LOCATION-AWARE ACCESS TO PATIENT RECORDS

by

Bulut ALTINTAŞ

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Yeditepe University

Faculty of Engineering and Architecture

Department of Computer Engineering

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LOCATION-AWARE ACCESS TO PATIENT RECORDS

APPROVED BY:

Assist.Prof.Dr. Tacha Serif ……………………

(Supervisor)

Assist.Prof.Dr.Sedat Şişbot ……………………

Prof. Dr. Şebnem Baydere ……………………

Assist. Prof. Onur Demir ……………………

Prof. Dr. Linet Özdamar ……………………

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ABSTRACT

LOCATION-AWARE ACCESS TO PATIENT RECORDS

Hospital personnel usually change their location to perform their works such as visiting patients, getting patient records for examination and updating patient records with new records. These records which are required by hospital personnel are mostly dependent on their location. Access to patient records is relevant when the personal is entering the patient's room. In this thesis, a location aware system that was developed to access patient records from Electronic Patient Records (EPR) by handheld computer is described. The system is based on handheld computer which includes location estimation system to estimate personnel's location and a client to access information from EPR that is relevant to personnel's current location.

ÖZET

AKILLI HASTANE: HASTA BİLGİLERİNE ETKLİ ULAŞIM

Hastane ortamında, PDA kullanan doktorların hastalarının odalarına girdiklerinde, PDA'in bulunduğu lokasyonu, ortamda bulunan normal olarak internet erişimini sağlayan kablosuz erişim noktalarından aldığı sinyal güçlerine bağlı olarak tespit edip, hangi odada bulunduğunu algılayıp o odada kalan hastanın bilgilerini Electronic Patient Record dan(hastanın bilgilerinin belli bir standartta veritabanında tutulması)alıp PDA ekranına getirdiği ve doktorların bu bilgilerle gerekli işlemleri yaptığı, gerektiğinde bilgileri güncelleyebildiği (gerek sesli mesaj, gerek yazılı mesaj olabilir) bir sistedir.

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LIST OF SYMBOLS / ABBREVIATIONS

AP	Access Point
EPR	Electronic Patient Record
GPS	Global Positioning System
HIS	Hospital Information System
IOM	Institute of Medicine
m	meter
MSS	Mobile Support System
MU	Mobile User
NCVHS	National Committee on Vital and Health Statistics
NNSS	Nearest Neighbor in Signal Space
PDA	Personal Digital Assistant
RF	Radio Frequency
RFID	Radio Frequency Identification
RP	Reference Point
RSS	Received Signal Strength
SS	Signal Strength
WiFi	Wireless Fidelity (IEEE 802.11a/b/g wireless networking)
WLAN	Wireless Local Area Network

1. INTRODUCTION

A recent trend in the development of positioning systems is the support for mobile computing devices that can be used in every field in our life. Rapid growth in mobile computing has caused an increase the interest in context-aware, especially location-aware, services. On the other hand hospitals are complex information-rich environments that include a significant technical and computational infrastructure, with a need for coordination and collaboration among specialists with different areas of expertise, an intense information exchange, and the mobility of hospital staff, patients, documents and equipment. As a result, this makes them an ideal application domain for mobile computing technology use.

On the other hand, a proliferation of PDA and Smartphone devices can be seen throughout the mobile phone user spectrum. The user community of IEEE 802.11 a/b/g wireless networks (Wi-Fi) is in the increase in order to achieve high-speed communications. WLAN provides local wireless access to wired network infrastructure. Obviously, WLAN is not designed and deployed for positioning purposes but in recent researchers have looked and studies possible ways of utilizing radio signal strength (SS) from access points (AP) or station which are included in the WLAN to identify the location of mobile device users'.

Munoz et al. [1] developed a system which is called Location-Aware Access to Hospital Information and Services in 2004. Location of the mobile user is calculated then the related records about patient can be accessed. Mobile user can change these records or insert new records. However, considering the data input issues on small touch screen, it should be clear that updating patient records can be a cumbersome task. In order to handle this problem voice message usage is designed in the system. User is able to change the records or insert new messages with voice message more rapidly.

The remainder of the report is organized as follows. Section II presents the related work about the medical systems, location aware systems and electronic patient record concept. Section III provides a brief overview of the methods that can be used in the design of a context-aware patient record system. In section IV, system architecture and implementation is described. Section V discusses presents the results and analyses the findings of our evaluations. Finally Section VI concludes with a discussion on possible future venues of this study.

2. BACKGROUND AND RELATED WORK

2.1 Medical Systems

Hospitals are complex information-rich environments that require coordination and collaboration among specialists with different areas of expertise for example hospital staff exchange information with each other or want to access patients' records, documents, equipments which can be all mobile things.

At hospitals, important part of the staff's tasks requires mobility and the coordination between the staff' due to their job description which includes big amount of the information exchange intensity, and resources or documents distribution. A hospital staff might be distributed in space which means different location within the settings and the needs of staff such as patient records, equipment information or other information are dependent on their location and other contextual conditions such as their role or time of day.

In addition to this condition, artifacts are generally used in hospitals to provide the staff's coordination. It has been pointed out that due to their different professional background, hospital personnel is likely to experience communication problems on artifacts [2]. Mistakes on artifacts can occur easily due to lack of communication among hospital staff. At many hospitals whiteboards on walls are used at hospitals to act as a communication link among hospital staff to information exchange regarding the conditions and locations to related person.

On the other hand, usage of handheld computers by hospital staff in their professional practice is in the increase. It was estimated that 26% of all staff in the U.S. used a handheld in 2001, and the number of staff who use a handheld had been expected to grow to 50% for 2004 or 2005. The proportion of staff that uses handheld computers had increased with an important ratio before 2001. However, some of these staff is using these devices mainly for personal activities. The number of professional using them as an integral part of their everyday practice has almost doubled (from 10% in 1999 to 18% this year). Use of handheld devices is higher among doctors under 45 (33%) than among older doctors (21%). It is also higher among those who are wholly or partly hospital-based (33% and 29%) than among those who are mostly office-based (23%). Mobile device (PDA) usage is also higher among physicians in larger practices than in solo or small group practices [3]. Nowadays most hospital staff are using handheld computers.

TABLE 2.1.1: Use of Handheld Personal Devices Such As The Palm Handheld or Pocket PC By Physicians

	Total		Group Size			
	2001%	1999%	Solo Practice%	2-9%	10-24%	25+%
Use as an integral part of my everyday practice	18	10	11	19	17	25
Use mostly for personal activities	8	5	5	9	10	8
Total who use	**26**	**15**	**16**	**28**	**37**	**33**

TABLE 2.1.2: Expected Use of Handheld Devices to Record Notes Among Those Currently Mainly Recording Notes Via an Assistant, Handwriting Notes and/or Dictating Notes Onto a Tape

	Total 2001 %
Expect to in the next 18 months	11
Expect to in the next 5 years	22
Do not expect to in the next 5 years	29
Not sure	38

However, handheld computers or mobile devices have important roles on the quality of patient care. A handheld computer can be used to access the patients' clinical notes, to store patient care guidelines, to facilitate communication through messaging (text or voice) and provide coordination of staff [4]. Staff may use their handhelds to:

- Access medical reference information
- Make medical calculations
- Code and bill for patient encounters
- Track patient data
- Write prescriptions

On the other hand, inadequate access to patient information can cause medical errors. In addition to this, hospital staff often ask themselves clinical questions and make decisions that require to access to both clinical and nonclinical resources. For example, Will adding a certain medication produce a drug-drug interaction? What is the appropriate diagnostic code for this condition? How do I adjust this medication dosage based on the patient's renal function? At what billing level may I code this patient encounter, given my documentation? Accessing information can be extremely useful in the growing amount of medical information, and the time limitations placed on staff. Handheld device can improve efficiency, and they might also help to avoid medical errors and achieve better patient outcomes [5].

Up to now, there are a lot of researches or developed systems about medical systems. One of them which is named 'Location-Aware Access to Hospital Information and Services' is developed by Munoz et al [1]. In this work they described a location-aware medical information system that was developed to provide access to resources such as patient's records or the location of a medical specialist, based on the user's location. In order to do this they explored the use of context-aware computing. They presented a handheld system that provides hospital staff with information based on their context of work such as their location. This system can be used to retrieve medical information relevant to the user's current activity. For instance, a patient's medical record can be made available when the physician is near her bed. This work is based on previous efforts we made to support context-aware communication of the hospital's staff.

Another related system is developed by Choi et al. [4] which is called MobileNurse. It was a prototype mobile nursing information system (NIS) using PDA. It was designed to communicate with hospital information system (HIS) with using mobile support system (MSS) which interchanges and stores clinical data. This system consisted of four components. The first was the medical order checking module. It enables nurses to retrieve patient information, such as physicians' orders or test results, anywhere and anytime. The second component was the nursing recording module. Nurses can record the results of their practices at the bedside. As a nurse executes the auto-synchronization module of MSS and PDA, the existing data of both systems can be interchanged and updated. The third component was the nursing unit care planning module, which retrieves the nursing care plans for all patients, such as patients' discharge, consultation, and transfer. The last component was the patient information management module with which nurses record the patients' demographic information during their interview of nursing assessment. With the use of PDA in the hospitals, nurses can spend more time on caring for patients by reducing time-consuming.

2.2. Location-Based Services

A recent trend in the development of positioning systems is the support for mobile computing devices that can be used by the hospital staff to access clinical records anywhere and anytime. Mobile computing fantastic growth has caused an increase on interest in context-aware, especially location-aware services. One of the most popular positioning systems is Global Positioning System (GPS), however it is not suitable for indoor positioning because it has accuracy of up to 15 meters for civilian users. [6]. GPS use triangulation of signals which are received from multiple satellites to determine location. Other techniques, actually used for indoor positioning systems, include ultrasound [7], infrared [8] and radio frequency identification (RFID) tags [9]. These positioning implementations require extra hardware and infrastructure which are often expensive. This is an important barrier to their deployment. Consequently, a wireless positioning implementation with non-specialized, relatively inexpensive hardware is desirable.

On the other hand, the user community of IEEE 802.11 a/b/g wireless networks (Wi-Fi) is in the increase. WLAN provides local wireless access to network architecture. Obviously, WLAN is not designed and deployed for positioning. In the recent years there are researches on radio signal strength (SS) from access points (AP) or station which are included in the WLAN. These researches pointed out that it possible to infer the position of a device with signal strength information from visible APs. We can see this condition in the one research experiment. [10]. In this experiment, while someone was walking around the hallway of one building, SS is recorded every second for four different APs. The results are shown in the Figure 2.2.1. If a reliable positioning system could be developed using this technology, mobile device position estimation can be improved by cheap technology.

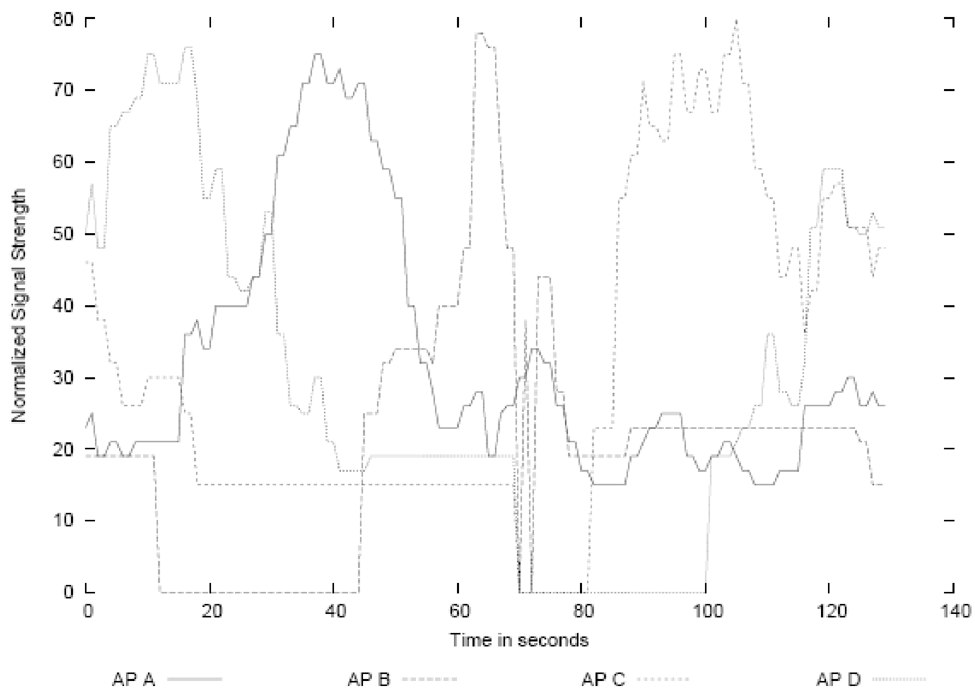


Figure 2.2.1: Signal Strength readings from vary with location of the device

Several different methods for calculating the mobile device position exist. Most popular techniques are Trilateration and Fingerprinting. In order to understand related works of positioning systems completely I make use of the descriptions of these techniques. *Trilateration* is based on observing the distance to three or more known positions then use this information to determine the current position. This approach requires that position of the observed APs is known and a propagation model can be used to determine the distance based on the observed signal strengths. *Fingerprinting* positioning methods depends on observations of signal strengths at known locations. These known can be used to compare with a Wi-Fi observation from an unknown position and search for the best matching position. Fingerprinting does not rely upon a propagation model and the position of the AP is not needed as trilateration.

There is plenty of work that rely on Wi-Fi signals to determine location. One of them was developed by Ekahau [11]. Ekahau is a company selling a Wi-Fi-based positioning system called Ekahau Positioning Engine (EPE). The EPE can be used to determine the location of Wi-Fi enabled devices such as laptops, PDAs and similar devices. The EPE relies on the fingerprinting algorithm. Another project about positioning system is the Skyhook Wi-Fi positioning system.[12]. The skyhook wireless provides no detailed information on how their positioning system Works, except that it is based on a database containing the locations of the APs. It tries to compensate for different signal propagation model for each AP hence it uses trilateration. Another related work which is the one of the most important research about positioning system is RADAR [13]. Their analysis pointed out that use of signal strength information to determine a position is viable. Furthermore, their comparison of fingerprinting and trilateration states that fingerprinting gives much accurate results, yielding a median resolution of 2-3 meters than trilateration yields a 5 meter median resolution.

Trilateration has some disadvantages because it may not be possible to get precise position of APs and also it requires knowledge of radio signal propagation model of the area to map signal strength to distance for the algorithm. Furthermore it is hard to for position estimation to the APs inside building because radio signals behave differently in walls and in air. On the other hand fingerprinting does not rely upon a propagation model for positioning and does not need to know the position of APs. In addition to these things since it has more accurate results than the trilateration model, it is used more commonly than the trilateration.

2.3. Electronic Patient Record

As is the case with many hospitals in Turkey, Haydarpasa Numune Hospital keeps very few records on its patients. When a patient visits the hospital his name, address, age and etc. are recorded and he is given a form. The doctors will use this form to record their diagnoses and prescribed treatments. It is the patient's responsibility to keep this form along with any other medical records. The information recorded at the hospital (name, address, age, etc.) is only used to create daily reports that show how many people visited on that day and where they came from.

The problem with this system is that the doctors have no way of knowing what treatments or prescriptions a patient has received in the past without relying on the patient's ability to maintain his records. So it is quite possible that patients could be receiving double doses of medications or taking medications that should not be taken together.

The solution to this problem is for the hospital to maintain the patients' records and design an Electronic Patient Record (EPR). The purpose of the electronic health record is to provide support for the clinical team to help them recall and communicate health status and treatments for patients in a coordinated way.

Electronic patient record systems have the potential to bring huge benefits to patients and are being implemented in health systems across the developed world. Storing and sharing health information electronically can speed up clinical communication, reduce the number of errors, and help doctors in diagnosis and treatment. Patients can have more control of their own healthcare. However, increasing access to data through EPR systems also brings new risks to the privacy and security of health records.

In the National Health Service (NHS) in England, implementing EPR systems is one of the main aims of the 10-year National Programme for Information Technology (NPfIT), the largest civilian IT project in the world, which was launched in 2002, building on earlier initiatives. The main plank of the NPfIT programme is the NHS Care Records Service (NCRS) which will create two separate EPR systems: a national Summary Care Record (SCR), containing basic information, and local Detailed Care Records (DCRs), containing more comprehensive clinical information. NCRS will also include a Secondary Uses Service (SUS) which will provide access to aggregated data for management, research and other 'secondary' purposes. England is firmly in line with trends in the developed world: EPR systems are being created in various forms in the USA, Canada and Australia, as well as in Scotland, Wales and many countries in the European Union [14].

Australia's proposed national health information network is called Health*Connect* [15]. The basic Health*Connect* model is to extract a summary record from locally collected patient data which is then aggregated to create a centralized Health*Connect* record that may then be shared among participating and authorized providers.

The long term goals of Health*Connect* include:

1. deliver enhanced clinical communication through standardized clinical messages;
2. enhance safety and quality through a shared electronic health record;
3. integrated models of care through a shared electronic health plan;
4. life saving information available in emergencies;
5. enhanced primary care communications networks; and
6. consumers better able to manage their health care.

In the United States, as is the case in Australia and the England, the purer EHR model is evolving at the national level. To date, the Institute of Medicine (IOM) and the National Committee on Vital and Health Statistics (NCVHS) have focused primarily on the *technical* aspects of EHR implementation in the United States. Both have identified two core components in the project: first, building a national health information infrastructure and, second, establishing data interoperability and comparability for patient safety data. In order to achieve data interoperability and comparability, NCVHS and IOM have recommended the adoption of core standardized EHR terminologies [16].

In our system, PDAs wirelessly connected to this electronic patient records (EPR) can give physicians access to patient medical records from anywhere within the hospital. Even with their limited screen size there are clear advantages from having this increased availability of information.

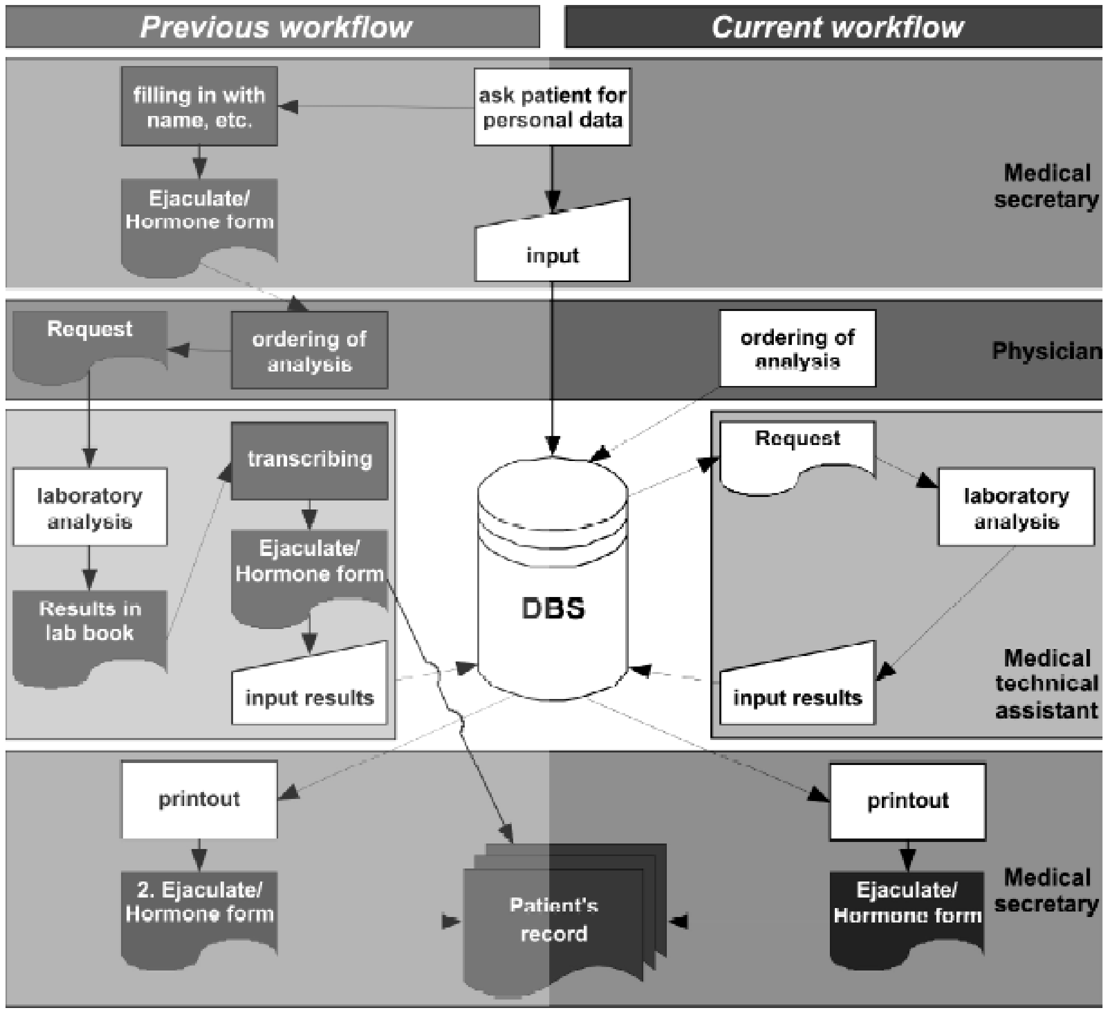


Figure 2.3.1: Example workflow in comparison between old style and new style based on EPR

3. METHODOLOGY

3.1 WLAN-based Positioning Systems

3.1.1 Trilateration

The trilateration approach is one technique about positioning systems. Three base stations (or more) with known coordinates are required. If the distance r from the AP to a Mobile User (MU) can be measured, a circle with radius r can be drawn. Intersection of the circles at one point is the position of MU. However, the measurements obtained are SS rather than the distance. Hence, the SS should be converted to a distance measurement first. So, the trilateration approach consists of two steps: the first step, using a signal propagation model to convert SS to AP-MU separated distance; the second step, least squares or another method (such as the geometric method) can be used to compute the location. The first step is the key point of this approach.

Since the environment varies significantly from place to place, the simplest way to find the relationship of SS and the separated distance is collecting some SS data at some points with the known coordinates. This means an extra procedure, named a learning procedure, has to be added to the trilateration approach. In the experiment, data was collected to determine the Radio Frequency (RF) propagation model; precisely the relationship of AP-MU separated distance and received SS (RSS) of AP. The experiment shows the accuracy of this approach is about 4-5 meters (using a general model for all the APs' signal). To improve the accuracy of the trilateration approach, a hybrid method was proposed [17]. This method is based on the fact that in small localities, such as in a room, the propagation model is better behaved. This method has two stages: in stage one, find the small area the MU is in; in stage two, using trilateration to accurately estimate the location of MU. The experiment shows that the hybrid method can improve the accuracy significantly. However, it is still slightly worse than using fingerprinting with a medium training phase.

The difficulty with the trilateration approach is obtaining the distance measurement from the SS accurately. Indoor radio signal propagation is very complicated, because of signal attenuation due to distance, penetration losses through walls and floors, and the effect of multipath propagation. Interference from other signals is also a problem. 802.11b uses the same frequency band as that used by microwave ovens, cordless phones, and Bluetooth devices etc. Hence, in the 2.4GHz frequency band, those devices can be sources of interference. Furthermore, the orientation of the receiver's antenna, and the location and movement of people inside the building, can affect the SS significantly [18]. It is extremely difficult to build a sufficiently good general model of signal propagation that coincides with the real world situation. Hence the fingerprinting approach is more attractive.

3.1.2 Fingerprinting

Location fingerprinting consists of two phases: 'training' or 'off-line' and 'positioning' or 'tracking' [19]. The objective of the training phase is to build a fingerprint database. In order to generate the database, reference points (RPs) must first be carefully selected. Locating a MU at one RP location, the SSs of all the APs are measured. From such measurements the characteristic feature of that RP (its SS) is determined, and is then recorded in the database. This process is repeated at another RP, and so forth until all RPs are visited. In the positioning phase, the MU measures the RSS at a place where it requires its position. The measurements are compared with the data in the database using an appropriate search/matching algorithm.

The outcome is the likeliest location of the MU. The whole process is illustrated in Figure 3.1.1. The fingerprinting approach has been accepted as an effective method for WLAN positioning although there are still a lot of problems. There are in fact two ways to estimate the unknown location. The simplest one is the deterministic method [13]. The average SS of each WLAN AP measured at each RP is used to create the fingerprint database. Since the variation of the SS measured at each point is large, in order to achieve more accurate results, the probabilistic approach has also been developed [18]. Unfortunately, the distribution of the SS is non-Gaussian. Even worse, it varies at different locations and at the same location when the orientation of the antenna changes [20]. Hence many measurements are necessary, and this takes more time to generate the RSS distribution at each RP. Furthermore, this increases the database size and the computational burden. Nevertheless, the establishment of the location fingerprint database is an essential prerequisite. To achieve a good estimation of user location, the more RPs, or in other words, the smaller the granularity, the better. And the more measurements obtained at each point the better.

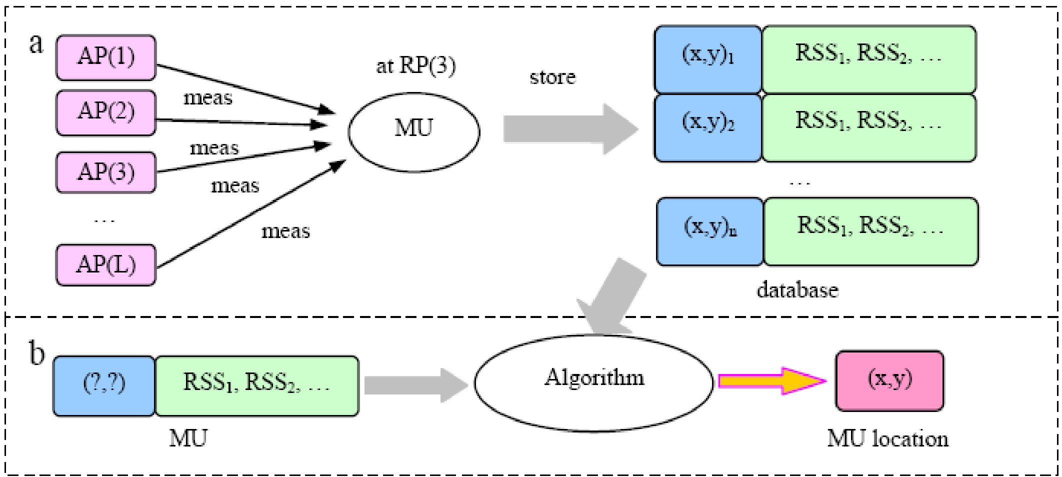


Figure 3.1.2.1: Two phases of fingerprinting: (a) training phase and (b) positioning phase

The structure of the fingerprint database is relatively simple and the feature of the RP is only determined by the average RSSs of each AP's (see Figure 3.1.1 (a)). Many algorithms can be used to estimate the position of MU. The basic one is Nearest Neighbor in Signal Space (NNSS). This algorithm uses *Equation 1* to calculate the Euclidean distance, between two points P and Q, in this case two points in signal space the live Wi-Fi signal reading and an observation in the search area. The reasoning behind the algorithm is that the observation with the shortest distance in signal space also has the shortest distance in physical space, and as such acts as a proper position estimate.

$$L_q = \left(\sum_{i=1}^{n} |s_i - S_i|^q \right)^{1/q} \quad (1)$$

The signal distance between the measured SS vector $[s_1 \; s_2 \; ... \; s_n]$ and the SS vector in the database $[S_1 \; S_2 \; ... \; S_n]$ is computed with this equation. Manhattan distance and Euclidean distance are L_1 and L_{21} respectively. Experiments show using Manhattan distance can obtain the best accuracy (although the improvement is not significant) [21].

The quantity L_q is a positive real value, where a lower value indicates a smaller difference between the two compared vectors. Using the resulting L_q , the NNSS algorithm ranks the list of RPs in ascending order. The location of the MS can then be estimated by using some kind of different techniques.

One of them is triangulation. Just like trilateration, three points need to estimate the location of the MS. Most lower three values chosen from the L_q values which mean the three nearest RPs to the MU. But here we don't need to know the signal propagation. Instead of this from the known RPs, triangulation algorithm is applied and location of the MU is estimated.

Location of MU is (*x, y*), the three nearest RPs locations are (x_1, y_1), (x_2, y_2), (x_3, y_3) and the distance to RPs are d_1^2, d_2^2 and d_3^2 respectively. Location of the MU is found with following method.

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2$$

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2$$

$$x = \frac{[(d_2^2 - d_1^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2)(y_3 - y_2)] - [(d_3^2 - d_2^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2)(y_2 - y_1)]}{2(y_3 - y_2)(x_2 - x_1) - 2(y_2 - y_1)(x_3 - x_2)} \quad (2)$$

$$y = \frac{[(d_2^2 - \ d_1^2 - \ x_1^2 + x_2^2 - \ y_1^2 + y_2^2)(y_3 - \ y_2)] - \ 2x(x_2 - \ x_1)}{2(y_2 - \ y_1)} \tag{3}$$

After this method location of MU is estimated as (x ,y). Disadvantage of this method is its complexity. Another method for estimating the MU location is averaging the nearest neighbors' coordinates. If K (K≥2) nearest neighbors (those with the shortest distance) (KNN) are taken into account, the average of the coordinates of K points can be used as the estimate of the MU location. Similar with KNN, but the weighting scheme is used in KWNN (K weighted nearest neighbor, K≥2). When the location of MU is computed the weighted average is calculated rather than the average. One of the weighting schemes is using the inverse of the signal distance as the weight. Other algorithms such as the smallest polygon [22] and neural networks can also be used.

Li, B. et al. [19] did an experiment about indoor positioning technique. The experimental test bed is shown in Figure 2. Five APs were installed at the locations and there are in total 132 RPs and 30 test points. To investigate the effect of the granularity, the number of RPs was intentionally reduced to 99, 66, 33, and 16. But the RPs were still spread as evenly as possible in the test area. Hence in total 5 fingerprinting databases were generated. Different algorithms were applied to compute the locations of the 30 test points based on a different size of the database. In KNN, K equals 2, 3, 4, 5 or 6. In KWNN, K equals 2, 3, 4 or 5. *Table 3.1.2.1* lists all the mean distance errors computed using the different algorithms for the different cases. When the granularity of the RPs is large, these techniques even perform better than some of the more complicated algorithms. When KNN is used, in general K equals 3 or 4 will yield the best result. This indicates that only using the two nearest neighbors is not enough (some of the useful information has been ignored), but too many nearest neighbors could decrease the accuracy of the estimator since some of the nearest neighbors are too far from the estimated points. KWNN slightly improves the accuracy of estimation. But none of these algorithms can always provide the best result.

TABLE 3.1.2.1: Mean distance error using different algorithm for different cases (unit: m)

	NN	2NN	3NN	4NN	5NN	6NN	2WNN	3WNN	4WNN	5WNN
Test1 (132 RPs)	1.75	1.47	1.29	1.23	1.38	1.31	1.49	1.29	1.19	1.31
Test2 (99 RPs)	1.63	1.52	1.38	1.31	1.36	1.39	1.53	1.37	1.27	1.30
Test3 (66 RPs)	1.74	1.47	1.51	1.60	1.52	1.60	1.48	1.44	1.49	1.43
Test4 (33 RPs)	1.78	1.93	1.94	1.72	1.99	2.12	1.79	1.79	1.64	1.75
Test5 (16 RPs)	2.55	2.34	2.65	2.98	3.41	3.99	2.11	2.28	2.45	2.69

Regarding the simplicity and accuracy of estimation, the 4WNN technique is preferred. The method used for weighted nearest neighbor is such that, simple interpolation implemented between 4 RPs. Each RPs has inverse ratio with their distance to MU. Simple mathematic representation of this method is such this.

$$x = \frac{\sum_{i=1}^{4}(x_i \times d_{4-i})}{\sum_{i=1}^{4} d_i} \quad (4)$$

$$y = \frac{\sum_{i=1}^{4}(y_i \times d_{4-i})}{\sum_{i=1}^{4} d_i} \quad (5)$$

In this method, x_i represents the x coordinates of the RPs and nearest RP to the MU is x_1 and distance to the MU is increasing respectively. Just like x_i , y_i represents the y coordinates of the RPs and nearest RP to the MU is y_1 and distance to the Mu is increasing respectively.

4. IMPLEMENTATION

4.1. System Overview

Basic architecture of the system has two parts. First part is the location estimation and second part is Electronic Patient Record. In the first part, location estimation process is implemented. In this part signal strengths of the access points are observed then the estimation is done. Then from this location it is calculated that in which room the user is. Finally patient records are accessed with using this room information and these records are shown to the user.

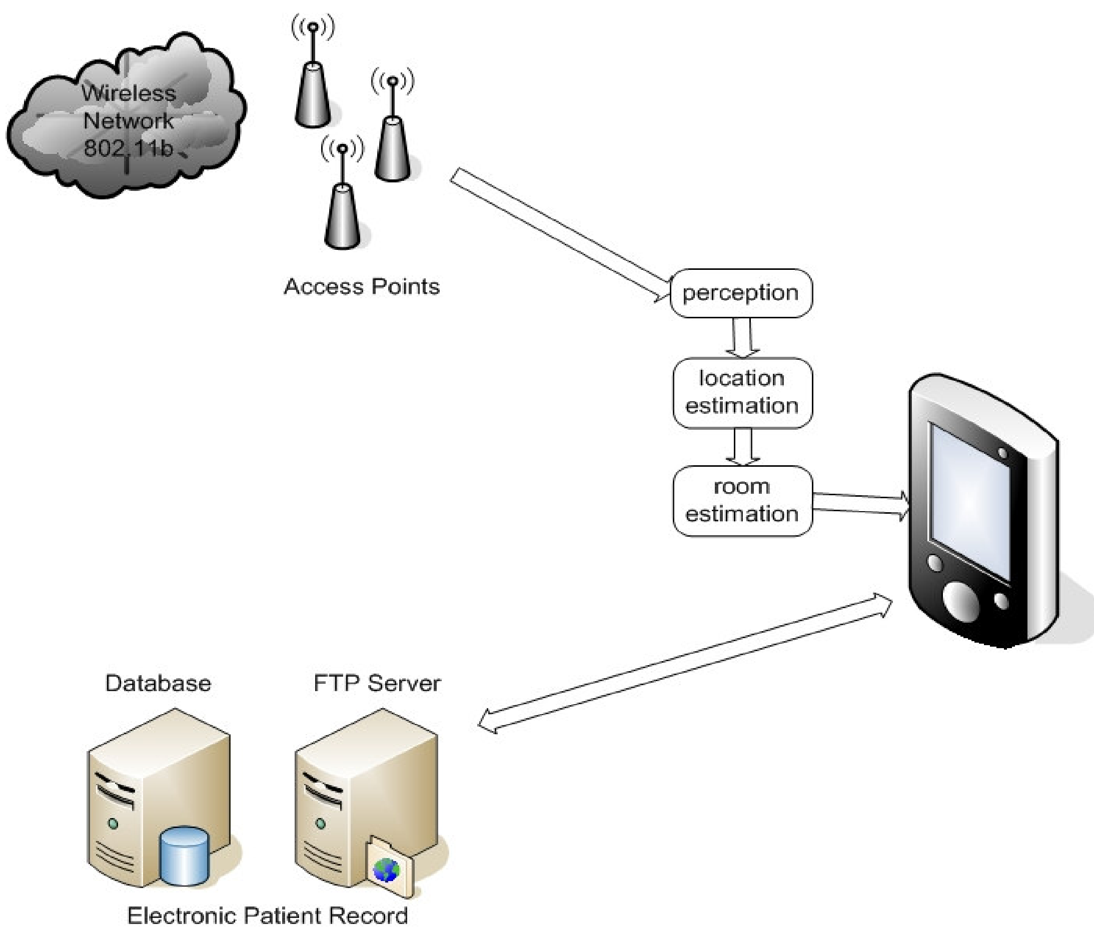


Figure 4.1.1: Basic architecture of the system

More detail architecture is shown in the Figure 4.1.2. Intelligent Hospital Application is developed in .NET compact framework and some auxiliary libraries are used with the system in order to provide requirements. One of them is OpennetCF which is used for read signal strengths of access points, another one is PInvokeCS which is used for record or play .wav files and the last one is FTP Client Library which is used for connect to FTP Server and transfer files.

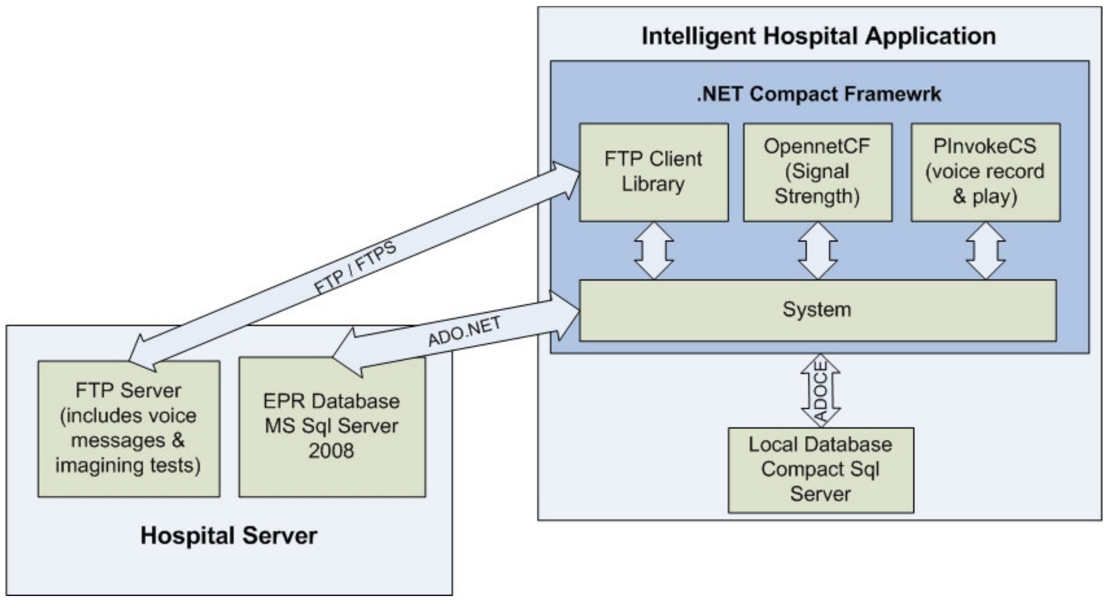


Figure 4.1.2: Detail architecture of the system

4.2. Location Estimation

This project was developed with .NET Compact Framework (CF) technology. CSharp was preferred as implementation language. In order to estimate the user location, signal strength from APs is required and there is no library on .NET CF about available wireless networks and retrieves configuration information from a mobile device's wireless network adapter. Robust shared-source (not open-source) library from OpenNETCF.org to write a feature-rich application for displaying network adapter properties and discovering nearby wireless access points was used for access the mobile device wireless network adapter and intended information [23]. OpenNETCF.org is a project run by OpenNETCF Consulting, LLP. It was started "in the spirit of the Open Source Movement." The project provides solutions to problems that the .NET Compact Framework development community began running into from the first beta releases.

A single namespace was used from the Smart Device Framework: "OpenNETCF.Net." The source code is roughly 3,800 lines, the namespace contains a large number of classes for network usage, including File Transfer Protocol (FTP), network statistics, and Bluetooth. But in this project, four classes were used: **Adapter** and **AccessPoint**, plus **AdapterCollection** and **AccessPointCollection**, which are, as their names imply, collection classes of the previous two. (Figure 4.1.1)

```
public List<Classes.WiFiSignature> readMeasure()
{
      m_adapters = Networking.GetAdapters();
      List<Classes.WiFiSignature> lst = new
List<Classes.WiFiSignature>();

      m_currentAdapter = adapter[0];
      if (m_nearbyAPs == null)
      {
          m_nearbyAPs = m_currentAdapter.NearbyAccessPoints;
      }
      else
      {
          m_nearbyAPs.Refresh();
      }
      foreach (AccessPoint ap in m_nearbyAPs)
      {

      Classes.WiFiSignature entry = new
Classes.WiFiSignature(ap.Name,BitConverter.ToString(ap.MacAddress),
ap.SignalStrengthInDecibels);
          lst.Add(entry);
      }
      return lst;
}
```

In this code part *m_adapters* is an object of AdapterCollection class which includes network adapters. *m_currentAdapter* is an object of Adapter class which includes all possible access points and *m_nearbyAPs* is an object of the AccessPointCollection which includes access points which are accessed at current time. Final for loop's work was for each access point that are accessed current time, get the access point MAC address and Signal Strength in decimal form.

This information is used on training (offline) phase of the location estimation firstly. Locating a MU at each RP location, the SSs of all the APs are measured with using this `readMeasure()` function. A sample of measured SSs at each RP includes 20-30 signal strength values of APs. Median value of the signal strengths on each AP at each reference point is calculated and inserted into the local database. This database is created with Compact Sql Server and includes four tables but two of them are related with this training phase records. These tables are Observation and WiFiSignature tables. Remaining two tables, Room and Coordinate, are used in the positioning (online) phase.

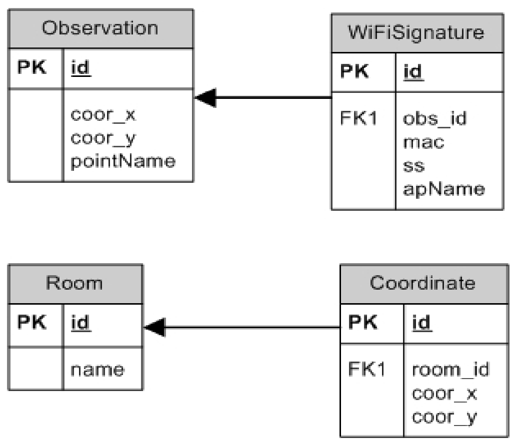


Figure 4.2.1: Local Database Model Diagram

Observation and WiFisignature tables include information about training phase. Observation table involves the coordinates of the each Reference Point and their name. Coordinates were inserted to this table with the floor plan of the test bed. WiFiSignature table involves the MAC address and the signal strength of each access point at each reference point according to the reference points which are in the Observation table. Comparison on positioning (tracking or online) phase is done with these values in these tables.

On training phase, instant signal strength values are reading with `readMeasure()` function. Then these values are compared with the values in the Observation and WiFiSignature tables. From this comparison, distances to RPs are calculated with Nearest Neighbor in Signal Space algorithm *(Equation 1)*. This equation is implemented in `NNSS()` function in the project.

```
public List<Classes.NNSSDistance> NNSS(List<Classes.WiFiSignature> lt)
{
      int i = 0;
      int total = 0;
      int index=0;
      List<Classes.NNSSDistance> distanceList = new
List<Classes.NNSSDistance>();

      foreach (Classes.Observation ob in obsList)
      {
           i = 0;
           if (ob.list.Count <= lt.Count)
           {
               foreach (Classes.WiFiSignature ssList in ob.list)
               {
                    index = indexCalc(ssList.mac, lt );
                    if (index == -1)
                    {
                        continue;
                    }
                    else
                    {
                        total += square(ssList.calSS - lt[index].calSS);
                        i++;
                    }
                }
            }
            else
            {
                foreach (Classes.WiFiSignature ssList in lt)
                {
                    index = indexCalc(ssList.mac, ob.list);
                    if (index == -1)
                    {
                        continue;
                    }
                    else
                    {
                        total += square(ssList.calSS -
ob.list[index].calSS);
                        i++;
                    }

                }
            }
            Classes.NNSSDistance entry = new
termProject1.Classes.NNSSDistance();
            entry.distance = ((Math.Sqrt(Math.Abs(total)))*1)/1;
            entry.obsId = ob.id;
            entry.numberOfAP = i;
            distanceList.Add(entry);
            total = 0;
       }

            //distanceList.Sort();

       return distanceList;
}
```

In this function, *Equation 1* is implemented with *q=2*. Here the number of APs which are accessed instantly may be greater or less than the RPs in the database therefore there is a comparison between numbers of APs then application of the *Equation 1*. The result of this function is a collection of distances to the APs which is named `distanceList`.

In this function, `obs` is the list of the RPs and it includes the SSs of APs at each RP. On the other hand `lt` is the list of the SSs of APs at MU instant position. These collections are run in the algorithm then the result is occurred.

Regarding the simplicity and accuracy of estimation, the 4WNN technique is preferred as mentioned in Methodology. In order to apply this technique the result of the `NNSS()` which is list of the distances to RPs is used. Four values which are the least values in the distances list are chosen from the `distanceList` and 4WNN technique is applied. The weighting operation is doing according to the inverse of the distances. The *Equation 4 and 5* are used then an approximate result is obtained. The result is *x and y* coordinate of the MU.

Next operation after finding coordinate of the Mobile User is finding out the in which room this coordinate lies. In order to calculate this Point in Polygon Algorithm was used.

```
ni = +1
for i=1 to n
    if x(i+1) != x(i) then
       if (x(i+1)-u) * (u-x(i)) >= 0 then
          if x(i+1) != u or x(i) <= u then
             if x(i) !=  u or x(i+1) >= u then
                b = (y(i+1)-y(i)) / (x(i+1)-x(i))
                a = y(i)-b * x(i)
                yi = a+b*u
                if yi > v then
                   ni = ni*(-1)
                end if
             end if
          end if
       end if
    end if
next i
```

In this pseudo code, the point is at *(u,v)* and the polygon has n points, *(x(i),y(i)), i=1,...,n* and is closed by making *(x(n+1),y(n+1)) = (x(1),y(1))*. Here point *(u,v)* implies the coordinate that is calculated after 4WNN technique is applied and the polygon implies our rooms in the test bed. Remaining tables in the Local Database, Room and Coordinate, are used here. Each room has four corner points and in Point in Polygon Algorithm, the estimated coordinate is checked whether it lies in these rooms or not. This algorithm is implemented in `findPositionFromCoordinates()` function. The result of this function is the room name in which the mobile user is.

Up to now, the location of the MU is estimated and from this location, it is calculated in which room the MU is. Next operation is getting information of the patient who stays in that room from the EPR.

4.3 Electronic Patient Record

While creating Electronic Patient Record Database, Haydarpaşa Numune Hospital patient follow up system is observed and requirements are defined. They are using filling documents called which is named 'Medical Examination and Observation Paper' in order to record patient information and related data such as diagnosis, medication. There are also laboratory test requirements such as biochemical tests, hemogram report or routine ureic analysis for diagnosing. These tests result are also on the papers.

Regarding all these conditions an EPR database was created and a GUI designed for PDAs. The EPR database includes seven tables.

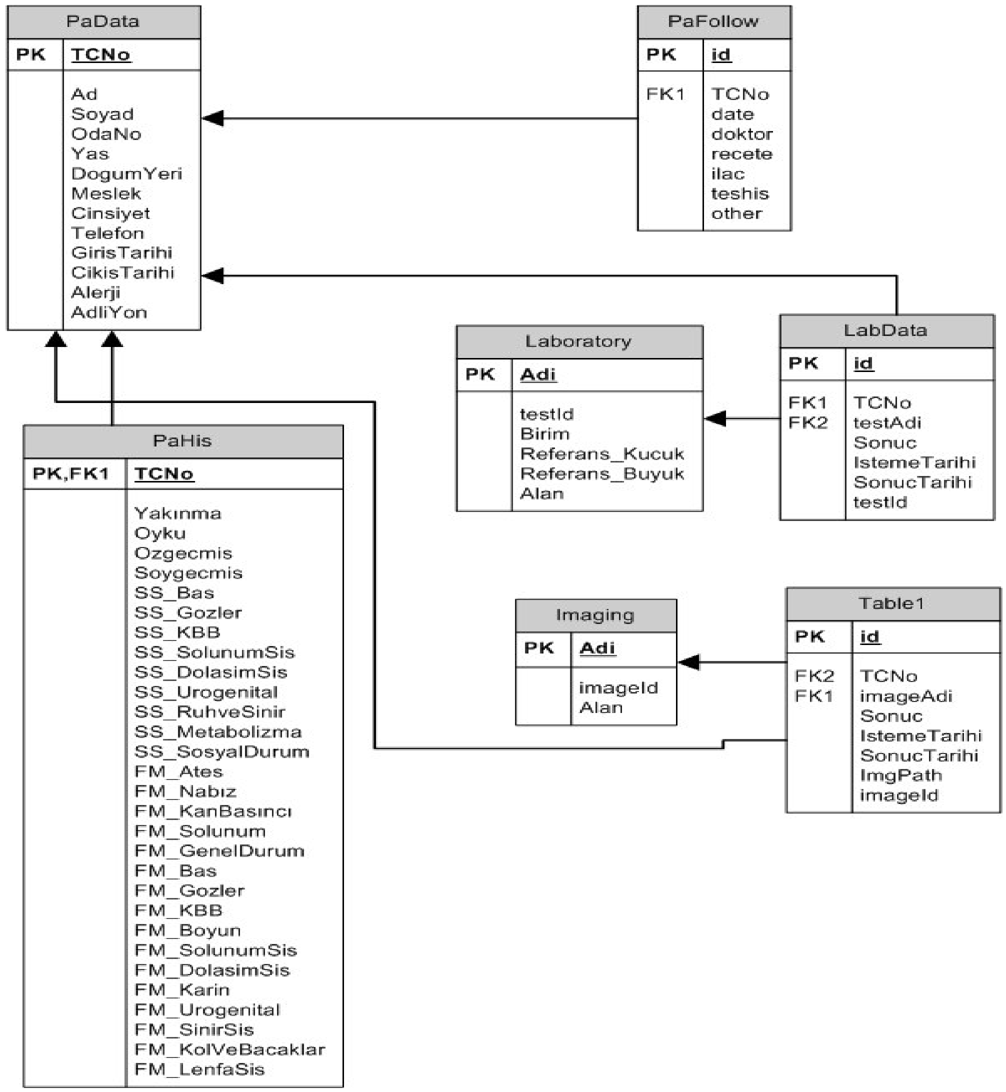


Figure 4.3.1: EPR Database Model Diagram

GUI is designed as simple as possible. The goal is that when a person who knows nothing about usage of a PDA can use this program. All records about the patient can be accessed on just one Windows Form. Tab controls are used frequently because there are a lot of records about a patient. These records are divided into four main tabs. These are 'Personal Information' that includes general information about patient 'History' that includes patient's previous information, system questioning and physical examination, 'Laboratory' that includes laboratory test results, laboratory test request, imagining (CT, X-RAY, MRI etc.) results and imagining request and 'Patient Follow Up' which includes prescription, medications and diagnosis part.

'Personal Information' tab includes general information about patient such as TCNo, name, surname, age, gender, telephone and etc (Figure 4.3.1). Doctor can also learn whether the patient has an allergy from this tab.

Figure 4.3.1: 'Personal Information' tab

'History' tab includes inner tabs(Figure 4.3.2). One of them is 'General' that includes patient's previous medical information that is complaints, 'Soygeçmiş' and 'Ozgeçmiş'. Other inner tab is 'Story' that includes patient's previous medical information. In this part user has two chances. User can read this information from the RichTextBox or he can listen to this information if there is voice message related to that patient. On the other hand he can leave voice message about patient's history. This mentioned voice message is uploaded to or downloaded from FTP server. Another inner tab is 'System Questioning' that includes information about patient such as head, eyes, respiratory system, and digestive system etc. Last inner tab is 'Physical Examination' which includes first examination of patient's body such as the system questioning head, eyes, respiratory system and digestive system etc.

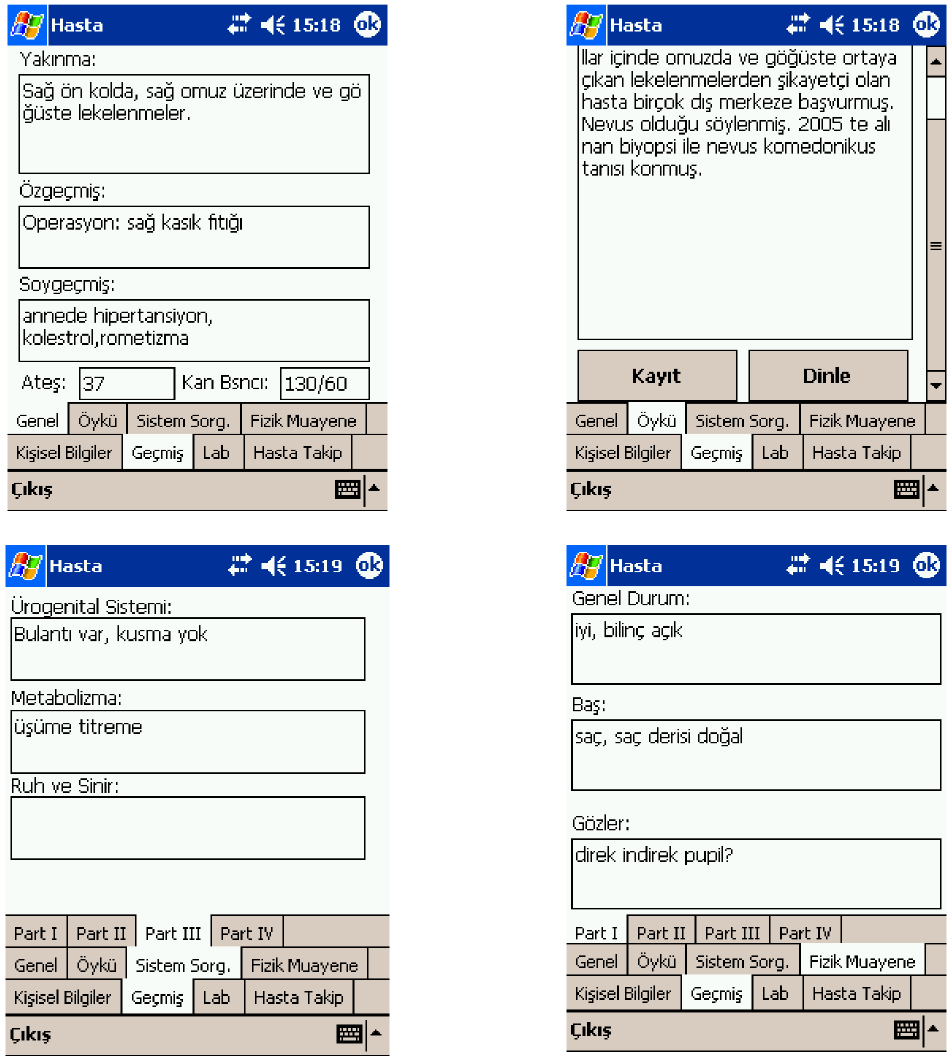


Figure 4.3.2: 'History' tab

'Laboratory' tab includes four inner split 'history' panels (Figure 4.3.3). First tab is 'Tests' which includes laboratory test results according to the request day and test type (for example 24-04-2009 Biochemical). Other inner tab is 'Test Request' that provides user to request tests whichever he wants. These intended tests recorded to the system and after these test are done the results can be accessed 'Tests' inner tab. Another inner tab is 'Radiology' that includes CT, X-RAY, MRI etc. imagining results as jpeg file. This jpeg file is downloaded from the FTP server as voice message. Final inner tab is 'Radiology Request' where the user can request radiology test such as CT, X-RAY or MRI etc.

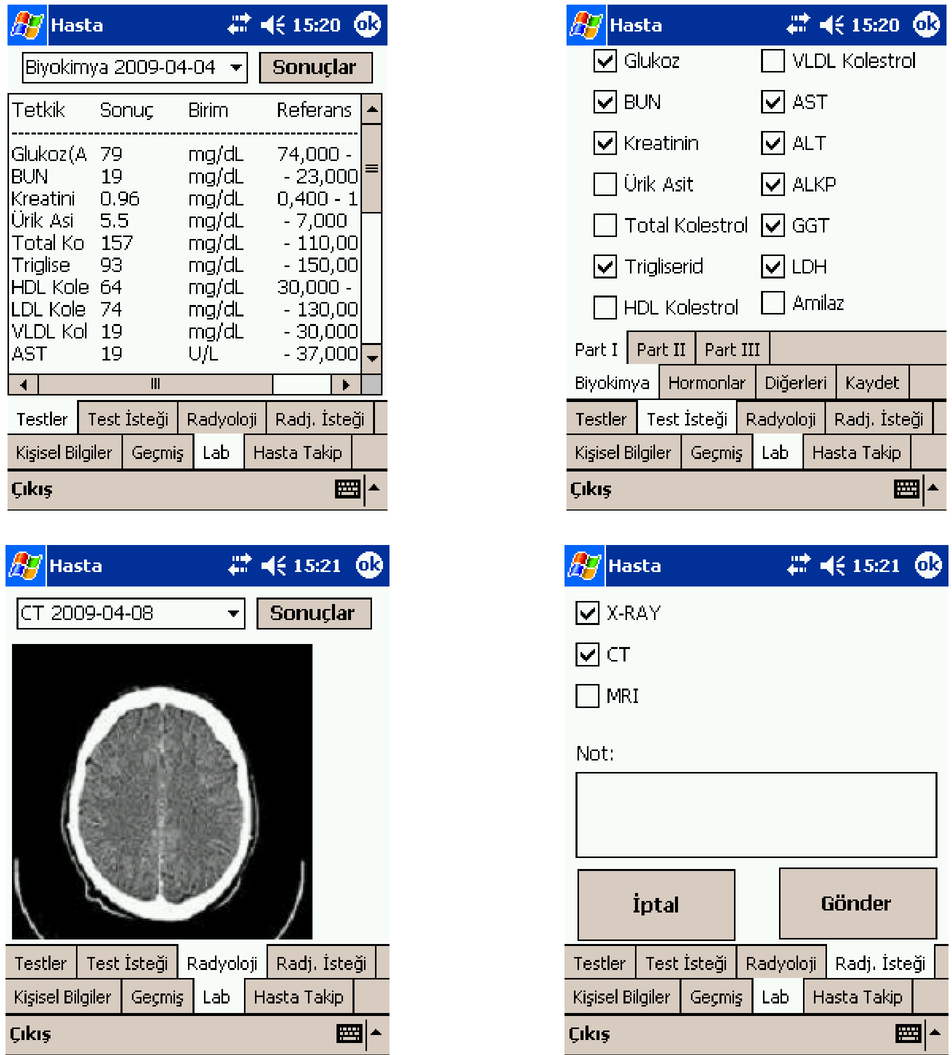


Figure 4.3.3: 'Laboratory' tab

'Patient Follow Up' tab includes two inner tab (Figure 4.3.4). One of them is 'New Record' tab where the user can insert new prescription, medications and diagnosis to parts. This record is saved to database and added to the patient's history information. The other one is 'History' which includes same parts but from this tab user can access previous Follow Up information.

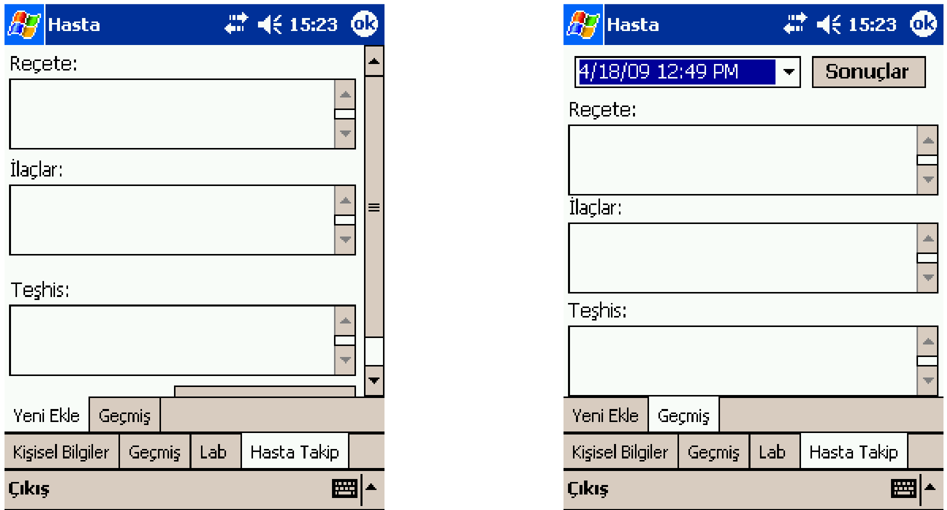


Figure 4.3.4: 'Patient Follow Up' tab

The FTP server part that is mentioned voice message and image transfer is developed on personal computer. An open source C# FTP Client Library is added to the project and accessed to server [24]. The security of connecting to the server is provided by authentication of the user. Only authenticated users can access to server then transferring files. Regarding to the confidentiality of the patient records, instead of FTP transfer, Secure FTP can be used. This is one of the future wok related to this project.

To sum up, after the location of the MU is estimated and in which room the MU is calculated user can access to the patient records through the designed GUI. He can change the records or he can insert new records or he can just read records. At this point user has two chances. User can use the system automatically means that when user starts this program and the positioning (online) operation run periodically. Every 10 second system calculates where the user is then calculates in which room user is then refreshes GUI with new records if the user changes its room according to the positioning estimation. Other chance of user is that user can taps related button on the screen and positioning estimation is executed then related records are accessed and GUI is filled. Then whenever user taps this button positioning estimation is executed again and related records are accessed.

The advantages of the automatically mode is user don't need to any tap operation he just deal with its job which is the disadvantages of the manually mode. Disadvantage of automatic mode is that positioning estimation is executed on every 10 second and sometimes there is no need to this execution which is the advantages of the manually mode.

5. EVALUATION & ANALYSIS

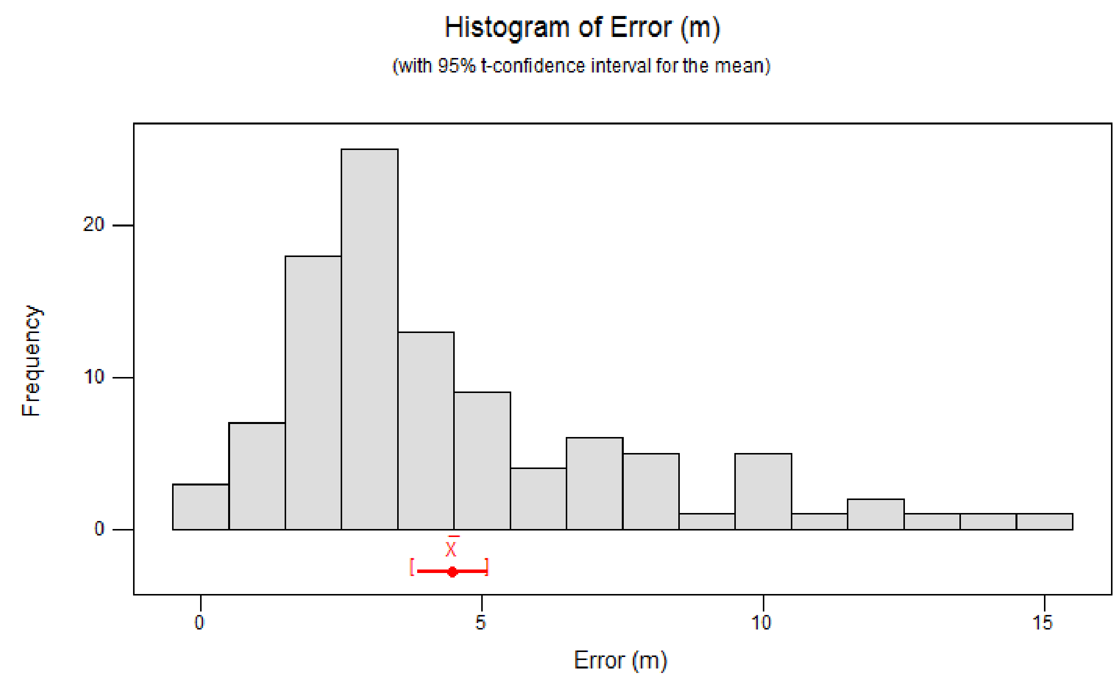
Experiments were carried out to evaluate the location estimation of the system. The experimental test bed is the first floor of the Engineering & Architecture Faculty building, where Computer Engineering Department stays (Figure 5.1). In this test bed, extra APs were not installed. There are existing APs but the location of most of these APs are not known. Accessible APs number varies between four and six. Only two of them are in the Computer Engineering Department floor. Locations of remaining APs which are possibly in other floors are not known. One of the advantages of fingerprinting technique is useful at this point. The locations of the APs are not necessary for fingerprinting technique. Known APs on test bed floor are shown in Figure 5.1 with stars.

The reason why extra APs are not installed is that, in real life these APs in the building provide the requirements and one aim of this system is that there is no extra infrastructure or extra hardware requirement while location estimation. For this aim, no extra APs are installed.

Figure 5.1: Experimental Test Bed

In test bed, there were 6 RPs in each room. Experiment was carried out in 8 rooms. There were total 48 RPs which are shown with red cross in Figure 5.1. Locations of RPs were chosen such that they stay center of the rooms as shown in the figure. Then tests were made. There were total 102 test points, approximately 12 test points in each room. These test points are randomly distributed but the direction of the test user were generally through to center of the rooms.

The results are shown in the Figure 5.2. The mean error value is approximately 4.5 meters and standard deviation is approximately 3.2 meters. This error rate is not proper for room estimation because generally rooms are not big enough to estimate with this error rate. The obtained results indicate a probability that only 50% of the time for delivery of the patient related information. This result is very close to Munoz's work [1].

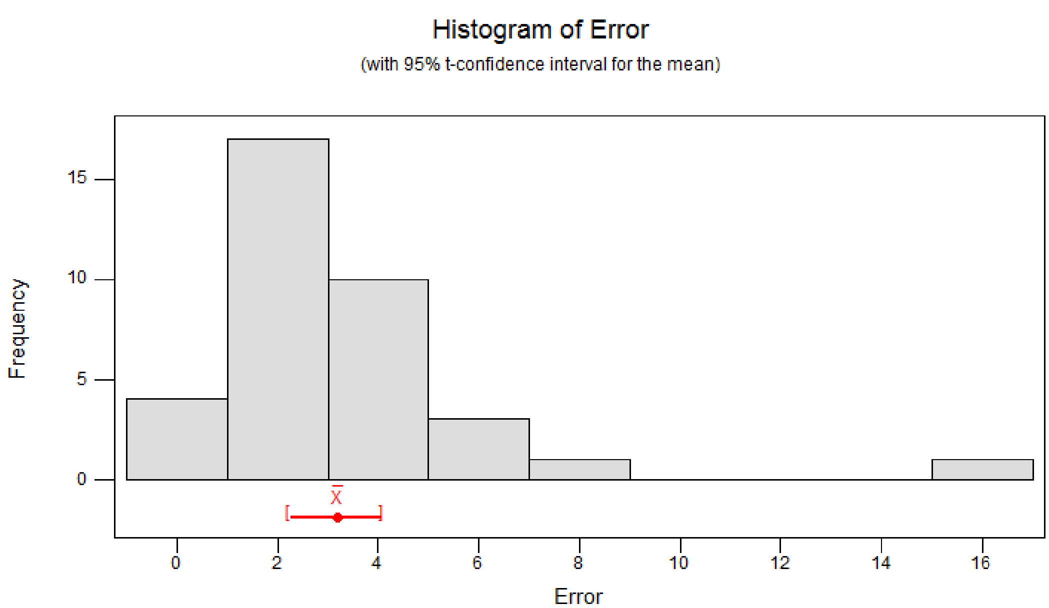


One-Sample T: Error (m)

Variable	N	Mean	StDev	SE Mean	95.0% CI
Error (m)	102	4.480	3.234	0.320	(3.845, 5.116)

Figure 5.2: Test Results

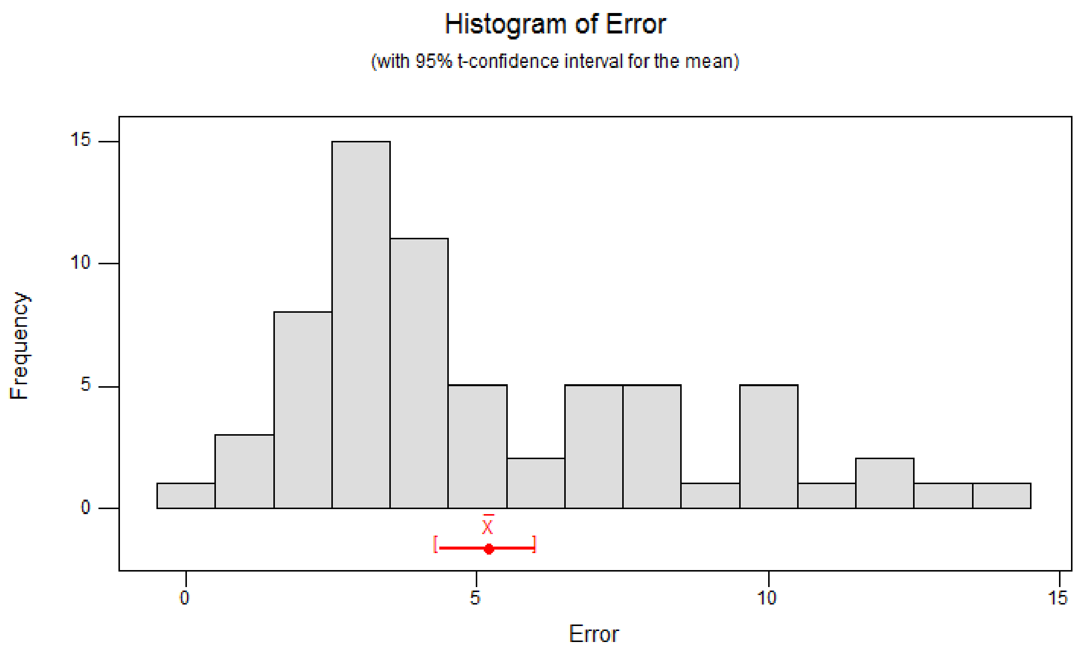
This error margin, 4.48, can be compared other academic work. The general error margin is 2-3 meters for fingerprinting algorithms and approximately 5 meters for triangulation algorithm. One of the reasons why this error margin is bigger than the other systems which use fingerprinting algorithms though fingerprinting is used in this system is that in other works it can be seen that, APs are installed for location estimation and they distributed homogenous but in our system used already installed APs in other words W-LAN which is in used for a long time. In the experiment it is shown that APs are not distributed homogenous. The rooms with numbers *4,5,6,7,8* which are shown in Figure 5.1 can access less APs than the rooms with numbers *1,2,3*. On the offline phase, while generating local database for location estimation it is observed that in the rooms *1,2,3* number of accessible APs is 6 or 7 but on the other hand the number of accessible APs in the rooms *4,5,6,7,8* is 3 or 4. This is one of the important points for this error margin. When the error differences compared in these rooms the results show that the error margin in rooms with number *1,2,3* is less than the rooms with numbers *4,5,6,7,8*.



One-Sample T: Error

Variable	N	Mean	StDev	SE Mean	95.0% CI
Error	36	3.181	2.636	0.439	(2.289, 4.073)

Figure 5.4: Test results in rooms with numbers 1-2-3



One-Sample T: Error

Variable	N	Mean	StDev	SE Mean	95.0% CI
Error	66	5.189	3.326	0.409	(4.372, 6.007)

Figure 5.5: Test results in rooms with numbers 4-5-6-7-8

It is shown that, the error margin of test in the rooms with numbers *1,2,3* is 3.181. This error margin is closer to the systems which implements fingerprinting algorithm but on the other hand the error margin of the test in the rooms with numbers *4,5,6,7,8* is 5.189. The basic reason for this condition is that accessible number of APs in the rooms 4-5-6-7-8 is less than the others and this is important for location estimation.

Another important reason for the error margin, 4.18, is that in our system only 48 RPs is generated and used but in other system this number is bigger. For example Li, B. et al. [21] generated 132 RPs in their systems and their area of test bed is approximately same size with our test bed. In their work, they tested number of RPs effect to their system and their result can be shown in the Figure 5.6.

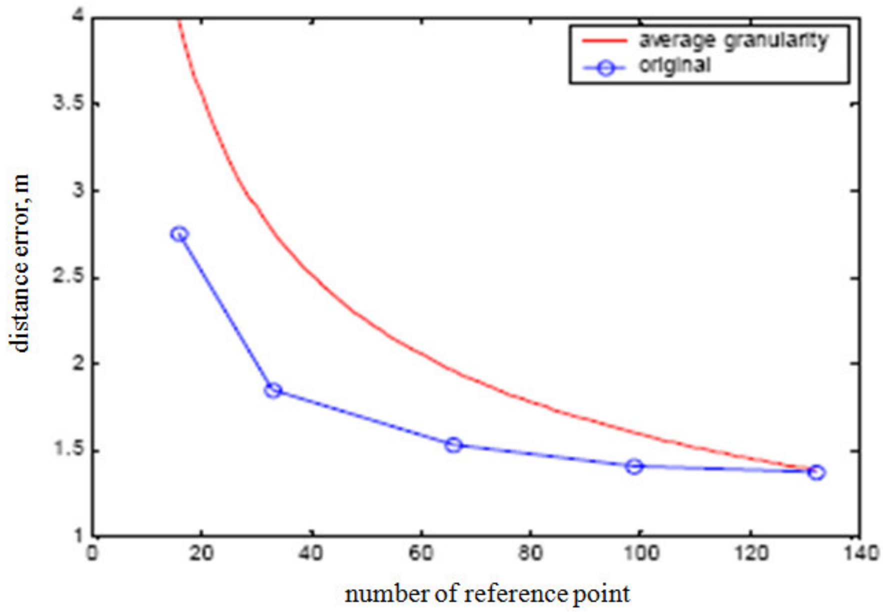
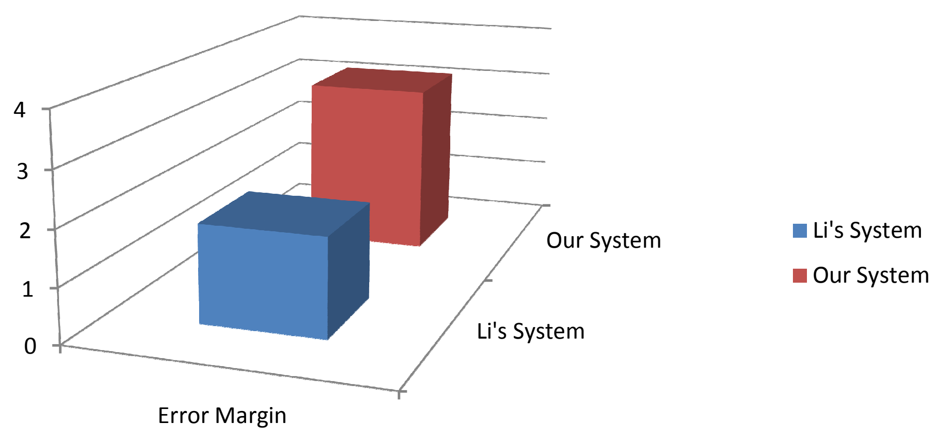


Figure 5.6: Mean of average distance errors using different number of RPs, [21]

It can be shown that when the number of RPs increases the distance error decreases. They had totally 132 RPs and their error margin is show with “original” curve. In our system only 48 RPs were generated and tests were carried out.



* Li, B. et al., ‘Indoor Positioning Techniques Based on Wireless LAN’, Auswireless Conference 2006, pp 1-7, 2007

Figure 5.7: Compression between our system and Li’s system with 48 RPs

When the number of accessible APs in the rooms *1,2,3* and number of RPs are taken into account, it can be seen that if the APs can be distributed homogenous and number of RPs are increased the error margin can be less than the 3 meters which is more proper for intelligence hospital application.

Another observation from the tests that, results indicate that estimation of the room in which the user situated has a 50% probability success. However, this result probability changes between the rooms with number *1,2,3* and rooms with numbers *4,5,6,7,8*. Tests in the rooms *1,2,3* has approximately %85 success for rooms estimation but it should be regarded that these rooms has bigger rooms and less error margin than the rooms *4,5,6,7,8*. The room estimation success is very low in the rooms *4,5,6,7,8*. Big error margin and narrow rooms are important factors for this low estimation success.

6. CONCLUSION & FUTURE WORK

Hospitals are complex work environments where information and people are distributed. Electronic patient records are an important step toward providing adequate access to clinical information. Context-aware systems can deliver information that is relevant to the user's location. In particular, location is an important factor to establish the information that is relevant to a given user and reduce the burden of locating people or data, or even worse, making decisions without it.

A location aware system was developed which is integrated with EPR. This system has a mean error margin about location estimation which is about 4.5 meters. However, when results are analyzed more APs access area has less error margin which is about 3.1 meters. In these conditions, correct room estimation has approximately 50% probability. Our results show that estimation errors are adequate to locate people but higher than required to deliver relevant patient information.

One of the future works in our system is the improving the location estimation error margin. In order to do this, extra APs are setup and generate homogenous area about APs access. With adding APs, new and more than current RPs are going to be generated to achieve more suitable error margin.

Another future work about this system is that, there are some RPs generating techniques. In order to be more impressive other techniques can be tried. In our system we generated RPs with traditional way, just record 15-20 times during the spin around.

Another future work can be adding voice recognition to the system. When user left a message, it can be processed and the commands can be inserted to the EPR. With this work system can be more powerful and there will be no extra work need and all works can be made more and more rapidly.

Providing security of the Electronic Patient Records is another future work. Electronic Patient Records are private information about people so this information could not be accessed by the people who have no permission. Furthermore some confidentiality properties could be added to system for patient record transferring security.

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