In-building Location Sensing Based on WLAN Signal Strength

Realizing a Presence User Agent

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Abstract

Exploiting context-aware environments, where sensors scattered in a environment update presence servers to indicate the environmental changes can be used to enable new services. Such systems have become feasible both in terms of technical difficulties and their cost. A current focus in this area of research is how a context-aware system should be designed so that it reduces both the cost and complexity of the infrastructure, but still provides the desired services. One of the key components of many context-aware systems is location sensing, because a user's location is one of the most used elements of information in context-aware services. In this paper, we address cost effective location services by utilizing measurements of WLAN signal strength. We derive from these measurements an estimate of a device's location, and make this location information available via a SIP Presence User Agent, thus making location information readily available to services that might wish to use this information - while hiding details of how this information is acquired from these services.

Sammanfattning

Genom att utnyttja kontextmedvetna miljöer, där sensorer i en miljö uppdaterar närvarande servrar med information omändringar i omgivningen, så kan man öppna upp vägar för nya tjänster. Sådana system har blivit utförbara bade när det gäller tekniska svarigheter och deras kostnader. Inom forskning som rör sådana här system ägnas mycket uppmärksamhet åt hur en kontextmedveten miljö borde designas för att minimera både kostnaden och komplexiteten av infrastrukturen, men fortfarande tillhandahålla den önskade tjänsten. En av huvudkomponenterna i många kontextmedvetna system är platsuppfattning, eftersom en användares position är en av de mest använda elementen av information i kontextmedvetna tjänster. I den här uppsatsen ägnar vi oss åt kostnadseffektiva platstjänster genom att mäta signalstyrkan av ett WLAN. Genom dessa mätningar uppskattar vi en enhets position och gör denna information tillgänglig via en SIP Presence User Agent, och gör på så vis platsinformationen tillgänglig för tjänster som kan vilja ha den – utan att avslöja detaljer om hur informationen har skaffats.

Acknowledgments

I would like to express my sincere appreciation to Prof. Gerald Q. Maguire Jr. for his considerate encouragement and support to complete this master thesis. His shrewd comments and gentle attitude helped me to have a rewarding experience at Wireless@KTH. My gratitude also goes to all the colleagues, staff, and faculty at Wireless@KTH for their kind help.

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Chapter 1

Introduction

1.1 Problem Statement

Recent enhancements to wireless technology, mobile computing, and sensing technology makes it feasible to bridge the physical world to virtual space, namely, via networked computers. Context-aware computing benefits from these technological advancements to provide richer services based on context information retrieved by detecting physical phenomenon. One of the most important elements of context is often location, as location information is required to deliver many services to the user on the fly. One of the most well known and commercially successful location sensing systems is the Global Positioning System(GPS). GPS is satellite-based navigation system and the main usage of GPS was assumed to be outdoors, unfortunately it does not provide sufficient penetration to be usable for indoor location applications.

In earlier research projects, numerous location sensing systems were proposed; primarily, these attempts focused on the enhancement of the location accuracy. However, the required accuracy of location sensing depends upon the services that need to utilize this information. It is highly desirable to create a cost effective solution that provides satisfactory accuracy for the task (or tasks) to be addressed. Our solution should provide an inexpensive location sensing solution to be used for interesting context-aware applications in an indoor office environment, specifically at the KTH Center for Wireless Systems (Wireless@KTH).

The objective of our research is to design, develop, and evaluate an indoor location system that provides location information as input to a context-aware application. Our goal is to implement a prototype location sensing system using commercially available IEEE

802.11 wireless local area network (WLAN) technology and the existing communications infrastructure to realize a context aware system.

1.2 Location Sensing in our Context-aware System

Figure 1.1 shows the overall context-aware system architecture which we are going to work with. Details of the earlier work concerning this system (as shown in black) can be found in the thesis by M.Z.Eslami[1]. The red highlighted portion of the figure is our specific part of the overall system, specifically an WLAN based presence user agent, which sends a PUBLISH message to the server so that the user's location can be used in the other components of the system. The presence user agent calculates the user's position, maps this to a meaningful location (for example, in front of the door to a specific room), and sends a PUBLISH message to the server. To put this into a more specific context, consider the floor plan shown in figure 1.2, the system should be able to tell if the user is in front of the door to room 6346 or 6347. If they are in front of the door to room 6347, an experimental laboratory, and they are authorized to enter this room, then the door should automatically be unlocked for them. The dashed lined smart projector is a topic of another thesis project which is being conducted in parallel with this thesis project. It represents an additional example of the type of application which could benefit from the output of our new presence user agent.

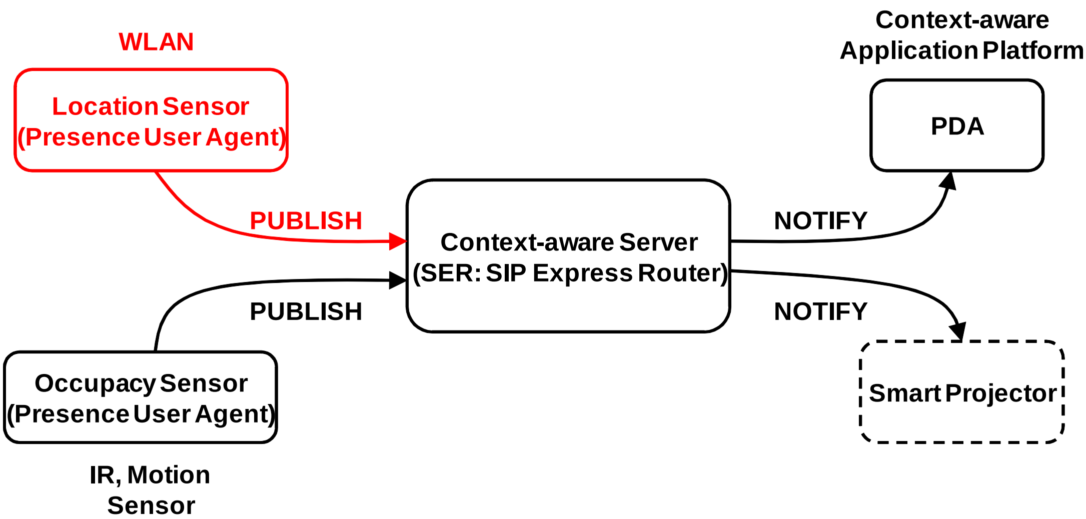

Figure 1.1: System overview

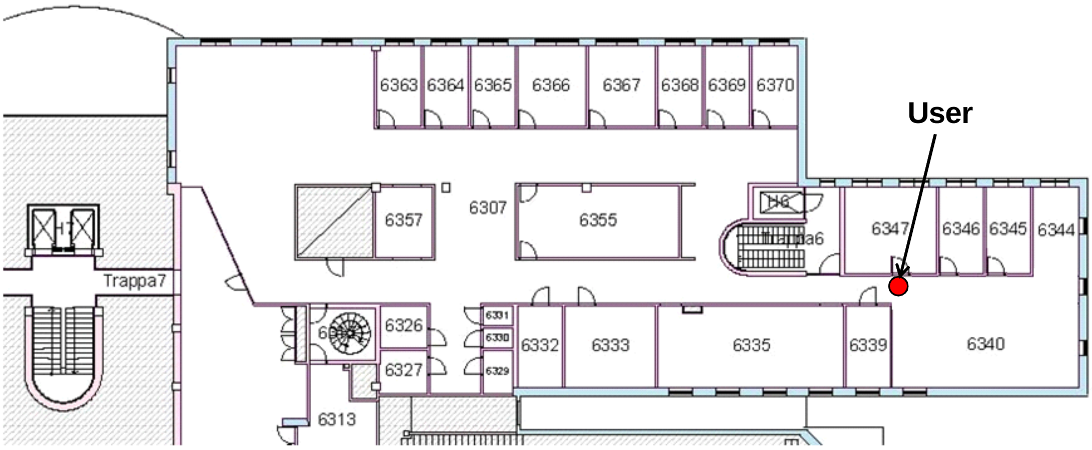

Figure 1.2: An example of a floor plan

1.3 Passive Location Sensing

WLAN is no longer restricted to laptop computers, which the technology was initially introduced for. More and more mobile devices have become WLAN capable. Furthermore, WLAN *can* be used to localize an object or person, although WLAN was not designed to play this role. The reason is that WLAN systems communicate at radio frequencies, thus enabling positioning based upon triangulation, signal strength measurements, etc.

Location sensing technologies can be categorized into passive or active solutions based on the manner of detecting a device's location. Passive solutions refer to location sensing in which the detected device, such as tag, phone, PDA, and so on, does not need to do anything specifically for location sensing; as other components listen to the signals coming from device in its normal operation in order to detect the devices's location. Conversely, in an active solution, the device itself actively participates in the location sensing process. The processing load in the mobile device depends upon the specific method being used and the services which will use this location information. For example, in the case of the GPS, the computation of the device's location can be performed in the mobile device or remotely - using information collected by the mobile device. Thus GPS based systems require the active participation of the device which is to be located.

The common way to detect a device's location in a passive manner include RFID[2] and cellular proximity detection. RFID based location detection was originally designed for proximity based location detection, where RFID readers are placed in each room to localize users who carry an RFID tag within the range of one of these RFID readers. Current research on RFID based location sensing is more diverse (Details of these new methods will be introduced in the background chapter). Cellular proximity detection is based on knowing the physical location of the access point that the user is currently accessing.

In this paper, we will investigate passive location sensing by utilizing WLAN traffic which is emitted by a device in the normal course of its operation, specifically based upon measurement of the emitted RF signal when the device is communicating. The motivation for this choice is that this approach does not require expensive installation costs, but may still provide sufficient accuracy to be utilized for interesting context aware services. An important part of our solution is to couple the location detection service together with a context aware infrastructure in order to enable location information to be an input to context-aware services. Hence we have chosen to implement our solution as a SIP Presence User Agent (as shown in figure 1.1). The motivation for this solution and an analysis of its performance and potential is contained the following chapters. It is important to note that this thesis is not an attempt to provide precise indoor location based upon WiFi signal strength measures (as there commercial systems, such as that of Ekahau, Inc. which focus on this), rather the key focus in on incorporating location sensing via a SIP Presence User Agent.

Chapter 2

Background

In this chapter, an overview of context aware systems and context-aware applications and the proposed architecture for our presence user agent are described. We motivate the need for a new presence user agent, by explaining what a context aware system is and why such a new source of context information is important. This is followed by an introduction to the basic concepts underlying such a presence user agent. The related research places this project in the context of other passive location detection research. Finally, the algorithms for location sensing techniques are illustrated with examples from existing systems. It is important to note that none of the systems described in this chapter on related work have incorporated their location sensing method as a presence user agent in a context-aware environment (as previously illustrated in figure 1.1).

2.1 Context-aware Application

2.1.1 What is Context?

With the growth of sensing technology and the increasing miniaturization of powerful processing units, context-aware computing has become feasible and has been attracting the attention of researchers. Context-aware computing provides a user with services based on their *context*, such as location, identity, activity, and time. For example, when a student is visiting his or her professor, the student needs to have a access to the professor's office. In the normal case, the student knock on the door and the professor opens the door, then, confirms that the student is the one with whom the professor is supposed to meet at that time. However, the professor might be in the middle of writing a paper, grading student exams, or in the midst of a telephone call with another student, thus after the arrival of the student the professor must either complete or postpone this task for a short while. With context-aware computing, when the student is standing in front of the office door, the infrastructure recognizes the presence of the student and informs the professor of the arrival, then after receiving the professor‘s permission the system opens the door. This example illustrates the context value of location (standing in front of a specific door), authentication (identifying the person as being an expected person), and time (the appointment time).

Before going into further details of context-aware applications, we would like to pose a question. What is *context*? There have been many definitions of context. Some simply focus on the environment or situation, such as the user's environment and application environment[3][4]. While others seek to define context and provide more specific interpretations[5][6][7]. Many of these definitions are quite limited in their notion of context; resulting in ambiguous boundaries. Dey and Abowd define the word "context" in a very clear way, therefore, we quote their definition here:

> *" Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."*[8]

This definition does not restrict the meaning of context to certain application boundaries as occurs in many definitions. Dey and Abowd also define *context-awareness* as follows:

> *" A system is context-aware if it uses context to provide relevant information and or services to the user, where relevancy depends on the user's task."*[8]

Although the meaning of context-aware seems to be limited to adaptation of the behavior of the application in many definitions, the above definition reflects the fact that context-aware does not necessarily imply the adaptation of behavior. For instance, an application that presents useful information based upon considering the user's situation without changing their behavior can still be considered a context aware application.

2.1.2 Context-aware Application Architecture

Figure 2.1 illustrates an example of a context-aware application architecture. This example architecture consists of four layers. We will explain each layer using the previous example of the automated door opening system. In the sensing layer, sensors detect physical information, such as the location of an object. The presence of a person standing in front of the door has to be sensed in order for an automated door opening system to

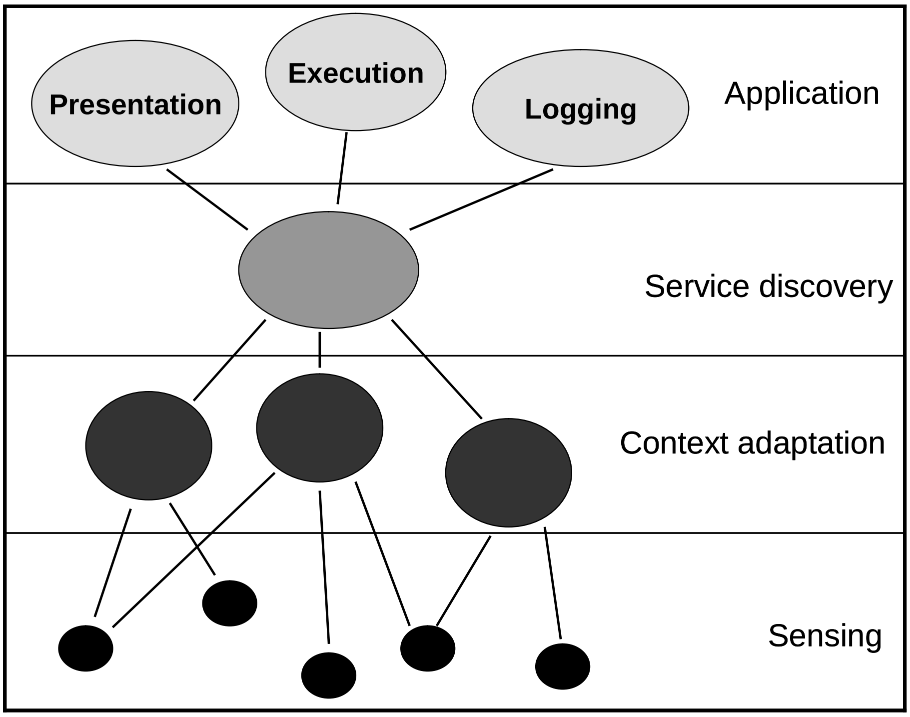

Figure 2.1: Context aware application architecture

open the door. The identification and authentication of the student can be proven by a negotiated security code or some sort of physical tag. It is also possible to prove the person's identity by using biometric information such as a fingerprint, although it requires having the hash of the fingerprint data beforehand in the database (Due to legal reasons, the raw data of a fingerprint can not be stored in Europe. Therefore, the hash is used to be compared against.). Sensors will communicate with the context adaptation layer, where the sensed information is interpreted in such a way that services can improve their decision making based upon the context. In this layer, the actual identity checking of the student will take place within the system, thus the sensor only detects the physical data. After the sensed data is mapped to a meaningful context, the context adaptation component looks for services that want this data by calling upon the service discovery layer. The service discovery layer coordinates the communication between the context adaptation components and one or more applications. Finally, the application retrieves the context information in order to accomplish its task. In the automated door opening system, the application utilizes the current context, i.e., who is visiting, in order to decide whether or not to unlock door by communicating with a networked door locking system, or it could simply log the presence of the visitor. It is possible to combine these solutions based on the user's desires and their needs.

2.1.3 Context-aware Systems

The Active Badge[26] was an early attempt to utilize the concept of context-aware computing to provide seamless services. Users carry a badge to reveal their locations. The prototype application provided call forwarding based on the location of callee.

There has been a lot of research conducted on context-aware computing, where Dey and Abowd[9] summarize this work. An example of an outdoor context-aware service is Cyberguide[10]. This application provides tourists with information relevant to their current location, for example, it can provide not only a description of the user's current location, but also relevant background information. This system allows tourists to leave a comment at the location, so that other tourists who visit the same place can benefit from their comments. The office assistant at MIT's Media Lab[11] utilizes pressure sensitive mats placed in front of each office door to detect the existence of visitors. An agent interacts with these visitors based on the owner's schedule. Visitors are asked to identify themselves; however, this might not actually be convenient nor does it offer seamless interaction.

While context-aware computing is feasible with current hardware, more attention is needed to design systems which can provide multiple services. Salber, Dey, and Abowd[12] designed a framework for context-aware applications, which makes it possible to implement a context-aware application in a efficient way. They introduced the idea of a context widget to reduce the design and implementation burdens upon the context-aware application developer. A context widget is a software component that resides between sensors and applications or services. This context widget hides complexity by providing abstract information to the application. For example, instead of providing the location of each user periodically, the widget only provides this data when a significant change in the environment happens. Such a widget is a highly reusable and customizable program component.

Imagine the situation where a large number of mobile agents are running on the network and waiting to execute tasks for the user. In a context-aware computing scenario, these agents need to be coordinated seamlessly in order to be helpful for the user. The key factor here is how to associate each executable program, in other words, services, to the context when they should execute. Chen, Finin, and Joshi[13] investigated a interesting approach using ontologies. Ontologies are used for reasoning about the context and mapping the agents to the context in which they are to execute. This approach is interesting especially because it is similar to the way human beings understand context. (Here, we are assuming that human beings think based on the words that they know.) Similar ontology based approaches can be found in [14] and [15].

2.1.4 Presence Messaging

To utilize the presence information such as location, there is a need for an underlying mechanism to carry the information from where it is detected to where it should be delivered. A standard model of presence messaging is proposed by Internet Engineering Task Force (IETF) in RFC 2778[16]; however, this model does not specify the communication protocol to carry the presence information. SIP for Instant Messaging and Presence Leveraging Extensions (SIMPLE) is an extension of SIP to deliver both instant messages and presence information. SIMPLE is one of the most promising candidates for a suitable presence protocol. This is because SIP enables mobility of endpoints; this application level routing capability of SIP is very useful for presence messaging.

Figure 2.2 shows how the presence information is delivered in SIMPLE [17]. The presence user agent detects the state of a presentity and updates the presence agent via a PUBLISH message. This presence agent is a central server where all SIMPLE messages are directed. The watcher is the endpoint that wishes to utilize this presence update, and has to subscribe to the presence agent beforehand by sending SUBSCRIBE message in order to receive this update from a presence agent. Once the subscription is confirmed, the watcher receives NOTIFY messages, which contain the presence information generated from presence user agent.

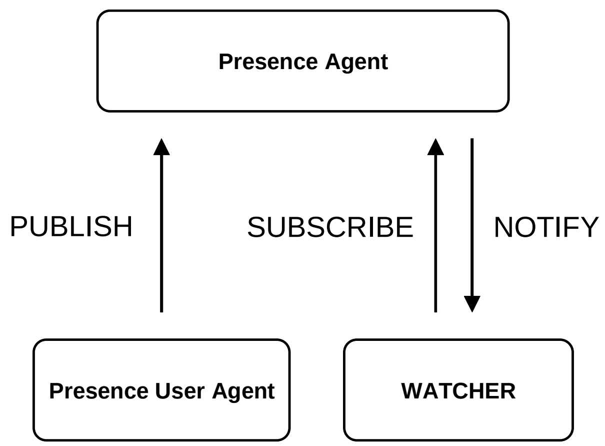

Figure 2.2: Presence messaging mechanism in SIMPLE

As the format for presence information, the eXtensible Makeup Language (XML) language can be used as described in RFC 3863[18], its use in this context is referred to as presence information data format(PIDF). The choice of an XML format has two main advantages. First, the structure of an XML document is hierarchical. Second, high extensibility can be achieved with XML. These features are very valuable for presence information. For further details and an example of using PIDF see [19].

2.2 Location Sensing

Hightower and Borrello[20] provide a survey and classify location sensing technologies into a taxonomy. Following their taxonomy, we classify location sensing technology into three main categories: proximity, triangulation, and scene analysis. Table 2.1 shows a summary of location sensing techniques.

2.2.1 Proximity

Proximity is the most intuitive way to sense location. Once an object is within range of a reader at a known location, we can determine that the object is somewhere nearby, otherwise the signal would not be detected. The location accuracy of this mode of location sensing is increased when short range communication is used, hence near field communication offers more precise localization. The tradeoff between cost and accuracy has to be carefully considered to design a location sensing system using this technique. Thus while accurate location information can be derived from proximity systems, the cost is a reader at every point which might be of interest in terms of a potential location. We now introduce three different existing implementations of proximity location sensing.

Physical contact

Physical contact is the most basic sort of proximity sensing, where location is determined by detecting direct physical contact with an object. Technologies such as pressure sensors, and touch sensors, and the Maxim i-button[21] are typical examples of this approach.

Orr and Abowd's Smart Floor[22] attempted to identify the user's location by monitoring pressure on a floor. This approach provides location sensing without requiring that users carry any devices or tags. Thus it is also desirable that the system can transparently identify users. The goal of their project was to identify the user by observing the footstep pattern of each user. They reported that the accuracy of this approach of identifying the user is 93 percent. Drawbacks of their smart floor are its scalability and the high initial

Table 2.1: Location sensing technologies

Name	Method	Accuracy	Precision	Cost(I/D)	Note
Smart Floor	Physical contact proximity	Spacing of pressure sensors	100%	High/None	Only where pressure sensors exists
Active Badges	Diffuse infrared proximity	Room size	100%	High/Low	Infrared interference
Wireless Andrew	802.11 cellular proximity	802.11 cell size	n/a	High/ Medium	Wireless NICs required
BlueSoft	Bluetooth, microcell ID	10m	n/a	Medium/ Medium	
SDRI	RFID, proximity	9x9cm^2	n/a	Medium/ Low	Tags and reader have to be within 10cm of each other
GPS	Radio time-of-flight lateration	1-5m	95-99%	High/ Medium	Outdoor only
Active Bats	Ultrasound time-of-flight lateration	9cm	95%	High/Low	
Cricket	Proximity, lateration	4x4 ft.	100%	Low/Low	No central management
PintPoint 3D-iD	RF lateration	1-3m	n/a	High/High	Proprietary, 802.11 interference
SpotON	Signal-strength, lateration	Cluster size	n/a	Low/Low	Less acurate than time-of-flight
BlueTag/ BlupNet	Bluetooth, Signal strength	1m	n/a	Medium/ Medium	
LANDMARC	Signal-strength, reference point	1.8m	50%	Low/Low	1 minute to scan the location, orientation
VOR	Angulation	1 degree radial	almost 100%	High/ Medium	30-140 nautical miles line of sight
Loop Antenna	Angulation	5 degrees	n/a	Low/ Medium	Requires distance from reader (min. 3m)
Easy Living	Vision, triangulation	Variable	n/a	High/None	Ubiquitous public camera
RADAR	802.11 RF scene analysis	3-4.3m	50%	Medium/ Low	Wireless NICs required

Cost (I/D) = Cost (Infrastructure/Device) cost to install the system, since a pressure sensor grid needs to be deployed through the building or at least in the limited area where location sensing is needed. K. Hinckley and M. Sinclair[23] and J. S. Son, E. A. Monteverde, and R. D. Howe[24] provide thorough introductions to touch sensing.

Access point

When the access points are scattered over an area, such as in the case of a wide area cellular network, it is possible to utilize proximity by monitoring which access points are in range. However, if the wireless communication link's range is long, then precise location sensing can not be achieved simply with this method. However, such systems have been widely used because the signal is available both indoors and outdoors; and the accuracy of this method is often sufficient for gross positioning (see for example Google's "My Location" service[25]).

The Active Badge[26] is a proximity system using diffuse infrared technology. To detect the badge's location, the users need to wear a badge which was carefully designed not to disturb the user, with a size of roughly 55x55x7mm and weighing 40g. Each badge emits a unique code for approximately a tenth of a second every 15 seconds. Sensors scattered through the building receive the signal and a central server collects, aggregates, and finally provides this data to an application programming interface. They tested the active badge using an application which routes received telephone calls based on the user's location. The disadvantage of this diffuse infrared system is that the infrared signal detection can be affected by fluorescent lighting or direct sunlight, because these light sources also generate infrared. The ParcTab system[27](designed by the same engineer) uses the infrared signal not only for location sensing, but also for the wireless communication itself. Carnegie Mellon University (among others) deployed a large IEEE 802.11 wireless radio network, which is able to track the user by detecting the access point to which the user is connected[28].

Automatic identification

Currently, there are many types of automatic identification systems, for example, these systems could be based upon barcodes, biometric identification, RFIDs, etc. Biometric identification uses the physical characteristics of individuals to identify individuals. There have been many different types of biometric identification procedures deployed, for example, fingerprint recognition is used in many implementations. Voice identification and retina identification are further examples of biometric identification. Although, different approaches have been explored to sense location using RFID, the standard and traditional way of using RFID falls into this category. As traditional RFID location sensing is based upon tags being readable by the readers which can receive the signal, the tag is assumed to be within range of the reader. We too will exploit this property, but utilize this information in a different way - as will be explain in section 3.

Super-distributed RFID Tag Infrastructures(SDRI)[29] proposed a location sensing system for ubiquitous computing based upon deploying passive RFID tags over the floor in the space which is to be used. Their focus was a new means of "bridging physical and virtual worlds" in ubiquitous computing environments, which was clearly identified by Want et al. in the late 1990s[30]. SDRI not only allows the user to retrieve location data, but also to store data in the fixed RFID tags. One of the examples of such an application is storing data with GPS-enhanced mobile devices, which permits GPS-less objects to obtain the location information from the nearby tag(s). It is also possible to store messages with links to bridge from a physical location to some virtual information. The virtual information can be any kind of information that might be useful in the location, such as information about stairs or obstacles. Leaving traces (i.e., information about visiting tags) is an attractive feature enabled by storing data in RFID tags. Figure 2.3 illustrates an example of tracing the mobile object. By leaving a unique ID in the tags and enabling new objects overwrite this earlier data with their own ID, the traced track will fade away.

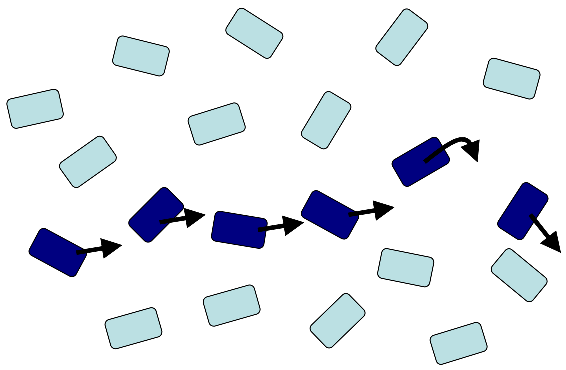

Figure 2.3: Tag distribution and tracking in SDRI

A drawback of this approach is that the RFID reader has to be placed within centimeters of the tag since the signal strength of a passive RFID tag is very limited. In the test environment, the distance between the reader (attached to the moving object) and passive RFID tags (placed in the floor) was 1 cemtimeter (cm). Similar proposals for location sensing by distributing RFID tags are seen in the areas of robotics and the navigation of mobile devices[31][32][33].

Ubiquitous Electronic Tagging[34] illustrates the growing deployment of electronic tagging and shows the potential that ubiquitous tagging will open in the near future. In this paper, Want and Russell predict that tags will have increased processing capability while requiring low power, thus tags will act as agents moving thorough the world collecting data and transferring it to the next destination. These tags will no longer be a static identifiers anymore, but will act more like active nodes attached to the network.

2.2.2 Triangulation

Triangulation is a location sensing technique based on the geometric properties of triangles. There are two main properties used to compute the object's location, by which triangulation is divided in two subcategories. The first property is the distance between the object and a reference points which are not collinear each other. The triangulation technique that relies on this property is called *lateration*. The second technique is called *angulation*, in which angles are used to determine the position of an object.

Lateration

As defined above, the term lateration means distance measurements, while angulation measures angles. By measuring distances from multiple reference positions, the position of an object is determined using lateration. As shown in Figure 2.4, we need to measure the distance from at least three non-collinear reference points to calculate an object's position in two dimensions. Distance measurements from 4 non-coplanar points are necessary for 3 dimension location sensing.

Time-of-Flight is one of the most commonly used solutions in practice for precise location sensing using lateration. Time-of-flight measures the time it takes a signal to travel between the object and point P at a known speed. Using the known propagation velocity and time, the distance between the object and point P can be determined. In the simplest case, the object is approximately stationary and we can simply observe the time difference of departure and arrival time of emitted signal either by having synchronized clocks at each end point or letting the signal traverse the distance. If the object is moving, the object's velocity and acceleration need to be taken into account.

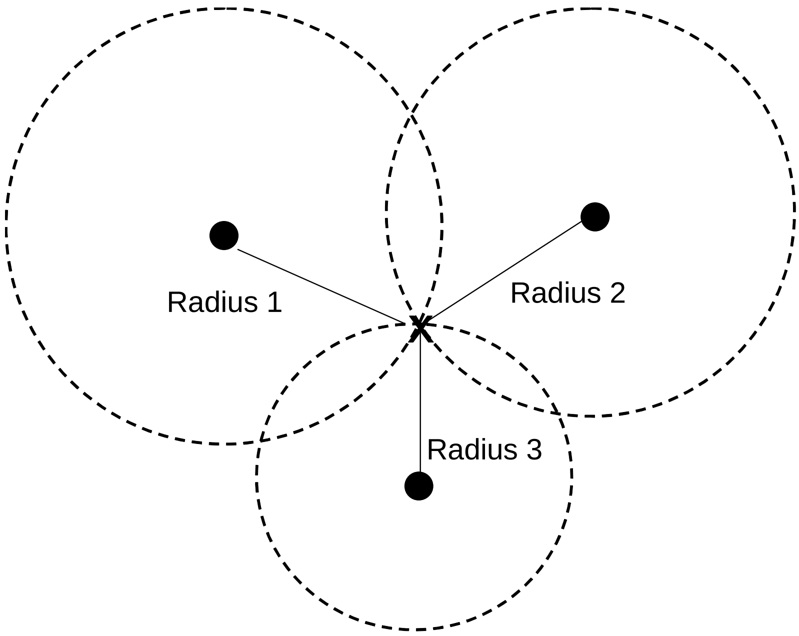

Figure 2.4: Determining 2D position by lateration

One of the most well-recognized systems based on time-of-flight method is GPS[35]. In the GPS system, the clocks in the satellites and the receiver are not initially synchronized; therefore, it is not possible to achieve a precise measurement of the time that takes the signal to reach the receiver from satellites by relying simply on the local clocks. To overcome this, the clocks in the GPS satellites are precisely synchronized with each other and send their local time in their signal so that the receiver can compute the difference in time. It is necessary to receive signals from at least four satellites for the receiver to compute its own location in 3-dimensions (latitude, longitude, elevation). The requirement for signals from four satellites might sound strange, since normally 3-dimensional positioning requires solving for only three valuables (X,Y,Z) by triangulation; However, the fourth satellite is used to solve for the forth unknown, which is the clock difference between the satellites' and receiver's clock.

Active Bat[36] uses ultrasound time-of-flight to compute the device's location. After receiving a request from the controller using short-range radio, an ultrasonic pulse is emitted by a Bat (which is a tag the users carry with them) to a grid of receivers attached to the ceiling. The controller resets the timers of sensors on ceiling in order to synchronize them, when it sends the request to the Bat. The time interval from reset to reception of the ultrasonic pulse is measured by each ceiling sensor, these values are subsequently used to compute the distance from each sensor to the Bat. Each measurement is sent to the central server to calculate the position of the Bat. Although the location accuracy is within 9 cm of the true position for 95 percent of measurements, the deployment of ceiling sensors is costly and the placement of the sensors affects the accuracy of the location sensing.

Cricket[37], on the other hand, does not require the deployment of a grid of sensors with fixed locations since the mobile receivers perform a lateration computation (similar to that in GPS); however, the accuracy of the location sensing is lower than for the Active Bat. Cricket also uses ultrasound time-of-flight lateration, but with the addition of a radio frequency control signal. The radio frequency signal is also used to delineate the time period during which the received sounds in the receiver are valid. The advantage of cricket is its scalability and privacy, while the disadvantages are the computational load and lack of monitoring (because there is not central server in the system).

Pinpoint 3D-iD[38] is an example of commercially developed location sensing solutions based on time-of-flight. Pinpoint utilizes 802.11 b/g communication systems to calculate the location of their Wi-Fi based tag.

Signal strength is used to estimate distance, because of the fact that the further the signal detection points are located from the source, the lower the signal strength received. In other words, signal strength decreases relative to the original signal intensity at the transmitter as the distance from the transmitter increases. Given a mapping between the distance from an object and the emitted signal strength, it is feasible to estimate the distance from an object by measuring the strength of the emitted signal from the source. However, if there are many obstructions, measuring distance simply assuming a fixed attenuation as a function of distance does not have great accuracy. Signal propagation issues such as reflection, refraction, and multipath cause signal strength to correlate poorly with distance, which results in imprecise distance estimates.

The SpotON[39] is the example of signal strength based location sensing technique based upon low-cost RF tags. (We will examine this system in detail in the section 2.3.) BlueTags[40] and BlipNet[41] are Bluetooth signal based location sensing solutions.

Angulation

Instead of distances, angulation computes the location of an object based on measurements of angles. In the common implementation of angulation, two angle measurements and one length measurement are required. One of the possible lengths used in angulation is the distance between the reference points as depicted in figure 2.5. It is also possible to use, even in angulation, the distance determined by time-of-flight method as we just described in lateration[42][43]. In the case of three dimension location sensing, one azimuth measurement is necessary in addition to the parameters which are used for two dimensional angulation. To implement angulation, a constant reference vector is used and could be chosen as the 0 degree direction.

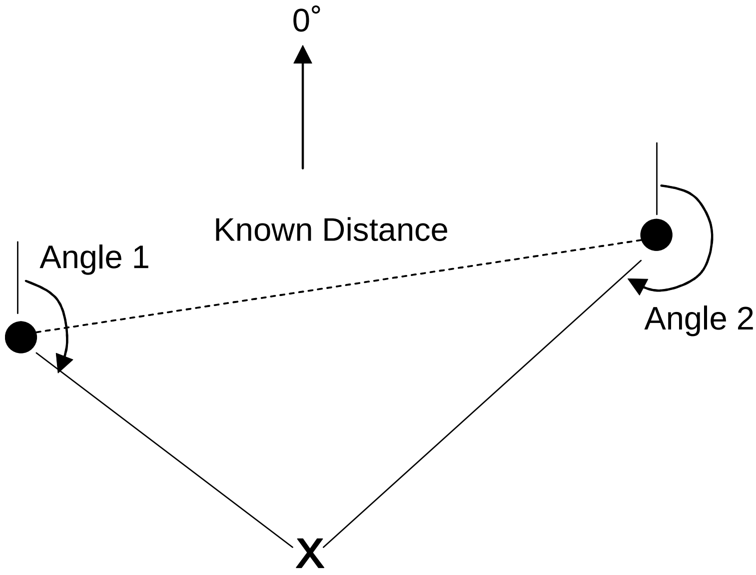

Figure 2.5: 2D angulation using two angles and the distance between two reference points

An intuitive location sensing approach with angulation would be detecting the angle-of-arrival(AOA) with directional antennas. Nasipuri and Li[44] and Takai, Martin, Ren, and Bagrodia[45] attempted to sense location with directional antennas for wireless sensor network and mobile adhoc networks respectively. Kim, Kubo, and Chong[46] have targeted RFID location sensing. (Further details of this will be presented in section 2.4.4.)

The VHF Omnidirentional Ranging (VOR) aircraft navigation system[47] is a example of currently used angulation location sensing technique for aircraft navigation. VOR stations, which are ground based transmitters repeatedly broadcast 2 simultaneous signal pulses. First, the omnidirectional reference, which has the station's identity, is sent. The second signal is swept rapidly through 360 degrees. Phase shift is measured at the aircraft in order to compute the "radial" (a line from the transmitter to the receiver with a specific angular direction). Two VOR stations are required to compute the location of aircraft with this angulation location sensing technique.

2.2.3 Scene Analysis

One location-sensing based upon scene analysis uses computer vision. Computer vision researchers have sought to build artificial systems that obtain information from images. In scene analysis based location sensing, features of a scene as observed from a vantage point are used to gain information concerning the location of the object within the scene. Some parameters, for example, a specific color are used to increase object and reference point identification in captured scenes. Such systems are widely used today for motion tracking in order to provide realistic movements for animated characters.

Static scene analysis examines features based upon a predefined dataset that maps them to object locations. Alternatively, in *differential scene analysis*, the difference between successive scenes are tracked to estimate location. Gaps among the scenes will correspond to movements of the observer, then, using knowledge of pre-known positions, the observer determine its own position. However, using cameras also raise some privacy concerns and in some countries (such as Sweden) are restricted by law (see for example section 3.2.2 in Daniel Hübinette's thesis[48]).

The location of objects could be inferred by passive observation and features are free from measuring the real geometric properties, such as distance or angle, in contrast to the aforementioned location sensing techniques. This is the advantage of scene analysis since other means of measuring geometric quantities normally requires emission of signals, which requires more energy.

However, the negative aspect of the scene analysis is that the observer needs access to the features of the environment against which it will compare its observed scenes. If changes happens in the scene, then the predefined dataset has to be updated accordingly. Scene analysis requires more processing power to calculate the location than other methods presented above.

The scene is not necessarily limited to visual images, but can consist of other measurable physical phenomena. EasyLiving[49] and the approach proposed by Starner, Schiele, and Pentland [50] fall into the first category, as they are based on computer vision techniques to figure out the location of the objects. On the other hand, Microsoft's RADAR research[51] is based on using WLAN. (We will examine this system in detail in the section 2.3.)

2.3 Related research

2.3.1 SpotON:An Indoor 3D Location Sensing Technology Based on RF Signal Strength

SpotON[39] performs three dimensional location sensing by means of analyzing the received RF signal strength. It attempts to create an accurate indoor location sensing system for seamless computing; in addition, it focuses on the hardware and embedded systems aspects of proposed solution. Hightower, Borriello, and Want began by examining if current RFID products could be used for fine-grained indoor location sensing. They chose RFIDeas[52] for performance testing and discovered that RFIDeas could be used. Using the key parameters that they obtained via RFIDeas, they implemented custom hardware based on the architecture shown in the figure 2.6.

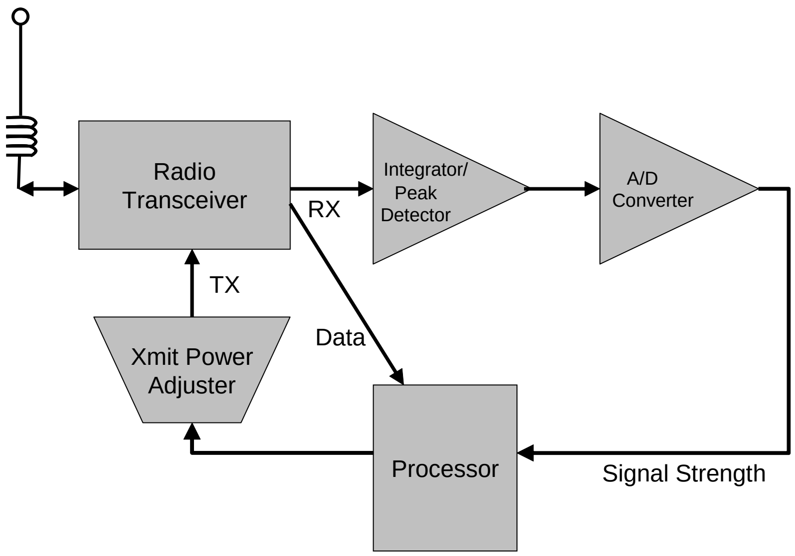

Figure 2.6: Hardware design of SpotON tag radio architecture

The actual location detecting algorithm, is based on a mapping between a signal strength and an approximate distance. To triangulate the precise location, the estimated distance from each of the base stations are submitted to a central server. To enhance the network connectivity of the RFIDeas receiver(which only supports an RS-232 serial link), a Hydra Microwebserver[53] is inter-connected between the (RFIDeas reader) base station and an Ethernet.

In the end of their paper, they mentioned that even if SpotON is to be a promising approach for location sensing, then data integration and sensor fusion also have to be considered since they are indispensable to location sensing. A robust and scalable location sensing system needs to implement a data model in order to create meaningful information from the locations as reported by various kinds of sensors. However, they view this as their future work.

2.3.2 RADAR

RADAR is an attempt to locate and track users by using signal strength of WLAN[51]. This location system detects the received WLAN signal strength and does not require explicit user actions. The signal strength data is collected in three access points placed in the same floor. Figure 2.7 shows the floor plan of their test environment with the location of the three base stations. They succeeded in localizing the user to within 2 to 3 meters (roughly the size of a typical office room), from which many different kinds of services could benefit, such as forwarding phone calls or automated printer detection services.

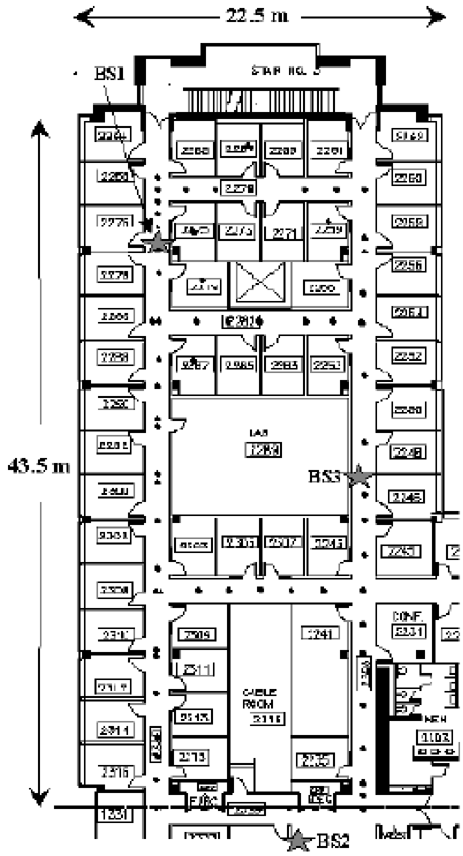

Figure 2.7: Floor plan: The black dots indicates the point where the data is collected. North is up and west is right in the figure.(This figure appear here with permission from Venkat Padmanabhan, the author of [51])

Figure 2.8 illustrates the signal strength values at each of the three base stations while the user walks around the floor in a counter-clockwise direction (see in figure 2.7). The start and end point of the walk is the north west corner of the floor. There is a clear trend in the changes of the signal strength based on user's location and the location of the WLAN base stations. It goes without saying that the weakest signal is received at the furthest point, whereas the strongest signal occurs at the closest point. This collected signal data shows that using the signal strength of WLAN can be promising way to detect the user's location in an in-building environment.

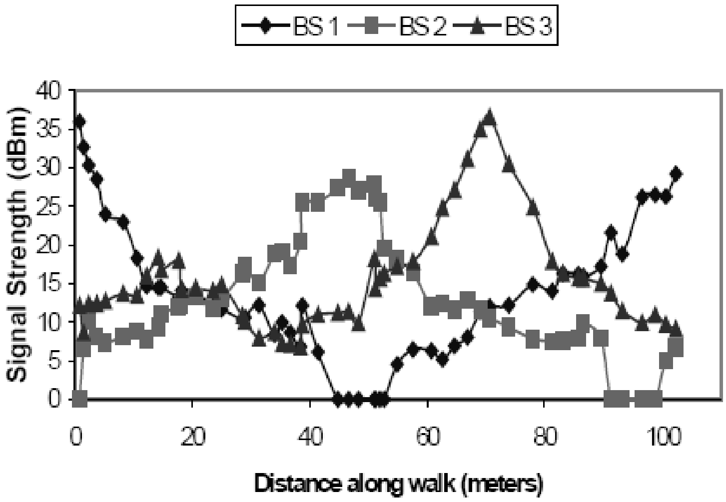

Figure 2.8: Signal strength recorded at three base stations (This figure appears here with permission from Venkat Padmanabhan, the author of [51])

To compute a physical position, RADAR first builds a table of locations and the signal strength detected by each of the three access points for each of these location. This table is subsequently used to map the measured signal strengths into a location. They used the Euclidean distance measure for the mapping, sqrt$((ss_1 - ss'_1)^2 + (ss_2 - ss'_2)^2 + (ss_3 - ss'_3)^2)$. Where (ss_1, ss_2, ss_3) indicates the observed signal strength values, while (ss'_1, ss'_2, ss'_3) is a pre-recorded value. After the nearest value is found using the above equation, the location is estimated to be the point where the closest matching signal strength value was recorded.

The advantage of RADAR is that it is a very cost effective solution (since it uses commercially availlable WLAN access points) and it does not require a complex system. However, the drawback of this approach is that it is easily influenced by environmental factors, such as the placement of furniture or any physical objects on this floor. If furniture is moved or new objects put in place, the sample data has to be collected again - in order to map the observed data into positions.

2.3.3 LANDMARC: Indoor Location Sensing Using Active RFID

LANDMARC[54] utilizes reference tags to calculate the position of a ”tracking tag” (i.e. these are tags whose location is being tracked, based upon the fixed reference tags). Reference tag serves as landmarks with a known location. Utilizing reference tags brings three main advantages. First of all, instead of requiring many expensive RFID readers, reference tags helps to enhance the accuracy of location sensing without requiring more tag readers. Secondly, reference tags enable the location sensing system to react to environment factors as reference tags are exposed to the same effect as the tracked tags, since they are also in the same environment. Finally, the resulting location information can be more reliable because the sensing accuracy is affected by the way both reference tags and readers are placed, potentially this solution could achieve quite accurate location results.

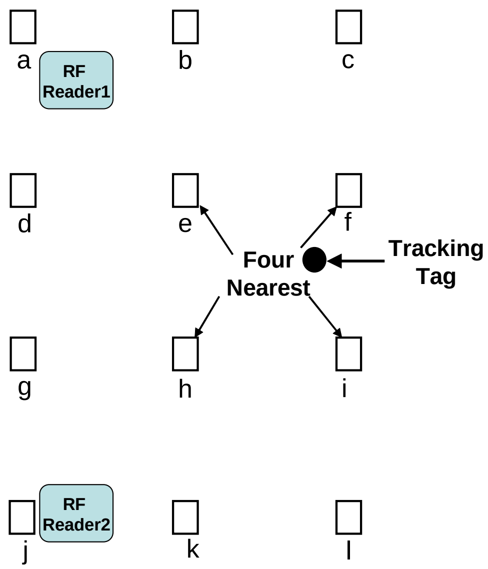

Figure 2.9: An example of a tracking tag and the nearest reference tags in LANDMARC

Figure 2.9 shows an example of location sensing in LANDMARC. Among the 12 reference tags in the environment, the nearest four tags are selected to calculate the location of the tracking tag by comparing the received signal strengths of each tag. In this example, the four nearest reference tags are e, f, h, and i. After detecting these four reference tags, a weighting algorithm is applied using data from each of these neighbors to reduce the error in the determination of the tracked tag's location. The reason for using four neighbors to determine the location is that this was shown to provide the overall best result based upon their study. Increasing the number of the reference tags can increase the accuracy of the location determination since this reduces the amount of the overall error in measurements.

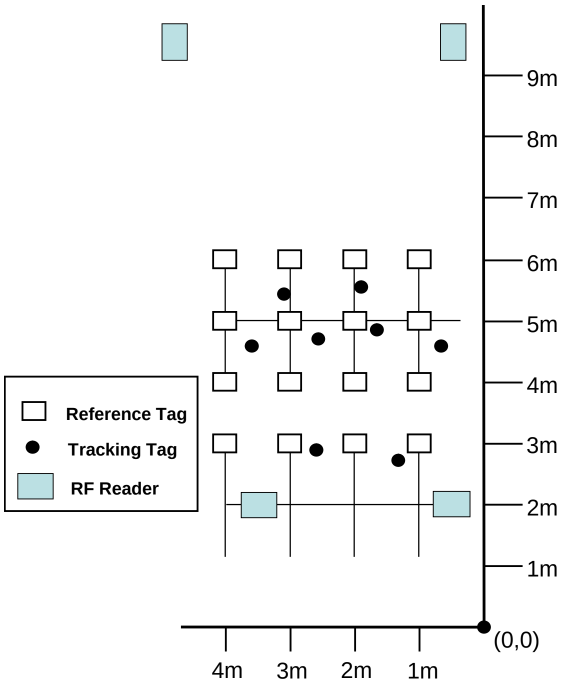

Figure 2.10: Testing environment in LANDMARC

The LANDMARC system was tested in the environment shown in figure 2.10. In this scenario, one reference tag per square meter was placed on a grid and four RF Readers were used, the resulting error in location is 2 meters in the worst case and 1 meter on average. Jin, et al., made some improvements to LANDMARC [55]. The main enhancement was to introduce triangulation with multiple RFID readers. The resulting data reduces the error in distance to 0.5 - 1.0 meter.

However, Ni et al. faced three problems because of the limitations of current RF readers in the market. First, there is no way to detect signal strength directly from the reader. Their alternative approach was to scan the tags using 8 discreet power levels, which requires 1 minute of time. The second problem is the long latency in computing the location after the tag is tracked. This is because of the first problem and because a long interval is required to avoid collisions in detecting tags. Finally, the power of the signal from each of the tags are not stable, even when the batteries are brand-new, because of the effect of subtle differences in each device's hardware. In addition to these problems, it is worth mentioning that the orientation of the tag has a significant impact on the accuracy of the location sensing. This is because the relative angle of the tracked tag with respect to the orientation of the reader's antenna cause changes in the signal strength received at the reader.

2.3.4 Loop Antenna

Kim, Kubo, and Chong[46] proposed a location sensing method which does not require reference points (such as were used in LANDMARC). To achieve this, they used a loop antenna to scan for a tags, then measure the received signal strength. By physically rotating the antenna they determine the angle to the transponder's location from the antenna. To calculate the transponder's location, triangulation is used with two angle measurements from different antenna to the transponder and a distance measurement between the two antennas. After analyzing the data from their experiment, they concluded that the error in angle is less than 5 degrees when the object is located 10m away.

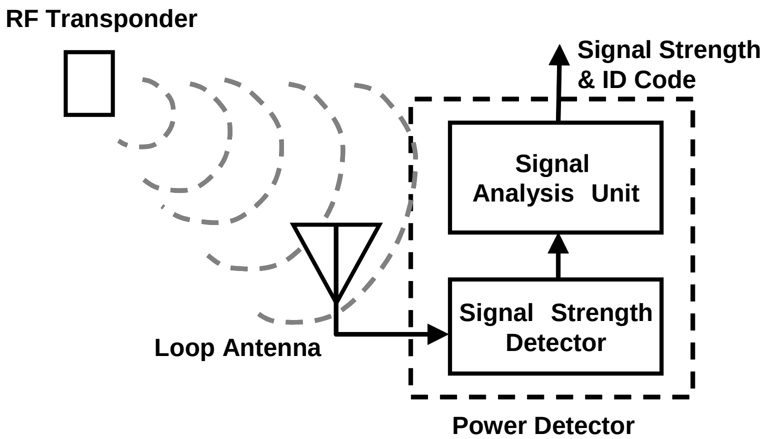

Figure 2.11: Schematic of loop antenna equipped with the signal strength detector

Figure 2.11 illustrates the main blocks in the hardware they developed. The loop antenna connected power detector is physically scanned by rotating the antenna. The power detector is composed of two blocks, a signal strength detector and signal analysis unit. After the signal is received by the loop antenna, the signal is coupled to signal strength detector. The signal strength detector converts the signal from the antenna to a DC voltage, and the voltage is passed to the signal analysis unit. In the signal analysis unit, the signal strength of the received signal is converted by a analog-to-digital converter into a digital value. Finally, the signal strength and serial number (encoded in the response from the transponder) are transmitted to applications, along with the direction information.

To enhance the location sensing ability in a dynamically changing environment, such as a moving transponder, they deployed the system with dual directional antennas[56]. The dual directional antenna is composed of two identical directional antennas placed perpendicularly to each other with a phase difference. Such a dual directional antenna makes it possible to sense the location without mechanically rotating the antennas, instead the phase information from the two antennas can be used to determine the angle of the signal's arrival. This approach was tested with the applications concerning mobile robot navigation.

Chapter 3

Data Analysis

In this chapter, we examine the WLAN signal strength in a real office environment in order to illustrate how the user's location can be estimated by measuring the signal strength of WLAN transmission. The experiment consists of two different cases, Received Signal Strength Indication(RSSI) as a function of the signal source distance from an antenna, and RSSI as a function of the receiving antenna's direction. The RSSI[57] used in our measurement represents a Signal-to-Noise Ration (SNR), but the difference of noise values is negligible so we use the RSSI value as an indicator of signal strength.

3.1 Case 1: Signal Strength As a Function of Signal Source Distance from an Antenna

3.1.1 Setup

To collect signal strength data for WLAN signals in a real office environment, we set up a Yagi-Uda antenna and laptop. The relationship between the antenna and the laptop are shown in figure 3.1. The direction of the antenna was rotated 90 degrees in order to analyze the signal strength as a function of distance parallel to the long axis of the antenna (here after referred to as "vertical movement") and perpendicular to the long axis of the antenna (here after referred to as "horizontal movement"). The distance from the antenna to a signal source is measured from the front edge of the antenna.

The experiment was conducted in the KTH Center for Wireless Systems (Wireless@KTH), Kista, Sweden. The antenna used in the experiment is a LevelOne model WAN-2118 18dBi Yagi-Uda antenna[58]. The antenna was attached to a D-link DWL-G520 WLAN PCI card, which was installed in a Dell OPTIPLEX GX620 desktop computer running the Ubuntu 6.10 operating system. The WLAN driver used in Ubuntu was the Madwifi driver (version 0.9.3)[59] and the RSSI values retrieved from this driver were used in this measurement. The laptop used as a source for a WLAN signal is a Toshiba PAMX495LS with a Lucent Technology Wireless LAN PC Card adaptor (model PC24E-H-ET 802.11b card) installed. The laptop was running the Ubuntu 7.10 operating system.

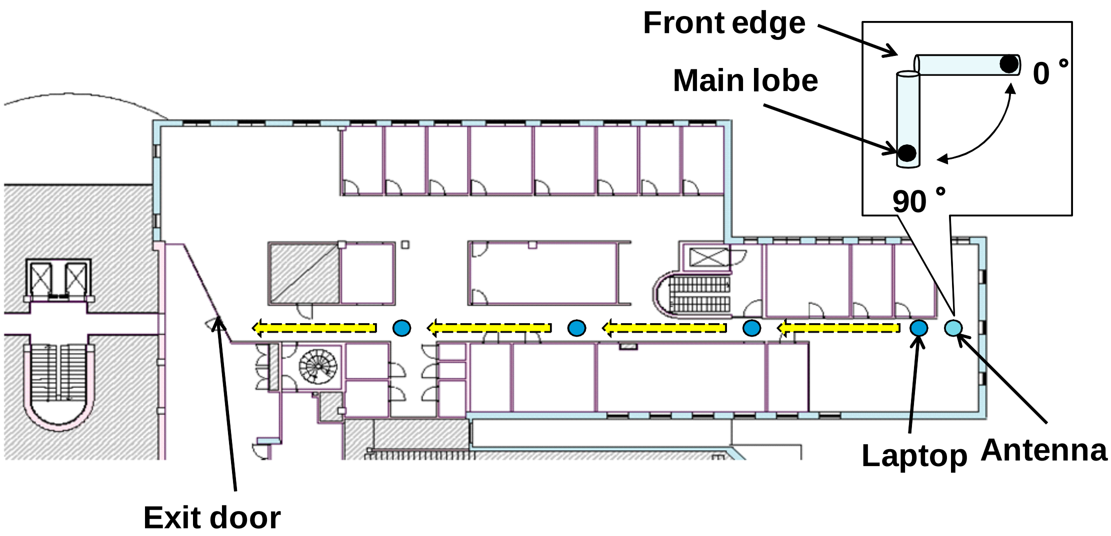

Figure 3.1: Data collection setup

Figure 3.2 shows how the antenna and laptop were positioned for the measurements concerning "vertical movement". As seen in the picture, the antenna was pointing toward the exit door for the first series of measurements (later, the antenna was rotated 90 degrees for the measurement perpendicular to the antenna) and the laptop was moved from one end of the floor towards the exit door (as shown in figure 3.1). The laptop was placed on a cart such the WLAN interface in the laptop was at the same height as the Yagi-Uda antenna (92 centimeters above the floor); and with the laptop rotated so that the WLAN interface was closest to the Yagi-Uda antenna (see figure 3.2).

3.1.2 Methodology

To generate a large number of packets so as to analyze the characteristics of the received signal at various distances, the laptop was running a simple program which periodically generates UDP datagrams. The UDP datagrams were sent to the IP address which belongs to the same subnet as the wireless access point (AP1 in figure 3.3) that the laptop was associated to. The IP address was selected in order to make sure that the packets are sent to the wireless access point from the laptop.

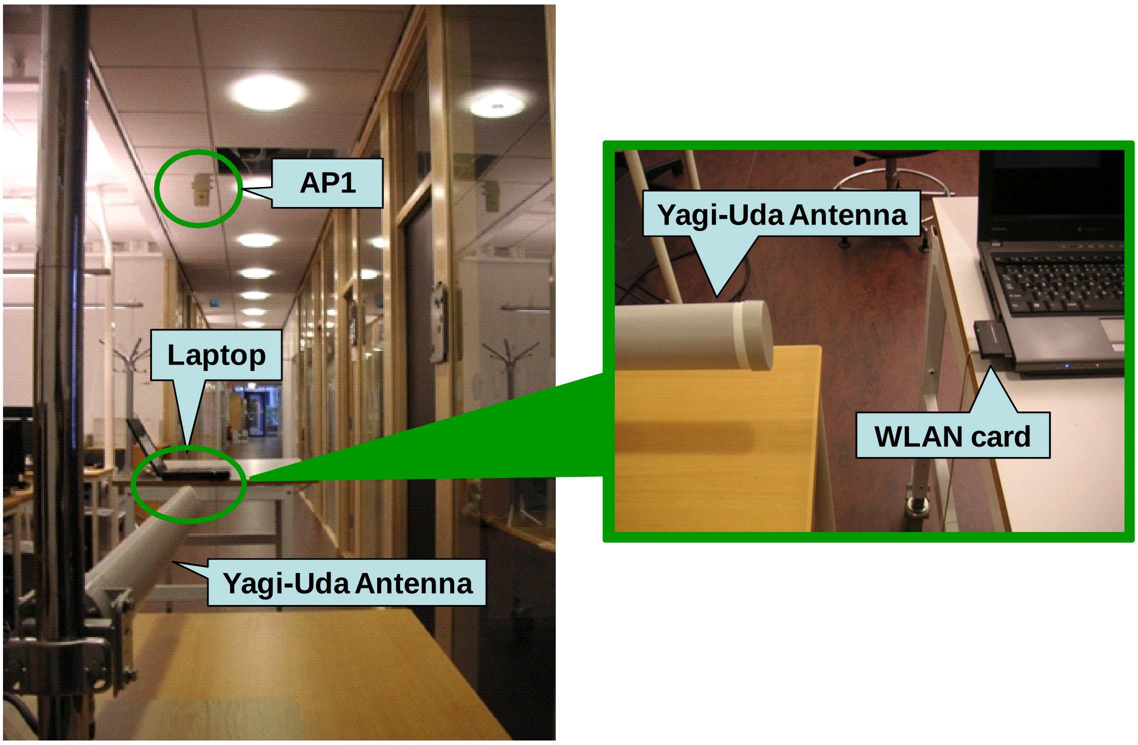

Figure 3.2: Antenna pointed towards the exit door and the laptop on a cart.

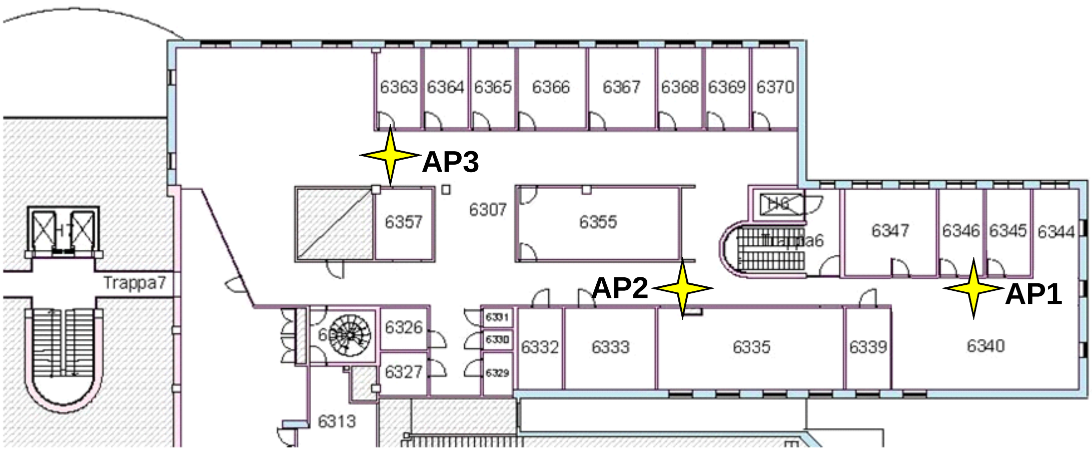

Figure 3.3: Wireless Access Points and the floor plan

To make it easy to extract the data collected at a particular distance from the antenna, the datagrams were sent to different ports depending upon the distance, using a simple encoding of 3000+d, where d is the distance in meters. For example, port 3001 corresponds to one meter of distance. The details of the program to generate UDP datagram can be found in appendix B. The WLAN interface connected to the Yagi-Uda antenna was operating in monitor mode, which allows the WLAN device to passively listen to the received WLAN signals without sending any signals.

The received datagrams were captured using the Wireshark application[60]. The captured data for each received frame includes an RSSI field (this field is added by the MADWIFI driver). After the data has been collected, the received frames are saved, then exported as a comma separated value (CSV) text file. The data can now easily be filtered and processed. For example, the first filter is based on the MAC address of the source (thus leaving only packets transmitted by the laptop's WLAN interface). A perl script was used to calculate the mean and variance of a series of RSSI values at each distance. The script first splits the file based on the destination port number, then generates a file that contains a mean and variance of a series of RSSI values at each distance. The further details of the perl script can be found in appendix C.

3.1.3 Analysis of Collected Signal Strength

The calculated mean, and $mean \pm standard\ deviation$ are plotted in the figures 3.4 and 3.5. As can seen from these figures, there is a trend of the gradual decrease in the collected RSSI values. For the case of vertical movement, the decrease of RSSI values is more clear when the signal source is within 25 meters. It is important to note that we can not simply use the RSSI value as an index into a table, since there are many distances which result in the same RSSI value. However, by using a series of RSSI values and the information about their variance, it is possible to estimate the location of the source. This is especially true if the source enters at the main entrance (marked as exit door in figure 3.1.)

On the other hand, the similar change in RSSI as a function of distance can be found even when the antenna is perpendicular to the direction of motion of signal source;however, the variance seems to be smaller in this case. The collected data indicates that the signal source can be located to within a few meters using the combination of the mean and variance. This is because the characteristics of the data are nearly unique at a resolution of approximately 2 to 3 meters. This is sufficient for our system as the spacing between doors is approximately 2.5 meters.

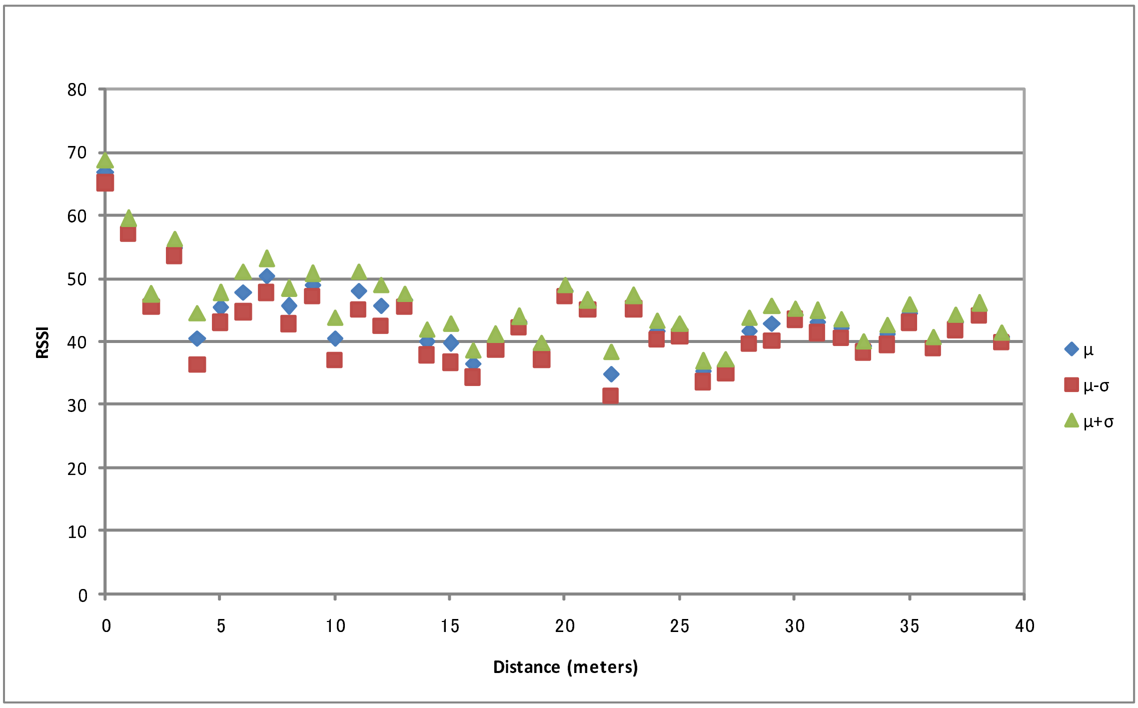

Figure 3.4: Vertical distance to signal source

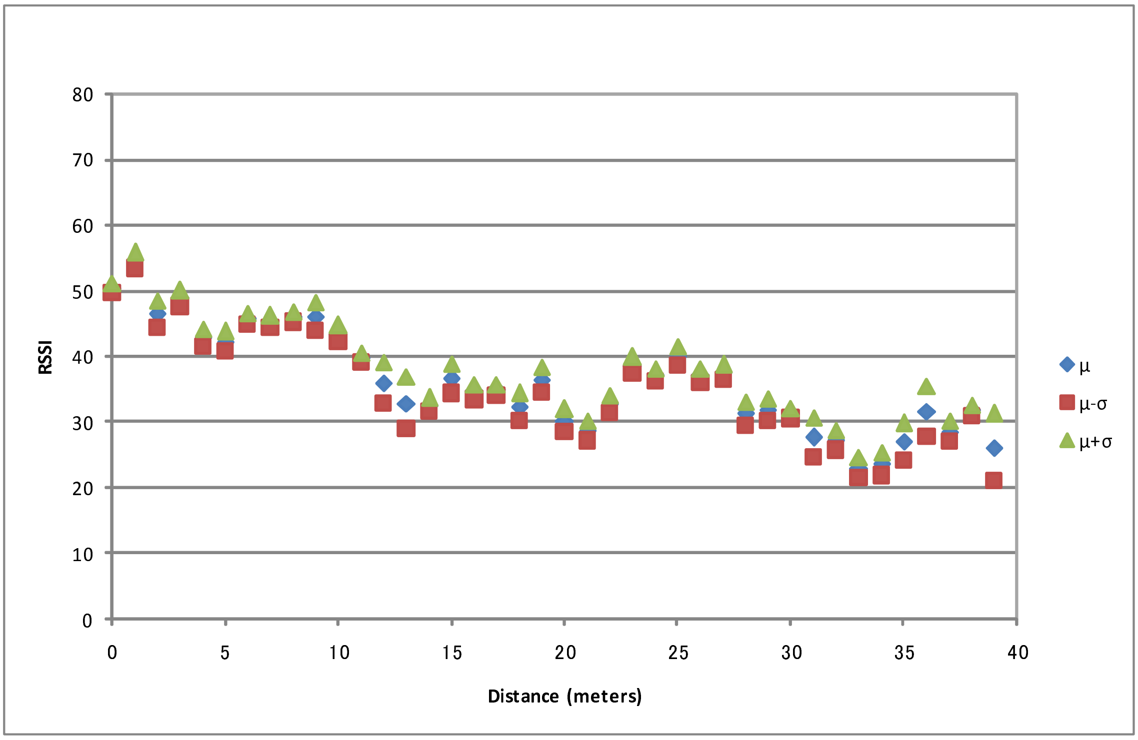

Figure 3.5: Horizontal distance to signal source

3.2 Case 2a: Signal Strength As a Function of Antenna Direction (coarse rotation)

3.2.1 Setup

In this set of experiments, the laptop and antenna were placed as shown in figure 3.6. The measurements started with the antenna pointing in the direction of the laptop and located 5 meters from the laptop, then the antenna was rotated in steps of 90 degrees in a clockwise direction. The office and the equipment are the same as case 1.

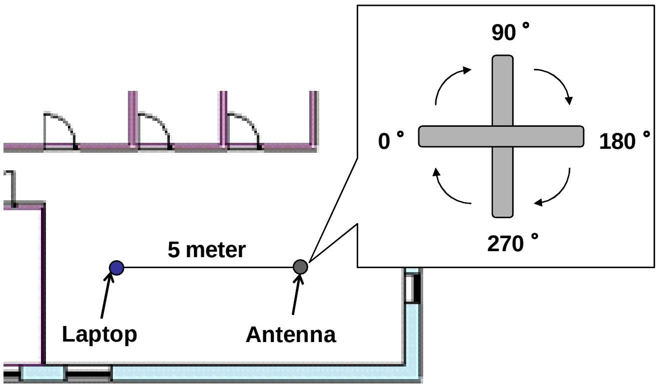

Figure 3.6: Data collection setup

3.2.2 Methodology

Instead of utilizing the port number to indicate the distance in the case 1, in this experiment, the port number is used to indicate the angle of the antenna for each measurement.

3.2.3 Analysis of Collected Signal Strength

Before collecting data, we expected to see the strongest signal when the antenna was pointing toward the laptop (which we label as 0 degree). We expected this to be followed by the signal strength decreasing for 90/270 degrees or 180 degrees. The data shows the signal is weakest at 90 degrees direction. We repeated the same series of measurements to validate this result which showed the same results. As shown in figure 3.7, there are distinguishable characteristics of the received signal with the antenna oriented in each of the directions (From the trend in the frequencies of RSSI value, the angle can be estimated). By recording the RSSI for each angle, it is possible to map the observed

RSSI data against recorded data to determine the signal source direction. The number of measurements in each orientation is 8409 and the relative frequencies comparisons can be found in the histogram shown in figure 3.7.

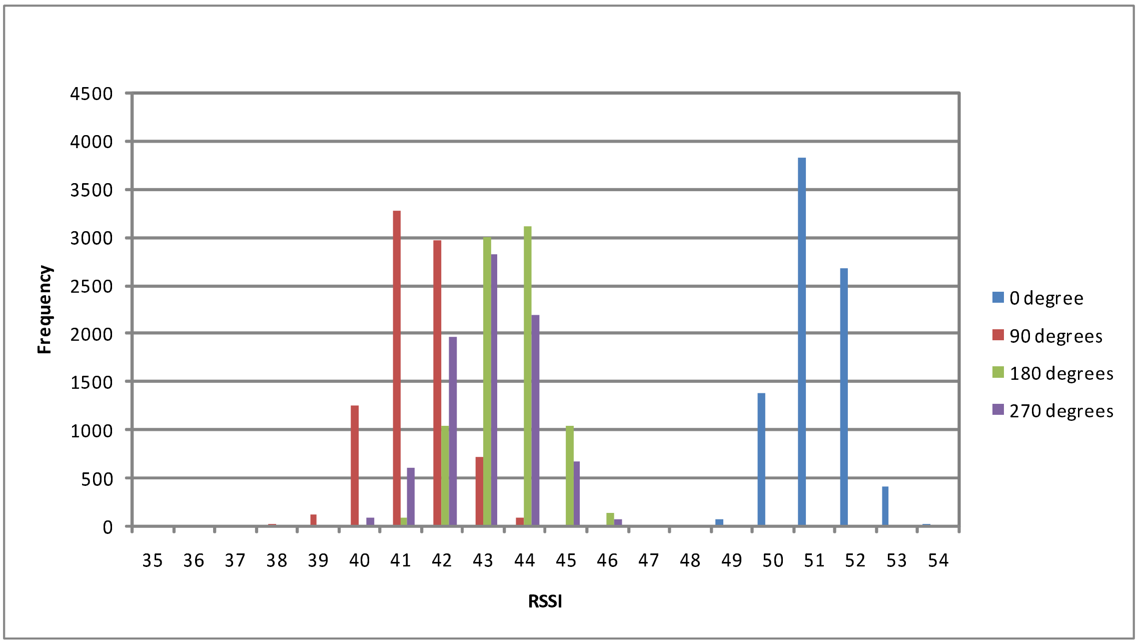

Figure 3.7: Histogram of RSSI values for four different antenna orientations

3.3 Case 2b: Signal Strength As a Function of Antenna Direction (fine-grained rotation)

3.3.1 Setup

The setup for this experiment is the same as case 1. To observe the signal strength characteristics with more narrow antenna rotation than in case 2a, the antenna was rotated from -30 to 30 degrees in steps of 10 degrees.

3.3.2 Methodology

The methodology in this measurement is the same as 2a.

3.3.3 Analysis of Collected Signal Strength

As can be seen in figure 3.9,it is difficult to estimate the angle of signal source based on the signal strength of each angles. In both of figure 3.8 and figure 3.9, the strongest RSSI

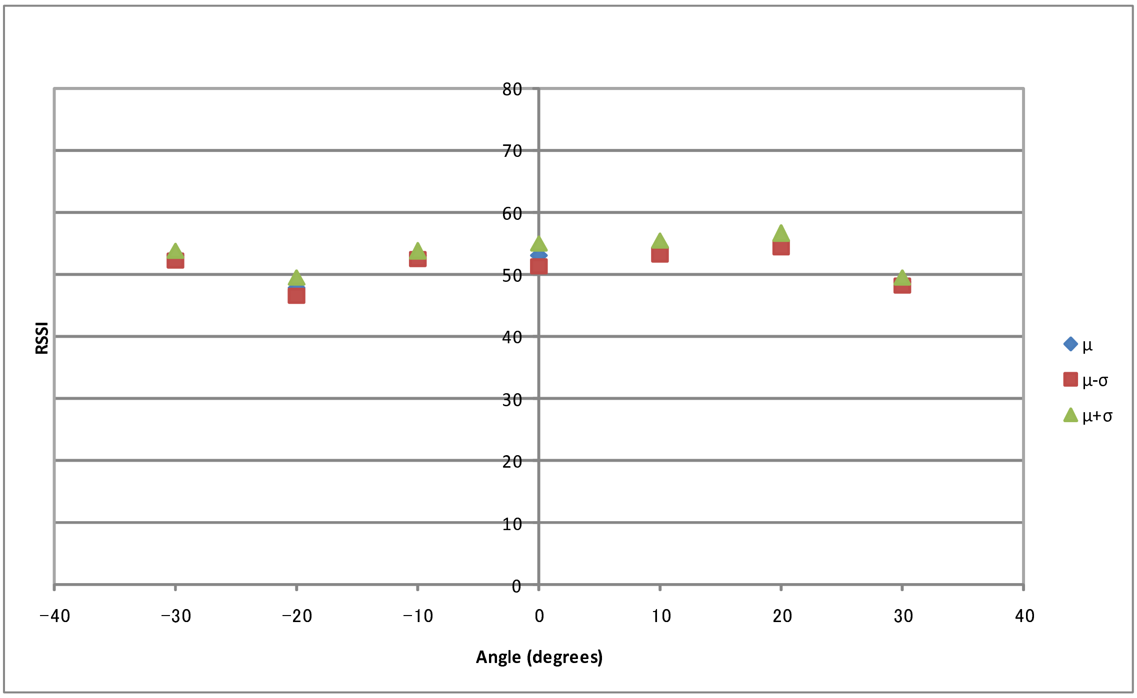

Figure 3.8: RSSI values at 10 degree steps with the antenna 3 meter from signal source

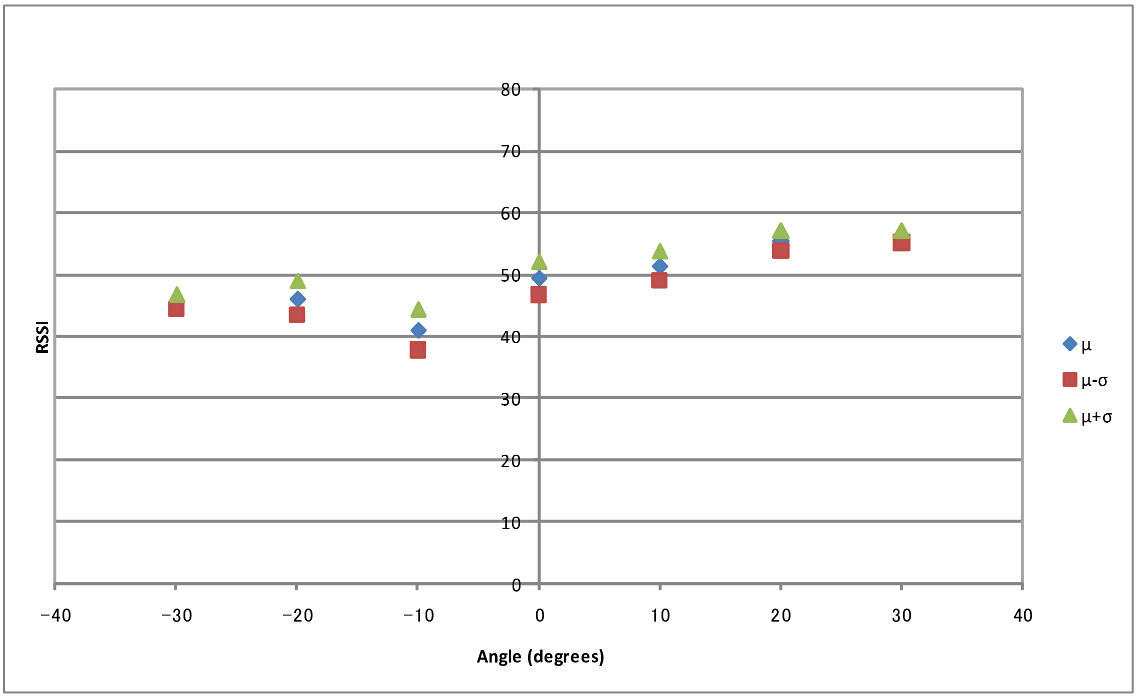

Figure 3.9: RSSI values at 10 degree steps with the antenna 6 meter from signal source

values were not observed at 0 degree, where the strongest RSSI values were expected.

Figure 3.8 shows that there is not significant differences in observed RSSI values with a small rotation of the antenna. The observed RSSI values are difficult to be distinguished with a small difference of angle. However, tt could be possible to map the RSSI values when the distance between an antenna and signal source is 6 meters because the RSSI values differ in each angles (see 3.9).

3.4 Case 3: Signal Source Orientation and Signal Strength

3.4.1 Setup

The setup for this experiment is the same as case 1. The distance from laptop to antenna is fixed in 3 meter. Orientation of signal source is defined as seen in figure 3.10. In the previous measurements, the orientation of signal source was fixed in 0 degree. This case is to understand the influence of signal source orientation when measuring signal strength.

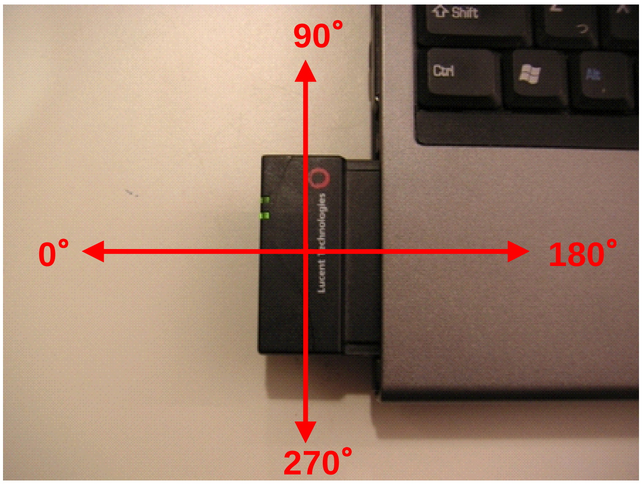

Figure 3.10: Orientation definition on signal source

3.4.2 Methodology

The methodology in this measurement is the same as 2a.

3.4.3 Analysis of Collected Signal Strength

The result of these measurements are shown in table 3.1.

Table 3.1: Signal source orientation

Orientation (degree)	Mean	Variance
0	54.989	14.54542
90	56.663	2.646077
180	58.879	3.964323
270	62.052	8.415712

The result shows that the strongest signal is observed at 270 degrees orientation from a signal source. To see the influence of signal source orientation, we repeated the vertical movement measurements of case 1 and case 2b. Those repeated measurements are shown in figures 3.11, 3.12, and 3.13.

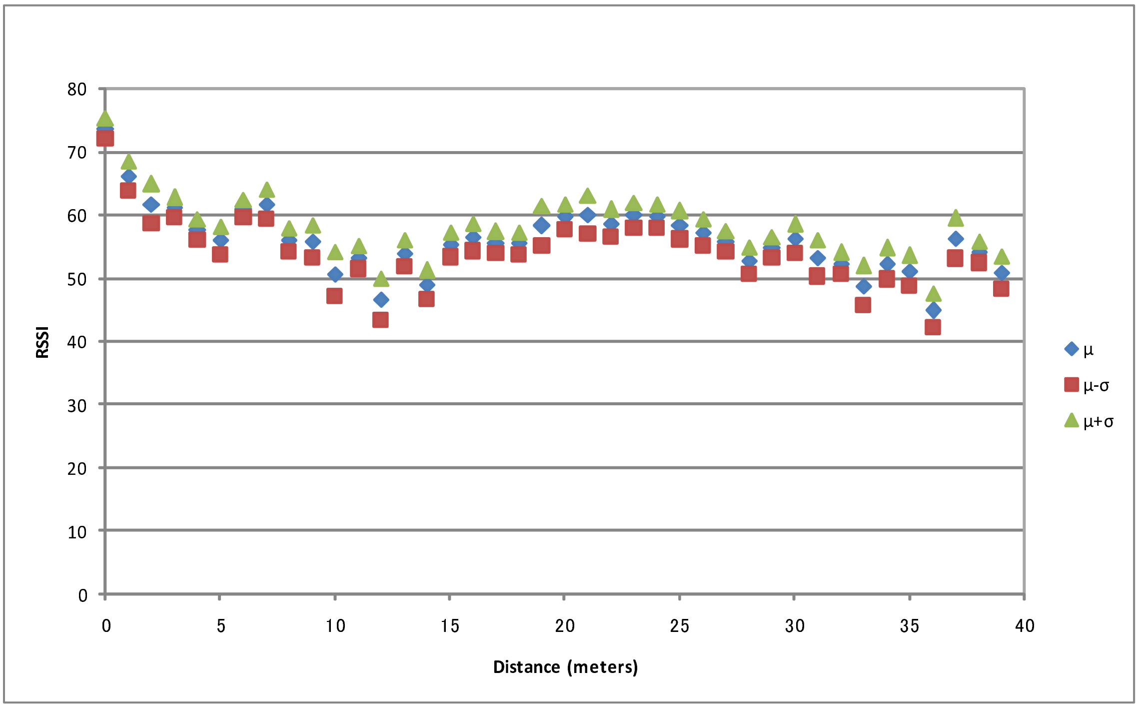

Figure 3.11: Vertical distance to signal source (orientation 270 degree)

Comparing figure 3.11 with figure 3.4, there is not a significant difference in the data characteristics except that the overall signal strength value is higher in figure 3.11. However, there is a noticeable improvement of angle detection. In both figures 3.12 and 3.13, the strongest signals are seen at 0 degree as we expect.

From this measurement, we found that the signal strength can be used to detect distance as long as the orientation of signal source is kept the same. On the other hand, fine-grained signal source angle can only be detected when the antenna of signal source is

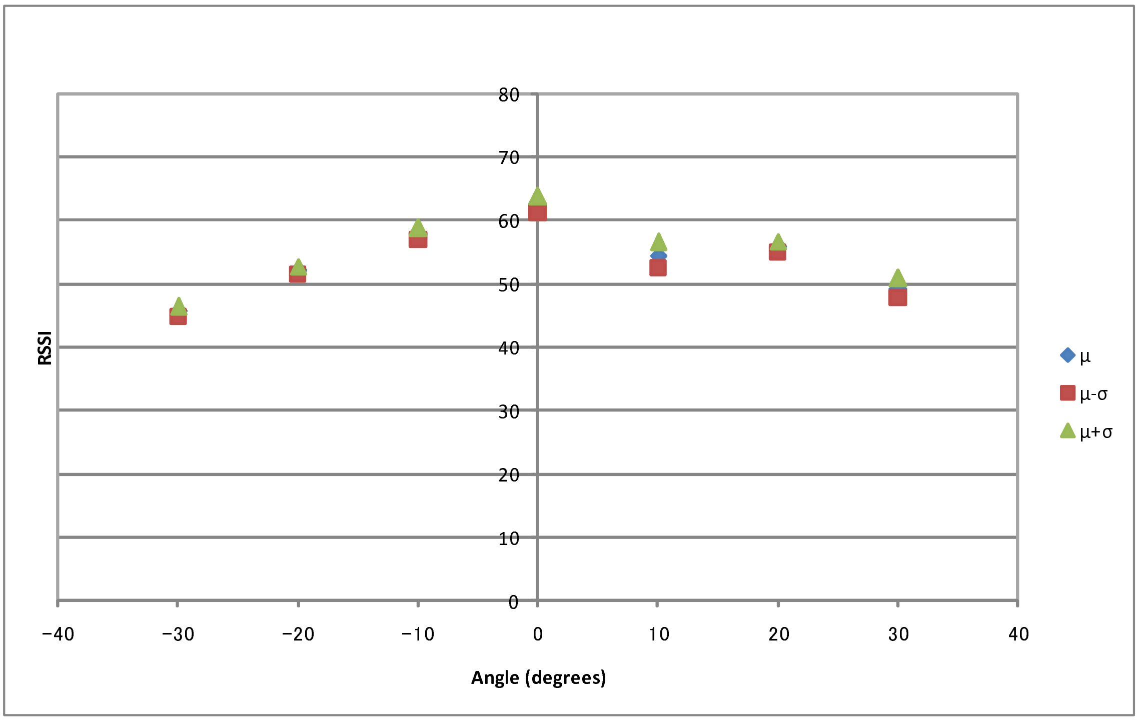

Figure 3.12: RSSI values at 10 degree steps with the antenna 3 meter from signal source (orientation 270 degrees)

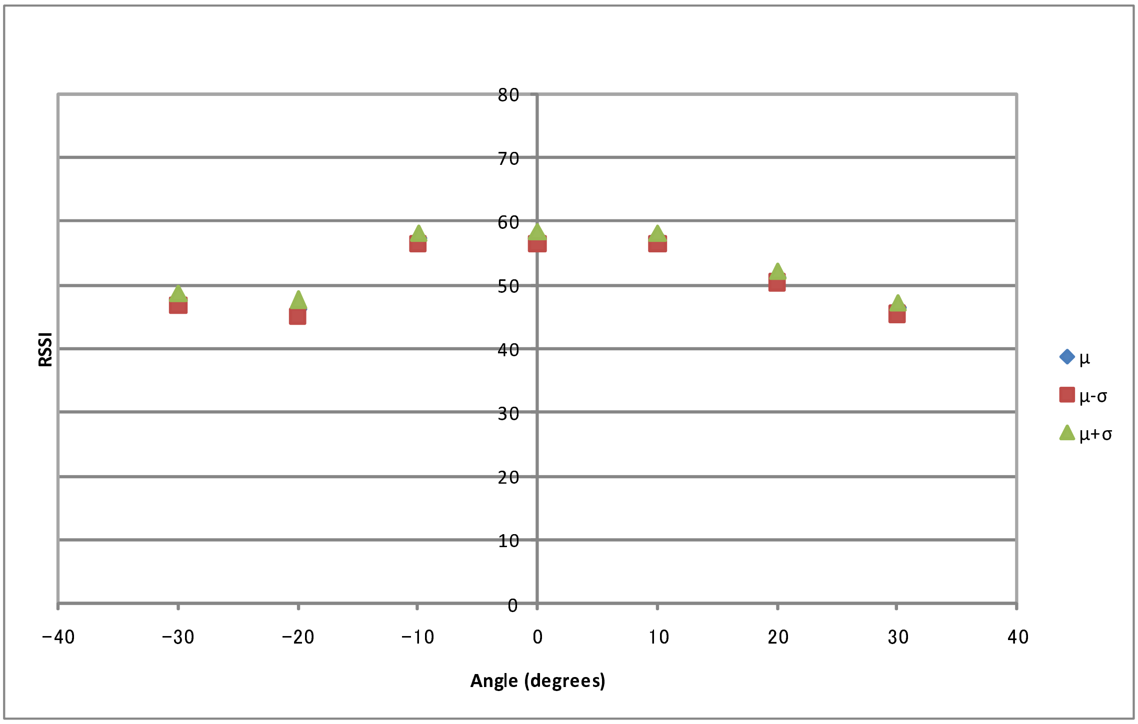

Figure 3.13: RSSI values at 10 degree steps with the antenna 6 meter from signal source (orientation 270 degrees)

pointed toward the antenna (which is listening to the signal). This is due to the reflection of signal and the fact that no reflected signal can be stronger when the signal source and listening antennas are directly pointing at each other.

Chapter 4

Implementation

In this chapter, we explain the details of designing and developing a presence user agent by utilizing Wireless LAN RSSI measurement. The evaluation of this agent will be presented in chapter 5. In section 4.1, the method we used to build a presence user agent is introduced. A prototype of our system, which describes the basic software components and data structures in the prototype, is presented in the section 4.2. Finally, the algorithm for estimating the user's location by measuring RSSI value is explained in section 4.3.

4.1 Method

The devices and equipment we used to implement a prototype are the same as described in section 3.1.1 of the previous chapter. In order to process the frames which are received by the WLAN interface attached to the antenna, the interface is set to monitor mode, and we use the libpcap library[61] to make these frames (with the extra data provided by the Madwifi driver) available to our application. This library provides basic functions needed to grab, filter, and process packets. We are only interested in retrieving two data. One is RSSI value, and another one is the source address of the frame. In order to retrieve a RSSI value from each frame, the frame has to be properly decoded. Prism monitoring header, which contains the RSSI value, is inserted by the Madwif driver when the WLAN device listens a signal with monitor mode.

Figure 4.4 shows how the Prism monitoring header is structured. The header items after host time in figure 4.4 have a different data structure. This data structure is shown in figure 4.2. The source address of the signal can be found in the source address contained in the IEEE 802.11 Header. The 802.11 header is shown in figure 4.3.

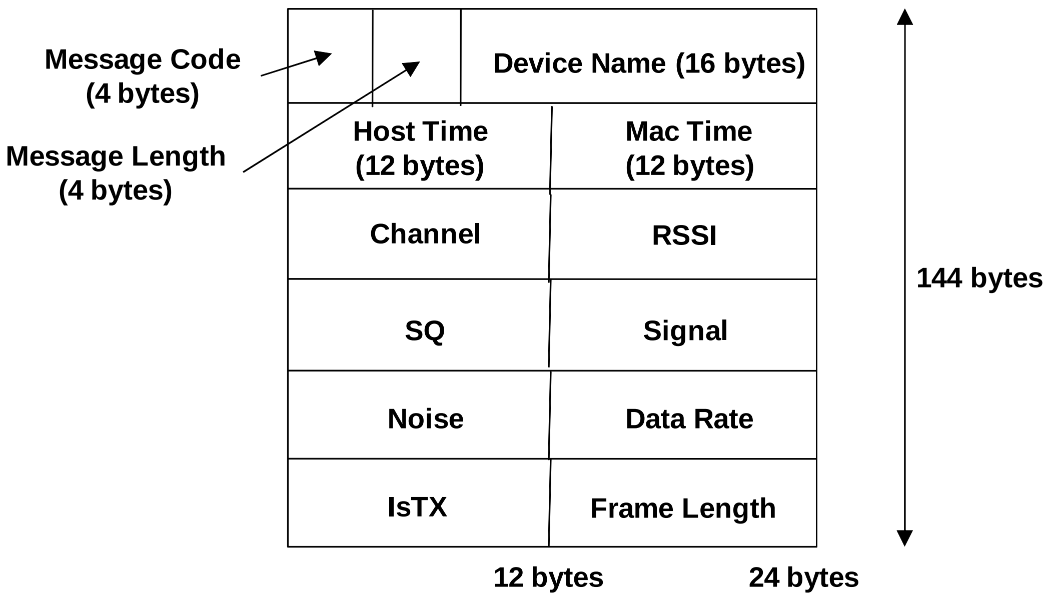

Figure 4.1: Prism monitoring header

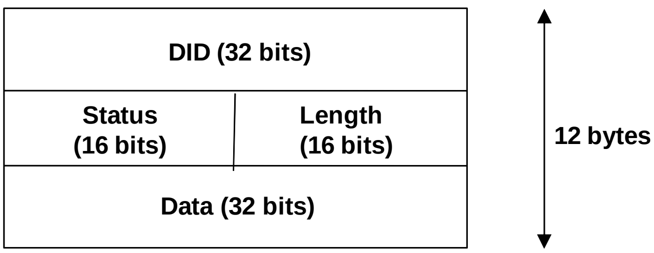

Figure 4.2: Data structure of prism monitoring header item

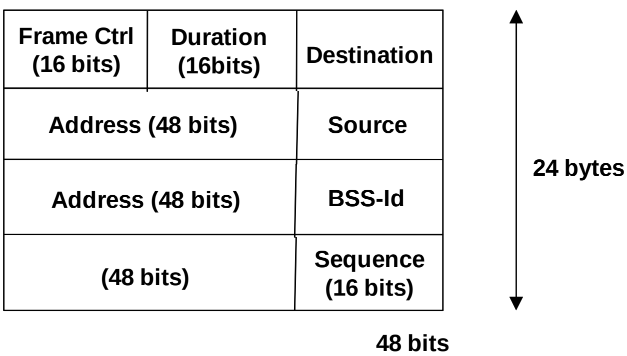

Figure 4.3: IEEE 802.11 header

Before designing our prototype application, we implemented a small prototype in perl[62], which collects a series of RSSI measurement data, compares this data to the recorded values (in this case, the mean and variance of RSSI are compared), and an estimate of the signal source location is based on the best match to RSSI values collected in the earlier measurements. This prototype showed that the implementation of a presence user agent by utilizing RSSI measurement is a promising approach because, even though the estimated location was not always correct, the estimated location showed that these measurements were repeatable. This implies that the estimated location can be improved by updating mapping based upon the recorded values or by using a comparison scheme to estimate the correct location.

Based upon the encouraging results from our initial rapid prototyping, we decided to divide the implementation process into two phases. The first phase is a prototype design and the programming in C language. We decided to use the C language to implement our prototype since a program written in C language has high performance (with respect to processing speed) and we wish to process frames which potentially can arrive at hight rate (in the case of an IEEE 802.11b with 11Mb/sec interface they could arrive at a maximum rate of more than ten thousands frames per second, assume that all frames were minimum size frames).

The second phase involves defining and optimizing the comparison scheme to estimate the transmitter's location. From the initial rapid prototyping, we found that the expected location estimation can not be obtained by simply adding the difference of mean and variance between observed data and recorded data in order to find the best match. This is the motivation for designing the further comparison scheme. The design of the comparison algorithm involves what parameters are to be used, for example: mean, variance, and standard deviation, and also how each calculated value should be compared in order to achieve accurate prediction of the transmitter's location to a resolution of 2 to 3 meters. This comparison scheme is the key to achieving adequate location sensing accuracy.

4.2 Design of a Prototype

Figure 4.4 shows the framework which we envision. The presence agent module in the SIP Express Router (SER) was installed and tested in the earlier thesis project at Wireless@KTH by M. Z. Eslami[1]. We utilized his research results and have focused on developing a new presence user agent using the RSSI values which are associated with the

WLAN signal received from a given device. Our presence user agent consists of five main modules. We explain the details of each module in this section.

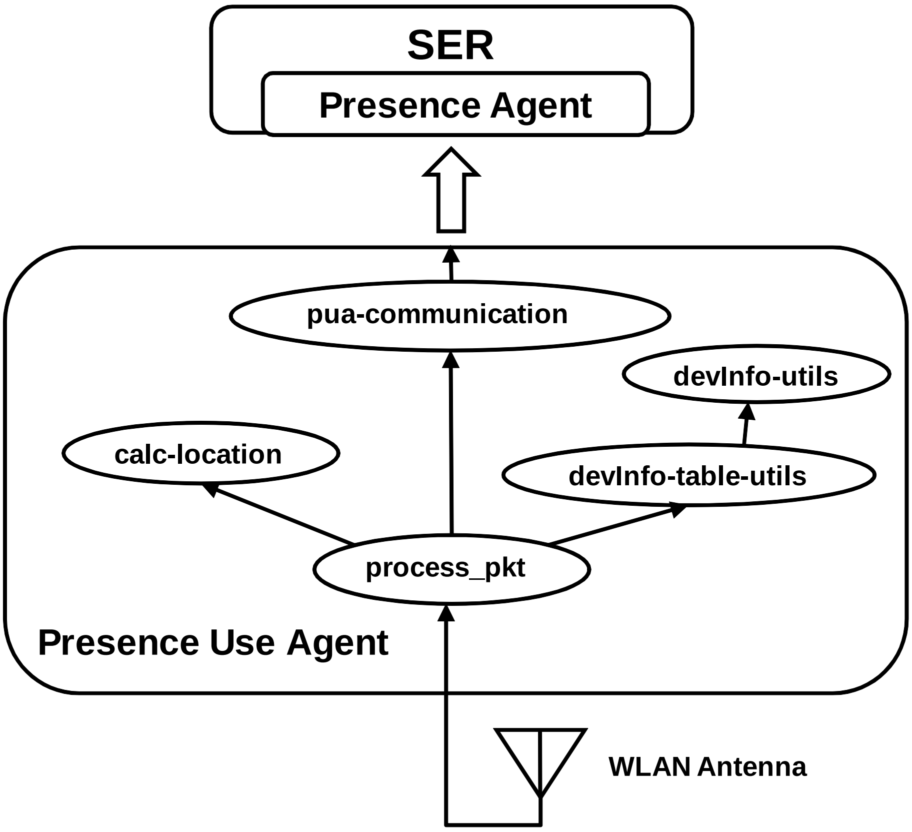

Figure 4.4: Prototype design

4.2.1 The process-packet module

The process-packet module processes each new frame that arrives. Each received frame is decoded to extract the values that we are interested in, specifically the RSSI value associated with this frame and the source MAC address. This component maintains a device information table to keep track of the devices along with the detected RSSI values associated with each of the detected devices. Once the frame is decoded, the RSSI value and source MAC address are used to update the location information in the table. Each frame is filtered based on its source MAC address to determine if the frame is of interest. Once sufficient RSSI data (we found that 30 RSSI data is enough from operational tests) is collected, a location calculation function is called to estimate this devices's location. The estimated location is updated to the presence agent by utilizing the communication module, then it further can be communicated to subscribing services (watchers) by the presence agent.

4.2.2 The devInfo-table-utils module

This module manipulates the device information table. The transmitter's MAC address is used as a unique identity for each device. This module offers not only table manipulation functions, such as addition and removal of device entities, but also provides functions to update the device information. Thus this module provides an interface to access to the device information table and the device information entity themselves. The motivation for this module is that it centralizes all of the access to the device information table - thus making the implementation details transparent to the other modules. The MAC address is used as the primary key to access all of the device information. The data structure designed to store the device data is shown in the figure 4.5. We chose to use an array since the maximum number of devices are limited (due to the expected limitation on the number of devices which are likely to be simultaneously located within a range of the receiver).

devInfo-table

index	In use	entity
0	1	devInfo
1	1	devInfo
2	0	devInfo
....		
n	0	devInfo

```
struct devInfo{
  char *hw_addr;
  long int rssi[N];
  int rssi_counter;
  int location[M][L];
  int location_counter;
};

N = number of rssi data
M = number of location element
 L = number of location data
```

Figure 4.5: Data structure used to store the device information

4.2.3 The devInfo-utils module

This component is designed for manipulating the device information. The device information of our interest are stored in devInfo data structure. This module provides utilities to allow convenient access to and easily update the device information. The device information contains a MAC address, RSSI history data, and location history data with the counters to track the number of updates as shown in figure 4.5. The counter for RSSI is used to know if the number of RSSI data which stored in order to estimate the location has reached 30. On the other hand, the counter for location is used to recognize how many instances of location data are stored in the array.

4.2.4 The calc-location module

Calculating the location of the device is one of the most important parts of this framework. This component consists of the utilities which are needed to estimate the transmitting device's location. These utilities include the calculation of mean, variance, loading data from file to compare against observed data. The function to load data returns the pointer to the data table; therefore, the function only needs to be called when the application starts. The algorithm to calculate location is explained in the following section. To keep it simple for the first prototype, we defined our coordinates to utilize the two orientations of the antenna in the initial measurements. The coordinate system is shown in figure 4.6.

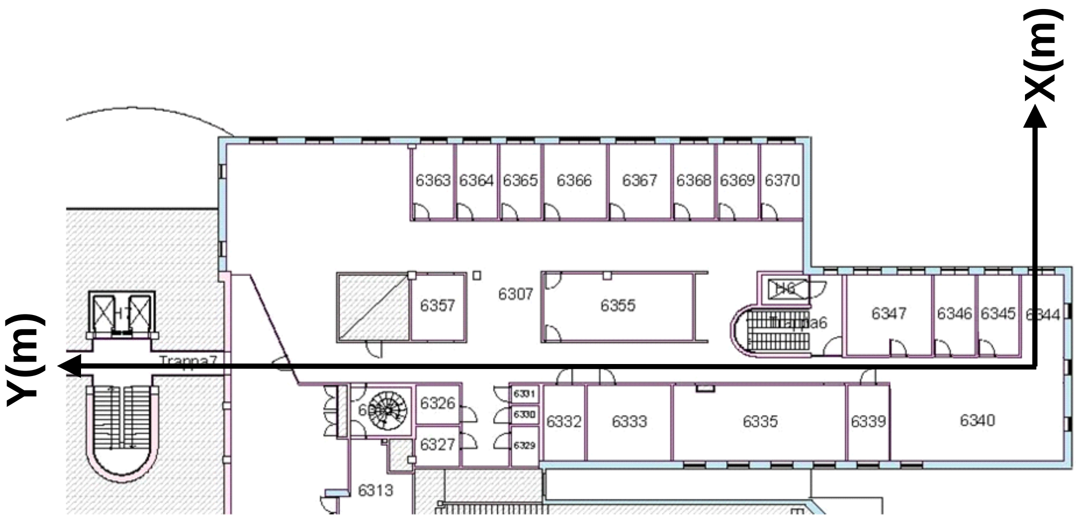

Figure 4.6: Coordinate system

The pua-communication module

The communication between a presence agent and our presence user agent is implemented in this component. The main role of this module is to provide a PUBLISH messaging handshake. Since there is a need to store the message until an acknowledgement is received from the presence agent, a message buffer is provided. Figure 4.7 shows how the message is stored in the buffer. When a publish message is attempted to be sent through this module, it first tries to send the message. In case of successfully sending publish message, the message is stored in the buffer with the status of "waiting acknowledgement".

In case of failing to send publish message, the message is stored with the status of "message not sent". This occurs only when a network connection to the presence agent is lost. The messages in the buffer are periodically re-sent until it receives an acknowledgement from the presence agent. Once the acknowledgement from the presence agent has been received, the message is removed from the buffer. The current implementation does not support an update of the PUBLISH message, so it simply creates a new PUBLISH message when a message is sent. This limitation should not be an issue in our presence user agent because of the following reasons. First of all, user's location is subject to frequent changes, thus, can not be valid for a long period. In order to avoid keeping invalid user's location in presence agent, the expiration period of the location information should be small enough (ex. within the scale of seconds). Therefore, in the presence user agent for location sensing, the frequent generation of a new PUBLISH message is more suitable than updating the PUBLISH message.

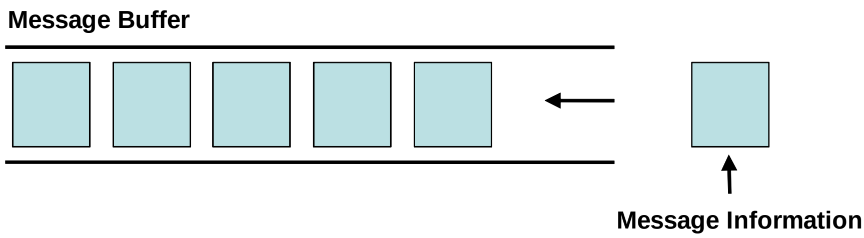

Figure 4.7: Message buffer

An example of the PUBLISH message is as follows.

```
PUBLISH sip:ccsleft@130.237.15.238 SIP/2.0
Via: SIP/2.0/UDP 130.237.15.238:5060;branch=V94HxEToLs4FHm
To: <sip:ccsleft@130.237.15.238>
From: <sip:ccsleft@130.237.15.238>;tag=iTrg
Call-ID: lCV5xRzF9I@130.237.15.238
CSeq: 1 PUBLISH
Max-Forwards: 70
Expires: 5
Event: location
Content-Type: application/pidf+xml
Content-Length: 467
```

The location information determined by the presence user agent is encoded in a Presence Information Data Format(PIDF) message. An example of a PIDF message is as follows.

```
<?xml version="1.0" encoding="UTF-8"?>
<presence
    xmlns="urn:ietf:params:xml:ns:pidf"
    xmlns:location="http://it.kth.se/~yusu/schemas/yusu.xsd"
    entity="sip:ccsleft@130.237.15.238">
  <tuple id="pua-location">
    <status>
      <basic>open</basic>
      <location>
        <description>x=0, y=3</description>
      </location>
    </status>
    <note>00:60:1d:1e:d3:9d</note>
    <contact priority="0.8">130.237.15.239</contact>
  </tuple>
</presence>
```


However, the message can provide more information by mapping our presence user agent specific data to the useful data, such as room, floor information, and global coordinate. This type of message is not provided in the current implementation. The example of this type of message is as follows.


```
<?xml version="1.0" encoding="UTF-8"?> <presence
    xmlns="urn:ietf:params:xml:ns:pidf"
    xmlns:location="http://it.kth.se/~yusu/schemas/yusu.xsd"
    entity="sip:ccsleft@130.237.15.238">
  <tuple id="pua-location">
    <status>
      <basic>open</basic>
      <location>
        <description>Room 6340, floor 2, Wireless@KTH</description>
        <room>6340</room>
        <floor>2</floor>
        <coordinates>
          <latitude>59_24'19.53''</latitude>
          <longtitude>17_56'59.61''</longtitude>
        </coordinates>
      </location>
    </status>
    <note>00:60:1d:1e:d3:9d</note>
    <contact priority="0.8">130.237.15.239</contact>
  </tuple>
</presence>
```

Figure 4.8 shows the messaging that has to be exchanged so that a WATCHER can receive the update of location from location sensor.

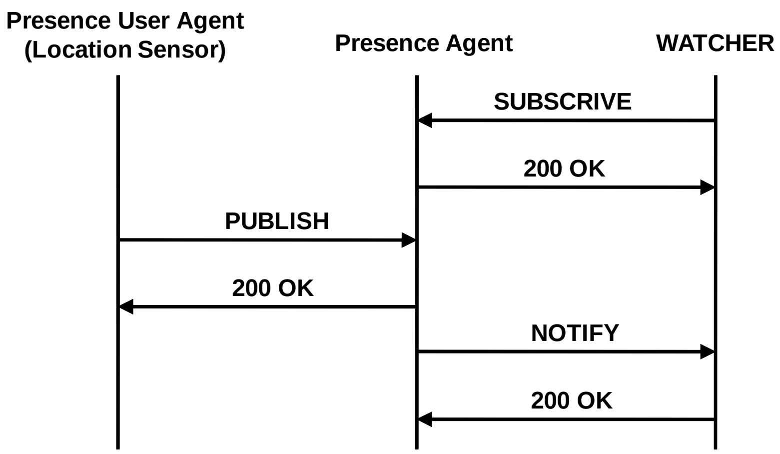

Figure 4.8: Message exchanged to update location from location sensor to WATCHER

4.3 Location Detection Algorithm

To estimate a location from observed RSSI values, we defined two different algorithm to compare each recorded data set in order to select the best match. Those two algorithms are distance model and correlation model.

4.3.1 Distance Model

Euclidean distance measure is used to compute the distance between recorded data (mean',variance') and observed data (mean, variance) in order to pick up the nearest data set among multiple location's data set. The following calculation to determine the distance between observed data and recorded data is executed for each recorded data set to select the best match.

$$\sqrt{(mean' - mean)^2 + \alpha(variance' - variance)^2}$$

When α equals 0, this calculation becomes the simple mean substraction between observed and recorded data. In this case, the pure mean values are compared, therefore, we call this case *pure mean comparison* to differentiate from other cases, where the variance of a series of data is taken into account.

4.3.2 Correlation Model

Correlation model is based on the relevance ration between each recorded data and observed data. The value is determined by percentile. Figure 4.9 shows an example of observed and recorded RSSI values. σ in the figure represents a standard deviation of the data set.

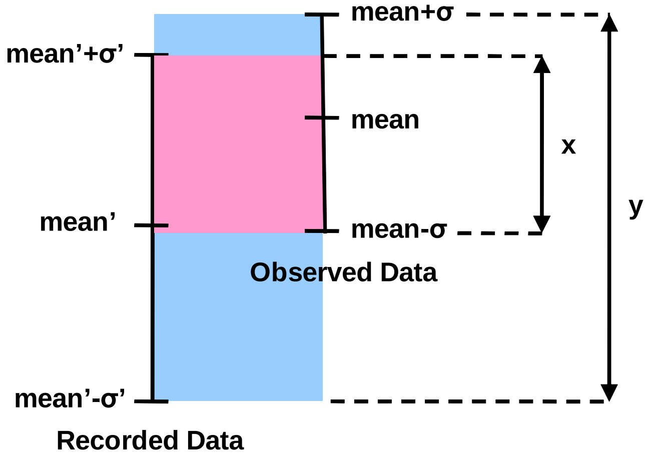

Figure 4.9: Correlation model

By means of the mean and standard deviation of the series of RSSI values, the correlation of recorded and observed data set is calculated as follows.

$$\frac{mean' + \sigma' - (mean - \sigma)}{mean + \sigma - (mean' - \sigma')} = \frac{x}{y}$$

This model calculates the degree of similarity between two different data sets. When the correlation value of two different data set is 1, that means the mean and variance of the data is exactly the same. On the other hand, even if the mean value is the same between two data set, the correlation value can be low when the variance of the two data set are significantly different. Therefore, this model reflects a correlation of variance in a high degree.

Chapter 5

Analysis

To evaluate the performance of WLAN signal strength based location sensor, we define 20 different locations as shown in figure 5.1. Those 20 different locations are mainly set to where doors are nearby. The reason behind this choice is that we aim to build inexpensive coarse grained location sensors to detect the user's location with the granularity of 2 to 3 meters, which is the distance between typical office rooms.

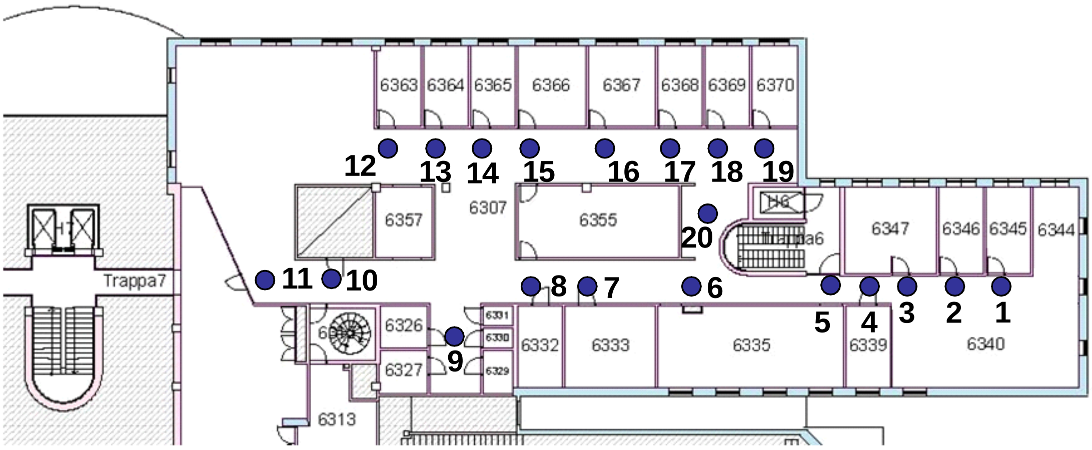

Figure 5.1: Location points to be used for evaluation

The position of antenna and the coordinate design are the same as shown in chapter 4. The coordinates of 20 different numbered positions in the figure 5.1 are shown in table 5. The orientation of the laptop was maintained to be the same in the whole evaluation (the orientation was 270 degrees based on the definition in section 3.4). The height of the laptop and the antenna were set to be the same.

Table 5.1: Coordinates for each location point

Location number	X (meters)	Y (meters)
1	0.0	1.8
2	0.0	4.2
3	0.0	6.6
4	0.0	9.1
5	0.0	10.2
6	0.0	18.8
7	0.0	22.9
8	0.0	26.0
9	-2.6	29.6
10	0.0	35.8
11	0.0	38.0
12	6.8	33.7
13	6.8	30.6
14	6.8	28.3
15	6.8	25.9
16	6.8	22.3
17	6.8	18.6
18	6.8	16.2
19	6.8	13.8
20	3.3	16.2

5.1 Algorithms

We introduced three different algorithms to select the best match from recorded data in section 4.3. In order to observe the performance of each algorithm, we conducted a test with, pure mean comparison, distance model (where, $\alpha = 1$), correlation model. The numbers of true and false estimate in each location are counted to obtain the probability of correct estimate in each location.

It is important to mention that in the correlation model, the data set are compared based on the percentile of the obtained correlation. In other words, in case no recorded data set gives the more than 0 correlation percentile, the best match can not be selected in this way. The case when no best match is found is not counted as neither true nor false.

Figure 5.4 shows the result of the test. Pure mean comparison resulted to have the highest probability of correct estimate among these three algorithm. Only in location 2, 7, and 17, the other algorithms have higher probability of correct estimate. Pure mean comparison shows high performance in most of the location condition since different location condition (location condition means the feature in the specific location, such as having chair or fan around, near to window).

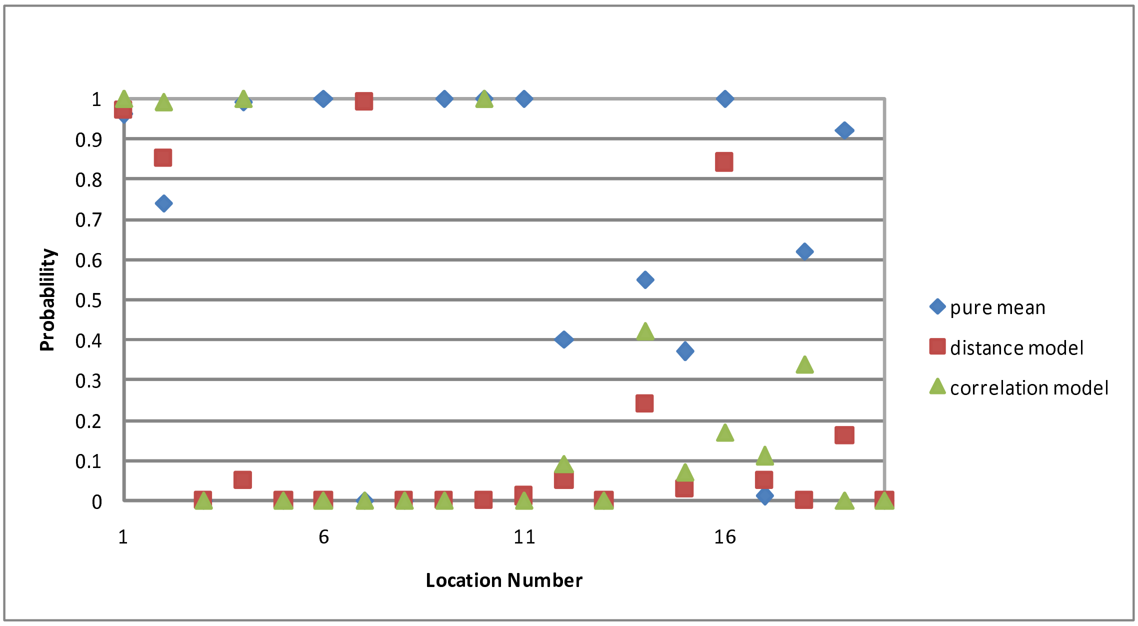

Figure 5.2: Probability of the correct estimate in each location

The average of the probability of a correct estimate in all locations are shown in table 5.1. Only pure mean comparison exceeded 0.5, while the other two algorithms remain around 0.25.

Table 5.2: Average percentile of correct estimate by three different algorithm

Location detection algorithm	Average percentile (correct estimate)
Pure mean	0.528
Distance model	0.212
Correlation model	0.2595

The reason for this result is that using variance of the data set is prone to failure. We observed that the variance changes significantly in different measurements due to tiny differences of the condition when repeating the same measurement.

5.2 Antenna Rotation

In the measurements of chapter 3, we realized that detecting the angle of signal arrival in the office environment is difficult because of the reflection of the signal in the room and the antenna orientation to the signal source. However, we also discovered that there is a distinct difference of signal strength when the antenna is rotated more than 20 degrees.

This implies that collecting the signal strength data from multiple angles can enhance the performance of the location sensor. In order to analyze this method, we modified the prototype to be able to compare the data from multiple angles. Since the pure mean comparison showed the best performance, the comparison to support multiple angles data is designed based on pure mean comparisons. The calculation to pick the best matching location data set, we defined the distance of two data set as follows.

$$\sqrt{\sum_{i=0}^{n}(mean'_i - mean_i)^2}$$

The n in the formula represents a number of rotation steps. We evaluated the cases where n = 1, 2, and 3. The angles of each rotation step are shown in figure 5.3.

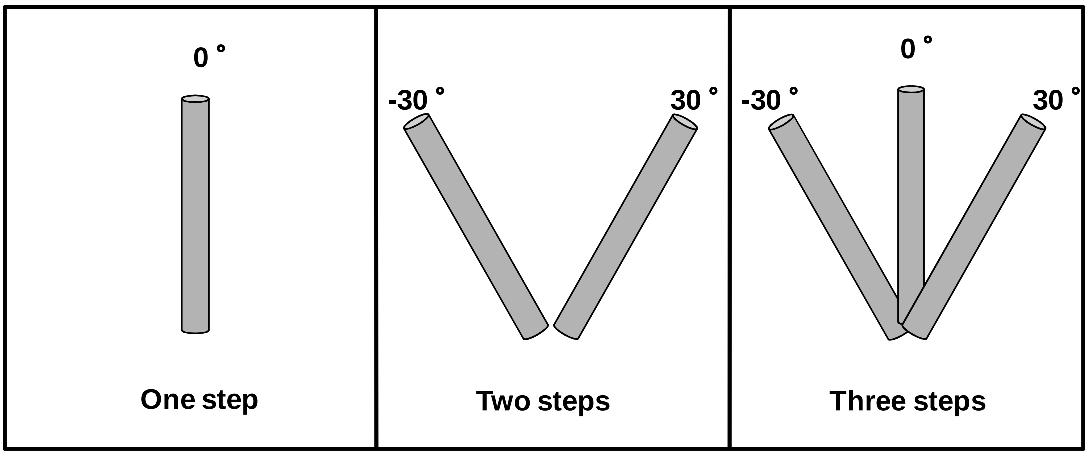

Figure 5.3: Antenna angles in each step

One step is the same as used for the initial algorithm evaluation. Two steps is designed to see the effect when the angle of 0 degrees is omitted (0 degree is where the antenna is directly pointing at a signal source when the signal source is in locations 1 to 11 (except for 8)). The three steps case simply adds measurements at two more angles.

Figure 5.3 shows the results of those three cases. One step and three steps have almost the same probability of exact match, which is around 50%. However, with three steps, 70% of the location estimates are within a error distance of 2.5 meters, while the error in the estimation is 7.9 meters in the case of a single angle (i.e., "one step"), where the error distance in this precision is 7.9 meters in the case of one step. This is a significant improvement for a location sensor and implies the usefulness of directional antenna even if it is hardly detect the angle of signal arrival in the office environment.

In addition, with two steps, the overall performance was significantly lower that the other two cases. This tells us that it is important to have a signal strength measurement at the angle where many locations are within a direct line of sight, as in the case of 0 degree in this evaluation.

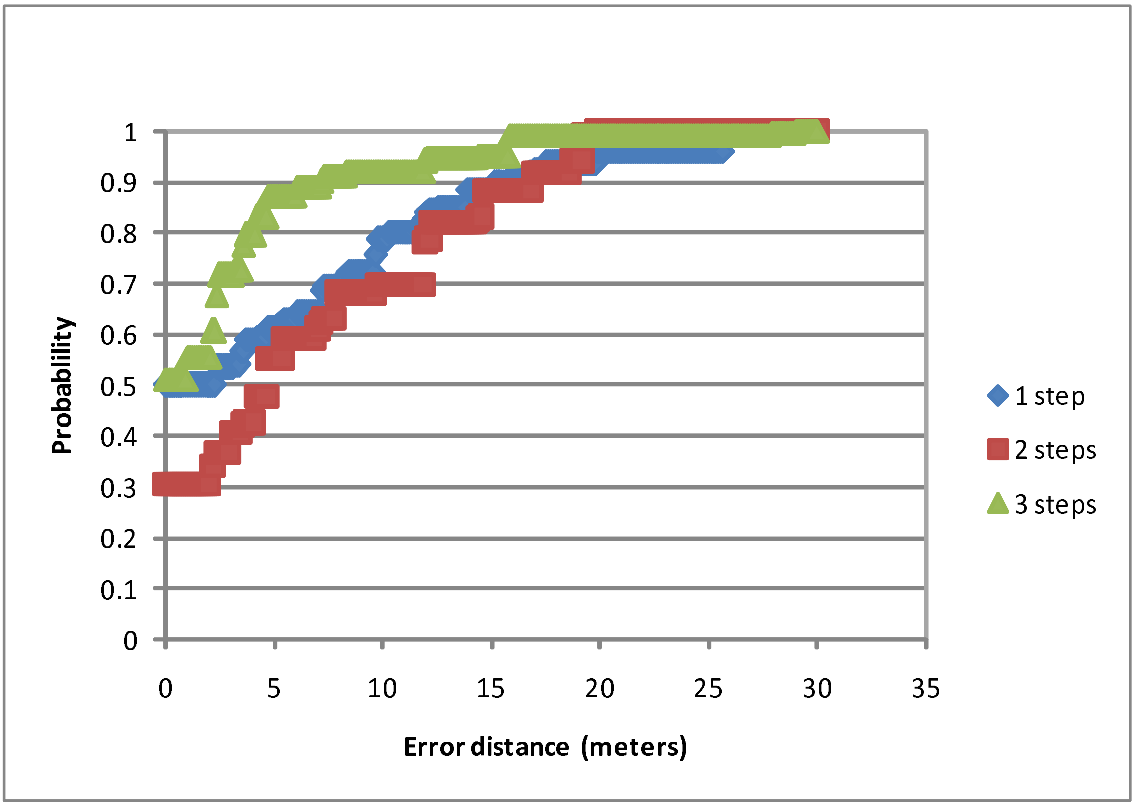

Figure 5.4: Cumulative distribution function of the error distance

Chapter 6

Conclusions and Future Work

6.1 Conclusions

In this thesis, we introduced our presence user agent using an inexpensive location sensing solution based on utilizing WLAN signal strength measurements. Through the study of existing location sensing techniques, we realized that there is an open area of location sensing using a combination of multiple measurements of WLAN signal strength and a directional antenna. The choice of SIMPLE protocol for the communication between location sensor and client device has not widely used in implements yet; therefore, this is also one of the contributions of our project. The implementation of a presence user agent means that the location data can easily be used by the other components of the context-aware infrastructure.

As the next step, we further investigated how the combination of WLAN signal strength measurements and the orientation of a directional antenna could be used in order to estimate the location of a WLAN equipped device. At a early stage of the measurements, we realized that the attenuation of signal strength can not be used to estimate the device location in a real office environment. Instead, we decided to use a fingerprinting method, in which the signal strength data is collected in selected locations, and this recorded data is used to compare with observed signal strengths in order to later estimate a device's location.

Based on the data collected during the measurements, we designed and implemented a prototype location sensor by using signal strength measurements. The performance of the location sensor was improved when it combines signal strength measurements from three different angles. The accuracy of the location sensor is 2.5 meter with precision of

70 %. This certainly satisfies our requirement because we were looking for the inexpensive solution to detect a user's location within 2 to 3 meters (a typical room size in a office) in a office environment.

Things could be done in a different way would be the way to use an antenna. The antenna could be placed in a central part of the office so that the angle to each location can be spread over 360 degrees. In this way, the directionality of antenna could be used in a different way.

6.2 Future Work

6.2.1 Investigation of Features to Improve Location Sensing Performance

In order to improve a performance of location sensing, refining the data collection is not the only way. A sequence of the detected locations could be used to enhance the performance. By making the location estimation decision considering the last series of locations, the estimated location sequence would be smoothed; thus, estimated location would be reasonable from the last estimated location. Exploring the features of location sensing to improve the performance could be the succeeding work from ours.

6.2.2 Radiation Pattern Study in a Office Environment

To utilize a directional antenna to detect the location, it is important to know the radiation pattern of sources at different locations in the specific office environment. We roughly estimated the radiation pattern through measurements by moving the laptop in directions parallel and perpendicular to the antenna. However, a more detailed exploitation of the antenna's radiation pattern might improve the location accuracy. Such a future study should also examine how changes in furniture's location affects the radiation pattern of an antenna.

6.2.3 Adaptive Location Sensor

Since the environment in a office is subject to change with time, it is preferable that the system can adjust its estimates based upon data collected during operation. This could significantly reduce the operational cost of setting up and operating such a location sensing system. It is also possible to use a signal propagation model so that data does not have to be collected for each and in every deployment. In order to use such a model, the effect of the walls between rooms and he location of furniture have to be carefully analyzed.

6.2.4 Location Based Application

It is always rewarding to consider how such a location sensing system can be used. How could this SIMPLE based location sensor be used to assist the user's to complete their daily tasks? To answer this question, a real application has to be implemented and evaluated in a real environment. One of the promising features of our WLAN based solution is that user can take a advantage of this service as long as they carry WLAN equipped device that communicate with the existing WLAN access points. Because location sensing is executed in a totally passive way, users do not need to install or execute special applications for their location to be made available in the proposed infrastructure.

As the operation of this location sensor is limited to when the user's are using the WLAN, web based application would be particularly interesting when combined with this location sensing. For example, an on-line calender (such as Google calender) could be linked together with this location service so that the location update can remind the user of something to be done at a particular place, such as returning a book to library.

Such a presence user agent based system can be also used to link location updates to a web based advertising system. When the user's location is detected to be near a shop, then the advertisement of a suitable product available in this shop can be sent to the user by mean of a web link. In order to avoid being flooded by advertisements, the user's preferences can be stored in the database so that the advertisements to be sent are filtered before initiating delivery.

6.2.5 Incorporating an existing location system into a PUA

Since the PUA separates the position sensing from the reporting of location, a future activity might be to examine how commercial location systems or other existing positioning system could be incorporated into a location presence user agent. This would enable the creation of location PUAs which could acquire their data from GPS, real-time location tracking systems such as that of Ekahau or Cisco, cellular base station IDs, etc. Therefore, location context aware application would be very independent of the actual source of the location data. Context refiners could even be used to combine the location data from different sources.

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Appendix A

RFID Basics

The cost of Radio frequency identification(RFID) technology has decreased dramatically. RFID technology has reached the price at which customers increasingly use it in practice. The practical use of RFID gained attention when Wal-Mart, a giant retailing company, announced their requirement for RFID-enabled shipments for their top 100 suppliers by January 2005. Supply chain management is one of the typical applications where the benefit of RFID deployment can be readily seen; however, the potential of RFID includes not only supply chain management, but also payment systems, security and access control, etc. RFID systems have countless variants in terms of different features. We will investigate these features in the following section.

A.1 Differentiation of RFID Systems

RFID systems can be differentiated by the following features[2]:

Operation type Communication can be of two different types: *full/half duplex* and *sequential*. The reader's RF field is active when the transponder sends a signal in full/half duplex systems. Since the transponder's signal is extremely weak compared to the signal of the reader, the appropriate procedures have to be selected to differentiate the transponder's signal from reader's signal. On the other hand, the field from a reader is deactivated at regular intervals when using sequential procedures. In this case, the transponder sends its signal during these gaps in the reader's emissions.

Data size The data size of the message sent from the transponder has to be selected based on the system's requirement. In the case of attaching a transponder to identify goods in a shop, only a few bytes are needed to store the unique identifier of the product. The most frequently used data sizes range from a few bytes to several kilobytes.

Programmability Whether the reader can write data to the transponder is another feature of RFID systems. In primitive RFID systems, the transponder is shipped with a fixed serial number and this number can not be changed by the purchaser (Although in some cases it may be possible to permanently disable the transponder - in order to provide improved privacy after the product is sold to an end customer.). In contrast, a writable transponder allows the RFID reader/writer device to write new data to the transponder's memory. In practice, the write operation consumes a lot of power and the number of write cycles is limited.

Power supply RFID systems have two different types of power supplies: *active* and *passive*. Passive tags do not have their own source of power, therefore, they rely on the power supplied by a reader. This power is obtained from an electric/magnetic field produced by the reader. On the other hand, active tags have their own power supply, usually supplied by an on-board battery. However, some active tags still need to draw power from the reader.

Frequency range The transponder's operating frequency has a significant impact on the RFID system. The transmission frequencies, generally used in RFID system, are categorized in three broad ranges: *LF (low frequency 30-300kHz)*, *HF (high frequency 3-30MHz)*, and *UHF (Ultra high frequency 300MHz - 3GHz)*. The different range of frequencies have different characteristics. For example, higher frequency produce a more directional wave and require smaller antennas. A suitable frequency must be chosen based on the requirements of the system.

Data transfer There are three different procedures to send data back to the reader from the transponder: *backscatter*, *load modulation*, and *subharmonics*. Backscatter uses the reflection of a wave emitted by the reader to send a signal back to the reader in the same frequency band as the reader is emitting. Load modulation controls a switch in a load resistor via the data, thus enabling data to be sent to the reader in the same frequency band. Subharmonics generate harmonic waves in the transponder and use the harmonic wave to send data to the reader.

A.2 Component of an RFID System

Figure A.1 shows the components of an RFID system, namely, *the transponder* and *reader*. The transponder, also known as an RFID tag, contains the data required to

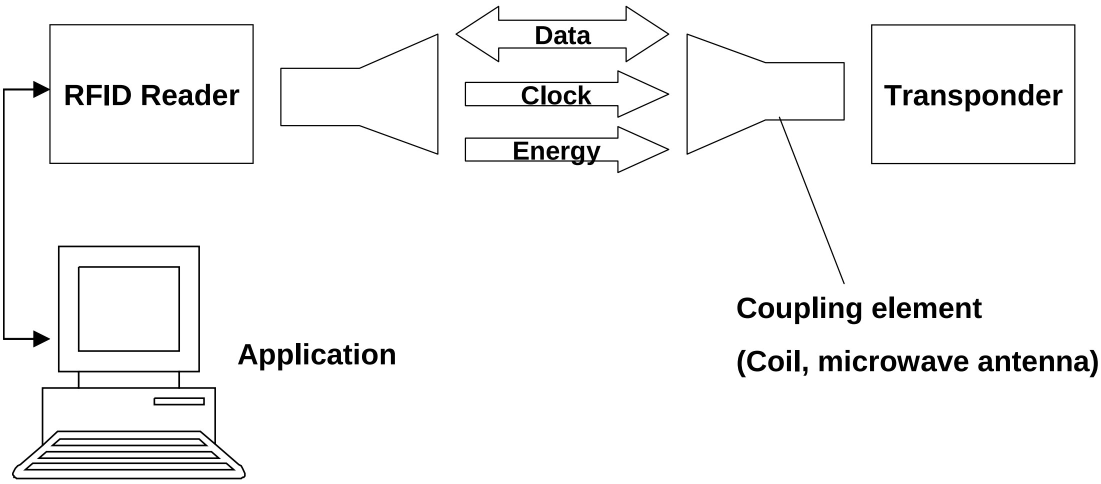

Figure A.1: Components of an RFID system (is adapted from [2])

identify it. It contains a coupling element, for transmission of data, and an electronic microchip, for data storage (see figure A.2). When the transponder is beyond the range of a reader, it is totally passive, awaiting the signal from a reader. Once the transponder is within the range of a reader, it is activated via the power supplied through the coupling unit. The reader consists of a transmitter, receiver, a control unit, and coupling unit. Many readers have additional interfaces to transfer the data to another system, such as an Ethernet. Despite the name "reader", as noted earlier some readers are capable of not only reading a tag, but also writing data to it. The use of the word "reader" simply refers to the data capturing devices in normal colloquial usage and, in this paper we will follow this usual convention.

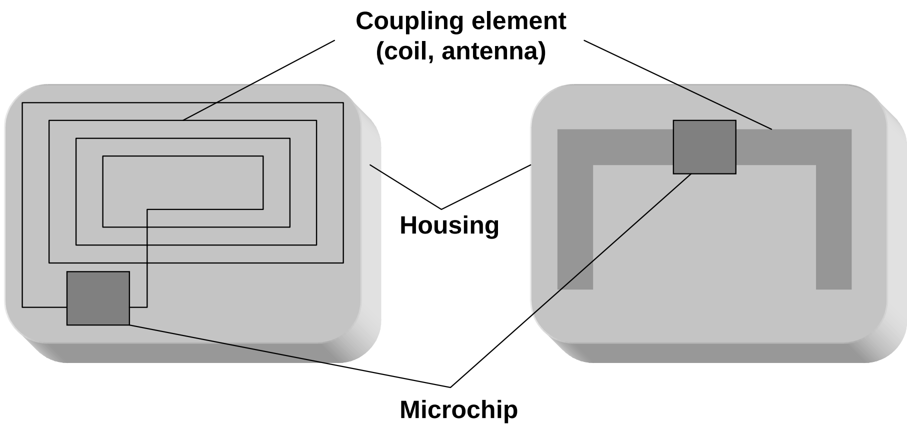

Figure A.2: Two examples RFID transponders (basic layout)(adapted from [2])

A.3 Business Applications

Numerous business applications of RFID exist. A great overview of RFID technology is available in [63][64]. Here, we briefly examine some applications in *supply chain management*, *payment system*, and *security*. The first of these shows an example of collecting identification information when the tag is in proximity of a reader, the second shows the potential of both short and long range communication, and the final shows proximity of a given tag being used for authentication and authorization.

Supply chain management

The motivation for RFID usage in supply chain management is that RFID enables seamless tracking of products from supplier to the retailer's store (based upon an RFID-reader equipped gate through which pallet loads of materials are forced to pass). Traditionally, bar codes have been used for product tracking; however, RFID systems provide greater efficiency since reading a tag does not require manual scanning nor does it require that the tag be visible to the reader. The U.S. Food and Drug Administration(FDA)[66] has propose using RFID tags for ensuring the authenticity of prescription drugs. The drugs are shipped together with a read-only RFID tag (containing a unique serial number) so that the supplier can track this tag at each step of distribution, logging tracking information in their database. The drug purchaser can lean how the drugs were delivered to the retail store using the serial number on the receipt to access the tracking data in the database.

Payment system

RFID offers convenience not only for supply chain management, but also for retail payment. For example, an active RFID-based toll system allows the drivers to pay without stopping, and such systems have been deployed in many countries. Passive RFID tags have replaced magnetic stripe cards; their contact-free reading avoids physical contact with the reader. Although the communication range for a passive RFID tag is short, it does **not** require physical contact with the reader. Magnetic strip cards used for transportation passes are increasingly being replaced by RFID embedded cards.

Security and access control

Security can be also enhanced by using RFID. Many current models of cars have RFID based key systems to reduce auto theft. The reader is placed in the steering column and the transponder in the key, so that the car will not start without the transponder being in range of reader.

A traditional RFID use was to control access to buildings by workers. More and more organizations have been deploying such systems using RFID embedded ID cards. The benefits of RFID includes their convenience and low maintenance (as explained above for payment systems).

A.4 Security and Privacy Issues

Security and privacy are among the biggest concerns of the user of RFID systems, as Sharama, Weiss, and Engels point out in their paper[65]. When RFID is used in payment systems, the content exchanged between RFID tags and the reader should not be intelligible to a third party. For example, if the identity of a transportation payment card is eavesdropped and copied to another card, then the new card can be used by others to pay their toll fee. However, strong authentication with RFID is difficult because of the limited processing capability of the tag.

Privacy is also an issue since the tag can be used to track the person who carries the tag. One of the ways to prevent this is to have kill switches to disable the tag, which can be done by sending a kill message to the tag.

Appendix B

UDP Datagram Generator C Source Code

```
/*
 * UDP datagram generator with sequence number.
 * This pakcet generator changes port number every 15 seconds.
 * The datagrams are sent for 5 seconds after waiting 10 seconds.
 */

#include <stdlib.h>
#include <string.h>
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <sys/times.h>

#define dst_ip_addr "130.237.15.247"
#define base_port 3000
#define bufferSize 256
#define timeOfShift 40
#define totalTime 600

struct payload {
  int  counter;
  char buffer[bufferSize];
};

int counter;          /* Counter to keep track of the sequence
number of UDP datagram */


int main(int argc, char** argv){
```

```
  int i;
  counter = 0;
  int start_time;
  time(&start_time);

  fprintf(stderr,"Start time: %d\n",start_time);

  /* Send UDP datagram to the stepped ports till each end time */
  for (i=0; i < timeOfShift; i++) {

    int result = send_udp_packet(base_port + i,
                 start_time+(totalTime/timeOfShift)*(i+1));
    if(result!=1){
      fprintf(stderr,"Error %d:when sending packet\n",result);
      return -1;
    }

  }

  printf("finished sending %d UDP packets\n", counter);
  return 0;

}


int send_udp_packet(int port, int end_time){

  fprintf(stderr,"time to set up for the next distance\n");

  /* Sleep 10 seconds */
  sleep(10);

  int current_time;
  time(&current_time);

  int socket_fd;              /* File descriptor of udp socket */
  struct sockaddr_in dst_addr;
  int sendto_flags=0;
  int i;

  /* create a UDP socket */
  if ((socket_fd = socket(AF_INET, SOCK_DGRAM, IPPROTO_UDP)) == -1) {
    perror("Unable to open socket");
    return -3;
  };

  /* Initialize the structure of destination address */
  memset( (char*)&dst_addr, 0, sizeof(dst_addr));
  dst_addr.sin_family=AF_INET;
```

```
  dst_addr.sin_port=htons(port);

  /* Check if the destination IP address is valid */
  if (inet_aton(dst_ip_addr, (struct sockaddr*)&dst_addr.sin_addr) == 0) {
    fprintf(stderr, "could not get an address for: %s", dst_ip_addr);
    return -2;;
  }

  /* Send the UDP datagrams */
  while(end_time >= current_time){

    struct payload udp_payload;
    memset( (char*)&udp_payload, 0, sizeof(udp_payload));

    counter++;
    udp_payload.counter = counter;
    sprintf(&udp_payload.buffer[0],
        "Current distance from antenna is %dm\n. This is a packet No.%d\n",
         port - base_port,udp_payload.counter);

    if ((sendto(socket_fd, &udp_payload, sizeof(udp_payload),
              sendto_flags, (struct sockaddr*)&dst_addr, sizeof(dst_addr))) == -1) {
      perror("Unable to send to socket");
      close(socket_fd);
      return -1;
    }

    /* For monitoring the progress */
    fprintf(stderr,"Port:%d - Packet No.%d is sent\n",port,udp_payload.counter);

    /* Sleep 1 milli seccond */
    usleep(1000);

    /* Get current time */
    time(&current_time);

  }

  /* Close socket */
  close(socket_fd);
  fprintf(stderr,"End of a phase\n");
  return 1;

}
```

Appendix C

Data Calculation Perl Script

```
#!/usr/bin/perl -w
# Each input line consists of a double: "Port","RSSI".
# Separate the file based upon making a file for each port containing only the RSSI.
# Then, create summary file called summary.csv.
#
# To run this program, the file name has to be passed as argument.


use Statistics::Descriptive;

my $filename = $ARGV[0];
my $port = '';
my $var = '';
my $var1 = '';
my $RSSI = '';
my $count = 0;
my $varrec = '';
my $output_filename = '';
my $numb_of_file = 0;

&create_tmp_file;

# Open the data file for reading
open(DATA_FILE, $filename) || die "Can't open data file: $!\n";

# Read the data from file and create separated files
while ($varrec = <DATA_FILE>) {

    # Skip the first line of file
    if ($count==0) {
    $count = 1;
    next;
    }
    else {
```

```
      chop($varrec);
      ($port, $RSSI) = split(/,/, $varrec);

      $port =~ s/"//;
      $RSSI =~ s/"//;

      $port =~ s/"//;
      $RSSI =~ s/"//;

      $var = $port - 3000;

      if ($count == 1) {
      $var1=$var;
      print PTMP "$RSSI\n";
      $count++;
      }
      else {
        if ($var =~ $var1) {
          print PTMP "$RSSI\n";
        }
        else {
          close PTMP;
          chmod 0664, '/tmp/ptmp';
          $output_filename = $var1 . "meter";
          system("mv /tmp/ptmp $output_filename");
          $var1 = $var;
          &create_tmp_file;
          print PTMP "$RSSI\n";
        }
      }
    }
}

close PTMP;

# Produce the last file
chmod 0664, '/tmp/ptmp'; $output_filename = $var1 . "meter";
system("mv /tmp/ptmp $output_filename");

close DATA_FILE;

create_summary();


# Open a new tmp file
sub create_tmp_file {

    open(PTMP, ">/tmp/ptmp") || die "Can't open tmp file $! for writing\n";
    $num_of_file++;
```

```
}

# Create a summary file of split files
sub create_summary {

    open(SUMMARY, ">summary.csv") || die "Can’t create summary file\n";
    print SUMMARY "#X,Y,Mean,Variance\n";

    my $i = 0;
    my $filename = ’’;

    while($i<$num_of_file){

    $filename = $i."meter";

    open(DATA_FILE,$filename) || die "Can’t open data file: $!\n";

    my $stat = Statistics::Descriptive::Full->new();
    my $mean = 0;
    my $variance = 0;

    while ($varrec = <DATA_FILE>) {
        $stat->add_data($varrec);
    }

    $mean = $stat->mean();
    $variance = $stat->variance();

    print SUMMARY "0,$i,$mean,$variance\n";
    print         "0,$i,$mean,$variance\n";

    close DATA_FILE;
    $i++;
    }

    close SUMMARY;

}
```

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