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Simulating a Remote Patient Monitoring System for a Typical Nigerian Hospital

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Abstract-

Remote Medical Monitoring is a component of telemedicine capable of monitoring the vital signs of patients in a remote location and sending the results to a central location where the paramedics can view the patients vital sign history and proffer timely and immediate intervention and decision. In a typical Nigerian hospital, the manual medical monitoring is done by the nurses who check the vital signs of patients two times in a day and this can be detrimental to the health of the patients because the vital signs can fluctuate throughout the day. This research work simulates the blood pressure, the pulse rate and the mean arterial pressure of patients using a data structure which includes age, smoking habits and alcohol intake. The simulated data are encrypted using the symmetric key encryption algorithm which employs the Advanced Encryption Standard to generate a secret key used for the encryption. The same secret key is used for the decryption in the server only by authorized staff. These vital signs are simulated every 25 seconds and sent to the server for the doctor's intervention when there is an abnormal reading. The result of this research work is the continuous unobtrusive monitoring of patients' vital sign which has the capacity of saving lives which could have been lost.

Keywords: Vital Sign, Remote Medical Monitoring, Encryption, Secret Key, Telemedicine

I. INTRODUCTION

Remote Patient Monitoring (RPM) is a technology to enable monitoring of patients' outside of conventional clinical settings (e.g. in the home), which may increase access to care and decrease healthcare delivery costs.

Incorporating RPM in chronic disease management can significantly improve an individual's quality of life. It allows patients to maintain independence, prevent complications, and minimize personal costs [3]. RPM facilitates these goals by delivering care right to the home. In addition, patients and their family members feel comfortable knowing that they are being monitored and will be supported if a problem arises.

This is particularly important when patients are managing complex self-care processes such as diabetes and hypertension [4]. Key features of RPM, like remote monitoring and trend analysis of physiological parameters, enable early detection of deterioration; thereby, reducing number of emergency department visits, hospitalizations, and duration of hospital stays [5]. The need for wireless mobility in healthcare facilitates the adoption of RPM both in community and institutional settings. The time saved as a result of RPM implementation increases efficiency, and allows healthcare providers to allocate more time to remotely educate and communicate with patients[6] [14]. The diverse applications of RPM lead to numerous variations of RPM technology architecture.

Many patients can benefit from continuous monitoring as a part of a diagnostic procedure, optimal maintenance of a chronic condition or during supervised recovery from an acute disease or surgical procedure [12].

Persons requiring critical care; patients who have undergone surgery or persons with chronic ailments require continuous health monitoring and real-time feedback for immediate action in emergency situations. The patients would be subjected to discomfort and inconvenience due to prolonged hospitalization. Frequent visits to hospitals may also be required for follow up treatment and care. Use of Body Sensor Network can provide an alternative solution for remote monitoring of patients residing in the comfort of the homes. Patients can move about and follow their daily routine without the necessity of being confined to their beds. Data obtained over a long period of time in the patient's natural environment would offer the doctors a better insight into the patient's health condition and such data can be analyzed to arrive at the correct diagnosis and provide the right care [12].

Communication of health related information between sensors in BSN and the remote medical server has to be strictly private and confidential to protect patient privacy. The sensor data sent using Internet and wireless transmission is prone to different types of attack such as eavesdropping, sending false values or replay of previous data. Medical professionals have to be certain that the data is not tampered in transit or at a point of origin as proper diagnosis requires accurate data.

II. RELATED WORK

Andrew & Alfred (2008) from the University of Virginia developed a Remote Medical Monitoring system which consisted of three tiers, where each tier is distinguished by its locality and functionality within the broader system.
The first tier is the set of sensors that discern signals of interest, and relay information to each other and the data hub.

Tier two, the data hub, is a device that provides more computational capacity, allowing data to be stored or further processed before transmission to some outside medical network via the Internet, GSM, or some other means.

The third tier is the medical network, which is operated by a healthcare provider such as a hospital or telemedicine center where the staff can handle emergency situations [1].

The major system issues in the design of Andrew and Alfred is that their system did not make provisions for adequate security of the patient's data as it travels across networks and this can have adverse effects on the patient's data.
Also, there is no form of authentication of the patient's data thereby making the system porous.

Anliker et al. (2003) developed a medical device called AMON (alert portable telemedical monitor); which encapsulates many sensors (Pulse oximetry, ECG, accelerometer, and skin temperature) into one wrist-worn device that is connected directly to a telemedicine center via a GSM network, allowing direct contact with the patient if necessary. The unit promises to be an important early prototypical remote medical monitoring system, but the results of testing in a medical study called for more research because most sensor outputs couldn't be used in a clinical setting—especially the ECG, which couldn't be detected reliably at the wrist [2].

Eliasz et al. (2011) described a wearable ubiquitous healthcare monitoring system that integrates electrocardiogram (ECG device) and an accelerometer sensor with a mobile device in a Bluetooth-based body surface network (BSN). The research focused on the right connection of the hardware units, combination of the detection of QRS complexes (The QRS complex is the name for the combination of three of the graphical deflections seen on a typical electrocardiogram (ECG)), calculation of heart rate (HR) and the detection of human falls. (Eliasz et al., 2011)'s main aim of this research was the early detection of abnormal situations (high/low HR, a fall) and the heart rate variability analysis. (Eliasz et al., 2011) stated that future works should be to develop more advanced algorithms for detecting non-standard situations and improve fall detection algorithm [7].

Juan et al. (2009) presented a paper on a distributed telemonitoring system aimed at improving healthcare and giving assistance to dependent people at their homes. The system implemented a SOA-based (Service Oriented Architecture) platform which is capable of allowing heterogeneous wireless sensor networks to communicate in a distributed way independently of time and location restrictions [8]. The approach provides the system with a higher ability to recover from errors and a better flexibility to change the behaviour at execution time.

Otto et al. (2005) proposed a wireless BAN composed of off-the-shelf sensor platforms with application-specific signal conditioning modules [10]. In this paper, Otto et al presented a general system architecture and described a recently developed activity sensor "ActiS" [11]. ActiS is based on a standard wireless sensor platform and a custom sensor board with a one-channel bio amplifier and two accelerometers. Steele et al. (2003) stated that as a heart sensor, ActiS can be used to monitor heart activity and position of the upper trunk [13]. The same sensor can be used to monitor position and activity of upper and lower extremities.

III. SYSTEM ARCHITECTURE

This paper proposes a four tier architecture where tier 1 is the patient whose medical information are collected and sent to the Intelligent Personal Digital Assistant.

Tier two is the Intelligent Personal Area Network (IPDA) which is the mobile phone which accepts the patients' personal data together with the data structure which includes age, smoking habits and alcohol intake to simulate the readings of the vital signs of the patients which are sent to the server.

The tier three is the data encryption software which encrypts the packets of data as they arrive to prevent them from unauthorised access and use.

Tier four is the Central Monitoring Station where the packets of data are kept after the analysis by the queuing system from where the doctor can access the patients' data.

The total system architecture is shown in fig. 1.

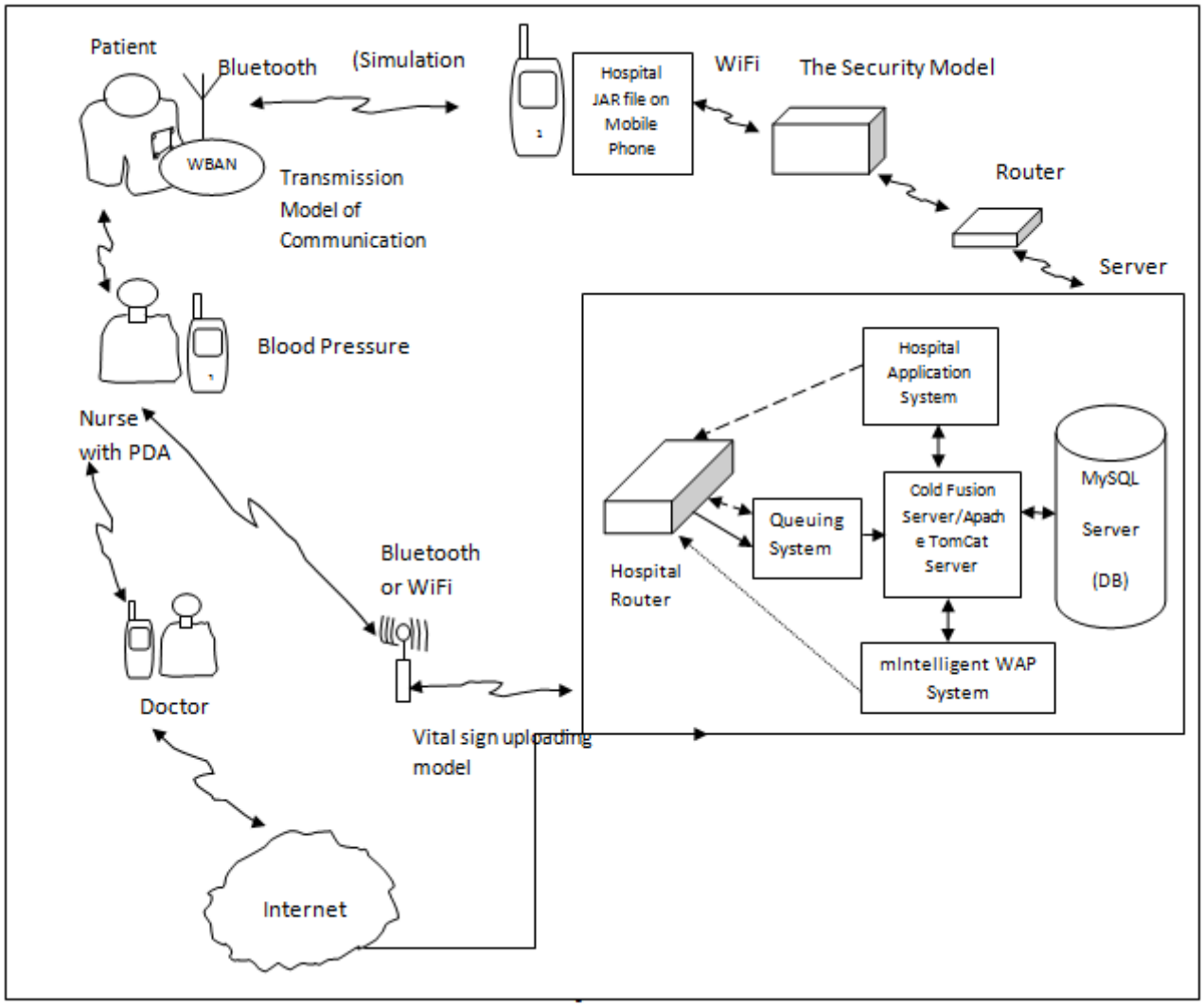


Fig. 1 The System Architecture of Remote Patient Monitoring

A. The Patient

The patient's medical information are collected and sent to the IPDA (Intelligent Personal Digital Assistant). The patient's medical information is a data structure which comprises of the name, age, alcohol intake, smoking habits etc. This information is sent to the mobile phone.

B. The IPDA

The Intelligent Personal Digital Assistant contains the **Mobile Health Information Management System software** that collects the medical records from the patients and simulates the vital signs (blood pressure and pulse rate). These vital signs are simulated every 25 seconds and sent to the server for further analyses. The simulation of the vital signs is done using the formulars:

C. Mean Arterial Pressure

The mean arterial pressure (MAP) is the average over a cardiac cycle and is determined by the cardiac output (CO), systemic vascular resistance (SVR), and central venous pressure (CVP), [9].

$$\mathrm{MAP} = (\mathrm{CO} \cdot \mathrm{SVR}) + \mathrm{CVP}. \tag{1}$$

MAP can be approximately determined from measurements of the systolic pressure P_{sys} and the diastolic pressure P_{dias} while there is a normal resting heart rate, [9].

$$\mathrm{MAP} \approxeq P_{\mathrm{dias}} + \frac{1}{3}(P_{\mathrm{sys}} - P_{\mathrm{dias}}). \tag{2}$$

D. Pulse pressure

The up and down fluctuation of the arterial pressure results from the pulsatile nature of the cardiac output, i.e. the heartbeat. The pulse pressure is determined by the interaction of the stroke volume of the heart, compliance (ability to

expand) of the aorta, and the resistance to flow in the arterial tree. By expanding under pressure, the aorta absorbs some of the force of the blood surge from the heart during a heartbeat. In this way, the pulse pressure is reduced from what it would be if the aorta wasn't compliant [9]. The loss of arterial compliance that occurs with aging explains the elevated pulse pressures found in elderly patients.
The pulse pressure can be simply calculated from the difference of the measured systolic and diastolic pressures, [9].

$$P_{\text{pulse}} = P_{\text{sys}} - P_{\text{dias}}. \quad (3)$$

E. The Security Model

Between the IPDA and the server is the security model which is responsible for the encryption of the patient's data as it travels to the server. The encryption is very important so as to safeguard the patient's medical records as it travels across networks.

The encryption is done by using the symmetric key encryption algorithm which employs the Advanced Encryption Standard (AES), where the patient's id is generated along side the vital signs and encrypted while it is sent to the server. This prevents unauthorized access to the patients' medical records. The records are decrypted in the server using the encryption key only by authorized personnel. The encryption and decryption diagrams are shown in Fig. 2 and 3.

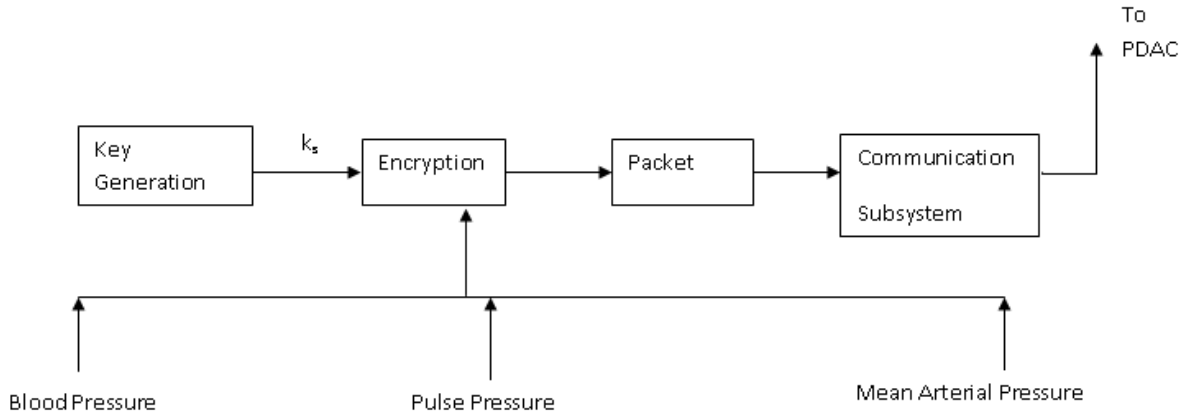


Fig. 2 Encryption/Authentication at SPDS

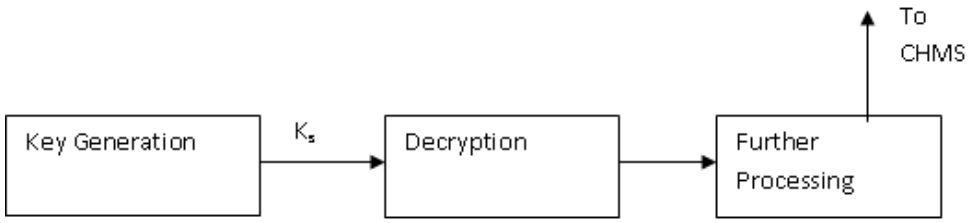


Fig. 3 Decryption/Authentication at PDAC

F. The Server

The server has four main applications viz: the complete hospital application, the database, the Electronic Medical records, and the queuing model. The complete hospital application contains the following modules: Medical Experts, Medical Equipment, Patient Registration, Dynamic Staff Worklist, Patient Discharged, In-Patient, Out-Patient, Pharmacy/Portal Reports, Drug Dispensory Unit, Hospital Administrator, Associated Communities Hospital, Operation Theatres, Drug Inventory and Medical Data Analyser.

The database was created using My SQL.
The Electronic medical Records consists of the records of the patients, which is simulated by the mobile phone (IPDA) and sent to the server. It contains the Mobile Users module where all the records of the patients' data simulated are kept. The records contains the patient's id, name, phone number, systolic pressure, diastolic pressure, pulse, Mean Arterial Pressure (MAP), Blood Pressure, suggestions and date and time. These are the readings generated when the simulation is done in the mobile phone. These readings are generated every 25 seconds and sent to this mobile users module. The doctor can look at the mobile users module at any time to see the detailed records of the patients.
The queuing model contains the Network Queues of Mobile Users module which contains the details of all the patients' records simulated by the IPDA. The simulation once done, will continue to send the records to the queuing model every 25 seconds and the total number of records sent will continue to increase until the simulation is stopped. Thus there is a

continuous monitoring of the vital signs of patients as long as the system is active. The doctor can easily look at the queuing model to see the summary of the readings generated for each patient. A detailed graph for each patient is also generated in the queuing model so that the doctor can look at a particular patient's graph to see the progression of his vital signs and will be able to make timely and well informed decision and prescription.

G. The Doctor
The doctor can access the server from anywhere and view any patient's medical records. The doctor can offer his medical advice and intervention when necessary.

H. The Nurse
The nurse gets information from the doctor directing her on what to do. The nurse also communicates to the patient through SMS if the patient is in a remote location or by direct oral communication if the patient is within the hospital premises. The nurse can also use the blood pressure loader to upload the patient's vital sign monitored over a period of time to the server and can send an SMS to the doctor whenever there is an abnormal situation.

IV. RESULTS and DISCUSSIONS
The IPDA simulates the blood pressure, pulse rate and mean arterial pressure of the patient and send the result to the server. These readings are simulated every 25 seconds for as long as the program is active. The queuing model in the server performs analysis on the packets of data received like calculating the arrival time, arrival rate and the traffic intensity and keeps record of the total number of patients' record in the queue. The patients graph is produced for each patient from where the doctor can have a quick glance at the patients' vital sign and proffer his medical advice. The patients' medical records are also encrypted as they travel across network thereby safeguarding the patients' records from unauthorized access. The outputs are in fig. 4 to 9.

Fig. 4 Instruction for users

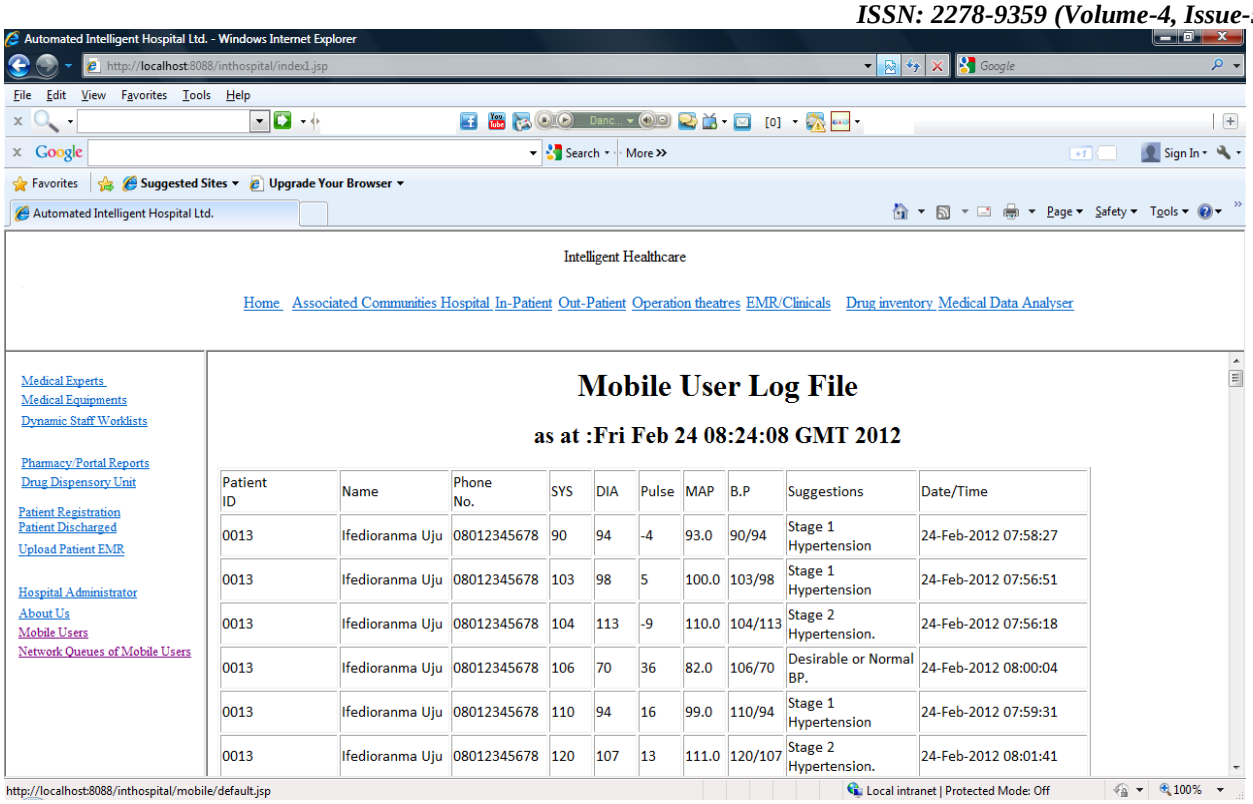
The fig. 4 above shows the instructions for the users. The users are required to respond to the instructions by providing the name of the patient, the age of the patient, the telephone number, the smoking habits and the alcohol intake. These responses will be used for the simulation of the blood pressure and the pulse rate.

Fig. 5 Mobile login

The fig. 5 above shows the mobile login from where the user will login into the application

Fig. 6 BP Transmission

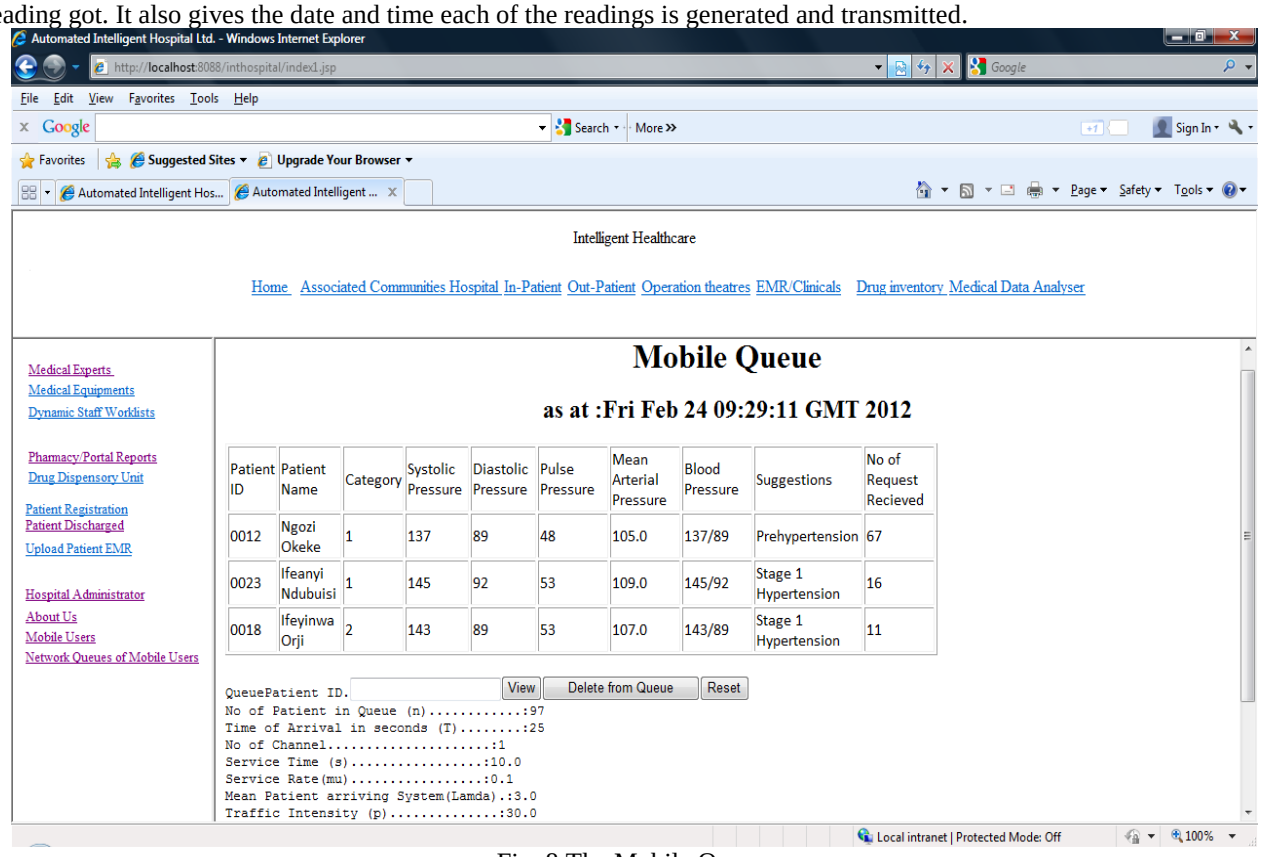
Fig. 6 shows the Blood Pressure transmission. At this point the blood pressure and the pulse rate are being generated and transmitted. The generation and the transmission of the blood pressure and the pulse rate are done every 25 seconds and they will continue to be transmitted as long as the application is on and active.



Patient ID	Name	Phone No.	SYS	DIA	Pulse	MAP	B.P	Suggestions	Date/Time
0013	Ifedioranma Uju	08012345678	90	94	-4	93.0	90/94	Stage 1 Hypertension	24-Feb-2012 07:58:27
0013	Ifedioranma Uju	08012345678	103	98	5	100.0	103/98	Stage 1 Hypertension	24-Feb-2012 07:56:51
0013	Ifedioranma Uju	08012345678	104	113	-9	110.0	104/113	Stage 2 Hypertension.	24-Feb-2012 07:56:18
0013	Ifedioranma Uju	08012345678	106	70	36	82.0	106/70	Desirable or Normal BP.	24-Feb-2012 08:00:04
0013	Ifedioranma Uju	08012345678	110	94	16	99.0	110/94	Stage 1 Hypertension	24-Feb-2012 07:59:31
0013	Ifedioranma Uju	08012345678	120	107	13	111.0	120/107	Stage 2 Hypertension.	24-Feb-2012 08:01:41

Fig. 7 Mobile User Log File

The mobile user log file contains the details of all the patients whose vital signs have been transmitted. It contains the name of the patient, the phone number, the blood pressure (which is the systolic pressure and the diastolic pressure), the pulse pressure and the mean arterial pressure. It also gives suggestions regarding the blood pressure depending on the reading got. It also gives the date and time each of the readings is generated and transmitted.



Patient ID	Patient Name	Category	Systolic Pressure	Diastolic Pressure	Pulse Pressure	Mean Arterial Pressure	Blood Pressure	Suggestions	No of Request Recieved
0012	Ngozi Okeke	1	137	89	48	105.0	137/89	Prehypertension	67
0023	Ifeanyi Ndubuisi	1	145	92	53	109.0	145/92	Stage 1 Hypertension	16
0018	Ifeyinwa Orji	2	143	89	53	107.0	143/89	Stage 1 Hypertension	11

Fig. 8 The Mobile Queue

The mobile queue gives a summary of the total number of readings received from each patient. It also produces the total number of patients in the queue, the time of arrival in seconds, the number of channels used, the service time, the service rate and the traffic intensity.

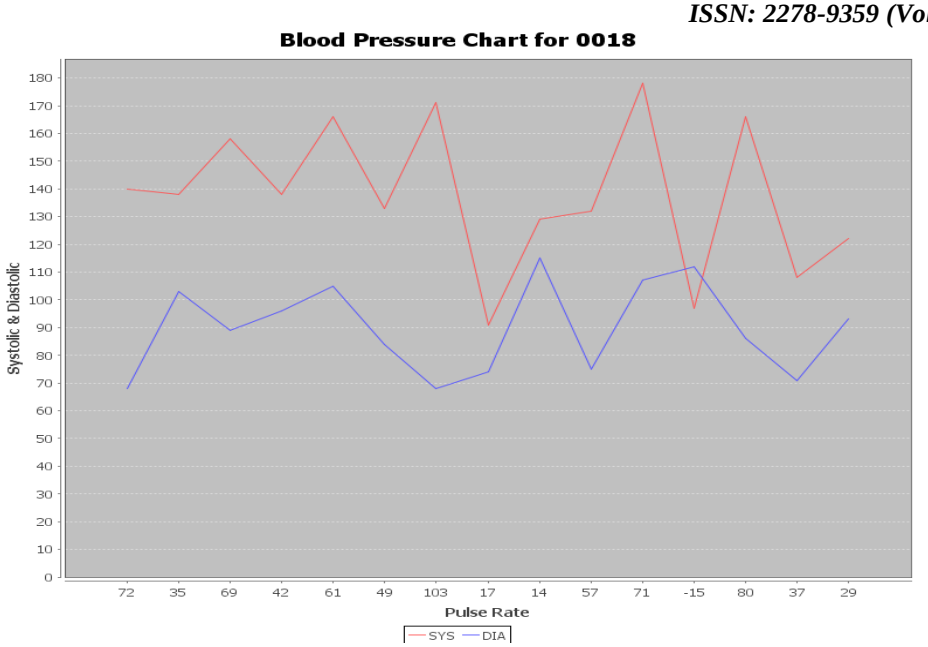


Fig. 9 The Blood Pressure Chart

The blood pressure chart displays the blood pressure for a particular patient chosen so that the doctor can have at a glance look of each patient by looking at the chart.

V. CONCLUSION AND FUTURE WORK

A remote patient monitoring system has been designed and presented. It has been shown that the Intelligent Personal Digital Assistant accepts the personal data from the patient and simulates the readings for the blood pressure, the pulse rate and the mean arterial pressure. These readings are sent to the server and a new set of readings are generated every 25 seconds making it possible for a continuous monitoring of the vital signs of the patients.

As the patients' medical records move from the IPDA to the server, they are encrypted using the symmetric key encryption algorithm which employs the Advanced Encryption Standard (AES) to generate the secret key which can be used to decrypt the patients' records only by authorized personnel. This safeguards the patients' records from unauthorized users and hackers who may want to intercept the patients' medical records as they travel through the networks.

The doctor can view the server from anywhere and see the detailed readings of the patients' and proffer his expert advice. The doctor can also be contacted by the nurse whenever there is an abnormal reading for any patient.

This has the capacity of saving many lives that could otherwise be lost if there is no timely intervention.

Future work can be done in areas of designing a remote monitoring system which may include other vital signs like Pulse Oximetry, Electrocardiogram (ECG), Electroencephalography (EEG), Electrooculography (EOG) and Electromyography (EMG).

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