Chapter XVII
A Preliminary Study toward Wireless Integration of Patient Information System

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ABSTRACT
This paper presents the results of a study toward generating a wireless environment to provide real-time mobile accessibility to patient information system. A trial system is set up where database, internet, and wireless personal digital assistants (PDAs) are integrated in such a way that the medical professionals like physicians, nurses and lab assistants can create, access and update medical records using wireless PDAs from any location in the hospital which is covered by wireless LAN. The same services which can be carried out via fixed terminals with internet connectivity can be carried out using wireless PDAs. The implementation has used and integrated many technologies like Active Server Pages (ASP), Visual Basic®, Structured Query Language (SQL) Server, ActiveSync®, IEEE802.11 Wireless Local Area Network (WLAN) technology and wireless security concepts. The paper details the architectural aspects of technology integration and the methodology used for setting up the end-to-end system. The proposed architecture, its performance data and the common implementation barriers are reported.
INTRODUCTION

Medical professionals have already recognized the importance of keeping patient information (medical records) in an electronic format rather than paper-based format because of the sheer size of records generated daily. Due to the extensive size and costly storage requirements, keeping paper-based records became more expensive than keeping records electronically. A study conducted in a 500-bed hospital indicated that a 7-inch stack of paper based laboratory reports must be filed daily. The informal survey was conducted with medical professionals among the American University of Sharjah medical center staff and a neighboring local hospital in which receptionists, laboratory and X-ray technicians, nurses and physicians participated. Most of them liked the idea of using electronic patient record (EPR) technology. Some of them expressed some concerns about the screen size and the resolution limitation of the personal digital assistants (PDAs) used in the trial. Others worried that if such ubiquitous systems are deployed, then medical staff will have to be available all the time even during vacations days. They stated that if such technology is available, they will be liable if they do not answer even during their breaks. “It is a matter of life and death” one of the nurses stated, “I should answer calls anywhere, anytime”.

The cost of maintaining paper based records and filing them in an ordered fashion to keep them accessible is over US$10 per record (Safran, Goldberg, 2000). Keeping records electronically also presented the opportunity of being able to access records over the internet from anywhere, anytime. Together with the powerful PDAs and wireless connectivity tools it became feasible to access EPR remotely without being tied to workstations. There are several records in the literature which mention successful implementations of web-based access to patient databases (Liu, et. al., 2001; Garcia, et. al. 2002). Others have reported wireless healthcare using wireless local area networks (WLAN) and discussed the electronics home healthcare concepts and challenges (Wang, Hongwei, 2005; Wickramasighe, Misra, 2004). A trial study conducted recently among medical professionals in real hospital settings indicated that medical professionals regard mobile access to the following data highly useful (Ammenwerth, et al., 2000):

- Medical knowledge like drug data,
- Medical coding references like ICD-10 codes (International Classification of Diseases) and literature databases,
- Patient database and administrative patient data,
- General information like telephone numbers and medical databases.

After using the system for a week, the respondents indicated that mobile communication and mobile information processing power offered by PDAs are very valuable. However, the respondents also reported that they were not satisfied with the 9600 baud rate communication speed offered by the early versions of PDAs and the mobile phones based on the Global System for Mobile (GSM) standard used in the study. During the study it also became apparent that the messaging ability offered by PDAs was much superior to personal accessibility provided by pagers and mobile phones (Ammenwerth, et al., 2000). Since then, the rapid change in the technology provided better connection methods, more durable and faster handheld mobile computing devices. The wireless accessibility provided by nowadays existing WLAN standards such as IEEE802.11g can support 54 Mbits/s data rate and the soon to come IEEE802.11n standard will support 540 Mbits/s data rate. This will clearly satisfy the need to higher access bandwidth required by healthcare providers. Along with the other contemporary software and database tools, this new connectivity method promised better EPR system and motivated many researchers in the healthcare industry to develop
integrated wireless applications for use on pocket PC, smart-phone PDAs and other portable device platforms (Lu et al., 2005).

In this study, we will design a prototype electronic medical database system and evaluate its performance in near-realistic settings. Another aspect of the research conducted is the design of a web-based database for hospital environment which could be equally accessed by wireline and wireless networks.

TECHNOLOGY IMPLEMENTATION BARRIERS

As is the case for many newly-introduced technologies, even with uncontested technological and economical benefits of the proposed architecture are tremendous however, the implementation may be impeded by the perceived steep learning curve for potential users. This fact is especially true for medical professionals who are in general uncomfortable introducing new technology due to the risks involved and required “protected time” to integrate it in their work environment (Van Ginneken, 2002). The flexibility and adaptability to change are regarded as the key factors for medical applications. Standardized and open-vendor systems are also important factors for getting new technology accepted by the user community. Acceptance of EPR by the medical community has improved after an initial hesitation. The technology to access patients’ information varies. Literature search indicated that there are several techniques that are currently being used:

- Hybrid architecture using PDAs and wireless GSM modems
- IEEE802.11 WLAN standard
- IEEE802.15 known as Bluetooth standard

Software applications were based on Wireless Application Protocol (WAP). The hybrid system using PDA and GSM modems combination was used in a trial study conducted in real hospital settings (Van Ginneken, 2002). This valuable study was aimed at determining expectations of medical professionals from potential wireless enabled hospital settings. The study indicated many points which are regarded important by medical professionals. But the study also indicated that the data rate offered by the hybrid solution is far lower than expected to be considered useful. Another connectivity method used in some studies was WAP connectivity which is used by mobile phones to transfer web contents to mobile devices. In a successful WAP-based system, patient data was sent successfully from patients monitored to WAP-enabled phone. Information like Electro-Cardiogram (ECG) signal was displayed graphically on the medical professionals WAP enabled phone (Hung, Zhang, 2003). Although the project was successful, the authors reported that the data transfer rate was low. Another major drawback of the system is the limited screen size of the WAP phone. Another similar study used WAP services for connectivity to biological databases (Riikonen, et al., 2002). The Mobile and PDA phones successfully queried the databases and displayed the contents in a browser page on the mobile device. PDA-based client-server architecture is preferred for flexible telemedicine systems (Nazeran, et al., 2004). The client uses a Pocket PC client because of its processing capabilities, low cost and compact size. The system could be used to transmit audio, still images and vital signs from a remote site to a clinic or a hospital web-server that implements standard Internet protocols.

Adoption of wireless solutions in the healthcare sector has many advantages and but also poses some challenges (Lu, et. all, 2005; Demiris, 2004). Time and cost saving, mobility and real-time access, reducing medical errors, enhancing productivity and quality of care are major advantages of using PDA in healthcare (Lu, et. all, 2005). However, speed, screen size, data entry, maintenance, interoperability issues, patient privacy issues, interference with medical equipment,
data security issue, negative patient perception of delicate devices are notable challenges (Lin, Vassar, 2004; Lu, et al., 2005).

**DESIGN CONSIDERATIONS FOR THE TRIAL SYSTEM**

Literature and informal surveys of medical professionals showed that the designed system should have the following requirements:

- The system should have an EPR database which is user friendly, robust and web-enabled.
- The system should be secure. Several layers of security should be established at different levels.
- Access speed to the system, data access and update speed should be high; PDA used for the system should have reasonable size and weight.
- The system should use off-the-shelf components and the cost should be reasonable.
- The system should be accessible at any time. Hence architecture should be robust to provide the needed high availability.

To achieve the above requirements a client-server model is designed and constructed. Figure 1 shows the system hardware architecture. A database is designed and managed by SQL-sever, website and wireless connectivity via PDA are developed. Figure 2 shows the system software tiers.

**Database Design**

A database system is designed to serve the requirements of the overall system. Entity Relationship

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*Figure 1. System hardware architecture*
Diagram (ERD) is used to describe the objects in the hospital database. The objects or entities and the relationship between them were translated into tables. This process helped us identify facts, known as attributes or fields, about these entities. Four entities are used namely; employee, patient, record, department and test. The entity employee consists of doctors, nurses and lab assistants. For example, each employee is identified by his/her ID number, first name, last name, department ID number, employee designation, address, contact number and nationality.

A table for each of the entities was constructed and the unique and primary keys for the entities were issued. The final design was implemented in SQL server. The SQL Server technology was chosen because it has enterprise data features, is better in maintaining data integrity, supports triggers and rollbacks, and stores procedures and dynamic data processing. Table 1 describes the entities and the attributes along with a brief description of each. Figure 3 shows the Entity Relationship Diagram.

**WEBSITE DESIGN**

A complete functional and interactive website for the hospital “Care Well Hospital” medical centre which is accessible through local intranet and from the Internet is designed. This site is developed using Active Server Pages (ASP®) and Visual Basic® scripting that were embedded in HTML files. The advantages of using ASP are fast execution, no client-side constraints, ODBC links to any data source and orientation towards Microsoft products. A snapshot of the home page is shown in Figure 4. A dropdown menu helps the users to activate one of the hotlinks to access any of the system functions such as medical services, visiting hours, login, logout, etc. An authorized person can access personal records, patient records, patients table and add new patients’ records. For example, the patients’ table link returns a list of all patients who are already registered in the system. Figure 5 shows the existing patients list. Search by a specific key such as “Patient ID” or “Last Name”. Figure 6 shows that a patient search
Table 1. Database fields corresponding to the system entities

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Entity</th>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Employee</td>
<td>ID</td>
<td>Unique identification number of the employee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FName</td>
<td>First name of the employee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LName</td>
<td>Last name of the employee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dept_ID</td>
<td>Unique department to which the employee belongs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Designation</td>
<td>Post of the employee in his/her respective department</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Address</td>
<td>Mailing address of the employee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contact_no</td>
<td>Contact information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>nationality</td>
<td>Nationality of the employee</td>
</tr>
<tr>
<td>2</td>
<td>Patient</td>
<td>P_ID1</td>
<td>Unique identification number(patient id) of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FName</td>
<td>First name of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LName</td>
<td>Last name of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOB</td>
<td>Date of birth of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>Height of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>Weight of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blood</td>
<td>Blood group of the patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Address</td>
<td>Mailing address of the employee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contact_no</td>
<td>Contact information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nationality</td>
<td>Nationality of the employee</td>
</tr>
<tr>
<td>3</td>
<td>Record</td>
<td>Record_ID</td>
<td>Unique identification of the record along with the P_ID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CDate</td>
<td>System Date when the record is stored</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dr_ID</td>
<td>Doctor id</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diagnosis</td>
<td>Diagnosis of the medical problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medication</td>
<td>Medication prescribed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comments</td>
<td>Further comments regarding the record</td>
</tr>
<tr>
<td></td>
<td></td>
<td>References</td>
<td>References to other doctors, medical staff, etc.</td>
</tr>
<tr>
<td>4</td>
<td>Department</td>
<td>Dept_ID</td>
<td>Unique identification of the department</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Name</td>
<td>Name of the department</td>
</tr>
<tr>
<td>5</td>
<td>Test</td>
<td>Test_ID</td>
<td>Unique identification of the test in combination with the record id and patient id</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type</td>
<td>The type of the test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Result</td>
<td>The results of the test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CDate</td>
<td>System Date when the record is stored</td>
</tr>
</tbody>
</table>
Figure 3. Entity relationship diagram

Figure 4. Homepage of “Care Well Hospital” website designed for the study
A Preliminary Study toward Wireless Integration of Patient Information System

by last name “Kumar” returns a list of patients records with matching last name.

PDA INTERFACE AND CONNECTIVITY

System Hardware and Software Description

To access the website that contains the patient information system via PDA, combination of hardware devices and software drivers are needed. As shown in Figure 1, the hardware requirements are:

- A web server along with internet connection to the service provider,
- PDA with WLAN access interface card,
- Wireless access points.

The software drivers used a set of protocols that provide client utilities such as client manager, link status, wireless client login, and encryption manager. The USB connection between the server and the PDA is used to install the above-mentioned software utilities on the PDAs. The USB cable is later removed and the wireless connection became available between the PDA and the LAN via the wireless access point.

The system provides two modes of connectivity, namely; server-client model and wireless model. The server-client model uses standard access method to the LAN of the hospitable where doctors, nurses and lab assistant can create, modify and access the patient’s information system via the Internet Service Provider (ISP) wired conductivity.

In the wireless model, the study used an off-the-shelf Compaq-200 PDA with the following specifications:

![Patients record table](image-url)
400MHz processor, Windows CE for Pocket PC operating system, 64-MB SDRAM & 32-MB Flash ROM memory.

- Interfaces: WLAN (IEEE802.11b) and Blue-tooth (IEEE802.15) compliant. The distance range of the PDA was 100 meters (class-2 radio).

- TFT liquid crystal display with viewable 64K color image size 2.25 inch wide by 3.02 inch tall.

For wireless access purposes, commercially available wireless access points are used in the study. The access point provides 40-bit and 128-bit wired-equivalent privacy (WEP) encryption.
security over the 100m coverage area. It is IEEE 802.11b compliant and works at self-adjusted data rates of 11, 5.5, 2 and 1 Megabits/s (Mbps) (3COM, 2004).

**Wireless Access Client-Server Synchronization**

Synchronizing the wireless access between the Server and the Client is done in two ways:

- Configuration of the wireless access through the Server being connected to the Internet: This was accomplished using a hub through which the server was connected to another network, which was connected to the Internet. The PDA accessed this server through the wireless access point and was able to access sites on the Internet as well.
- Configuration of the wireless access through Terminal Services on LAN: Wireless access through terminal services was introduced as a safety procedure in case Internet access is not available. Terminal services are implemented using Windows 2000® Advanced Server.

**SECURITY ISSUES**

Two levels of security were implemented, one for the advanced server and the other for the SQL server:

**Windows Advanced Server Security**

Using the Administrative tools, privileges are granted to users and groups. Privileges include restarting the server, modifying certain settings, accessing databases etc. This is done by creating different profiles for the users and then granting the required privilege. For instance, if an employee is registered under the group “Lab Assistant”, upon logging-on to the Windows 2000® system as a Lab Assistant, he/she is given those privileges assigned to the group ‘Lab Assistant’. The privilege denies the lab assistant to reboot the system.

**Microsoft SQL Server Security**

The SQL Server authentication mode used is “Windows Authentication Only”. In other words, SQL Server automatically authenticates users based on their Windows user account names or their group membership. If you’ve granted the user or the user’s group access to a database, the user is automatically granted access to that database.

The SQL Server security model controls access to the database using the server login, permissions and roles.

**IMPLEMENTATION AND TESTING**

**Trial System Implementation**

One of the problems encountered during implementation was due to the mismatch of screen resolution of PDA and the web page. The problem occurred because the contents were being directly viewed from the server’s default browser. The problem was solved by using a built-in browser of the PDA. Setting of wireless configurations presented another problem. Initially, a personal LAN was set up using the 3COM wireless access points. Following this, the wireless network card was registered with the Information Technology department of the American University of Sharjah (AUS), so that the PDAs could access the AUS network. Problems such as conflicting devices and security issues had to be dealt with. The solution was to select the auto channel setting when configuring the access point.
A Preliminary Study toward Wireless Integration of Patient Information System

**Trial System Testing**

The designed system has been implemented using AUS infrastructure and tested by doctors, nurses and lab assistants of AUS health care center. AUS infrastructure provided large number of workstations and wireless points distributed throughout the campus. Two wireless PDAs with wireless jackets are used for testing wireless functions.

Each one of the users logs on to network with his/her unique ID and password. The system first validates the ID and password, and then gives access based on the assigned privileges. The following instance shows how the SQL Server database is accessed to retrieve or modify data.

Doctors have the following options and privileges:

- View Personal Records
- Update Address and Contact Number
- Search for a Patient using Patient’s last name or ID
- Search for the general record details of a patient using the unique patient ID.
- View the specific record details for a particular record given the record number and Patient ID.
- Create new records for the patient. View a list of all those patients who are under him.

*Figure 7. System output using patient’s ID key search*
• Can add a new patient to the Patient Database.

The options given to nurses are:
• Update, Create Personal Records.
• Update, Create Patient Records.
• View Patient Table.
• Add New Patient.

The authorized privileges for lab assistants are:
• View Personal Records
• Can update Address and Contact Number
• Register Test Results for a patient by entering the patient ID number and the record number view the test results for a patient by entering the patient ID number and the record number.

When the nurse chooses to view the patient table, a list of all the patients is generated. This list contains the Patient ID, First Name, Last Name and Contact Number of the patient. Figure 7 shows the system response for such a query. It shows the number of record for the patient, data of the visit, visited physician ID and Name and the diagnosis by each physician.

The ASP Code accesses the database from the SQL Server because the nurse has been authenticated by the login process. Following this, a selected set of columns is retrieved from the database and is displayed to the end user. All of the above activities are tested using wireless PDAs. Also, it is found that they can be carried out and viewed just as it can be done using wired servers.

The ASP Script appends the entered data into the Record Table of the Hospital Database. Furthermore, the ASP Script also stores the Doctor ID (which is a session variable) and the System date into the Record Table. It is worth mentioning that once a patient record is accessed for editing, the database locks the file and it cannot be updated by the another user until the current session is finished. However, the stored version of record can be viewed while the update session is in progress.

Figure 8. Simultaneous access times through web-based database using wired and wireless PDA combinations
A Preliminary Study toward Wireless Integration of Patient Information System

Figure 9. Impact of concurrent Internet access on the access times through web-based database

![Graph showing impact of concurrent Internet access on access times]

Figure 10. System access failure rate as a function of distance for different numbers of mobile users

![Graph showing system access failure rate as a function of distance]

SYSTEM PERFORMANCE ANALYSIS

The system is implemented on AUS network which covers the entire campus with wired and wireless links. Two wireless PDAs are used for measuring performance of the system. Figure 8 indicates the access time performance values measured during the trial. The access time values were measured while the PDAs were trying to access the server...
A Preliminary Study toward Wireless Integration of Patient Information System

simultaneously. Even though the manufacturer specifications indicate that wireless devices should work with up to 100 meter distance from wireless access points, our tests indicated that the maximum reliable distance from wireless points are around 60 meters.

Our tests also indicated that network traffic over the intranet which is not related to electronic patient record database increased the above mentioned access times about 20% as shown in Figure 9.

System access failure rate was studied as a function of PDA-access point separation. The results are shown is Figure 10. As it can be seen, the success rate drops drastically as the distance approaches 60 meters.

CONCLUSION

A wireless PDA-based patient’s information system was designed, implemented and tested. Hospital personnel can access, create and update the patient’s record using standard internet browsing method through wireless mobile devices. The system gives the health personnel the mobility feature where they can check their patient’s record from anywhere in the hospital using the wireless PDA or using internet browser from any other location. Limited system performance tests indicated satisfactory performances as long as the hospital’s environment is well covered with wireless access points with access distance not exceeding 60 meters. Although it is not implemented in the test system, the users indicated that the inclusion of a practical messaging system similar to pagers will make the system even more useful.

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A Preliminary Study toward Wireless Integration of Patient Information System


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