous, it is important to build a Wireless Network Coverage model to enable every user to see where there is WLAN network coverage. Present methods to create such a coverage map require a lot of work to collect data, both indoors and outdoors. Currently a lot of human effort is needed to collect, process, and format this data. The method proposed her could provide an easier way of gathering data from the field and be simple enough that even a normal user could collect data and contribute it to help generate a coverage model of areas where they visit.

The measurements reported indicate that it is possible to combine data from multiple devices of the same and different types, but only when the signal strength is high. Fortunately, it is just these areas where the signal quality is good which are of interest to users. The thesis also shows one way of presenting this data in an easy to understand visual manner as an overlay on Google Earth.

Sammanfattning

Trådlös LANs blir mer och mer populär emedan de kanna skaffa hög datanhastighet nätverken tillträde till computern förbrukaren utantraditionen kabel. Ytterligare rörlig anordningen tillåta folk tillhar connectivity, jämn när flyttanden från ställe till ställe, ochblir liten i storlek och ljus i vikt. Fördriva tiden sådan anordningenbara erbjudande något om anlagen av PC de er mer bekväm till användaän en desktopen PC när resande. Cellular telefonerna och "smart"telefonerna har mer funktion än framför, med något nye modellernatelefonerna har inbyggd GPS. Den här GPS ta emot kanna skaffaförbrukaren med ny tjänsten, dessutom till läge informationen. Mångaav de här handheld omfatta trådlös LAN funktionellitet, sättande istånd till folk till gå från en ställe till en annan med enkontinuerlig nätverken tillträde, via WLAN eller den cellularnätverken. Vid användande röst över IP, en trådlös sättet i stånd tillhand anordning blir en Verklig cellular telefonerna sättande i ståndtill låg kostnad telefonsamtalen via den WLAN när förbrukaren ertäckningenhåll av en tillträde punkt vilken vilja ger dem tillträde,eller via den normal cellular telefonerna nätverken (när i täckningenhåll).

Emedan den WLAN täckningen är inte allmänt utbredd, den er viktig tillbygga en Trådlös Nätverken Täckningen modell till möjliggöra varjeförbrukaren till se var där er WLAN nätverken täckningen. Föreställametoderna till skapa sådan en täckningen karta behöva mycket verk tillsamla datan, båda indoors och utomhus. Just nu en masse mänskliganssträngning är behövde till samla, förlopp, och formaten den härdatan. Metoden föreslå här kunde skaffa en lättare väg av samlingendatan från fält och bli enkel nog så pass jämn en normal förbrukarenkunde samla datan och bidra med den till hjälp generera en täckningenmodell av områdena var de besöka.

Måtten rapportera ange så pass den er möjlig till kombinera datan frånmångfaldig anordningen om det lika och olik typen, utom bara närsignalen styrka är hög. Lyckligtvis, den er rättvis de här områdenavar signalen kvalitet är god vilken är om intresse tillförbrukaren. Theses också visar en väg av presenterande den här datani en lätt till förstå visuell sätt så en täcka över på GoogleEarth.

Acknowledgements

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Chapter 1 - Introduction

Users with a wireless capable device would appreciate seeing the general map of their wireless network service provider's coverage area. If this coverage map shows exactly wireless network access is available, it will enable wireless network users to select their travel path to enable them to utilize their wireless services as they travel. Network service providers could use such a wireless coverage map to show their customers their wireless network, clearly indicating where their customers can access the network and where they can have good service in the city. This information could help network planners to relocate or add more access points where there is poor or no wireless LAN coverage. City wide wireless networks are being created in many big cities around world. Because of the large area which needs to be covered and the lack of sufficient frequencies to allow non-interfering cells - there will be a need to also visualize which channels are being used where to allow network operators to adjust the parameters of this heterogeneous network. The existence of a network coverage model can help this process. Wireless local area networks enable high data rate network connection at a low price because there is no traditional cabling which needs to be installed to each device, but rather the cables only need to run to the access points. A city wide IEEE 802.11 wireless network would enable everyone living, working, or visiting in this city to have a flexible way to acquire information. Wireless cities could build a digital infrastructure to help residents obtain information about jobs, entertainment, to enhance their education, etc. It could also help businesses, schools, and community organizations make use of wireless technology to encourage economic development and achieve their goals. But all these scenario will come to true only if the potential users know where this wireless network access is available (as it will not be ubiquitous for quite some time), otherwise they will not trust in the availability of such a wireless network, unlike the traditional wired network because they can see where the network outlet is on their wall. Thus a key aspect of a wireless coverage map is to help manage the user's expectations, i.e., if the user believes that there is coverage in a given area and can easily find this are they are happy and if they are told that an area does not have coverage, then they are not surprised when there is no coverage there; hence they can accept this lack of coverage if they are warned about it.

Today, more and more wireless access points have been set up for both business and residential use. In the downtown area of most cities, there is thousands of IEEE 802.11 wireless networks put in place by restaurants and cafés for their customers. Some of these networks are totally free and usable by a person who wants to surf on Internet when he or she is outside on the street. However, a wireless home access point is usually design for indoor use only. The purpose of wireless access point is to provide IEEE 802.11 wireless network coverage inside the house, but wireless signals also propagates to some areas outside the house. Generally the home owner who wants to set a small area wireless network does not think about this unexpected coverage, expect to consider it in terms of the increased security risks. Therefore, may people with such home access points use some means to try to limit who can access the network via their access point. Some of these methods, such as Wired Equivalent Privacy (WEP) had severe security weaknesses, and turned out to be easily cracked[1], other methods provide to provide only the illusion of security (such as hiding SSID or MAC address access control list)[2], and some seem to provide higher security, such as WPA(Wi-Fi Protected Access)[3] and WPA2(also known as IEEE 802.11i)[4].

A residential wireless access point usually has a range of 30 to 40 meters indoors and 150 meters outdoors.Enterprise access points are designed for working in environments such as factories and warehouses. Additionally, ruggedized access points have been designed for outdoor use. One type of access point using in Forum is CISCO Aironet 1200 Series, and it is a component of the Cisco Unified Wireless Network [5]. Aironet 1200 can be deployed and managed easily with improved security, scalability, reliability. But its coverage range shows in Table 1.

Table 1: Range of Cisco's Aironet 1200 Series [5]

Outdoor	Indoor
· 110 ft (34m) @ 54 Mbps	· 90 ft (27 m) @ 54 Mbps
· 200 ft (61 m)@ 48 Mbps	· 95 ft (29 m) @ 48 Mbps
· 225 ft (69 m) @ 36 Mbps	· 100 ft (30 m) @ 36 Mbps
· 325 ft (99 m) @ 24 Mbps	· 140 ft (43 m) @ 24 Mbps
· 400 ft (122 m) @ 18 Mbps	· 180 ft (55 m) @ 18 Mbps
· 475 ft (145 m) @ 12 Mbps	· 210 ft (64 m) @ 12 Mbps
· 490 ft (149 m) @ 11 Mbps	· 220 ft (67 m) @ 11 Mbps
· 550 ft (168 m) @ 9 Mbps	· 250 ft (76 m) @ 9 Mbps
· 650 ft (198 m) @ 6 Mbps	· 300 ft (91 m) @ 6 Mbps
· 660 ft (201 m) @ 5.5 Mbps	· 310 ft (94 m) @ 5.5 Mbps
· 690 ft (210 m) @ 2 Mbps	· 350 ft (107 m) @ 2 Mbps
· 700 ft (213 m) @ 1 Mbps	· 410 ft (125 m) @ 1 Mbps

For both family and enterprise use, one of the most import aspects of a wireless network is the network, for example, avoiding dead zone where the user wants to have access and avoiding too much overlap by several access points as this wastes resource. Good coverage helps the user to get good service and save money when deploying wireless networks.

Because IEEE 802.11 uses radio as its medium, there is no way for a person to see the actual network. For the enterprise user, a professional control system, such as Cisco’s Wireless Control System [6], can help them to plan, configure, and manage their wireless network. However, these professional tools need experienced engineers to use them. For individual user, there are pocket devices such as the Wi-Fi finder which is a small key chain attached device which can be used to detect Wi-Fi signals to help people get online. It is an easy-to-use device usually having only one button for control. If there is a wireless networks around, the LED will indicate this by blinking. Both the professional tools and simple pocket devices can give user some information about nearby wireless networks, but they both have disadvantages. The professional tools are too complicated for users to control; as such users do not have sufficient background knowledge about the complex variables shown by such tools. While the simple pocket finder is too simple, since it does not tell the user where the network coverage begins and end - so the user has to manually search to determine this coverage area.

It is highly desirable that there be some way of indicating to users what the coverage area of a WLAN is. This information could be collected by engineers who build the wireless network or by users who have used a given wireless network. Thus the skill of how to handle equipment or special operation is of the average level.

However, if the network service provider only does a site survey for their internal use, the result may be in a special file format which can only be read by the special commercial tools. Thus there is a need to produce a version of the data in a format which the normal user can utilize.

As noted above, in addition to coverage it is also useful to know which channel(s) each access point uses. This is because although there are 14 radio frequency channels defined by 802.11, the high data rate modes utilize more than a single frequency channel. In fact, in the 2.4 GHz band it is only possible to have three non-overlapping 802.11b channel assignments (such as 1, 6, and 11). Therefore when considering the collection of data to create a wireless coverage model, it is also useful to collect information about which channels are being utilized by each access point, However, displaying this information will not be a focus of this thesis.

Chapter 2 – Background

This chapter provides general information about what has been done by individuals or groups, along with some background knowledge about the technology using in this thesis.

In many places WLANs are able to provide high data rates, without the constraint of a cable. Thus a business man or woman can check his or her email while waiting at the airport. If there were only RJ45 jacks then everyone would have to connect via a cable to one of these jacks. It is already bad enough that travelers have to scramble on their hands and knees to find an electrical outlet when their battery is near to running out of power. With the help of WLAN technology, travelers can sit on the coach at their gate while surfing the Internet, uploading or downloading files, photos, audio and video clips, etc. Thus while many hobbyists have collected information about hot spots, there is no readily available means for the average user to find out where there is WLAN coverage. As for the business man or woman at the airport, it is not fun to see him or her carrying a laptop and pulling a suitcase, while simultaneous trying to find a place with stronger wireless signals.

In order to conduct a survey of WLAN coverage, we will use a handheld computer. In this project we have used an HP iPAQ 5550 Pocket PC with Microsoft's Pocket PC 2003 Premium operating system.

2.1 Previous Wireless System Modeling

Visualization of WLAN coverage began in late 2001, with a number of wireless visual modeling projects [8]. Some groups made exact coverage maps of a specific area. Several applications have used GPS location technology to make precise coverage maps.

Initially, a lot of work was done by people who were interested in wireless networks or by an organization. Both wanted to show the public how and where the WLANs are. Today there are a number of programs which can be used to collect data to create a wireless network coverage map. These range from simple applications to complex WLAN sniffers.

2.1.1KC Wireless

Figure 1 shows an example of a WLAN access point map. This project was created by KC Wireless. KC Wireless is a wireless hobby group in Kansas City, Kansas, United States [7]. The map uses red flags to show the location of each known access point.

From the Figure 1, we see that there are not so many access points in this city. But some of the areas have a high density of access points, which can be seen where some red flags overlap each other.

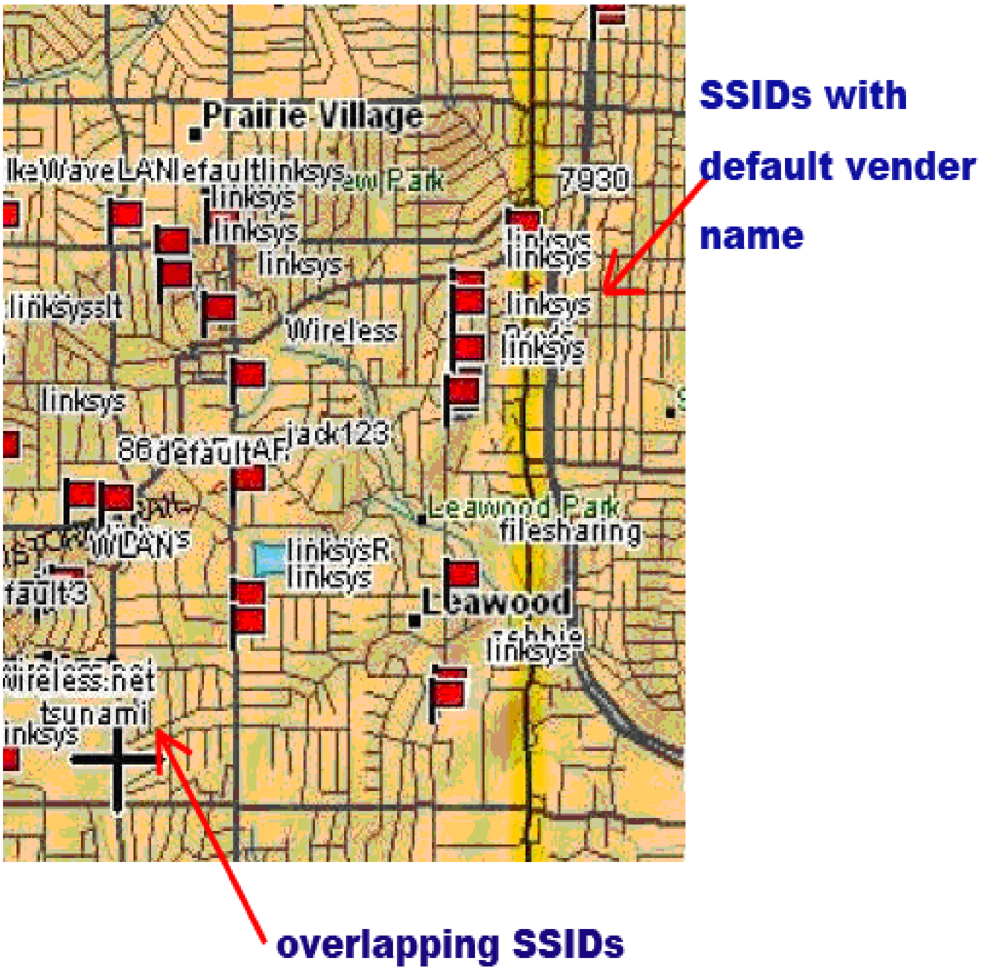

Figure 1: Map of AP's location in Kansas City
(A portion of a map based on larger map shown as figure 5-1 in [8]
- which in turn was taken from [7])

The map shows the SSID and approximate location of each access point. There is no signal strength or WEP status indications for each access points. The background image does not show much information about individual buildings, thus leading to some people getting the wrong idea about where the actual location of a particular wireless network access point is. While such a map could give the user advice on where to find the strongest signal of each specify network, it does not give any useful advice that would let a user select a path from one place to another place to maximize their WLAN access along the way.

The model shown in Figure 1 simply describes the locations of the access points. The map provides the user with information about where a specific access point I,s how many access points in the area, and where he or she is planning to during the next hour. If a company uses their company's name as their SSID, it may be obvious from the map (assuming that the user has sufficient context knowledge to recognize this). Giving the high density of the same default manufacture SSID value, such as “linksys” in Figure 1, this must be a residential area with a lot of inexperienced wireless users, who did not set up their SSID to a meaningful string.

2.1.2 Wi-Fi Hot Spot list

Wi-fihotspotlist.com is a website that allows WLAN hobbists to upload known Wi-Fi hot spot locations into a database. Users could use their website to find whether or not a WLAN network exists at a given location. There are several other web sites like Wi-fihotspotlist.com, such as WiFinder, Inc [9], and JiWire [10].

The search function on wi-fihotspotlist.com is quite simple, see Figure 2 below. The user types in the address of a desired location. Clicking on "Find a Hotspot" button, results in a page which might show several hot spots in that area- assuming that there one or more stored in the database.

Figure 2: Address searching interface of Wi-Fi Hot Spot list
(Figure from Wi-fihotspotlist.com on 2006.12.15)

Each hot spot which is shown has a link which will lead the user to further information, such as the page shown in Figure 3. This page could show details of the specific hot spot, i.e. phone, description, service provider, etc. This additional information might include a small map telling user the exact location of this Hot Spot. However, there is usually no indication of the coverage of that Wi-Fi access point(see Figure 3).

Users simply enter an address and learn whether there is a wireless network or not near this address. Users do not learn the coverage of this access point and they have to go to the indicated place and try to see how far away they can carry the computer while still having an Internet connection. It is helpful for a business person to know if he or she can use his or her wireless enabled laptop to show his or her clients a presentation in two conference rooms via a wireless internet connection. If he or she is told that both potential conference rooms have 802.11 wireless network coverage, but he or she does not know if the corridor between the two conference rooms has wireless signal coverage. Then he or she may need to re-login if looses wireless network connectivity when walking to the second conference room.

The Wi-Fi Hot Spot list is one application to help people find an 802.11 compatible wireless network. Many hobbyists have contributed to this wireless hot spots database. This sharing of data saves each company or user a lot of human resources to collect data about where a wireless client can find a hot spot. The web site is open to any internet user around world, so the database contains information about Europe, Asia, America, etc. There is no general map with all the information area because it is difficult to find a suitable interface and representation for this data. According to the statistics on JiWire WiFi HotStats, hotels and restaurants have more records than any other type of location (46.52% of total 132,157 records) [11]. So if someone try to find a wireless access point, he or she can find the hotel or restaurant nearby.

Similar to the Kansas City project, Wi-Fi Hot Spot has no way to tell the user about the coverage of each hot spot. The data in the database simply contains normal address data. It contains no status information about wireless network, such as SSID or MAC address.

With the help of a database, everyone could search for a hot spot through this database. By using a well known map system, such as Microsoft MapPoint [12] used by JiWire, makes locations more useful as the viewer can put them into context and thus avoid confusion. Other business information stored in this map system could make travel easier and more comfortable.

WIRELESS HOTSPOTS -- LOCATION DETAILS	
HOTSPOT LOCATION NAME	Svinesund
ADDRESS	Svinesund
CITY ZIP	Svinesund, 452 80
COUNTRY	Sweden
PHONE	
DESCRIPTION	
CATEGORY	
WIRELESS NETWORK CARRIER	IP-Sone
WIRELESS PROTOCOL	802.11b

Description of Access Point

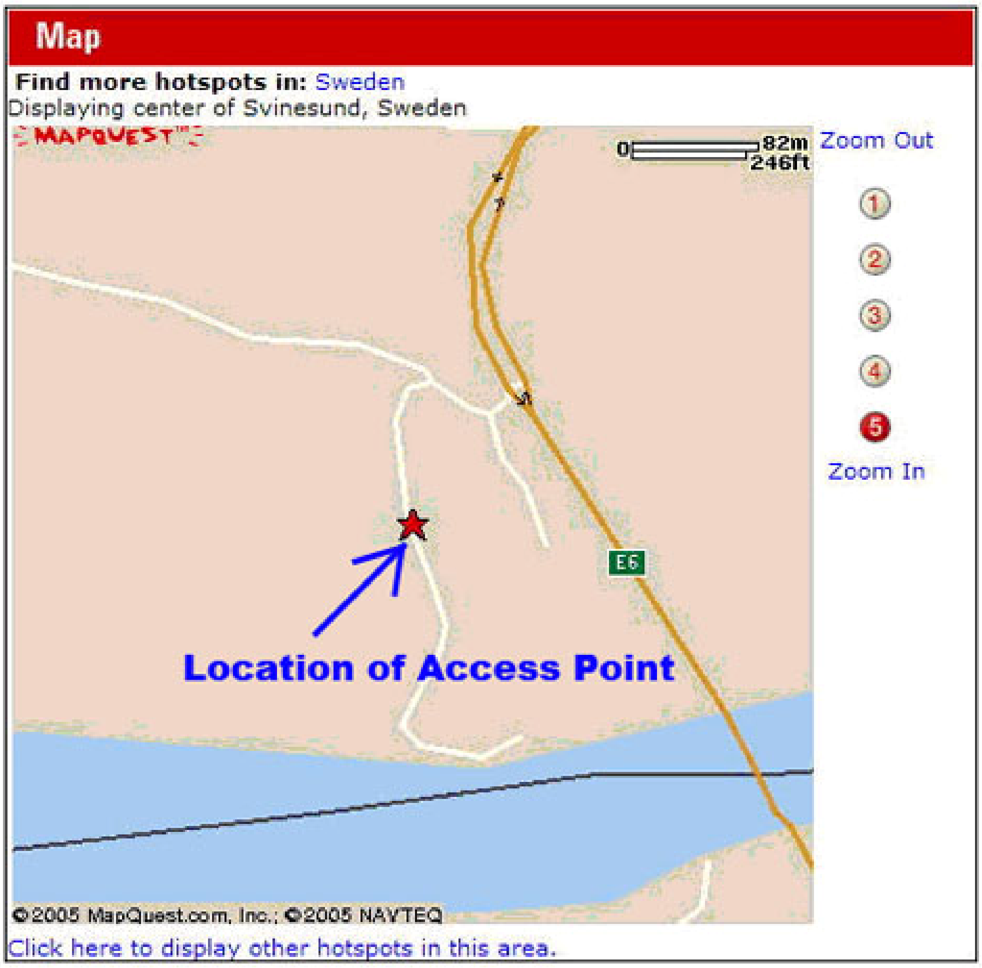

Figure 3: Wi-Fi Hot Spot list searching result
(Figure from Wi-fihotspotlist.com on 2006.12.15)

2.1.3 Drone

Drone is a GPS-based mapping tool for Wi-Fi using Yellowjacket PLUS 802.11b/g Wi-Fi Analysis receivers [13]. It consists of three components: Projector, Collector, and Analyzer. This tool is shown in Figure 4.

Figure 4: Yellowjacket PLUS [13]
Used with the permission of Berkeley Varitronics Systems, Inc.

Drone Projector could import a bitmapped picture for the background of a survey map, and it also could create survey projection files with geo-coded information. The user would carry this equipment(see Figure 4) to collect WLAN information. The GPS function could associate requested survey information with user current location which include latitude and longitude value.

Drone Collector can scan for the WLAN channels to collect data such as RSSI, SSID, and MAC address which could be stored into a file and used for future plotting. The dashed line between data points shows the survey path (see Figure 5). Due to the sampling rate, not all the points are close enough to cover each other. Pressing the stylus and holding it over any data point will popup an information screen showing survey data for this point. The collection procedure is really simple: People walk or drive within the survey area. GPS provides the location information, so there is no need to click on the screen to enter the location of the survey points.

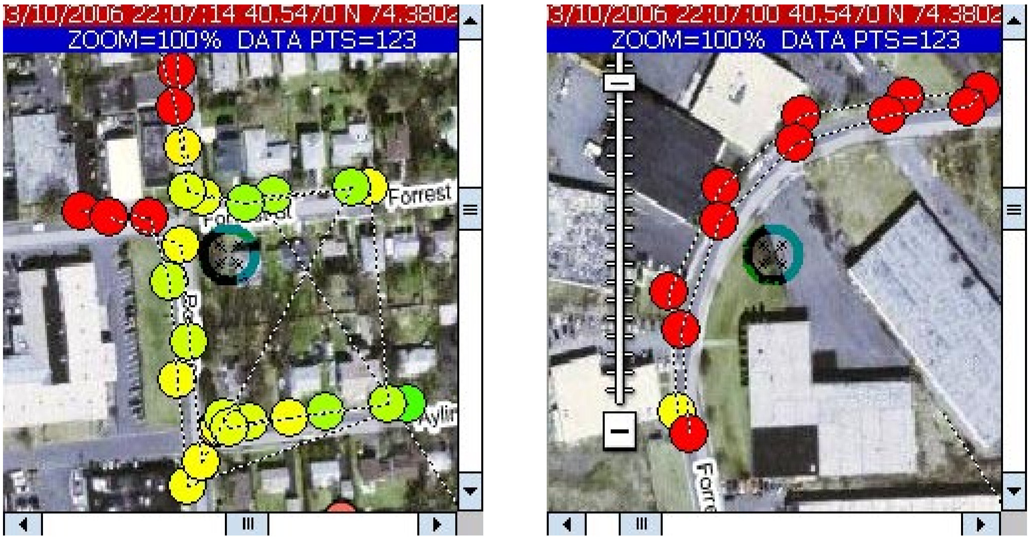

Figure 5: Drone Collector [14]
Used with the permission of Berkeley Varitronics Systems, Inc.

The Drone Analyzer uses geo-coded map data from the Projector and data recorded using the Collector. Access points can be sorted by SSID or by channel. Users can plot the data for a single access point or based on a given SSID (which usually identifies more than one access point), or manually by selecting multiple access points. A range of wireless network signal strength can also be selected. The location of each access point can be placed into a model and contour lines of wireless signal strength displayed [15].

The results can be output in many different formats. The first is a simple coverage map simply showing the wireless network, e.g., where all the access points are, and their measured signal strengths. The second is a table view of data from the Collector. This output format has many options to customize the data output. The third is a KML file. The forth is an HTML file which can be opened by Internet Explorer.

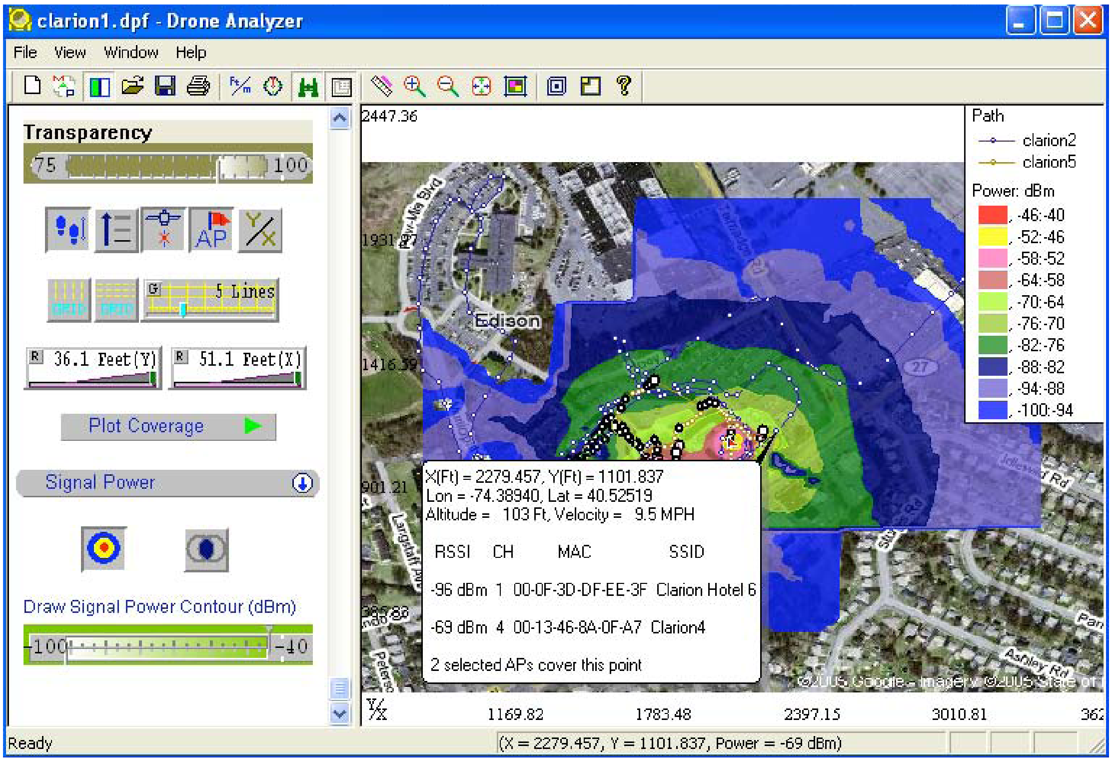

Figure 6: Drone Analyzer [15]
Used with the permission of Berkeley Varitronics Systems, Inc.

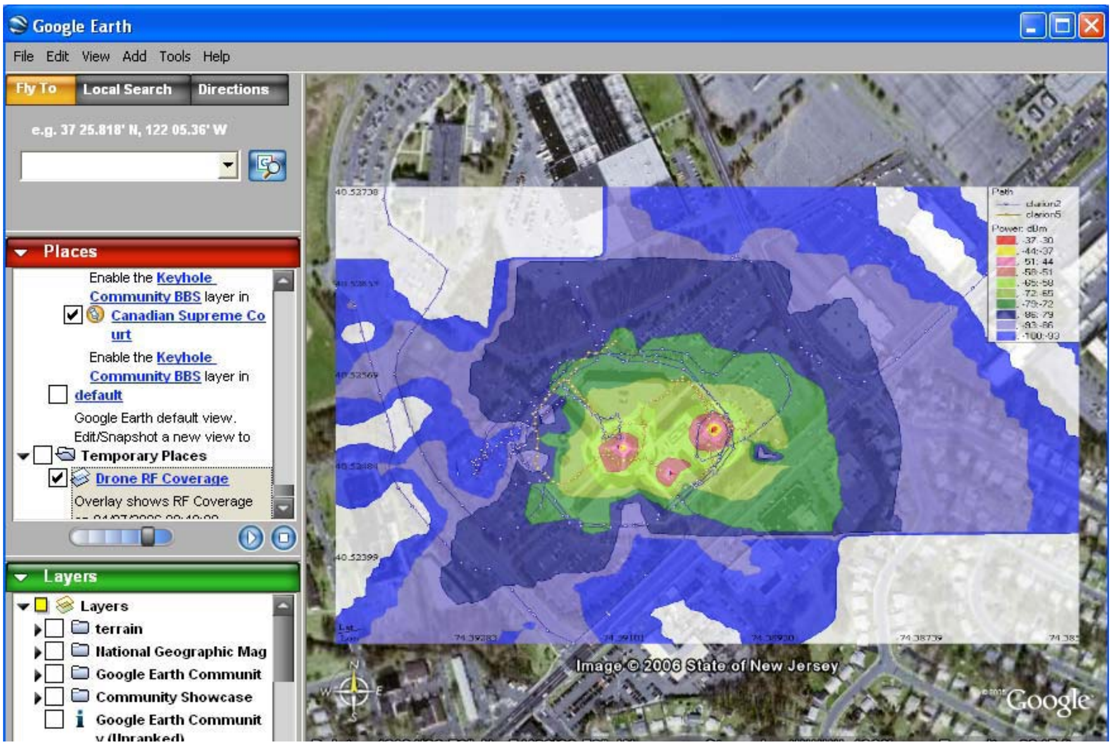

Figure 7: Survey result display in Google Earth [15]
Used with the permission of Berkeley Varitronics Systems, Inc.

The survey path from the data collection procedure and all of the coverage pictures displayed in Drone Analyzer can be displayed on top of Google Earth by using a KML format output file. In Figure 7, the path displays the roads traversedfrom the survey start to the survey end.

Drone makes a complete solution to survey WLANs, provides a good example of how to present coverage data. Drone gets outdoors position through a GPS receiver and can use Google Earth as an interface to show the results of a survey to the user. The data collection path is recorded for later analysis, and data collected while wardriving[1] is used to generate a WLAN coverage map. However, this special equipment is expensive(Yellowjack - $2,800 [16] and Drone software $2,500 [17]), and the Analyzer is too complicated for general use.

[1] Wardriving: searching for the wireless LAN network information by moving vehicle.
Warwalking: searching for the wireless LAN network information by walking.

2.1.4 Wardriving and Google Maps

Most earlier wardriving, which is a search for wireless networks used a laptop with Wi-Fi in a car or in a small airplane. Many wardrivers use GPS to obtain spatial information and record coordinates in a log file. In a small area, warwalking, which means carrying a mobile device to measure wireless network information and record data with location information, gives an easy way to collect data about the wireless network.

One of the most famous wardriving projects is WiGLE (Wireless Geographic Logging Engine). It is a wireless geographic logging engine, and has mapped global wireless networks since 2001. It has a worldwide database containing 8,134,004 wireless networks, based upon 416,904,616 observations [18].

WiGLE uses a Google Maps interface to a web site that consolidates location and information about wireless networks world-wide in a WiGLE central database on a popular map system. Thus it combines digital mapping and information about wireless hot spots. Users can type address in an address search box to find the wireless hot spot nearest that location. The address could be in US zip-code or street address. The result in Google Map with icons below shows the location with basic access point status. User could click on the location to pop up a bubble contains wireless network information. The information of all hot spots locate in that area will show in the right side of result page including MAC of access points. Every location could have only one icon above due to the order of icons.

Figure 8: Icons used in WiGLE Google map[19]

WiGLE could also be used to present in Google Earth, and this makes it more friendly. Each of access point could be turned into KML (Keyhole Markup Language) file which is easy to import into the Google Earth desktop application.

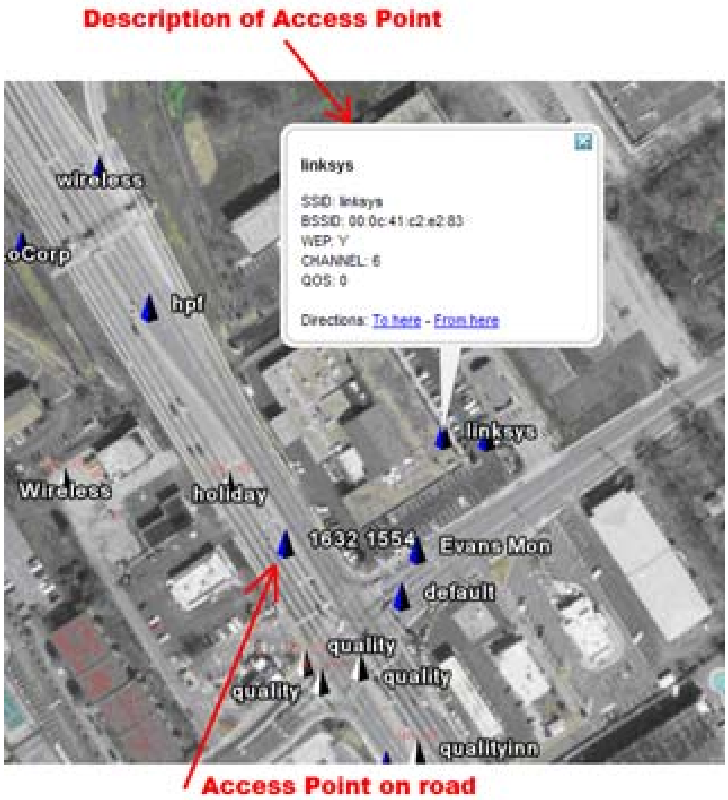

Figure 9: WiGLE data showing in Google Earth
(Figure from Google Earth on 2006.12.15)

As shown in Figure 9, WiGLE data is shown on top of Google Earth. Each white triangle indicates an access point without WEP/WPA while each blue triangle indicates an access point with WEP/WPA. Clicking on one of these triangles pops up information dialogue about that access point, such as SSID, MAC address, WEP, Channel, etc. The location of each access point may be not accurate, for instance some of access points are shown on the high-way. Looking at Figure 9, a user would have some idea about a given network's coverage based upon knowledge of the general coverage of different types of wireless network equipment. However, the coverage information is not explicit.

2.1.5 Navizon

Navizon has developed a peer-to-peer positioning solution to utilize the effort of the public to generate a huge database contains information about wireless networks and their locations. Navizon combines GPS with positioning information from Wi-Fi or GSM Cell Tower signals. Thus a GPS capable device could help people to determine the exact location of each Wi-Fi access points and GSM Cell Tower [20]. The application can run on Pocket PC or SmartPhones which use Windows Mobile or the Symbian operating system.

Anyone can download the Navizon software from their web page. http://www.navizon.com/ When the user downloads the application and finds a Wi-Fi access point or GSM Cell Tower, he can upload that information into a central database to gain some rewards. The rewards are:

- 2 points per Wi-Fi access point
- 10 points per cell tower[20]

Once a user has 10,000 points, the company will pay that user 19.99 US dollars to his Paypal account. This business solution could save a company a lot of human resource that would otherwise be needed to collect data by wardriving or warwalking.

If subscribers to Navizon are in a Navizon database covered area, they can get exact location information and even though they do not have a GPS capable device. Additionally, users can search for the nearest post office, restaurant, shopping mall, or anything else near where his is standing. This service, similar to GSM Location Based Services, provides personalized services to the subscriber based on their current position, along with a decent visual map to give user a better understanding of their location. Buddy tracker is one of Navizon's functions. People can track their friends, but only if these friends want to share their position with you.

In Navizon, the business model is based upon the database being built by customers' contribution, and each of these customers who contribute to use a GPS receiver collects position data is rewarded for their work. Users who do not want to collect network information and do not have a GPS capable device can get position data by paying the company 19.99 US dollars to have Premium service [21].

2.2 Wireless network technology

Today there are four important types of physical layers used by IEEE 802.11 Wireless LANs, i.e., 802.11a, 802.11b, 802.11g, or 802.11n. 802.11a offers the highest capacity at 54Mbps for each of 12 non-overlapping channels and freedom from most potential RF interference. 802.11b provides 11Mbps data rates, with only three non-overlapping channels (channel 1, 6. 11). 802.11g extends 802.11b networks to have an increased data rate of 54Mbps, but the three non-overlapping channels limitation still exists. 802.11n is a draft standard with a 540Mbps raw data rate. If someone needs maximum performance now, then 802.11a or 802.11g is the way to go, but many more access points exist for 802.11b - hence since 802.11g is also backwards compatible with 802.11b - it makes the most attractive near term solution (but the 3 non-overlapping channel limitation is sever is some settings).

If access points are too far apart, then users will only be able to communication at less than the maximum data rate. For example, users close to an 802.11b access point may be operating at 11Mbps; whereas, a user at a greater distance may only have 2Mbps capability. In order to maximize performance, ensure that RF coverage is as spread out as possible in all user areas, especially the locations where the bulk of users reside.

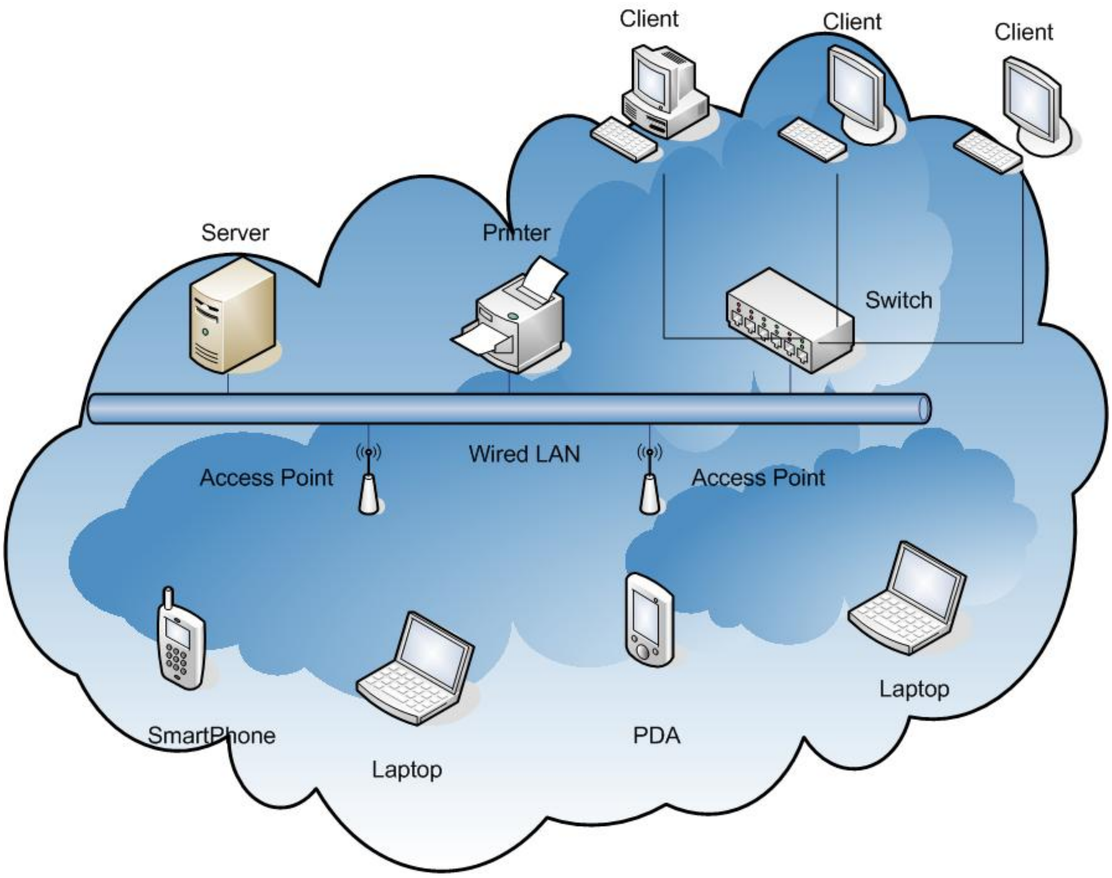

Figure 10: WLAN using multiple access points

Dynamic Rate Scaling

One design feature of 802.11 wireless networks. When a computer is connected via 802.11, the network data rate may change automatically based upon the quality of the wireless connection. A connection limited to lower data rates extends the range at which wireless devices can connect to each other and increases the number of devices that can be accommodated since low data rate devices can use more of the channels.

For an example, a computer using 802.11b wireless network in close proximity to an access point will often associate at 11 Mbps which is the maximum bandwidth 802.11b can support. If the computer is moved further away from the access point, the connection speed will automatically degrade from 11 Mbps to 5.5 Mbps, or even lower because of the Dynamic Rate Scaling. If that computer moves still further, the wireless connection will eventually fail because WLAN signal is too weak in comparison to noise and the receiver's minimum received signal strength..

Wi-Fi devices scale their data rate in defined increments. For 802.11b, the data rate will scale to one of the follow speeds:

- 11 Mbps
- 5.5 Mbps
- 2 Mbps
- 1 Mbps

2.3 GPS technology

The Global Position System (GPS) is a satellite navigation system. A constellation of GPS satellites use radios to transmit precise timing signals. A GPS receiver can use the radio signals from GPS satellites to determine its location. The minimal number of satellites necessary to compute a position in three space is 3, so the GPS receiver can compute its location (longitude, latitude, and altitude). Using satellites only works outdoors today and it is the most popular way to make an extremely precise map. In most situations, GPS gives accuracy better than 10 meters.

2.3.1 Accuracy

Selective Availability is an international degradation of civilian GPS signal because an enemy could guide their missile to a precise target. It adds an error signal of up to 10 meters horizontally and 30 meters vertically. However SA finally was turned off in 2000.

There is a lot of ways to increase the accuracy of a GPS signal. The most common is Differential GPS (DGPS). DGPS uses fixed ground reference stations to increase the accuracy. The ground station calculates differential corrections for its own location and time, and broadcasts the difference between the real location and the location determined from GPS satellites, so that nearby GPS equipment (maximum distance from the fixed receiver is 370km) can correct its calculations using the correction from fixed ground reference station to determine more precise coordinates.

The European Geostationary Navigation Overlay Service (EGNOS) is a satellite navigation system. The aim of EGNOS is to enhance the GPS system, by improving the reliability and accuracy of GPS signals. The specification of EGNOS gives a horizontal position accuracy smaller than 7 meters. There are three geostationary satellites and a group of ground stations in the EGNOS system. In practice, GPS combined with EGNOS can be used to determine coordinates within meters. Operation began in July 2005, and results in extraordinary precision with an accuracy of less than 2 meters in 99% of situations.

2.3.2 Multipath Effect

Multipath is the corruption of the direct GPS signal by one or more signals reflected from the local surroundings. The reflected signal might also interfere with the signal from the direct path. The reflection from the surfaces surrounding the GPS receiver antenna can cause a range of errors as high as 15cm for the L1 carrier (which is the GPS frequency used in this project) and leading to errors of up to 15-20 meters. [22]

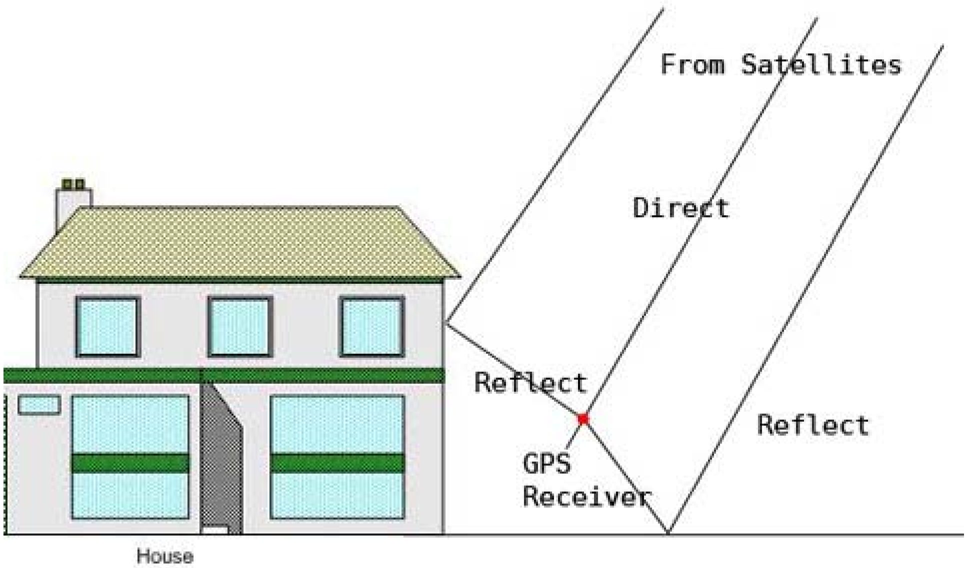

Figure 11: Multipath in GPS

The effect of Multipath will be reduced by using a special antenna and receiver. However, the GPS receiver used in this project is a small compact one with a built-in ceramic patch antenna (the specification is shown on next page). Thus measurements taken on the Kista campus, where there are a lot of buildings can confuse this simple GPS receiver, resulting in errors of 30 meters.

The GPS receiver used in this project is a GlobalSat BT-338 compact receiver. It utilizes the integrated SiRFIII Low Power Chipset with 20-channel architecture for high sensitivity, fast acquisition, and short fix times. BT-338 can communicate with other equipment via Bluetooth Serial Port Profile. It has high performance and low power consumption. 3 LED to show the Bluetooth connection and battery information.

Table 2: Specification of GlobalSat BT-338 GPS receiver [23]

Chipset	SiRF Star III
Frequency	L1, 1575.42 MHz
C/A code:	1.023 MHz chip rate
Channels	20 channel all-in-view tracking
Antenna Type	Built-in Ceramic patch antenna
Position Horizontal	10 meters, 2D RMS
Velocity Accuracy	0.1 m/s (95%)
Time Accuracy	1 micro-second synchronized to GPS time
Default	WGS-84 Acquisition Time (Open sky, stationary)
Reacquisition	0.1 sec., average
Start Time	1 sec (Hot), 38 sec (Warm), 42 sec (Cold)
Altitude Limit	18,000 meters (60,000 feet) max
Acceleration Limit	Less than 4g
Velocity Limit	515 meters/second (1000 knots) max
Operation Time	17 hours after fully recharged
Connection	Via Bluetooth Serial Port Profile
Protocol messages	NMEA-0183 output protocol
Output format	GGA(1sec), GSA(5sec), GSV(5sec), RMC(1sec),VTG(1sec)
Dimensions	72.5mm × 40.4mm × 23mm
Weight	75g

2.4 Microsoft .NET, C# and OpenNETCF

C# is the newest of Microsoft’s Object Oriented languages and one component of Microsoft's Visual Studio. Visual Studio offers an integrated development environment for developing software that is to run on Windows based smart devices such as Pocket PCs and Smart phones. A developer can write Visual C# applications to run on Microsoft's .NET Compact Framework. Visual Studio also provides emulators for smart devices. Starting a project with right device such as Pocket PC or Smartphone, the emulator will be look just like the device. Microsoft’s ActiveSync will be used to connect to the iPAQ running Microsoft Pocket PC 2003 Premium. Using this connection to Visual Studio, application can be debugged and deployed into a Pocket PC. The developer is able to run an executable file deployed just like running it on a desktop PC.

OpenNETCF is a third party solution designed as a shared source. The use of shared source code could make development faster. OpenNETCF is an extensive set of classes, using the name space OpenNETCF because we are using .NET is using in this project, we have chosen to use OpenNETCF because it contains many classes which support using different types of networks, such as Bluetooth, and WLAN; additionally it supports network statistics.

2.5 Google Earth

Google Earth uses satellite image to give Internet users geographic information. It can be used to find exact locations, buildings, or for sightseeing. Via this application user can virtually explore places they have never been before. The application can be installed in a personal computer for planning a trip or for find a street. Data can be viewed in multiple layers. Basic version is free for personal use. The Plus version, professional version, and enterprise version have more functions, as well as perform faster and better. The plus version support GPS data input of the user's coordinates, but the imagery is the same in all the versions.

Google Earth is popular. People who have a stable Internet connection can visit this virtual globe at anytime for free. Some new features such as 3D building give the user a general image of the place. The quality of imagery in large cities, such as New York, London, and Tokyo, is quite good. It is possible to easily see the streets and even houses, in fact, the type of cars can be easily recognized.

The search function can be active by entering addresses, coordinates, or by manually click on the virtual globe. If user finds an interesting location, he can learn the coordinates of that location by simply placing his mouse at that place on the screen, and coordinates will be displayed on the Google Earth status bar.

Another product, called Google Maps contains only the basic information about a city. It has no imagery about streets, buildings, or any other attractions. However, Google Maps are available on many platforms and Google Mobile Maps are available via my cellular phones.

2.5.1 KML / KMZ

Keyhole Markup Language is an XML grammar and file format for modeling and storing geographic features such as points, lines, images, and polygons for display in Google Earth and Google Maps. The name Keyhole is the name of a company that produced Earth Viewer, a predecessor of Google Earth. KML was designed for Google Earth. Note that Google Maps only supports some features of KML [24]. KMZ is a compressed version of a KML file using ZIP format. The image folder of a KMZ file could store picture to be used as an overlay on top of Google Earth.

Each place in KML is marked with its longitude and latitude. The shape of an area in KML is defined with polygons, with longitude and latitude of each vertex. Another way to describe an area would be to use KMZ to include a picture for that area; by using a transparent color this picture won’t cover anything on Google Earth. However, the four values of north, south, east and west corners of the border must be specified. When a user clicks on a KML or KMZ file, the default program for them is Google Earth.

2.6 Origin

Origin is scientific graphing software. It provides extensive scientific graphing and data analysis capabilities and includes several new tools that simplify common operations. Origin has easy-to-user graphical user interface. It is becoming more and more popular among scientists and engineers. There are many types of licenses for Origin. The evaluation version can be downloaded from the webpage of OriginLab Company (http://www.originlab.com). The OriginPro 7.5 Student Version offers all the functions of Origin and OriginPro but at a lower price. However, it is only available for student customers in the US and Canada to run on his or her own computer [25].

Origin has a very wide selection of built-in 2D and 3D graph types, and has a large number of formatting options. The numerous ease-of-use enhancements help scientists and engineers to quickly and easily get the graphic result they want. The integrated C programming capabilities can be used by experienced users for sophisticated analysis.

Origin can open Excel format files (*.XLS), along with many other times of data files, such as Lotus, dBASE, Matlab, etc. Data can also be export in many formats, such as PNG, JPG, BMP, and PDF.

2.7 HP iPAQ 5550 Pocket PC

The hand held device used in this project is the HP iPAQ 5550. The iPAQ 5550 has a build-in Bluetooth interface that can connect with the GPS receiver we are using (see Table 2) and a build-in 802.11b WLAN interface which can be used to detect WLAN access points nearby. The Wi-Fi antenna of the iPAQ 5550 is shown in Figure 12. The antenna is inside a rubberized bump, the actual antenna is a tiny piece of copper wire. The reception is good. The built-in WLAN and Bluetooth interfaces enable a user to access the internet through access points. If there is more than one access point in the surrounding area, the function “Automatically connect to non-preferred networks” will associate the iPAQ with at least one of them. The Wireless Networks configuration dialog support selecting the types of networks to access, such as all available, only access points, or only computer-to-computer. The current connectivity is shown on the top line of iPAQ screen shows the user current wireless interface signal strength by a bar chart, but this is too coarse to evaluate the quality of your wireless connectivity.

There is an additional PC Card Expansion Pack Plus that has a backup battery which helps to increase the time available to collect measurements. The Expansion Pack also helps protect the iPAQ incase of dropping.

Table 3: iPAQ specifications [26]

Processor	Intel XScale 400 MHz
RAM (Random Access Memory)	128MB SDRAM
Operating system	Microsoft Windows Pocket PC 2003 Premium
ROM (Read Only Memory)	48 MB ROM
SDIO slot	SD memory and SDIO card support
Expansion	PC Card with backup battery
Display	240 x 320 pixels, 64K-color support, TFT
Bluetooth	Class II device; up to 4 dBm transmit, typical 10 meters range
Weight	206.8 g (without Expansion Pack)

The large random access memory (128 MB RAM) allows the user to store a number of program and data files. This memory can be written to at a higher speed than a SD memory card. In our survey application, we use the random access memory as we wish to collect data at smaller intervals.

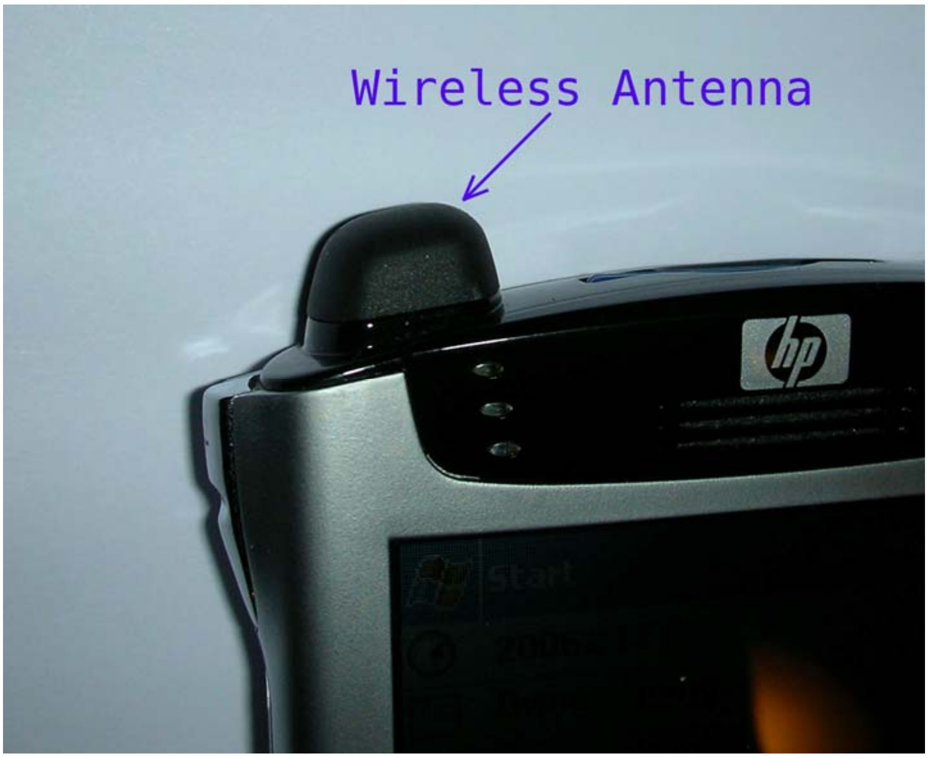

Figure 12: Cover for WLAN antenna on the iPAQ

The integrate Bluetooth interface allows us to communicate with the GPS receiver using a virtual serial port. The Bluetooth transceiver of the iPAQ 5550 is a standard Class 2 device, thus it has a maximum range of 10 meters according to the specification. However, to correctly receive the location of the iPAQ, the GPS receiver should be kept near the iPAQ. In this project the two were always closer than 0.5 meter.

Chapter 3 – Method

The goal of this project is to build a modeling describing the IEEE 802.11 WLAN available to potential users at the KTH Campus in Kista. The modeling system should provide a visualization of radio signal strengths/quality. The goal of this visualization is that the user should be able to easily understand coverage map. Most existing modeling systems simply use the position of wireless access points to tell users where they may associate with a given network. However, despite a large number of access points shown on a map, the user has no way to know where the actual network coverage is because location of the access point itself does not really indicate where the coverage extends to. Signal coverage imagery should display the locations where users can receive network service. Using an appropriate background map together with the coverage data, even a beginner should know where to go to get network access. For professional users, the raw signal strength data is available to subsequent analysis.

In the data collect procedure, warwalking is unavoidable. However, with a light weight Pocket PC and a compact GPS receiver, this should not be a tough job. For the industrial area in Kista, especially the campus area, searching for wireless signals by foot is feasible. But for a huge area such as a whole city, warwalking is infeasible; however wardriving offers a good way to gather such WLAN coverage information, in this case a laptop with a high gain antenna outside the vehicle might be utilized.

3.1 Design

3.1.1 WLAN signal strength gathering

Using software developed based upon .NET measure the signal strength of nearby access points. The use of the .NET Compact Framework 2.0 and the OpenNETCF.NET shared source library enables us to create an application to detect nearby wireless networks and to gather information about these networks. This application will be referred to the WLAN survey application.

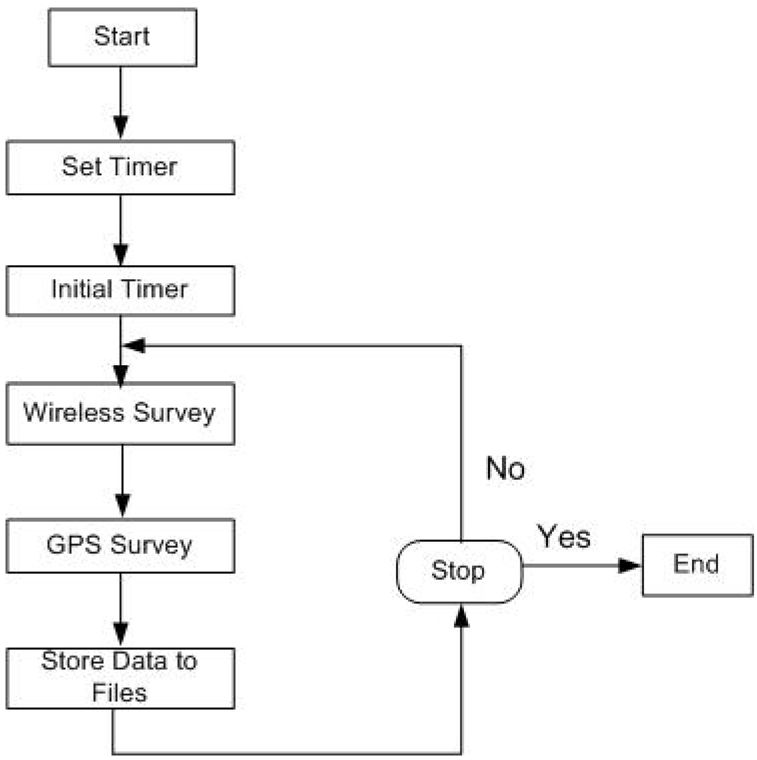

Figure 13: Data flow of Survey Application

A data flow diagram is shown in Figure 13. While performing a survey, a lot of data will be collected for each measurement concerning nearby networks. This data includes:

1. SSID: the identifier of service set;
2. MAC address: the identifier of each Access Point;
3. Signal strength: a value indicating the signal strength of this Access Points;
4. Quality: the signal strength of nearby Access Points;
5. Longitude: longitude of the measurement location;
6. Latitude: latitude of the measurement location;

This application gathers signal strength measurements concerning the access points it detects. Because some access points have encryption enabled, they will only permit devices which know the key to associate with them. In some cases we will not be able to collect all the data that we might want, thus the resulting model will be incomplete. However, we will attempt to build a model that is as complete as possible - despite not being able to associate with all the detected networks.

The SSID identifies each wireless network. While the MAC address provides a globally unique for each access point. These two values can be used by the user to select either a specific network to collect data for or to display the coverage of a specific network. Note that at a single measurement location, there could be more than one access point belonging to the same wireless network. Thus, the same SSID will appear more than once in the collected data. However, since the MAC address is unique, only one instance of each MAC address should be detected at a given location. To visualize the coverage of a single wireless network, the user simply selects a given SSID (as the name of that wireless network). If multiple access points were observed at a location, only strongest one is shown by default.

Signal strength is the main variable used to build our coverage model. The signal strength value returned by the OpenNETCF library has two formats: one is in units of decibels and other is an indication of quality. The decibel value is more precise, but the quality value is perhaps more useful because it describes the network in human terms, i.e., “Excellent, Very Good, Good, Low, Very Low” .

Other information about the access point that may be useful includes: channel, number of current users, and status. These values could be found via an Simple Network Management Protocol(SNMP) query using the unique MAC address of each access point. Network status could be helpful for the users who want to get service from a specific access point. The goal is to present the user with the coverage of a given network, rather than simply the coverage of each access point - as the former is more useful to the average user. However, the collected data could be used by a more advanced user or network administrator to optimize their use of the network or to optimize the network itself.

3.1.2 Location

A GPS receiver is the best way of determining the measurement location in an outdoor environment. The buildings near Forum and Electrum in Kista are not so high that they block GPS signals to an unacceptable level. However, there are still be some dead zones for GPS signals, like in Figure 14 with red numbers. Locations number 1 and number 2 face the problem that the user is below a "bridge like building", i.e. the sidewalk passes under part of a building. The signals from GPS satellites will be blocked and reflected, this affects the accuracy of location data. Location number 3 is at a crosswalk under the bridge over the street. At this location, the GPS signal can be blocked by the bridge overhead, thus the GPS receiver can not get signals from the satellites directly. The resulting accuracy will not be good. In these 3 places, the signals from satellites to GPS receiver can bounce from the wall of the building or the ground where person is standing.

Figure 14: Positions which can result in inaccurate GPS estimates of location (Figure from Google Earth on 2006.12.15)

The three locations shown in Figure 14 are only some of the locations where GPS signals can lead to low position accuracy. At these locations, the measured location from the GPS receiver indicates that the user is located at other place: however, the difference is not systematic (i.e., one can't simply compute a correction offset). Therefore there must some manual work to correct for inaccurate locations, due to the wrong GPS results. However, the path taken during each measurement session is known hence the location can be interpolated between places where the location measurements were more accurate.

In Figure 15, the place marked with red ellipse is a small garden in the middle of two buildings. But it is not too near either building. Thus most of the time the signals from the GPS satellites reach the GPS receiver directly and there appears to be little effect upon the accuracy of the location data.

Figure 15: An open place which has good signals from GPS
(Figure from Google Earth on 2006.12.15)

The use of a collocated GPS receiver gives the coordinates of the hand held device which is making measurements of WLAN signals. In open areas, the location provided by the GPS receiver is acceptable for this project, but in some cases, the coordinates are not accurate. The HDOP (Horizontal Dilution of precision), VDOP (Vertical Dilution of precision), and PDOP (Position Dilution of precision) indicate the geometric accuracy of the satellite configuration. The lower the value of DOP, the more accurate the result is. GPS receivers with EGNOS (European Geostationary Navigation Overlay Service) functions build-in could give an accuracy within 5 meters. The GlobalSat BT-338 supports EGNOS, but it must be a new hardware version, or sent to company to have a fireware update. In this case the version used did not support EGNOS. During the process of collecting data for this project, the GPS receiver was used to determine the coordinates for person walking along a path, rather than for a car driving down a street. On a street, buildings generally are not too near the road which means the GPS signals do not suffer significantly from multipath. When people walk between two buildings as shown in Figure 15, the walls of buildings reflects signals from the GPS satellites causing multipath which reduces the accuracy of the coordinates. In a vehicle GPS navigation system, some special algorithm such as map matching can be used to position a car always in the right position, even if the GPS location would indicate that the car has gone off the road. In map matching, the algorithm uses recent direction, GPS coordinates, and a known polyline set (defining the road) to calculate the vehicle's position on a selected polyline[27]. As these measurement are made while walking, there is no algorithm to correct the GPS position using knowledge of the path because a person is so small when compares with the path that the person is walking on and it is possible for a person to walking on either the right or left side of the road. Therefore I will use the raw coordinates from the GPS receiver and record the path taken during the measurement by using KML file. The KML file can be used to display the path on Google Earth. Each data collection point will be shown on the screen. At the obvious locations which are too far from the right position, I will manually correct the coordinates based on the coordinates which can be extracted from Google Earth.

Differential GPS takes into account the difference between the correction (known) position and the value determined from GPS, this can be used to correct other data. Differential GPS is a method of improving the accuracy of a regular GPS receiver by utilizing data from a fixed reference station to augment the information available from the satellites. Unfortunately, for this project, differential GPS is not suitable because the position from the GPS receiver suffers from multipath due to surrounding building.

Most GPS receivers have only 10 meters accuracy of horizontal positions in an open space with a clear view of the sky on or near the surface of earth. With a lot of surrounding buildings, this accuracy could be worse. As Figure 16 shows, the difference between the correct and incorrect positions is about 30 meters. The scale of Figure 16 is 6.8cm for 125ft.The distance between these two points is 5.5cm, hence the actual distance is:
125 (ft) * 5.5 / 6.8
=101.1 (ft) * 12 * 2.54 / 100
=30.8 (meters)

In this measurement I was holding a GPS receiver while standing in front of the Forum building's main entrance where the both wings of the Forum building block most of the direct satellites signals hence what I received was reflections of the satellite signals. Using the path recorder file, I recorded the path I choose for this collect data. Thus at a position, where the GPS value is easily recognized as incorrect (such as that shown in Figure 16), I could correct the position from the blue point to a red one. Although this requires manually input the effort required is modest, while resulting in a great improvement in the location accuracy.

Figure 16: Multipath effect
(Figure from Google Earth on 2006.12.15)

In Figure 17, the black dots show a trace of my location as carried the GPS receiver while walking through the small garden on the way from the Electrum building to the Galleria (the Kista shopping center). Some points show great accuracy. These accurate points are mainly located in the middle of the small garden (i.e., in an open area that suffers little from the surrounding buildings). This area was shown in Figure 15 by a red ellipse. However, the data points shown in the middle of either building are of course inaccurate - as I didn't walk through the walls of these buildings! Most of these points are ~2 meters from their correct location, despite the DHOP show a value smaller than 2 meters.

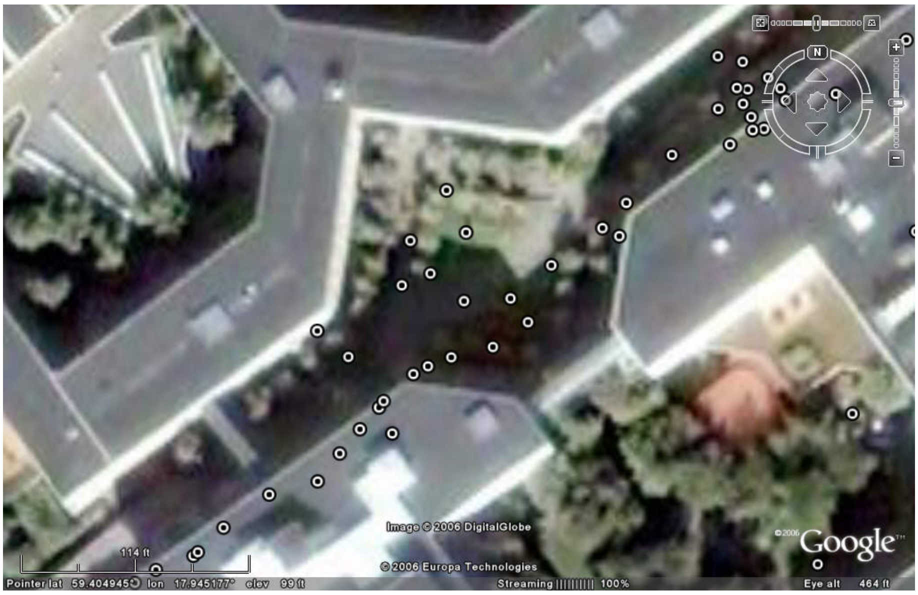

Figure 17: Trace of GPS locations
(Figure from Google Earth on 2006.12.15)

3.1.3 Walking pattern

GPS porvides latitude, longitude, altitude, and time; provided that you log this information as you go a long making measurements you can trace the route that you walked. This can reveal the basic path which the user took while collecting data (similar to the paths shown from BVS's Drone in Figure 5). Before walk through the whole KTH’s Campus in Kista, a set of paths to collect the data must be selected. The walking pattern should cover the area and make only a small number of turns in each session. The advantage of minimizing turns is that you can predict roughly where the user was as a function of time, hence positions which obviously do not lie along the path taken (for example due to shadowns and reflections) can be corrected manually. For the purpose of determining the coverage of WLANs, the area should be larger than the wireless signal rangers.

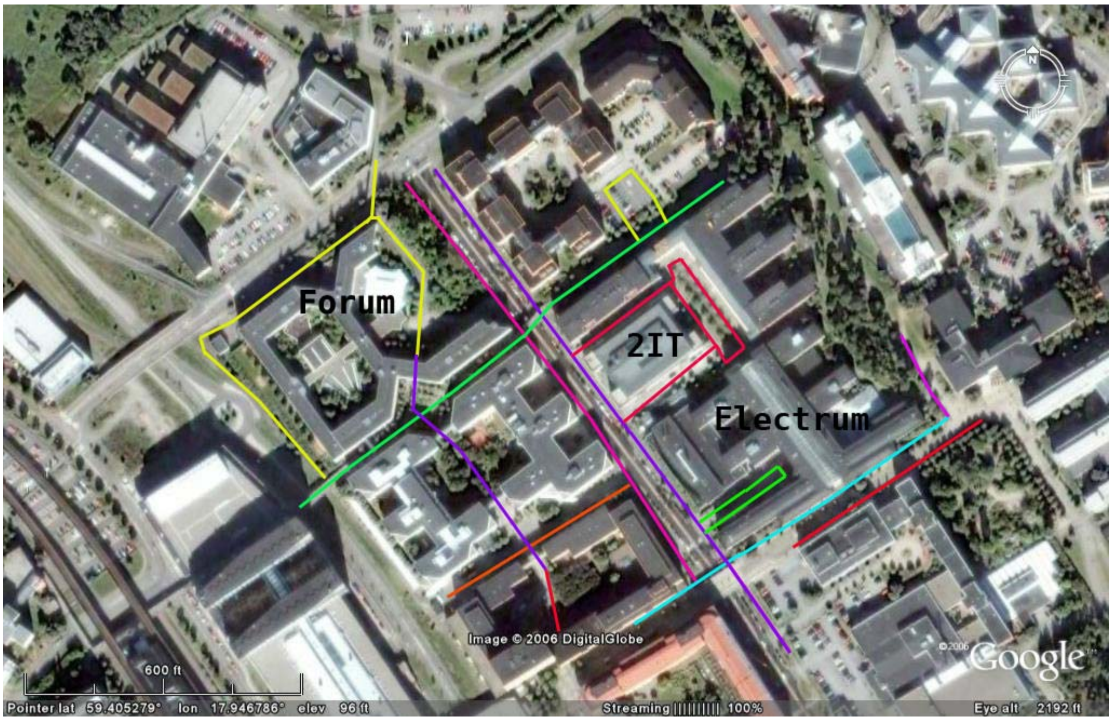

Figure 18: Walking pattern
(Figure from Google Earth on 2006.12.15)

The user walked along the set of paths as indicated in Figure 18. As can be seen these paths cover the KTH's campus in Kista, and concentrate mainly around the Forum, Electrum, and 2IT buildings. The different walking paths were shown in different colors. All routes were on sidewalks. I walked each route for twice, each along a different side of the sidewalk. The data collection should done on the days with optimal sky visibility and late at the night when few people and cars are moving about; this is in order to avoid these moving objects affecting the measurements. On each selected route, the following procedure was executed:

1. At the begining of each route, turn on equipment and connect the iPAQ with the GPS receiver.
2. Start the wireless survey program to collect data. Press the Start button to initialize the program, then press the button with label number 1, 2, or 5 to select the sampling interval(in seconds) and start the recording progress.(a screen capture of this survey program is in Figure 21)
3. At the end of the route, click the Stop button to finish data collection.

Before starting data collection, I measured my walking speed. On average, I take 89 steps a minute, and each step is 0.9 meter. So I walk 1.335 meter per second, thus for the three sampling intervals (1, 2, and 5 seconds), the distance between two data points will be 1.335 meter, 2.67 meters, and 6.675 meters(respectively).

3.1.4 Map selection

Google Earth is one technology to present a virtual global map. Satellite imagery gives users good understanding of geographic information. The user can see buildings and streets, and recognize the roof of their house.

Google Earth can be used to describe a specific area, for example by placing a ground overlay on top of Google Earth. A region is defined by a bounding box (<LatLonAltBox>). This region describes an area of interest defined by geographic coordinates (longitude and latitude) and altitude(s). In addition, a Region contains an LOD (level of detail) extent (<Lod>) that defines the range of the associated region in terms of projected screen size. A region is said to be "active" when the bounding box is within the user's view and the LOD requirements are met. Objects associated with a Region are drawn only when the region is active. When the <viewRefreshMode> is “onRegion”, then the Link or Icon is loaded only when the Region is active [28]. When used in a Container or NetworkLink hierarchy, this calculation uses the region that is the closest ancestor in the hierarchy. An example of <LatLonBox> is given in section 3.2.2.

In Figure 19 below, two different ways to describe a data collection path from Galleria to Wireless@KTH in Kista are shown. Figure 19(a) contains a red line indicating the path from Galleria to the Electrum building. The element <LineString> was used to generate such a path using several line segments. Figure 19(c) uses the KML element <Placemark> to describe scattered data points. The description in each <Placemark> could be used to describe wireless network information at that location (as shown in Figure 20); the description in a placemark could store the information about the measurements at that specific point. Figure 19(b) shows these two sets of data combined. The combined data makes it much easier to understand how these data point are related to each other and which measurement points are no in their correct location.

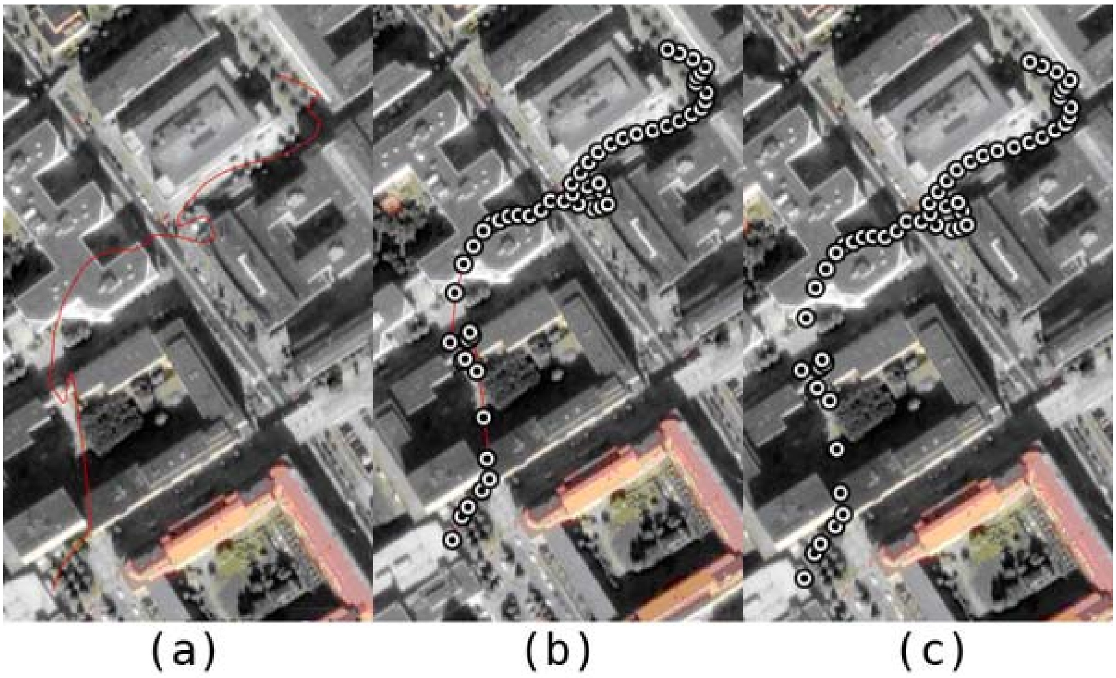

Figure 19: comparison between path and scatter points
(Figure from Google Earth on 2006.12.15)

Figure 20: Network description as display in Google Earth
(Figure from Google Earth on 2006.12.15)

The <Placemark> element could describe all information collect at this measurement point. So it makes more sense than using <LineString>. Additionally, at each point, it is easy to recognize when the data point is far from its correct location, such as the scatter points located on the top of a building. The survey shown in Figure 13 had two steps. The first step was to acquire the position from GPS receiver and to it associated with the data gathering from WLAN Survey application. The second step is to make a path recorder using the GPS positions and the <Placemark> element in KML. This path information can be used by a human user in a post processing step to manually correct the location data.

3.2 Implementation

3.2.1 Collect data

For this project, we created an application to do the data collection. The goal of this step is to collect data that will be suitable for subsequent modeling work. To facilitate this data collection I constructed a simple application as described below.

The survey system consists of two parts. The first conducts a wireless network survey and the second combines this with GPS data to label the data collection location. Given the limited processing power of the iPAQ, the modeling work will be done on a laptop after data collection, thus the WLAN measurements and coordinates are stored and later uploaded to the laptop.

To collect data I wrote an application using C# and the .NET Compact Framework. To get location information from the GlobalSat ST-338 GPS receiver, I used a virtual serial connection between the iPAQ and GPS receiver with Franson GpsTools[29]. Franson provides a set of tools which are integrated with the Visual Studio .NET environment. A trial version of the Franson GpsTools can be found on company's webpage [29]. This version can be used for 30 days free.

The Franson GpsTools library has extensive functionality, such as reading data from a serial port, drawing a simple raster map using polygons, polylines, and multipoints to create a user defined map. I based by application on the example program that Franson provides for the .NET Compact Framework called "SerialPortNoEvents". This proved to be the easiest example to follow. The source for my data collection program is included as Appendix A.

Movement method will tell the traveling speed of GPS receiver which is not so important in this project because of the speed of a person's walking is not so fast that it can be measure in km/hour. But for a large area when vehicle has to be involved, the velocity will be an important parameter can affect the result on data collection. So the speed from the GPS receiver was included in this survey program to indicate the traveling speed of user and equipment.

WLAN survey

When dealing with traditional wired local area networks, a network diagram creates which shows the wires in order to visualize the whole network. However, the wireless networks which we are concerned with use radio as a medium, so a scanning is necessary to identify the several networks which might be present at a given location as radio signals traveling in free space. Information about these WLANs will be obtained using an IEEE 802.11b enabled Pocket PC, specifically the HP iPAQ 5550 used in this project. The application I developed gathers the network data as described in section 3.1.1 and the GPS location of this measurement. The program saves all the information into a text file and generates a KML file to identify the route taken when collecting the measurements. The channel used by each access point can not detect by the OpenNETCFG.ORG library. However, if the access points do not change their channel frequently, then other software or SNMP could be used to collect the channel information.

The application was running on the iPAQ 5550 with the GlobalSat BT-338 Bluetooth receiver. The user interface is quite simple as shown in Figure 21; the text box on left side shows the result when clicking on one or more of the buttons on the right. The function for each buttons:

- Satellites: the status of satellites
- Speed: the velocity
- Quality: HDOP,VDOP, and PDOP
- Position: equipment position
- Status: connection information between iPAQ and GPS receiver
- WLAN: SSID of access points nearby

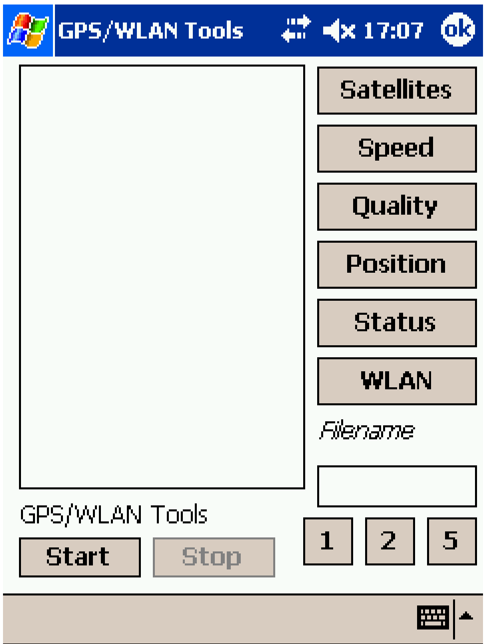

Figure 21: Application to collect data

As shown in Figure 22 the result box shows GPS position when the user clicks on the Position button. The value of this position is the location of where I made the analysis after data collection.

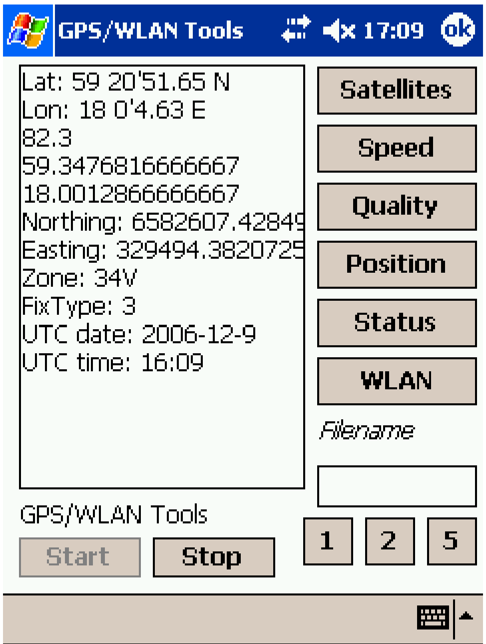

Figure 22: Position value display on iPAQ

The three buttons on the right bottom corner set the sampling interval in seconds. When the use clicks the "Start" button the application communicate with GPS receiver via Bluetooth Serial Port, and user can click on the buttons on the right to get the position information. The filename is entered in the text box under the “Filename” label. The file name begins with a testing date and ends with interval value (as set early by the user). Thus the user enters a filename and clicks one of the three interval buttons; this will initial the recording procedure and data will be save to a file using the previously set parameters. When user wants to end a recording, he clicks on Stop button and two files will be written. Part of the data collected shown below in Table 4. At a single location, the longitude and latitude are constant (as shown in Table 4). At this specific location there are two access points for the KTH open network and 4 other access points with different SSID values. The signal strength value and quality value for the KTH open network, “hansta51”, and “ispace” network are excellent, but not so good for networks “OP5” and “mesnet”. The Quality column should describe the quality of wireless network connectivity if the user were able to associate with this network. The decibel value for signal strength is saved for future calculations of details of the coverage area.

Table 4: Example of data collected

SSID	Signal	Longitude	Latitude	Quality	MAC address
open	-24	17.94403333	59.404505	Excellent	00-02-2D-09-AB-FD
OP5	-76	17.94403333	59.404505	Low	00-0D-54-A9-86-8E
open	-40	17.94403333	59.404505	Excellent	00-60-1D-22-3C-8A
mesnet	-76	17.94403333	59.404505	Low	00-0F-66-5B-6E-12
hansta51	-56	17.94403333	59.404505	Excellent	00-0F-B5-E5-D7-C0
ispace	-40	17.94403333	59.404505	Excellent	00-50-DA-93-4E-18

3.2.2 Data processing

The first step in processing this data was to transfer the raw data out of the hand held device. The program I developed exports the raw data in a comma separated value (CSV) data format. As testing was conducted on several different dates and times, and each session one data file is produced, I used the date as a prefix to the file name. Using a meaningful filename can give helpful information to the user when they want to concatenate files from several measurement sessions into a single file. However, this proved not to be sufficient. So I created another KML file to show the walking path, this enabled me to both concatenate multiple exported data files together easily, and it helped me to manually fix the obvious inaccurate position values. It made it easier to use tools to concatenate the files and remove the duplicate parts.

The second step was to import the text file containing comma separated values into Microsoft's Excel. This step enables us to extract general information about network propagation through simple analysis. Having the data in a spreadsheet enables it to be analyzed in many ways. All the network information from each data collection session could be easily processed with a filter. The use of files together with Microsoft's Excel was an alternative to using a database in this project. In addition, the Microsoft's Excel data file can be easily imported to any popular database for future use. In order to generate a coverage map of the KTH's open wireless network, one simple sets a filter to "open" on the SSID column. If one just wants to know the coverage of a specific access point with MAC address "00-02-2D-92-01-99", one simply sets the filter to "00-02-2D-92-01-99" for the MAC address column. Even the location value (from the latitude and longitude columns) could also be used as a criteria of where place a data point on the map. In the future this might be done via a database and a suitable user interface, however for the purposes of this project an Excel spreadsheet was sufficient.

After the data selection process in Excel, the selected data was input into Origin. By using the plotting functions in Origin, the coverage data could be generated based upon the GPS coordinates which fulfill the selected parameters. Origin made it easy to generate a nice looking plot. This program features a number of different types of symbols, and user can set the color and size of the symbol to be drawn at each location.

Figure 23 shows an example plot generated by Origin from a small part of the measurement data. The symbol used for each data collection point is a hexagon. The color green was chosen because it stands out when put it on top of Google Earth.

Once the overlay has been generated by Origin, the next step is to put it on the top of Google Earth. Axis X is the longitude, here the highest value was 17.9485, and the lowest was 17.9450. Axis Y is the latitude value of location, here the highest value was 59.4060, and the lowest was 59.4042. The border value of this picture is the area range where this layout should placed in Google Earth. Thus in Google Earth, the <LatLonBox> is:

```
<LatLonBox>
  <north>59.4060</north>
  <south>59.4042</south>
  <east>17.9485</east>
  <west>17.9450</west>
</LatLonBox>
```

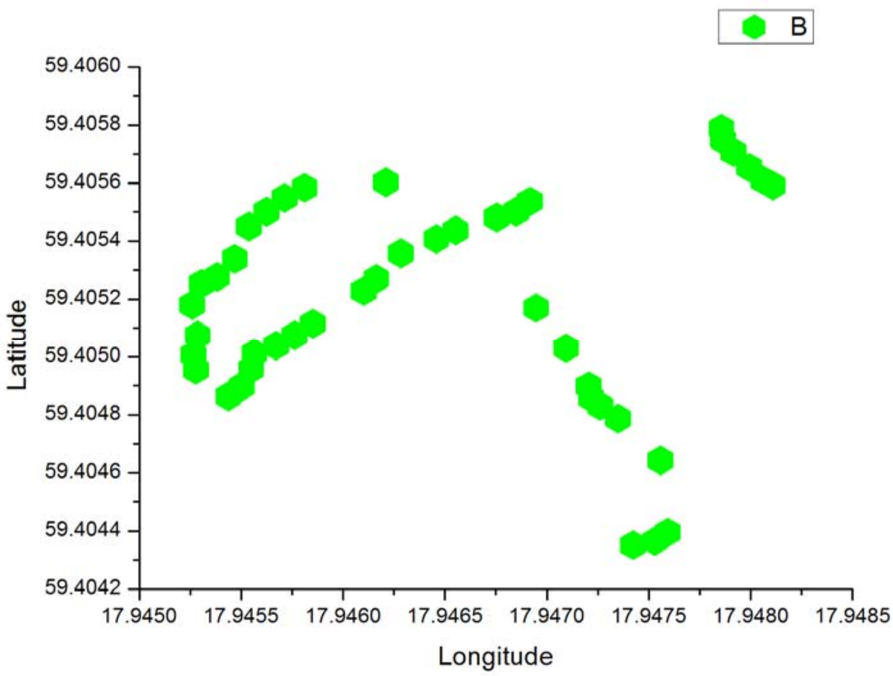

Figure 23: Result from Origin
Showing where is the “open” network along the route

Figure 23 can be placed on top of Google Earth using a KMZ file which describes the overlay in a <LatLonBox> and Figure 22 by the name of *kista.png* in the *images* folder. The content of doc.kml in KMZ file shown below:

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.0">
<Folder>
  <name>Kista</name>
  <open>1</open>
   <LookAt id="kista">
      <longitude>17.947462</longitude>
      <latitude>59.405152</latitude>
      <range>500</range>
      <tilt>0</tilt>
      <heading>0</heading>
    </LookAt>
  <GroundOverlay>
    <name>show about kista</name>
    <description>A example of WLAN coverage</description>
    <color>7cffffff</color>
    <Icon>
      <href>images/kista.png</href>
    </Icon>
    <LatLonBox>
      <north>59.4060</north>
      <south>59.4042</south>
      <east>17.9485</east>
      <west>17.9450</west>
    </LatLonBox>
  </GroundOverlay>
</Folder>
</kml>
```

Element <LookAt> in KML defines a camera displays any scenes in Google Earth. <longitude> and <latitude> are the position values that camera look at, they are in degrees format. <range> is the distance between aim position with the position in LookAt, it is measured in meters. <tilt> is the angle between the direction of LookAt and the direction plumb to the ground. <heading> shows the direction, the default 0 is north.

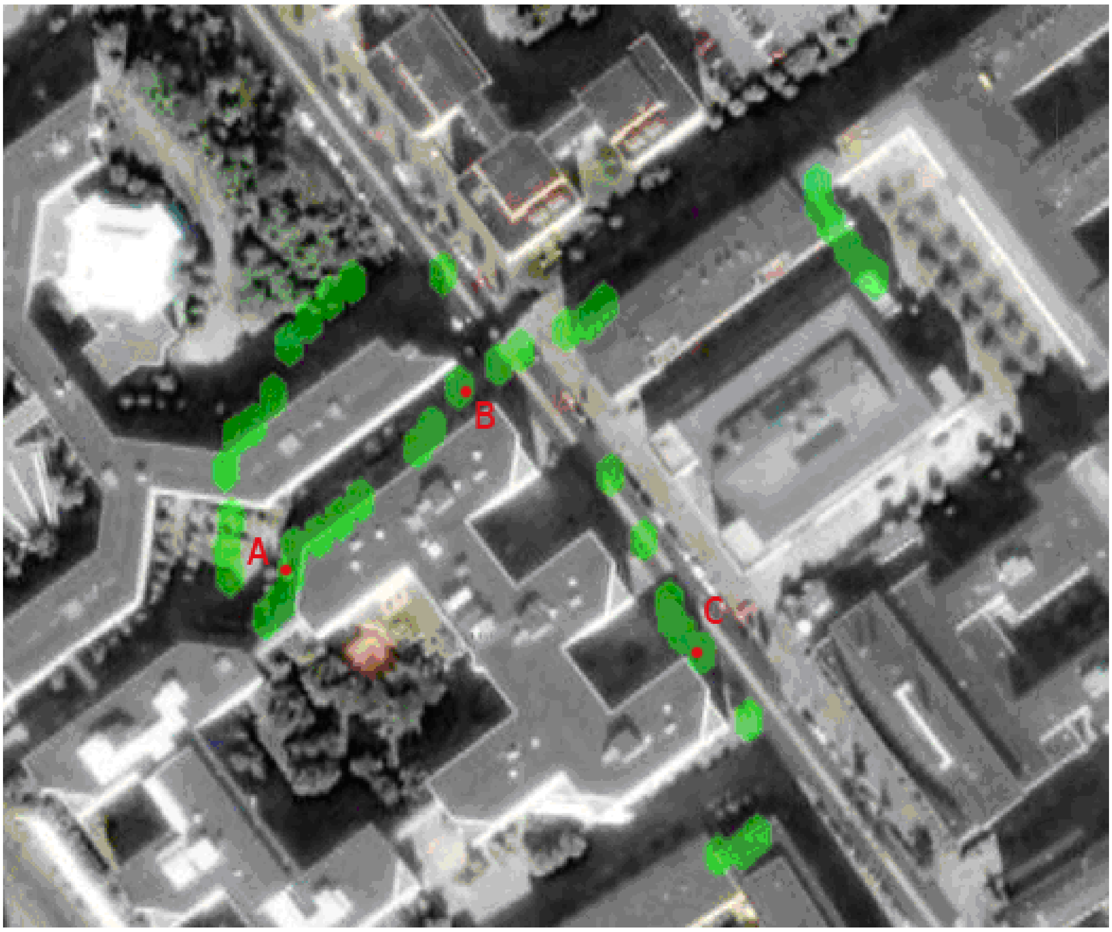

Figure 24: result in Google Earth
(Figure from Google Earth on 2006.12.15)

The result is shown in Figure 24. This seems acceptable, except for at some places where the GPS signal shows low accuracy, i.e., where green hexagons touch the side of a building. This may be due to GPS multipath or some other source of interference. However, it seems to be a good way to show the user where they are likely to have good WLAN service.

Chapter 4 –Analysis

The solution proposed in this project enabled us to build a WLAN coverage model. For a coverage map such as that shown in Figure 24, we can check the actual coverage at certain locations using the map with a laptop to check the wireless signals. The evaluation criterion is that we should get the same access point information as the earlier collection data did. In this evaluation step, another program called NetStumbler [30] was used as the WLAN measurement software. NetStumbler is a wireless diagnosis tool running on Microsoft Windows 2000 or XP. The laptop used in this step was an HP NC6000 with a D-Link AirPlusG+ 802.11g/2.4GHz Wireless Cardbus Adapter. We found that the signal strength from different devices (which have different hardware, such as receiver chip, antenna geometry, and software) used in measurement were also different. However, I checked to if the values from these different devices were strongly correlated with each other.

4.1 Comparison of two different WLAN devices

A comparison between these two receivers should be done to establish if there is inter-device comparability. The first device is the iPAQ 5550, with its internal WLAN interface, and my own wireless survey program. The second device is the HP NC6000, D-Link AirPlusG+ 802.11g/2.4GHz Wireless Cardbus Adapter, and NetStumbler. The comparison was made in the environment shown in Figure 25. It is outside the Wireless@KTH building, the access point in this test is a KTH open network access point with MAC address is 00-02-2D-92-01-A0. This access point is deployed at Wireless@KTH building, Room 3359. The blue point was the position where the access point was and the red position was the position where the two sets of equipment were being test. One hundred measurements were taken with each device. Tables 5 and 6 show the measurements for both devices.

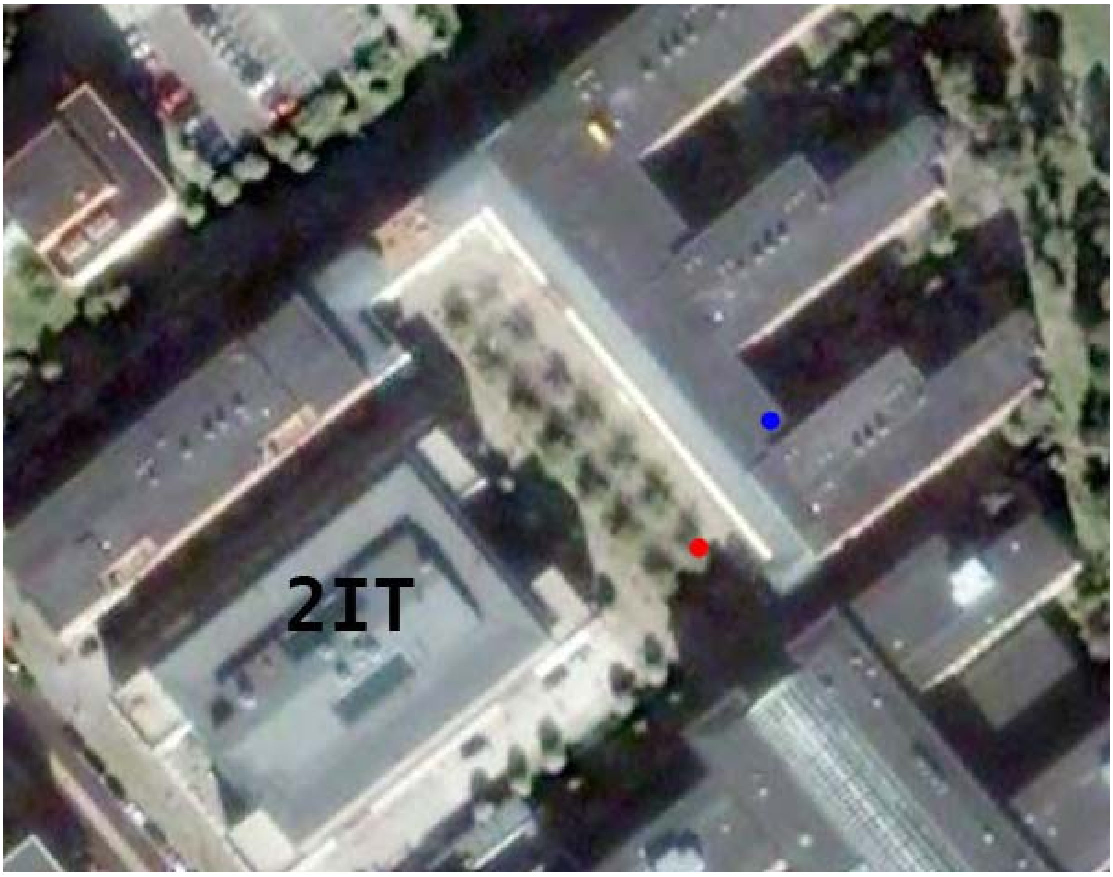

Figure 25: Deployment of different equipment
(Figure from Google Earth on 2006.12.15)

Table 5: Test result from iPAQ:

-32	-32	-40	-52	-44	-52	-40	-40	-40	-52
-32	-32	-40	-52	-44	-40	-40	-44	-52	-48
-44	-40	-40	-52	-40	-36	-44	-44	-40	-40
-44	-36	-36	-36	-68	-40	-44	-40	-44	-40
-36	-32	-44	-44	-32	-40	-44	-52	-60	-40
-52	-40	-60	-36	-44	-44	-44	-44	-40	-40
-36	-52	-40	-44	-48	-40	-40	-44	-36	-44
-40	-36	-36	-40	-44	-48	-36	-36	-36	-44
-40	-44	-36	-64	-44	-40	-52	-52	-40	-44
-40	-36	-40	-52	-60	-40	-40	-44	-52	-36

MIN= -68 MAX= -32 Average= -42.8
Standard deviation= 7.02

Table 6: Test result from HP laptop:

-40	-40	-32	-42	-32	-40	-44	-38	-38	-44
-44	-42	-40	-36	-40	-42	-38	-36	-40	-38
-42	-44	-36	-42	-52	-44	-38	-42	-40	-44
-38	-36	-40	-40	-40	-44	-42	-42	-38	-40
-42	-32	-42	-42	-36	-40	-34	-42	-38	-38
-42	-40	-32	-54	-32	-42	-40	-36	-40	-42
-38	-40	-40	-36	-40	-40	-40	-38	-38	-54
-40	-44	-56	-44	-52	-36	-42	-54	-40	-44
-40	-40	-48	-40	-46	-44	-40	-54	-38	-42
-38	-38	-54	-36	-46	-44	-40	-44	-42	-42

MIN= -56 MAX= -32 Average= -41.08

Standard deviation= 4.91

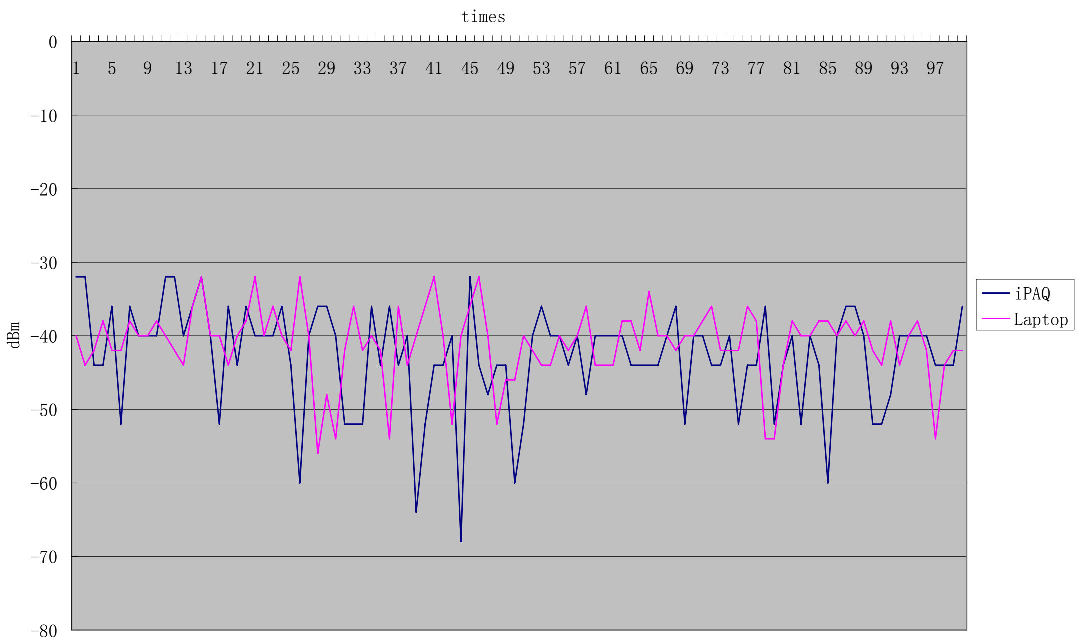

Figure 26: Comparison between different equipments

When testing two set of equipment in the same location, in the same environment, using the same access point, the 100 values of HP laptop had an average value of -41.08 dBm while the average value of 100 value of iPAQ was -42.8 dBm. Figure 26 shows these two hundred measurements. They showed that the collected values for the two devices are consistent, but different. It also shows that the data collected from the iPAQ had higher variance than the data collected using the laptop. The difference between average values of laptop and iPAQ is small. The signal strength measurements from these two set of equipment shown that there is inter-device comparability.

4.2 Comparison of two (identical) WLAN devices

The comparison between two identical WLAN devices was taken inside the Wireless@KTH building. The access point with MAC address is 00-02-2D-92-01-A0 is shown with a blue dot in Figure 27. Three places were marked with red point and labeled with letter A, B, and C. At each location, two iPAQs with the same wireless survey program made same measurement.

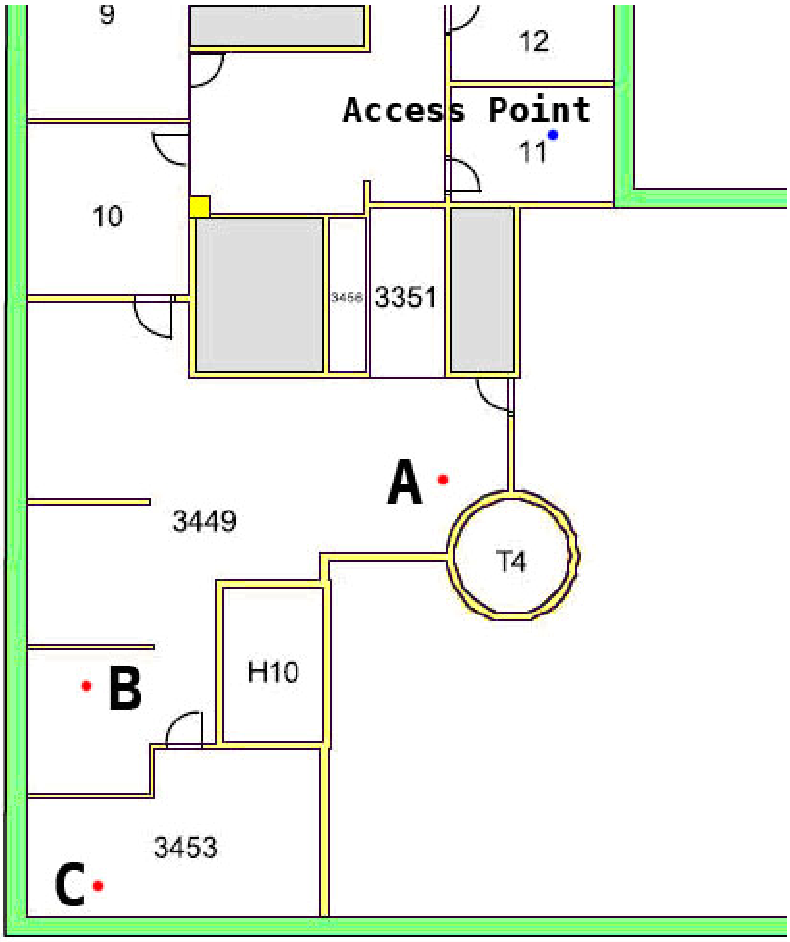

Figure 27: Deployment of different iPAQ

The complete set of 600 measurement values are included in Appendix A. A summary of this test is shown in Table 7. At location A, the signal strength of each iPAQ was excellent, with a value of -24 dBm in all 100 times measurement. At location B and C, both iPAQ had similar signal strength. iPAQ 1 had a smaller average signal strength value in location B, but had a bigger one in location C. The standard deviation of iPAQ 1 was bigger than iPAQ 2. However, the differences between these two iPAQ was small.

Table 7: Comparison summary of two identical devices

	Location A		Location B		Location C	
	iPAQ 1	iPAQ 2	iPAQ 1	iPAQ 2	iPAQ 1	iPAQ 2
Average	-24	-24	-42.14	-43.2	-53.8	-51.9
MIN	-24	-24	-60	-52	-76	-76
MAX	-24	-24	-28	-32	-44	-40
Standard Deviation	0	0	5.27	3.83	12.42	11.82

Location A had a great connectivity with the access point, the signal strength showed -24 dBm all the time on both iPAQs. Location B had a good connectivity, the minimum value of the signal strength on iPAQ 1 is -60 dBm and -52 dBm on iPAQ 2 which are sufficient to have a wireless connection; the maximum values of both iPAQ are around -30 dBm. The average value at location B is at the level of good connection, and result of two iPAQ shows a similar signal strength in 200 measurements. At location C, the average of two iPAQs had a value at -50 dBm level which is enough to associate with the access point. However, the minimum value showed a value of -76dBm on both iPAQs, and it was not possible to establish a wireless connection. But the maximum value at location C of each iPAQ showed at the -40 dBm level, and this is sufficient for a wireless connection. Note that at location C, the standard deviation of each iPAQ was greater than at location B. As expected the signal strength standard deviation increases as the signal quality decreases.

4.3 Reproducibility

The reproducibility test is verify the wireless LAN network information get from data collection procedure by going back to the same spot and redo the measurement again. For the reason of there is inter-device comparability between iPAQ and HP laptop, so we used the laptop to do this test. and three location was selected in Figure 24.At the selected point A, we measured the results shown in tables 5 and 6.

Table 8: OPEN network signal strength during data collection:

Open	-32	Excellent	00-02-2D-02-89-37
Open	-76	Low	00-02-2D-02-88-80
Open	-72	Low	00-07-50-D6-48-F9
Open	-76	Low	00-14-F2-FC-6B-D0

Table 9: OPEN network signal strength in evaluation step:

open	-77	Low	00-02-2D-02-89-37
open	-78	Low	00-02-2D-02-88-80
open	-71	Low	00-07-50-D6-48-F9

Comparing Table 8 and Table 9, the coverage map shows there is an open WLAN at location A. During the data collection procedure, there were four access points detected, one of these access points had a signal strength of "-32 dBm (Excellent)" - its MAC address was "00-02-2D-02-89-37". When later checking this data, the same access point had a signal strength of only "-77 dBm (Low)". A second access point with a MAC address of "00-02-2D-02-88-80" had a signal strength of "-76 dBm (Low)" during the data collection procedure and a signal strength of "-78 dBm (Low)" subsequently. The access point "00-07-50-D6-48-F9" had a "-72 dBm (Low)" and a "-71 dBm (Low)" both cases. Additionally, detected during the collection procedure is missing from the later data. The forth access point was deployed in the Forum's 7th floor IT-Admin Meeting Room 7209, which is at least 45 meters away from location A. From the collection data we can see that the signal strength was "-76 dBm (Low)", so the forth access point probably has unstable coverage at location A. The greatest difference in observed values is for access point "00-02-2D-02-89-37". This access point is deployed in the Forum's 6th floor room 6210, it is a large room for group discussions and is located at the same side of Forum building as location A. The difference between all the signal strength value was from many reasons. The signal of WLAN can be affect by many things[31], such as people walking between the access point and wireless client, other equipment using same radio frequency nearby, a door opening, etc. As for one possible scenario during data collection, a student may have opened the window of Room 6210, so the signal strength was Excellent at that moment. But when I was doing check, the signal strength was Low. So the data from survey procedure can be different from the post analysis data. However, the data requires frequent updates to maintain its function.

From the data file in both survey procedures at location B, the access point (with MAC address “00-07-85-B4-13-6D”) has a value “-60 dBm (Very Good)” during the data collection step and a value of “-76 dBm (Low)” during analysis step. The access point is deployed at Forum in the 7th floor DSV room 7536B which is quite far from location B. At location C, the collection data value was “-48 dBm (Excellent)” while the subsequent analysis data was “-40 dBm (Excellent)”, and they have the same connection quality.

Many things can affect WLAN signal strength, such as a door opening, a cart passing through a nearby hallway, a wrist passing over a PC card [31]. So there is not a very precise way to record the signal strength at one moment. As shown in Table 5, the maximum value is -60 dBm and minimum value is -76 dBm. It was taken at the same place with same device of the same environment without any accidentally interruption, such as a person walking, a door opening. The difference between these values is big. From last section, multiple observations at same location which the signal quality is not so good show the signal strength of iPAQ often changes a lot, such as the difference of minimum and maximum is 36 dBm at location C from iPAQ 2 in Table 7. So for the walwalking used in this project, the collected data can only show the status of WLAN at the collection time, give user a general knowledge about coverage.

Chapter 5 – Conclusions and Future Work

5.1 Conclusion

At the beginning of this project, I tried to divide the whole area into several small areas and tried to make a single measurement of each such small area. This would result in only a single value for each such small area. However, dividing a large outdoor area has little meaning (in comparison to such a measurement indoors). When doing a survey indoors, it is meaningful to measure smaller areas such as each room in a building, where the room number would identify the measurement. But outdoors, a small part of a road has no simple name, although one could think of using the nearest street address - but this is too coarse for the measurements which I was making. However, an outdoor survey can use positioning technology such as GPS as in this project. The result is that each measurement has geo-coordinates and hence can be directly connected to a geographic information system. In this case we have used Google Earth.

The sampling frequency (which is related to resolution) is one of the most important parameters in our modeling. The data collection program used in this project used a sampling interval of 2 seconds, so with my normal walking velocity this corresponds to a spatial sampling resolution of 2.67 meters which sufficient for our model. Increasing this sampling interval (i.e., decreasing the rate) means that distance between two sample points will be too large; while decreasing this value, the distance moved will be too small to make much of a difference in the signal strength The value of 2 seconds was selected based upon some preliminary data collection sessions. However, the application can be set to use an interval of 1, 2, or 5 seconds, so it is possible for someone else to use this application to gather network information at a different temporal (or spatial) resolution. Unlike the high precision survey equipment such as the Drone and Yellowjacket (described in section 2.1.3) which are designed for network optimization, the aim of our model was to provide information to users about where there was potentially good connectivity. Therefore the most important aspect is knowledge of the whole campus area - in order to understand where there was very good or excellent signal quality. Given the coverage map of the campus, a user can go to the nearest location with good quality if they want higher data rates. Thus the user avoids having to search for such locations.

In this project, I have learned many things about wireless networking and basic spatial data sampling, and how to combine these two important subjects. Google Earth provided a great tool to present our network data combined with spatial information.

5.2 Different design if done again

If I had the chance to do this project again, I would try to update the fireware of the GlobalSat BT-338 GPS receiver in order to use the EGNOS function to see if there is any improvement in accuracy. Otherwise I would use another GPS receiver with a different antenna to reduce the effect of multipath, in order increase the accuracy of the location information; thus would reduce the effort to manually correct the locations which are obviously in error.

Additionally, I would also try to find where the GPS receiver suffers a lot from multipath, and treat those areas specially. For example, I would gather network information avoiding these special areas. Then for these special areas, I would use manual positioning methods to get accurate position data, for example, using optical surveying instruments to supplement the GPS receiver (see for example [32]). Another method would be to change the planned walking paths to enable the correct position to be interpolated from the earlier positions (i.e., by exploiting the fact that the user was walking along a know path at a know rate).

5.3 Future work

The result of this project is a model of WLAN coverage which is usable by KTH students, faculty, and staff; business persons visiting the KTH Campus in Kista; or city planners considering public wireless network coverage. The method used in this project utilizes software to handle the data collection, data processing, and generates a coverage overlay. The use of Microsoft's Excel to store and select data from files is not suitable for a large area and is not automatically. Hence this component should be replaced by a database and suitable queries. Because I did not have much experience in developing software, I was not able to develop a single program to process the data file, perform the data selection, generate an overlay image, and the corresponding KMZ file. Thus a future enhancement would be to integrate all of these steps in such a way that many people could collect data and upload it to a database, which would then periodically be used to update the overlay. (see for example [33]).To create a complete solution, there should be a business model for the project, including a mechanism to reward users for contributing to the data collection process, as Navizon does [20].

For someone continuing this project a first step would be to find a more accurate GPS receiver and antenna combination. The next step would be to develop a fully automatically application with a friendly user interface, or perhaps with a web interface. A database should be utilized to store all the network information, so that a user simply selects the relevant data from their client and the program generates the corresponding KMZ file for the user. In fact, many overlays could be pre-computed and the correct one simply selected, downloaded, and displayed.

Appendix

A: Result of identical devices

A		B		C	
iPAQ1	iPAQ2	iPAQ1	iPAQ2	iPAQ1	iPAQ2
−24	−24	−44	−48	−64	−76
−24	−24	−28	−34	−68	−76
−24	−24	−34	−44	−68	−44
−24	−24	−44	−40	−72	−44
−24	−24	−40	−48	−68	−44
−24	−24	−32	−52	−68	−76
−24	−24	−36	−52	−68	−76
−24	−24	−36	−46	−72	−44
−24	−24	−36	−44	−68	−48
−24	−24	−36	−44	−64	−44
−24	−24	−40	−52	−76	−44
−24	−24	−40	−42	−76	−44
−24	−24	−40	−44	−76	−48
−24	−24	−40	−44	−76	−68
−24	−24	−44	−46	−76	−64
−24	−24	−40	−46	−72	−76
−24	−24	−32	−44	−72	−44
−24	−24	−36	−44	−72	−48
−24	−24	−36	−46	−76	−48
−24	−24	−36	−44	−76	−44
−24	−24	−42	−38	−76	−48
−24	−24	−42	−40	−76	−48
−24	−24	−42	−38	−44	−40
−24	−24	−42	−38	−44	−40
−24	−24	−56	−44	−44	−40
−24	−24	−34	−44	−48	−40
−24	−24	−32	−40	−48	−42
−24	−24	−44	−42	−44	−44
−24	−24	−44	−42	−48	−48
−24	−24	−40	−42	−44	−44
−24	−24	−44	−42	−44	−44
−24	−24	−44	−52	−44	−44

−24	−24	−40	−40	−48	−48
−24	−24	−40	−44	−44	−44
−24	−24	−42	−42	−44	−44
−24	−24	−42	−42	−44	−44
−24	−24	−38	−42	−48	−48
−24	−24	−44	−40	−44	−52
−24	−24	−44	−40	−44	−68
−24	−24	−52	−44	−44	−64
−24	−24	−52	−44	−48	−76
−24	−24	−44	−42	−48	−76
−24	−24	−40	−42	−44	−76
−24	−24	−40	−40	−44	−56
−24	−24	−44	−38	−44	−60
−24	−24	−40	−38	−44	−60
−24	−24	−40	−38	−52	−60
−24	−24	−44	−44	−48	−72
−24	−24	−44	−42	−44	−72
−24	−24	−44	−44	−48	−72
−24	−24	−40	−44	−44	−44
−24	−24	−46	−44	−48	−48
−24	−24	−52	−48	−48	−44
−24	−24	−52	−48	−44	−44
−24	−24	−46	−44	−44	−44
−24	−24	−46	−44	−48	−48
−24	−24	−40	−44	−48	−44
−24	−24	−40	−44	−44	−44
−24	−24	−44	−46	−44	−44
−24	−24	−44	−46	−48	−48
−24	−24	−40	−44	−44	−42
−24	−24	−40	−44	−48	−46
−24	−24	−44	−40	−44	−60
−24	−24	−44	−40	−44	−76
−24	−24	−44	−44	−76	−72
−24	−24	−40	−40	−60	−76
−24	−24	−40	−40	−44	−72
−24	−24	−44	−40	−44	−44
−24	−24	−40	−44	−44	−76
−24	−24	−44	−44	−44	−76
−24	−24	−40	−42	−44	−44
−24	−24	−40	−42	−44	−44
−24	−24	−44	−42	−48	−44
−24	−24	−40	−44	−44	−46
−24	−24	−40	−40	−44	−48

−24	−24	−44	−42	−44	−48
−24	−24	−44	−42	−48	−44
−24	−24	−44	−40	−44	−44
−24	−24	−28	−44	−48	−44
−24	−24	−44	−44	−48	−44
−24	−24	−44	−42	−48	−52
−24	−24	−48	−40	−48	−48
−24	−24	−60	−40	−48	−44
−24	−24	−38	−40	−48	−48
−24	−24	−42	−38	−44	−42
−24	−24	−42	−32	−44	−42
−24	−24	−42	−32	−76	−42
−24	−24	−42	−48	−76	−44
−24	−24	−42	−48	−44	−44
−24	−24	−32	−44	−48	−52
−24	−24	−44	−48	−44	−48
−24	−24	−48	−48	−44	−44
−24	−24	−48	−48	−44	−44
−24	−24	−52	−48	−48	−48
−24	−24	−48	−48	−68	−48
−24	−24	−48	−44	−64	−52
−24	−24	−48	−42	−70	−52
−24	−24	−44	−52	−70	−48
−24	−24	−48	−48	−70	−44
−24	−24	−46	−44	−70	−48

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