**UNIVERSITY OF NAIROBI**
**COLLEGE OF BIOLOGICAL AND PHYSICAL SCIENCES**
**SCHOOL OF COMPUTING AND INFORMATICS**

# A Service Oriented Architecture Approach to Implementing an Omnichannel Personal Health Record System

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## DECLARATION

This research project was my original work and has never been presented for examination in any other university.

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# ABSTRACT

The overall objective of this research was to implement an Omnichannel Personal Health Record (PHR) System based on Service Oriented Architecture (SOA) framework to facilitate patient-centred self-care and collaboration with healthcare providers. The specific objectives under the study were to understand people's perception on personal health record systems, establishing the current mechanisms of identifying patients in health facilities, developing a Service Oriented Architecture (SOA) model and prototype for the proposed Omnichannel PHR System, and finally testing, evaluation and validation of Omnichannel PHR prototype system developed. The omnichannel solution enabled availability of PHR data anytime, anywhere as well as any terminal over cloud technologies. PHR data need to available anytime, anywhere and any terminal (channel or device) with patient consent.

IBM's Service Oriented Modelling and Architecture (SOMA) phases were used to model, identify, select, implement, deploy and monitor the services in the Omnichannel PHR solution. Questionnaires and interviews were the primary data collection tools. A sample of patients (individuals) and healthcare personnel provided responses to questionnaires. Healthcare personnel were also interviewed about the current patient identification methods and medical data handling processes.

The findings of the study revealed that most patients had never heard nor used PHR systems whereas the majority were willing to use it if their physicians recommend them. Even though more than half the health facilities in Kenya have a unique patient identification scheme, they are not interoperable between hospitals which further hampers medical data sharing among healthcare facilities. Post-implementation results revealed that data sharing between patients and healthcare personnel significantly improved by rolling out device agnostic means (omnichannel systems) where patients and healthcare personnel such as physicians can share and access medical history using web, mobile or other platforms. This was facilitated by adoption of Service Oriented Architecture. The findings have implications on patient care improvement, lower costs of treatment and reduced cases of misdiagnosis.

Although not all aspects of PHR were addressed, only the generic functional requirements of an Omnichannel PHR System, the Service Oriented Architecture provided integration layer that can facilitate interoperability of different channels, devices and third-party systems or applications. The prototype demonstrated the possibility of universal patient identification and medical data interoperability by making it possible for patients to be able to record their medical information using different platforms (web and mobile), as well as monitoring devices (Internet of Things), made possible by SOA without having to carry paper records or cards whenever they are to seek healthcare services. Healthcare professionals can assist the patients in updating their profiles whenever they seek medical treatment. Patients are very cautious about the privacy of their data and were comfortable with having control over who can read or write their records. This research, therefore, recommends open APIs using SOA for central identification and management of personal health records, use of open source technologies and adoption Internet of Things to collect vital patient medical information in real-time. As such PHR data can be available anytime, anywhere, any terminal over cloud technologies.

# DEDICATION

This research is dedicated to my family for their immense supported. Special thanks to colleagues who gave ideas in the design of the Personal Health Record system mobile application.

## ACKNOWLEDGEMENTS

Special thanksgiving to the Almighty God for giving us the strength and will to accomplish this Research Project. Many contributed to this project right from its inception to its successful completion. Special appreciation is given to the project supervisor, Prof. Peter W. Wagacha for his valuable and inceptive guidance that led to the successful completion of the project. We also thank the respondents, who took time off their busy schedule to fill in the questionnaires.

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# ABBREVIATIONS

DHIS2 - District Health Information Systems version 2.

EHR – Electronic Health Record

EMPI – Enterprise Master Patient Index

EMR – Electronic Medical Record

E-PHI - Electronic Protected Health information.

ESB – Enterprise Service Bus

FSB – Facility Service Bus

GSM – Geographical Subscriber Module

GPRS – General Packet Radio Service

HIPAA - Health Insurance Portability and Accountability Act.

HTTP – HyperText Transfer Protocol

HTTPS – Secure HyperText Transfer Protocol

IDE - Integrated Development Environment.

IoT- Internet of Things

IPRS – Integrated Population Registration System

JMS – Java Messaging Services

JSON – JavaScript Object Notation

KHEA – Kenya Health Enterprise Architecture

MPI – Master Patient Index

MSOAM - Mainstream Service Oriented Methodology.

NEMIS - National Education Management Information System

NMPI – National Master Patient Index

NUPI - National Unique Personal Identifier

OTP – One Time Password

PHR – Personal Health Record

REST – Representation State Transfer

SOA – Service Oriented Architecture

SOAP – Simple Object Access Protocol

SOMA – Service Oriented Modelling and Architecture

SQL – Structured Query Language

URL – Universal Resource Locator

USSD – Unstructured Supplementary Data

WI-FI – Wireless Fidelity

XML – eXtensible Markup Language

## DEFINITION OF TERMS

**Enterprise Service Bus** – A middleware that converges data from various channels or third-party systems and then queues, transforms, validates, process and routes messages destination systems.

**Internet of Things** - Refers to a type of network to connect anything with the Internet based on stipulated protocols through information sensing equipment to conduct information exchange and communications in order to achieve smart recognition, positioning, tracking, monitoring, and administration (Keyur & Sunil, 2016).

**National Master Patient Index** – A nationwide electronic database that stores basic demographic information of patients (Rouse, 2017).

**Omnichannel System** – A multichannel approach to interacting with users by providing seamless experience irrespective of channel device, e.g. mobile application, USSD application, web application, internet of things and e.t.c.

**Personal Health Record** - An electronic collection of health information of an individual. A PHR may include information about treatment by doctors, including test results and medications, as well as information entered by the individual. Some PHRs allow the individual full control of who has access to all or parts of the PHR and for how long this access lasts.

**Service Oriented Architecture** - An approach to designing, implementing, and deploying information systems such that the system is created from components implementing discrete business functions called "Services" (Sonic Software Corporation, 2005) that can be distributed across geography, across enterprises, and can be reconfigured into new business processes as needed (InApp, n.d.).

# 1 INTRODUCTION

## 1.1 Background of the study

Electronic Health (e-Health) systems have played a very critical role in the healthcare sector by taking advantage of the increased power of computing devices. The benefits offered include but not limited to patient data storage which ensures patient medical history is available on a need basis, reduced costs to the patient by eliminating duplicate test procedures as well as faster processing and high accuracy (Bell & Sethi, 2001). The eHealth systems have now been widely used not only by the physicians in aiding decision-making process but the patients are also quickly adopting Mobile Health (mHealth) systems which have evolved from simple feature phones to powerful smartphones and wearable sensors in delivering patient-centred self-care in developing countries for disease prevention and management. Kenya has a mobile penetration of 90.4% whereas internet penetration has hit 112.7% by the year 2018 (CAK, 2017) means every household has access to mobile device and internet connectivity.

Interoperability among health information systems is essential in eHealth systems because patients possess unlimited clinical needs necessitating integration to other eHealth systems within and outside a health facility (Heerden, Tomlinson, & Swartz, 2012) at the comfort of their mobile devices. While seamless mHealth system interoperability has immense benefits, especially to people in developing countries who reside in rural areas, lack of it is a threat to taking advantage cost efficiency associated with mHealth (ITU, 2012; Heerden, Tomlinson, & Swartz, 2012; GSMA, 2011) which would lead to improved healthcare.

The failure to accurately identify and match a patient data has had negative consequences to health care workforce. The existence of no reliable matching criteria or rather duplicate records makes it impossible for physicians to rely on the existing data to get a complete view of a specific patient's medical history. The unreliable patient matching criteria will either result in unnecessary procedures or misdiagnosis and administration of wrong prescriptions to the patient. The inability to uniquely identify a patient may be as a result of by several factors such as different EMR systems and associated subsystems which work in isolation, failure of healthcare staff to inquire and record adequate and correct patient demographic information (HealthLeaders Media Magazine, 2015).

Research has shown that patient record matching using manual interventions or algorithms is still a nightmare due to variations in data elements used in matching (Genevieve Morris et al., 2014). It is proposed that a unique patient identifier that is consistent nationwide is the ultimate solution to patient matching across different healthcare provider's systems. Other countries have succeeded in implementing the nationwide patient identification (Arzt, 2017), Kenya has not yet implemented. However, it will be adopted once the Kenya Health Enterprise Architecture is finally implemented (Kenya National e-Health Ploicy 2016-2030, 2016). Although there are several modes of identification documents in Kenya like National ID Number, Military ID, Passport Number, Job ID, however, this adds more problem as the same patient may end up using the identification documents interchangeably in the same or different health facility.

The private healthcare facilities in Kenya, like other private sectors, for example, have advanced in the adoption of eHealth technologies as far as EHRs systems are concerned. Most of them have adopted the Master Patient Index (MPI), some have gone further to implement an Enterprise Master Patient Index (EMPI). However, MPI and EMPI are unique to the internal healthcare facility thus cannot be easily shared and accepted across organisations and thus patient matching issues persist (HealthLeaders Media Magazine, 2015) across healthcare facilities.

Medical insurance providers, on the other hand, assign members a member number, which is unique or known to the individual insurance providers and cannot be therefore used by healthcare providers or across other insurance providers. This is because the unique patient identifier is only used for verification of a patient to belong to the insurance provider and claims management by the healthcare facility from a specific insurance provider.

In order to facilitate the linkage of patient medical records from different EMR systems which may span multiple health facilities, there should exist a universal patient identification method. The ability to accurately identify a patient means that doctors can obtain accurate information about the patients from EHRs. Although the caregivers and physicians provide patient medical information, they are usually hard copies, preserving them is usually a daunting task (S, L, & H). Also, most of the data are not shared across health facilities. This study proposes the establishment and implementation of an Omnichannel Personal Health Record based on Service Oriented Architecture. The Service Oriented Architecture will allow a single window to all the PHR components which include high availability and load balancing, loose coupling (interoperability and platform independence), location transparency and re-use of services. The highest level of securing the identifiable patient information shall be enforced through encryption and role-based access. The Omnichannel PHR will ensure that patients can take the responsibility of managing their electronic medical history with the support of the doctors and care givers. The data shall be accessed from multiple devices (Web portals, Mobile applications or USSD). Patients will decide when to opt-in, what will be stored in the Omnichannel PHR, who accesses it, what actions to be performed (read, write, delete), for how long and finally have the ability to opt out. The unique identifier which will be present nationally (National Master Patient Index) could also be stored in the local hospital's EMR systems. In so doing, their medical data can easily be inquired from any remote facility using the unique identifier for a patient.

## 1.2 Problem Statement

Interoperability of eHealth systems has been a problem that has been unresolved due to variations in platforms, protocols, data formats and patient matching criteria. Even with the availability of a multitude of message exchange standards, the systems still operate in isolation, with little or no potential to interoperate due to lack of universal patient identification. Most of the eHealth systems are owned and controlled by individual hospitals and not exposed to other third parties by choice or fear of losing competitive advantage when they share with other institutions (Ge, Ahn, Gage, & Carr, 2013). The popular Personal Health Record (PHR) systems are also institution-specific and have not been concerned with data interoperability and data protection with other PHR vendors, which explains why there is low uptake especially in Kenya (Jingquan, 2017). Existing mHealth solutions are proprietary, expensive and hence unsustainable as patients are unwilling to use and pay for multiple applications which do not share data with other systems but stand-alone 'siloed' applications. As a result, patient records are spread across different institutions that cannot easily be accessed by patient nor caregivers. According to (Arzt, 2017), a universal identification of patients within a nation would result in a safe and secure exchange of patient healthcare information since it ensures an accurate, timely and efficient matching of the patient between different EMR systems, in and out of a healthcare facility. The burden of patient matching and lack of data exchange falls on the patients who are forced to pay for duplicate consultations, tests, treatments that were not necessary at all including succumbing to negative side effects of misdiagnosis, hence the need to establish and implement a framework for patient-centric universal patient identification and sharing of data. Most of the PHR solutions permits patients to collect and enter all their medical information manually as only a few physicians or hospitals submit their medical information electronically to a PHR (PharmD, 2016). There is a need to manage and avail PHR data anytime, anywhere and any terminal with patient consent.

## 1.3 Objectives of the study

The main objective of this research was to implement an Omnichannel Personal Health Record System based on Service Oriented Architecture (SOA) framework to facilitate patient-centered self-care and collaboration with healthcare providers.

The specific objectives are stated as follows:

i) To learn of people's perception of personal health record system in mitigating current healthcare data sharing (interoperability) between different healthcare facilities.
ii) To identify the current mechanisms of identifying patients in health facilities and alternatives for universal patient identification.
iii) To develop SOA architectural model and prototype for the proposed Omnichannel PHR System
iv) To test the Omnichannel PHR system developed.

## 1.4 Significance of study and justification for research

Several healthcare facilities and medical insurance providers have invested a lot in health information systems in order to deliver the better services to patients. However, the different entities (organisations) still cannot share patient data due to the patient matching problem or general reluctance to share data yet the data belongs to the patient. Successful implementation of this solution contributes to increased accuracy in patient identification and patient data exchange across different healthcare provider systems. Patients will have direct control as to whom to grant or revoke access to their historical data. The patient could be rewarded for participating in research or by the sale of the anonymised data for research purposes with the consent of the patient. According to Hassan (2003), the SOA-based centralised patient registry solution delivered will not only create knowledge in the application of Service Oriented Architecture in eHealth systems but also solve universal patient identification problem that results in benefits such as:

i) Enhanced data access and sharing among care-givers across healthcare providers,

ii) Improved timely decision-making and patient care by eliminating duplicate test procedures by making use of patient medical history.
iii) Revenue generation through advertising on mHealth mobile application, participation in research or sale of anonymised data to patients and for sustaining the platform.
iv) Reduced expenses to the patient, e.g. eliminating unnecessary tests and surgeries
v) Easy addition of new services/systems on demand (Continuous deployment of new services) at the Omnichannel PHR system.
vi) Practical application of the SOA architectural design pattern in healthcare information systems.

## 1.5 Scope and limitations of the study

Whereas the National Master Patient Index is expected to be implemented and accepted by all healthcare providers, real-time integration medical data sharing between hospitals eHealth systems to the Omnichannel Personal Health Record system is out of scope of this project. Future researchers are encouraged to take this up having solved the patient identification and matching problem at the end of this study. The scope is limited to budget on time and cost for this academic paper.

## 1.6 Ethical Consideration

The medical data must be kept private and confidential. It should only be made available to authorised users have sought consent from the patients themselves. It therefore expected that the strictest code of ethics to be upheld whenever handling the data to prevent unauthorised access or malicious use of patient medical data. The healthcare and dentistry board have to determine the suitability of this project before the actual implementation of the project.

# 2 LITERATURE REVIEW

## 2.1 Introduction

In this chapter, we reviewed the current state of the art architecture (SOA) in implementing an Omnichannel Personal Health Record system that is managed by patient as to opt in or out, what data to store as well as who accesses specific medical information. The section starts with reviewing the concept of Master Patient Indexing as, a way to uniquely identify patient across multiple systems including the centralised patient registry, then followed by existing solutions to solve intra-organizational patient identification and then inter-organizational patient identification, alongside case studies of nationwide patient identification. Based on the limitations of this existing work, we take a step in reviewing the best practices in patient identification as a unique nationwide identifier as well as a suitable architecture that ensures high availability, scalability and security of the MPI to thwart any misuse (identity theft). In order to protect the privacy and security of patients, we reviewed the existing regulations and compliance requirements plus security considerations to be deployed. We also reviewed the extent of usage of the IPRS as a central database of all Kenyan Citizens and foreigners by other institutions like banking and its potential to healthcare. Lastly, reviewed the SOA concepts and methodologies used in the design and implementation of SOA-based solutions (Conceptual framework).

## 2.2 Patient identification in Kenyan health facilities

In Kenya, we have different categories of health facilities owned and managed by the government, charitable institutions as well as private entities. The various institutions have different types of EMR systems or no systems at all where manual recording on patient information is done. Despite having systems in place, most health care professionals fail to capture important information about the patient or fail to be able to search or inquire with the patient whether they are returning patients. This ends up in duplicate entries of the same person in the EMR system, thus hampering a complete view of the patient's historical records by the physicians. Patient matching within a health facility's systems is still a nightmare, as they may not be able to exchange messages (no capacity to interoperate) or the individual systems generate patient identities that are unique to one system and not shared across the other systems. Therefore, there is a need to uniquely identify a patient within and beyond a health facility using a Master Patient Index (MPI).

Medical insurance providers, who are regulated by the Insurance Regulatory Agency (IRA), assign members a member number, which is unique or known to the individual insurance provider and cannot be used by health care providers or other insurance providers. This is simply because the unique patient identifier is only used for verification of a patient to belong to a specific insurance provider and also used in claims management by the health care facility from the insurance provider for the services rendered to the insured. In Kenya, it is a mandatory requirement that all employed citizens above 18 years were members of the National Health Insurance Fund (NHIF) for which they must contribute monthly through their employers. The rest of the public can sign up and contribute to the fund and access medical care at registered healthcare facilities. There are some other medical insurance firms which provide customised medical cover to various types of individuals depending on the amounts contributed to the medical fund through premiums. Majority of the employers sign up for such medical insurance providers for their employees. The medical insurance companies are the primary champions of implementing the universal patient identification regardless of the medical insurance firm nor healthcare facility. The machine-readable electronic cards should have the National Master Patient Index (NMPI) written and printed on it and be readily accepted by the healthcare providers in the proposed adoption of NMPI through the centralised patient registry.

## 2.3 Typical Uses of Patient Identifier

Patient Identifier is very critical in patient care across different providers, care settings and time. Below are typical uses of Patient Identifier:

i) Co-ordination of Patient Care Services across multiple domains like x-ray, laboratory, consultations, etc.
ii) Record Keeping/Information Management such as orders, results, procedures, notes, etc.
iii) Administrative Functions like billing and reimbursement.
iv) Storage and Retrieval of Historical Information like allergies, surgical procedures, diagnosis, diseases.
v) Aggregation of information from multiple patient information for treatment efficacy, research, statistical reporting, and planning

## 2.4 Components of Unique Patient Identifier

Below are essential components of a Unique Patient Identifier:

i) Identifier (numeric, alphanumeric, etc)
ii) Identifying Information

iii) Index
iv) Mechanism to hide, or, the tool to encrypt the Identifier
v) Technology infrastructure including the software, hardware and communication
vi) technologies to search, identify, match, encrypt, etc.
vii) Administrative infrastructure including the Central Governing Authority.

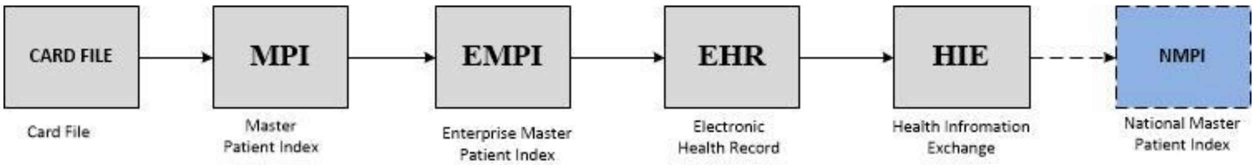
### 2.5 Master Patient Indexing

Master Patient Index is an electronic database that stores basic demographic information of patients in a healthcare facility (Rouse, 2017). on registration and assigned to each patient as a unique patient identifier. The goal of the Master Patient Index (MPI) is to uniquely identify and link a patient record in an EMR system or all systems within an organisation accurately. Having an MPI is a step forward in ensuring eHealth systems interoperability by allowing different source systems or organisations to exchange patient information (Purkis, Morris, Afzal, Bhasker, & Finney, 2012) by matching patient information correctly. Therefore, hospitals need to give the implementation of MPI the highest priority it deserves for interoperability to succeed (Lenson, RHIA, & M, 1995) since preventing errors is very costly, complicated and time-consuming. In health facilities, especially where staff are few, healthcare staff spend valuable resources (telephone bills and time) during registration of patients that could be better spent elsewhere. Kadish believes that this first stage of receiving a patient (registration) is the best place to begin that are costly and sometimes impossible to prevent correcting duplicates and overlays as well as to prevent future errors (Chapman, 2014). Without MPI, physicians can treat patients without having a complete view of the patient's historical information (Good Practices for the Implementation and Management of an NMPI, 2015) which is not desirable.

An Enterprise Master Patient Index (EMPI) is a unique patient index used across an individual organisation in patient matching and linking across different eHealth systems, ranging from EMR, mHealth, medical laboratory, radiology systems and other Health Information Systems (IBM). Since EMPI is used internally within a health facility's systems, it cannot be readily used or accepted across various healthcare organisations. According to Judith Gash and RHIA, the patient matching and records linking problem could be solved by viewing from a national perspective as the best strategy hence the need of a National Master Patient Index (NMPI).

## 2.6 Evolution of the MPI

Below are the phases of evolution of MPI from card file to Health Information Exchange and ultimately the proposed National Master Patient Index (NMPI)




Patient identification was being recorded on a card, which was given to a patient when they visit a health facility and must produce during subsequent visits. The card could not be used in any other health facility or system, as this was still manual. Master Patient Index (MPI) came, which was still unique to a facility as well as a department or Electronic Medical Record (EMR) system. Enterprise Master Patient Index (EMPI) extended the MPI to organisation-wide Electronic Medical Systems, Laboratory Systems, Pharmacy. Electronic Health Record (EHR) consolidates all patient information in one system, without having disparate systems hence patient record retrieval becomes easy since it is in one place. The rise of Health Information Exchange (HIE) similar to EHR, spans multiple organisations within a region or a hospital. Ultimately, the National Master Patient Index (NMPI) will allow the universal identification of patients across organisations, hospitals, regions and up to the whole country.

**Importance of MPI**

1. Quality Care for Patients
   - (i) Critical link between disparate health information systems
   - (ii) Facilitates information exchange
2. Financial Health for the Organization
   - (i) Operational efficiency
   - (ii) Risk and cost reductions
   - (iii) Accurate billing and reimbursement

## 2.7 National Master Patient Index

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) authorised the United States of America (USA) government to introduce a National Patient Index (NPI) as a way to make medical records more portable (Terry, 2015). An NMPI allows unique identification of patients receiving medical services at different health care providers. Thus the patient information can be exchanged easily by linking all data in the different facilities to one patient (Good Practices for the Implementation and Management of an NMPI, 2015). Any healthcare facility can access a complete view of patient medical and treatment history from multiple institutions which are essential to provide quality care as well as ensuring a continuum of care (OpenHIE, n.d.). It benefits both the patients and caregivers in a big way.

Within the proposed Omnichannel PHR architecture, on signup, a patient or healthcare provider submits basic demographic information on a mobile app, USSD or a web portal via Application Programming Interface (API). The information is first validated against IPRS system. If the demographic data are validated, the registry is queried if the patient exists and returns the existing patient's existing unique patient identifier (NMPI) including additional demographic information along with pointers to the local systems (hospitals) that house the detailed clinical data. If the patient registered doesn't exist in the registry it generates and returns the patient NMPI to be stored in the EHR system.

Although the NMPI does not solve the interoperability of eHealth systems, interoperability would not be realised without a universal patient identifier (Keith Fraidenburg, executive vice president and chief strategy officer of College of Health Information Management Executives (CHIME)). According to Fraidenburg, the current method of matching patients with demographic information only without NPI is not accurate. Similarly, EMPI solutions have their limitations and cannot be readily used or accepted by other providers external to the organisation.

According to (Scott , 2010), maintaining a centralised registry that contains basic patient demographic information transmitted by health care providers has immense benefits which include:

i) Guaranteed reliability, accuracy and high performance since the patient information is centralised hence can be queried easily and not subject to data format conflicts but trusted by all stakeholders.

ii) Leads to proactive patient healthcare, e.g., sending alerts to the patient's doctor/hospital in case of emergency if the patient is admitted to a different hospital.

iii) Patient information privacy is ensured as only the basic information is stored in the centralised registry, which is protected by a single security system.

Due to the potential benefits of NMPI being very critical to patient care so is the NMPI service if not available. It can as well be a potential single point of failure (SPOF). It is prudent that the central patient registry be highly scalable and available 24/7. Therefore, SOA architectural style is preferred due to its potential desirable features. Various kinds of devices, protocols, message formats from different healthcare providers in desperate locations means that the central patient registry needs to support backward compatibility with existing EHR systems with potential scalability in future to support additional services like hospital-to-hospital seamless integration.

In Kenya, the Ministry of Health and its stakeholders are working towards development of a National Unique Patient Identification (NUPI) system.

Below is a typical implementation of an NMPI architecture.

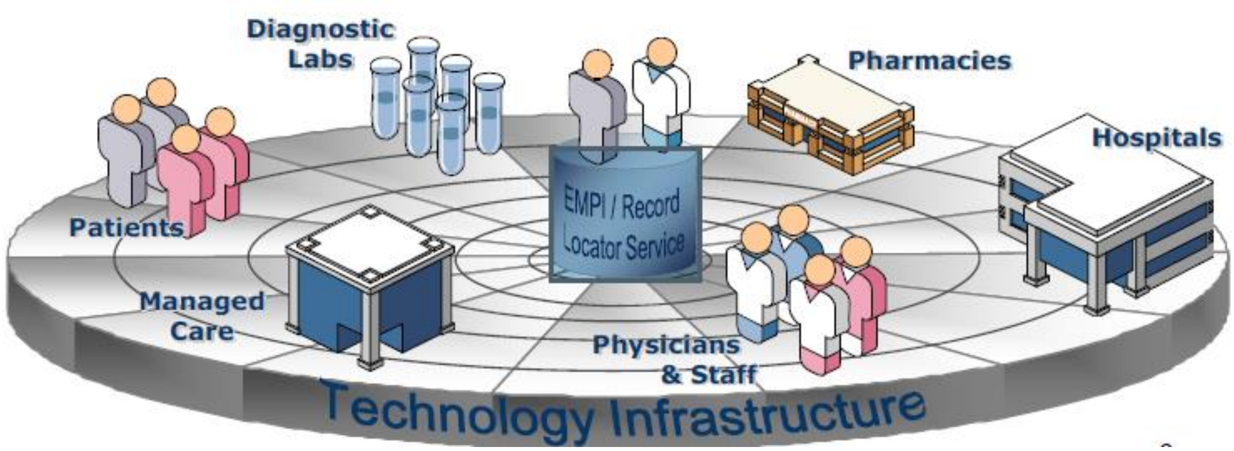



*Figure 1:A typical implementation of an NMPI architecture (Adopted from American Health Information Management Association - AHIMA)*

## 2.8 A Case study of MOH Client Registry in Rwanda

Rwanda's Ministry of Health (MOH) Client Registry maintains demographic information about residents including family information (e.g., dependents) and social categories that are being used by the health insurance providers (Jamie, 2015).

In Rwanda, the Ministry of Local Government (National ID Office) issues a National ID (NID) to persons above sixteen-years-old alongside biometric information. The NID is a smart card with a bi-dimensional barcode containing the biometric data, person name and date of birth that is printed. The smart card has a resident's basic demographic information including a photograph. Those under sixteen years are not issued with identification cards nor biometric information captured, but they possess a number generated by the NID system (Ministry of Health Rwanda, 2011).

The drawback of this solution is the reliance on cards. Patients do not always carry their cards, especially during emergencies. The reliance on national ID is not sufficient as it is prone to identity theft. Sometimes, people share the same national ID like in Kenya due to erroneous data entry. The patients below the age of 16 mean that their unique identification is not preferred as their biometric information is not captured.

## 2.9 A Case Study of e-Estonia Patient Portal

Over 95% of Estonia's health data is digitized in a national eHealth database. It integrates nearly all the healthcare providers in the country with a common record which every patient and healthcare can access via e-Estonia Patient Portal (e-estonia, n.d.).

Each person in Estonia that has visited a doctor has an online e-Health record that can be tracked. Identified by the electronic ID-card, the health information is kept completely secure and at the same time accessible to authorised individuals. The system uses KSI Blockchain technology to ensure data integrity and mitigate internal threats to the data.

Unlike Kenya and other developing countries, Estonia has a comprehensive coverage of broadband in public facilities as well as homes. It is estimated that all schools have broadband connectivity and 80% of households have a broadband connection by the year 2014. Nearly all citizens transact electronically (bank transfers). Similarly, the citizens pay tax, cast votes and participate in census electronically too.

In Estonia, it is mandatory that all healthcare providers to send data to the Central Health Information System by the licensed medical professionals. The patients can voluntarily opt out of the Health Information System. Identity cards and digital signatures are used for authentication. Patients and physicians can access the patient data from a Patient portal.  A doctor can use a patient's ID code to read time-critical information, such as blood type, allergies, recent treatments, on-going medication or pregnancy. The system also compiles data for national statistics, so the ministry can measure health trends, track epidemics, and make sure that its health resources are being spent wisely (E-Estonia, n.d.).

Below is the high-level architecture for e-Estonia Patient Health Portal

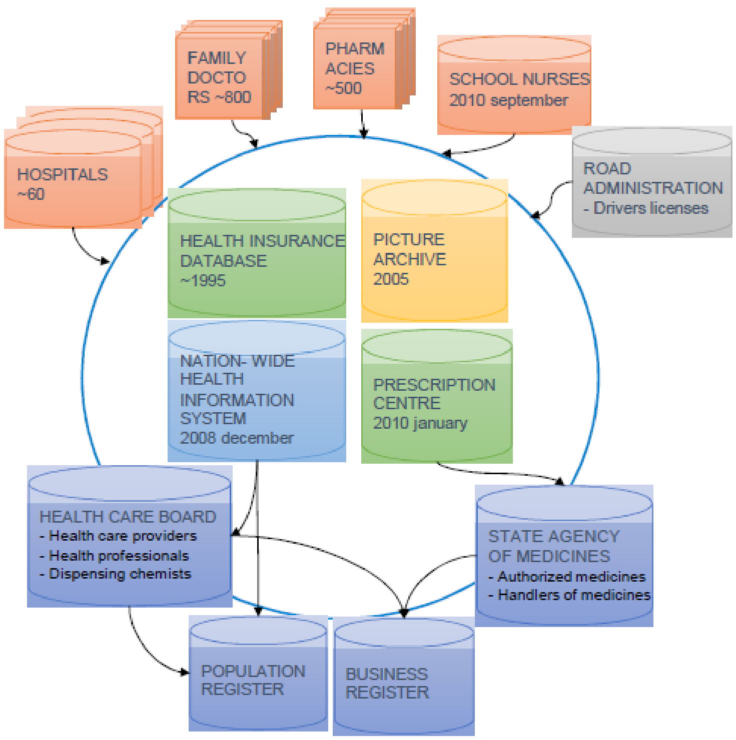



*Figure 2: High-level architecture for e-Estonia Patient Health Portal*

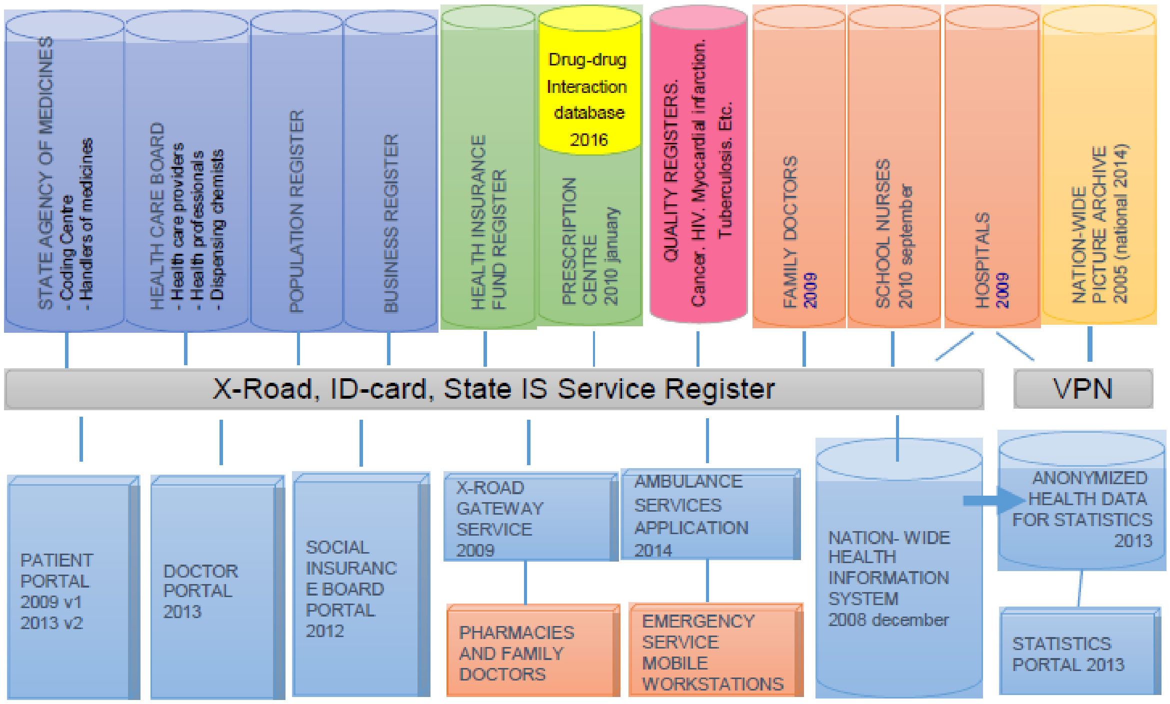



*Figure 3: High-level architecture for e-Estonia Patient Health Portal*

The Estonian Patient portal has its shortcomings which include no permissioned access as patients cannot grant or revoke access by themselves. They can only opt out the system which makes them disadvantaged as far as patient care is concerned. The electronic ID-card being used to uniquely identify a patient is susceptible to identity theft since it is publicly known to everyone. The Estonian Patient Portal does not have incentives for use by either patient or care providers. This is because it is a statutory requirement to submit data to the system, which may easily be sabotaged by patients or care providers. Lastly, in the Estonian Patient Portal, no mobile technologies are being used as everything accessed from the web portal. This is due to the fact that nearly 90% of the population have access to internet, computers and probably cheaper internet, unlike in developing countries like Kenya.

### 2.10 Case Study of Kenya National Education Management Information System (NEMIS)

The Ministry of Education of Kenya has rolled out the National Education Management Information System (NEMIS). The objective is to provide quality, reliable and timely education statistics which will be used or planning purposes. In order to achieve this, all the learners, staff and schools are issued with a unique identification. Learners are issued with a globally unique 6-character Unique Personal Identifier (UPI). The UPI will be used in their entire lifetime of the learner, in any institution and every stage of the learner's education. Schools, on the other hand, will be issued with a unique school code as well (NEMIS, n.d.).

With the implementation of NEMIS, it is the right direction in towards the unique identification of persons at early stage of their life, either for education or health. Both are basic rights for all the children in the country. Successful implementation of NEMIS UPI and other universal identification of persons will foster evidence-based decision making and planning. Monitoring and evaluation will also be effective since accurate statistics of persons is able to be collected with no duplicates or missing persons. The NEMIS is expected to be the single source of truth for education sector.

### 2.11 The National Unique Patient Identifier (NUPI)

Although the Ministry of Health are working on NUPI, this project is not duplicating effort but rather a catalyst for promoting independent growth and maturity of the various options This course of action will provide an opportunity for the competing options to mature.

### 2.12 The Kenya Health Enterprise Architecture

The Kenya Health Enterprise Architecture (KHEA) guides in system interoperability in the health sector in that it forms the basis for information exchange between players in the sector. KHEA was developed as a combination of Federated Architecture Framework (FEAF) and The Open Group Architecture Framework (TOGAF) approach in 2011 and included in the Kenya National e-Health Strategy for period 2011-2017 (Kenya National e-Health Strategy (2011-2017), 2011). The KHEA health information systems consists of several pillars as embodied in the Kenya National e-Health Strategy (2011-2017). They aim implement a shared health records though development of Client Registry (CR) that encompasses National Unique Patient Identifier (NUPI), Master Patient Index (MPI), Terminology Service (TS), Health Information Exchange (HIE), and Personal Health Record (PHR).

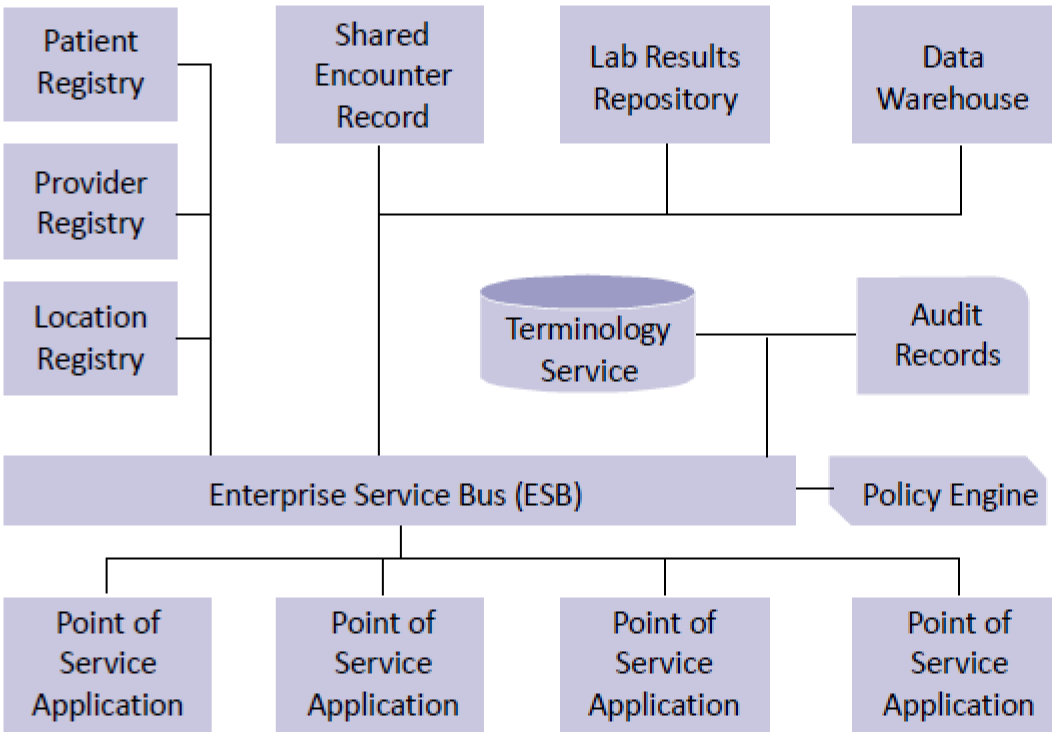



*Figure 4: Graphic Representation of an Enterprise Architecture for the health sector*

The objective of implementing KHEA is to realise a unified and integrated countrywide health information system that allows quality data sharing across levels hence improving health service delivery (interoperability). KHEA implementation is based on Service Oriented Architecture (SOA) guided by principles of shared services, interoperability standards, and security and privacy. Below is the conceptual model for KHEA:

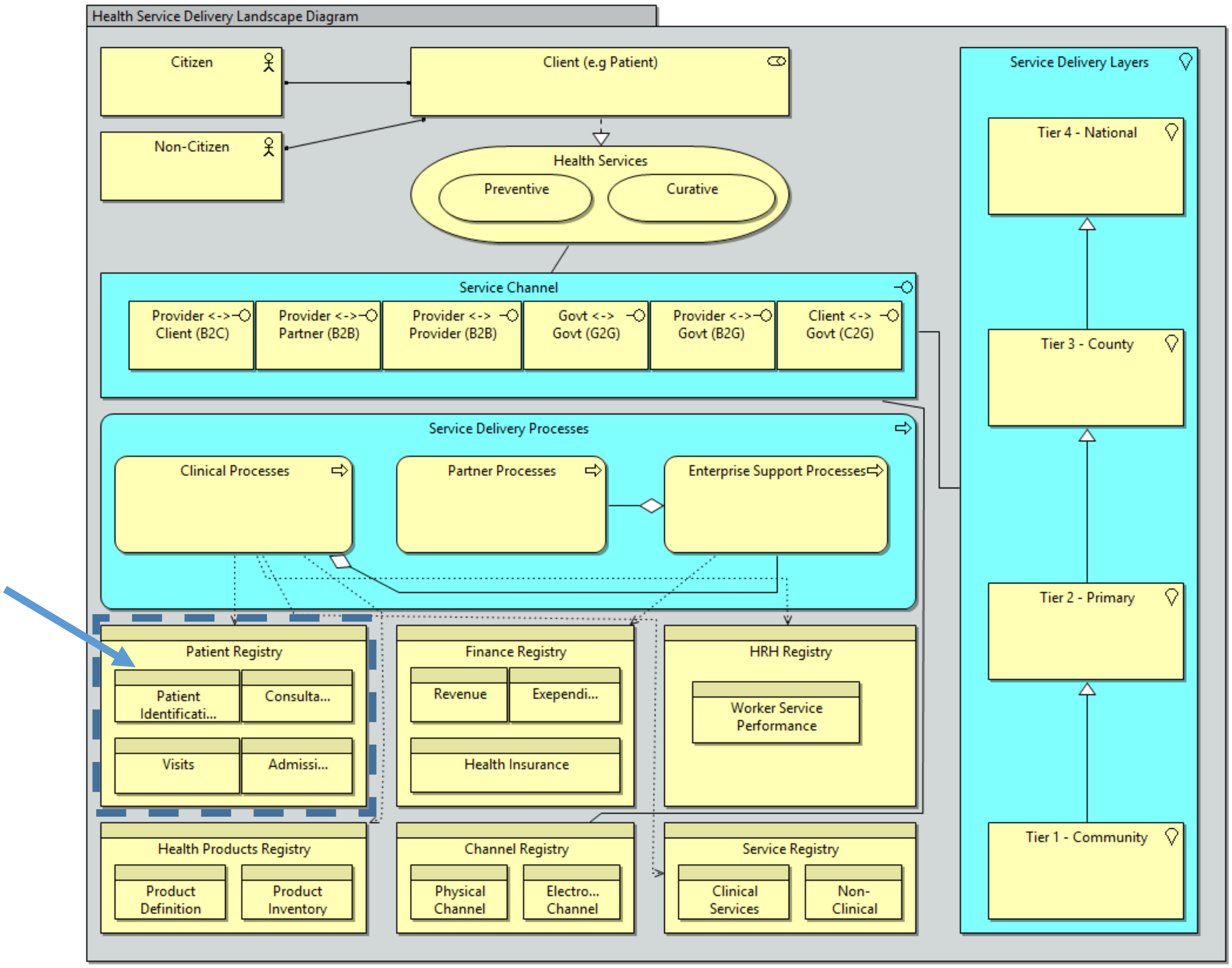



*Figure 5: The Health Service Delivery Landscape diagram for KHEA*

In the (Kenya National e-Health Ploicy 2016-2030, 2016), it recognises the need for shared health records through the development of a Client Registry that encompasses National Unique Patient Identifier(NUPI), Master Patient Index among others. In so doing the patient data will be readily available physicians and other healthcare providers. All the eHealth systems shall be linked to District Health Information Systems version 2 (DHIS2) and other data aggregators once this policy is fully implemented. Previously, summary data were available in DHIS2, but with the adoption of a universal patient identifier, it eliminates duplicate patient records and thus allowing 360 degrees view of patient medical history.

The main objective of this project is to contribute to the implementation of the Patient Registry under KHEA based on Service Oriented Architecture.

### 2.13 Privacy and Security

The HIPAA Privacy Rule protects the privacy of individually identifiable health information, called protected health information (PHI), as explained in the Privacy Rule. The Security Rule protects a subset of information covered by the Privacy Rule, which is all individually identifiable health information a covered entity creates, receives, maintains or transmits in electronic form. The Security Rule calls this information "electronic protected health information" (e-PHI) (Summary of the HIPAA Security Rule, n.d.).

Specifically, covered entities must:

a) Ensure the confidentiality, integrity, and availability of all e-PHI they create, receive, maintain or transmit;
b) Identify and protect against reasonably anticipated threats to the security or integrity of the information;
c) Protect against reasonably anticipated, impermissible uses or disclosures; and Ensure compliance by their workforce.

Patient privacy is very critical. If breached, it has legal consequences which negatively impacts patient care. Patient data confidentially is the recipe for increased willingness to sharing data. For this work, we give the patient the power to control access to their data by deciding who they want to share with or revoke access to already authorised access. The patient's identifiable information will not be stored in plain text but must be encrypted in storage and transit. For research purposes, the data is first anonymised then shared after it's being consented by the patient. As such a patient may want their data shared only for research of a certain type, or for a given time range.

### 2.14 Internet of Things

We are usually accustomed to the internet of people; now we have internet of everything. Internet of Things refers to a network of objects (things) that can sense and share information, with other objects, devices, machines through specified protocols. IoT encompasses Machine-to-Human communication (M2H), Radio Frequency Identification (RFID), Location-Based Services (LBS), Lab-on-a-Chip (LOC) sensors, Augmented Reality (AR), robotics, and vehicle telematics as it exists today (Lake, Rayes, & Morrow, 2018).

IoT devices are quickly evolving and adopted due to its characteristics such as they are typically small and inexpensive devices that are designed to operate autonomously anywhere, either in the field, embedded in other devices including the human body. IoT's ability of building "intelligence" into "things" differentiates them from the ordinary internet (Keyur & Sunil, 2016). Such characteristics make them suitable for healthcare, manufacturing, finance, agriculture and many other sectors.

### 2.14.1 IoT Characteristics

Below are the essential characteristics of IoT:

**Interconnectivity**: IoT devices can connect anything with the internet

**Things-related services**: IoT devices are capable of providing thing-related services, e.g., privacy protection.

**Heterogeneity**: IoT devices are based on different hardware platforms and networks. They can communicate with other devices in different networks using various protocols.

**Dynamic changes**: IoT devices interact closely with objects in their environment. The environment can change dynamically and as such the IoT devices' state change accordingly such as speed, temperature, sleeping, connected/disconnected, e.t.c.

**Safety**: Whereas IoT devices provide immense benefits (any data), the IoT devices should ensure the safety of personally identifiable information from unauthorised access and use.

**Connectivity**: Connectivity enables IoT devices to connect to a network device as well as consume and produce data

### 2.14.2 IoT Architecture

IoT architecture consists of interrelated layers of technologies that allow the IoT devices to communicate and exchange data. They include:

**Sensor Layer**

The sensors allow interconnection to physical and digital worlds to collect data in real time. Examples include temperature, pressure, speed, etc. The sensors are small in size, require low power and need to connectivity to sensor gateways like GSM and GPRS to transmit data to the physical world.

### Gateways and Networks

IoT sensor devices product lots of data and that it requires a transport medium to communicate and exchange the data to the digital world (e.g., a cloud server). Gateway networks include GPRS, WI-FI, GSM. The network gateways and sensors are attached to an IoT (microcontroller, a microprocessor).

### Data Management Layer

Data management service layer provides information access on a need basis. This information can be accessed from other devices such as mobile apps and web applications. It also ensures that data privacy is ensured and the data is disclosed in the correct format.

### Application Layer

This layer encompasses the end user applications such as the web, mobile and dashboard applications. The data and functionality is presented to specific consumers of the IoT data such as

Agriculture, Health Care, Supply chain, Energy, etc.

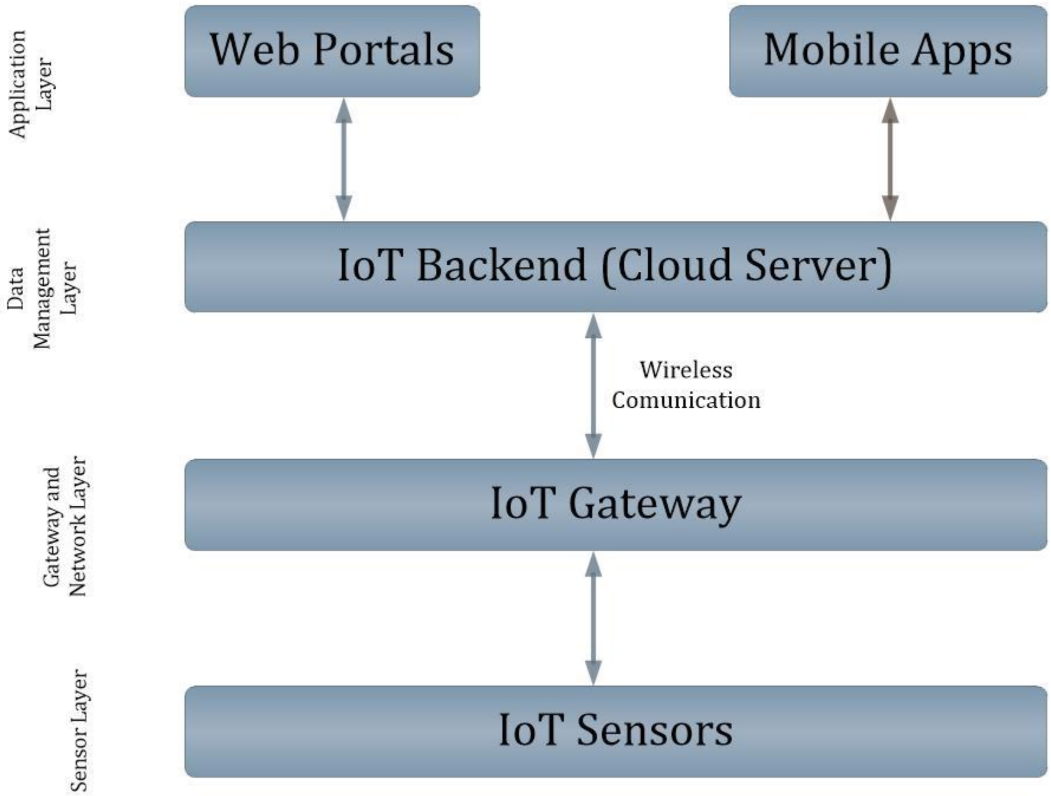



*Figure 6: IoT Architecture*

## 2.15 Service Oriented Architecture

Service-oriented architecture (SOA) is an approach to designing, implementing, and deploying information systems such that the system is created from components implementing discrete business functions called "Services" (Sonic Software Corporation, 2005) that can be distributed across geography, across enterprises, and can be reconfigured into new business processes as needed (InApp, n.d.).. It is an orchestration of services that interact with each other in servicing a business process in a client/server design approach (software services versus software consumers/service requesters). It is different from traditional client/server model in that it advocates for loose coupling of services and autonomy of services (Gartner). SOA has vital potential desirable benefits not limited to interoperability, reusability, loose coupling and protocol independence (Pulier & Taylor, 2006). According to Rosen et al. (2008), SOA divides the complex organisational environments into smaller functions called services, that are designed to do one thing hence re-usability. The services are exposed using standard Web Services using a Web Service Description Language (WSDL) that can be consumed by any programming language in any platform thus realising interoperability and protocol/platform/technology independence.

The discovery of Web Services and Extensible Markup Language (XML) has been embraced by many as a defacto integration framework. This led to the adoption of Enterprise Service Bus (ESB) which is still dominant today despite mushrooming of Micro Services. ESB uses Hypertext Transfer Protocol (HTTP) web services to expose business services to client systems while at the same time takes advantage of various existing messaging services like Java Messaging Services (JMS) for routing requests to and from disparate systems. ESB has been accepted as a single point of integration of an organisation’s business services in a service-oriented architecture (Masava, 2013).

According to Rosen et al. (2008), Service Oriented Architecture describes several aspects of services within an enterprise:

a) The granularity and types of services
b) How services are constructed
c) How the services communicate at a technical level
d) How the services are combined (i.e. orchestrated)
e) How the services interoperate at a semantic level (i.e. how they share common meanings)
f) How services contribute to IT and Business Strategy

Service Oriented architecture is characterised as:

i. Based on open standards
ii. Foster inherent reusability
iii. Foster intrinsic interoperability
iv. Emphasizes extensibility
v. Fundamentally autonomous
vi. Promotes dynamic discovery

vii. Promotes architectural composability

viii. Promotes loose coupling throughout the enterprise

ix. Supports incremental implementation

x. Services are platform independent, self-describing interfaces (XML)

xi. Messages are formally defined

xii. Services can be discovered

xiii. Services have quality of service characteristics defined in policies

xiv. Services can be provided on any platform

xv. Can be governed

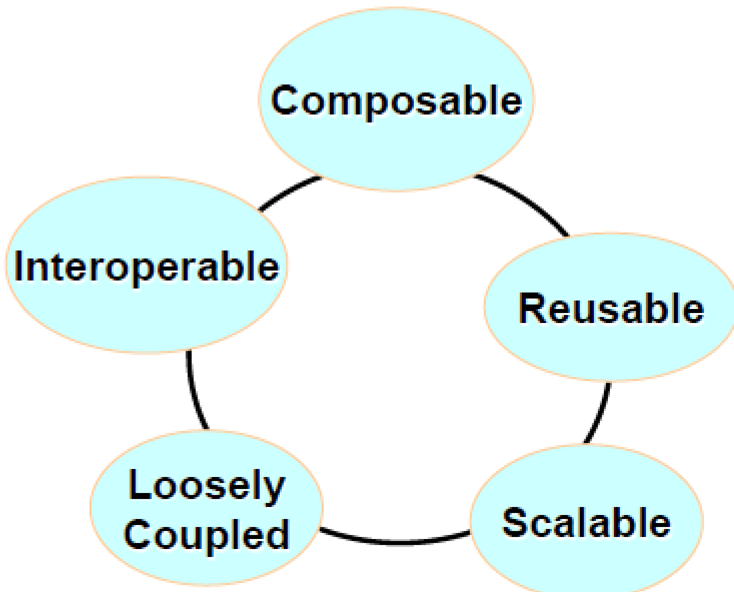



*Figure 7: SOA Characteristics*

Rosen et al. (2008) encourages the adoption of good SOA practices and patterns to rich models like Health Level Seven (HL7) and OpenEHR by creating interoperability specifications and not just integration solutions as Master Patient Index integrates data, but not workflows

SOA provides the following benefits (Rosen, Lublinsky, Smith, & Balcer, 2008):

1. Re-use of services:

   By multiple applications

2. Efficiency:

New services can be added or existing services modified into new services with a focus on data shared and not implementation.

3. Loose Coupling:

   Services independent of each other

4. Platform independence

   SOA services can be deployed and consumed anywhere regardless of hardware and software platform. This eliminates vendor lockdown.

5. Division of responsibility: -

   Business vs technology

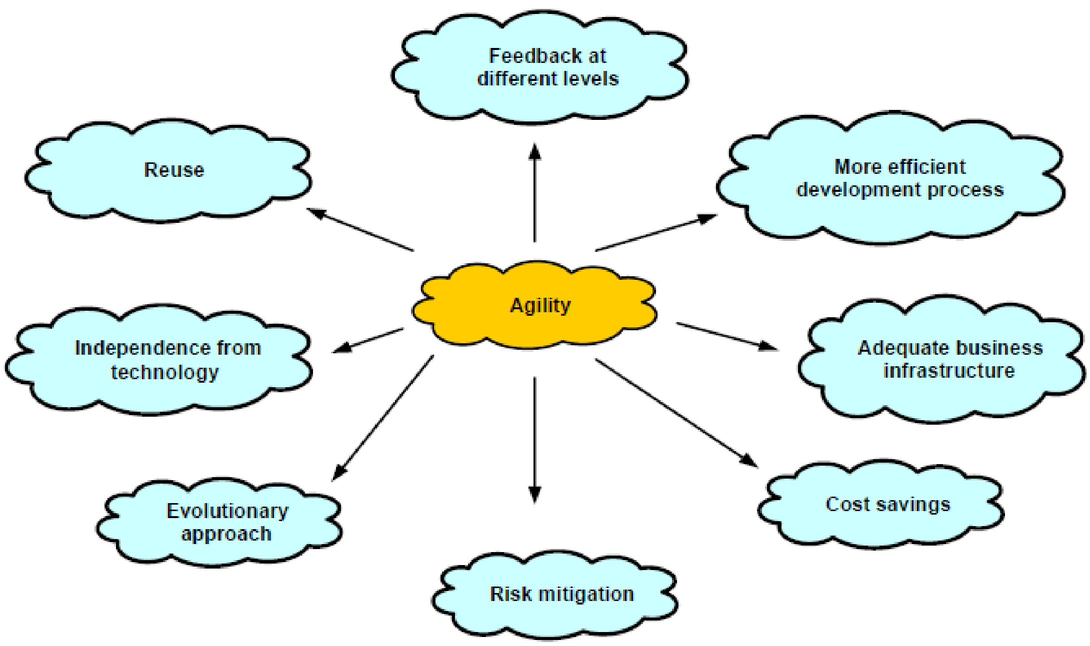



*Figure 8: Benefits of SOA (Arabinda, 2007)*

## 2.16 The proposed Omnichannel Personal Health Record System

The Personal Health Record (PHR) is an Internet-based set of tools that allows people to access and coordinate their lifelong health information and make appropriate parts of it available to those who need it. PHRs offer an integrated and comprehensive view of health information, including information people generate themselves such as symptoms and medication use, information from doctors such as diagnoses and test results, and information from their pharmacies and insurance companies. - Markle Foundation's Personal Health Working Group, Connecting for Health (2003).

This study proposes an establishment of a central patient registry responsible for maintaining a database of patient demographic information and assignment of a unique patient identifier (NMPI). Besides the patient demographic information, the central patient registry shall also store the health facility where a patient last visited. In order to achieve this solution, several systems must be able to interact with each other which include:

a) IPRS system
b) Hospitals and other healthcare facilities
c) Medical Insurance firms (optional)
d) Pharmacies (optional)
e) Physicians (optional)
f) mHealth solutions (optional)
g) Medical Laboratories (optional)

The IPRS system is currently being used by several entities predominantly financial services like banks and mobile money operators hence the capability of being used at the central patient registry is feasible.

As recommended by the American Health Information Management Association (AHIMA), below core data elements shall be used for generation of the national master patient and searching/matching patient records include:

i. Patient Names
ii. Date of Birth
iii. Gender
iv. Ethnicity
v. Postal Address
vi. Alias/previous name
vii. National Identification documents (National ID, Birth Notification, Military ID, Date of Birth)
viii. Facility identification
ix. Universal patient identifier (if available)
x. Phone number
xi. Admission date

xii. Next of Kin Names
xiii. Next of Kin identification documents
xiv. Biometric data

A matching algorithm shall be used to retrieve an NMPI (for registered patients). Deterministic and probabilistic method searches shall be employed to match exact and approximate matches when other national identification documents are not provided. The World Health Organization recommends implementation of standardised identification approaches including biometric settings (Kolly, Cleaphas, Bovier, Ganerin, & Perneger, 2004). In addition, a patient can voluntarily request their specific medical data to be uploaded to the centralized patient registry upon given write access. The patient can also upload clinical records by themselves.

At a minimum, a PHR shall contain the following elements:

i. Personal identification, including name, birth date, and Social Security number
ii. Next of kin or people to contact in case of emergency
iii. Names, addresses, and phone numbers of physician, dentist, and specialists
iv. Health insurance information
v. Living wills and advance directives
vi. Organ donor authorization
vii. A list and dates of significant illnesses and surgeries
viii. Current medications and dosages
ix. Immunizations and their dates
x. Allergies
xi. Important events, dates, and hereditary conditions in the family history
xii. Recent physical examination
xiii. Opinions of specialists
xiv. Important tests results
xv. Eye and dental records
xvi. Correspondence with provider(s)
xvii. Permission forms for release of information, surgeries, and medical procedures

## 2.17 Conceptual framework

This project will be based on the adoption of a Service Oriented Architectural design pattern (SOA) in the implementation of an omnichannel personal health record system. Service-oriented architecture is an architectural style where software resources are packaged as services to be consumed by users and other systems to meet business goals through integration regardless of state or context, device, operating system, programing language nor the location of other services (Papazoglou & Heuvel, 2007).

From the review of literature, the SOA architecture is a very popular design that has been adopted by most leading business organisations and have satisfied their critical strategic and business goals. Examples include but not limited to easy and flexible integration to legacy systems, conformance to business processes, cost reductions and ease of adding new services or innovations as need or change arises (Phil Bianco;Rick Kotermanski;Paulo Merson, 2007; Karimi & Modiri, 2011). Karimi (2011) posits that prior developing SOA services, the first activity is to model the services to realise high quality and flexible system that adapts to future changing business requirements which include re-usability, loose coupling, service discovery, abstraction, autonomy, (Nadhan, 2004). Similarly, Gartner proposes that while planning for SOA, one should think strategically and tactically.

### 2.17.1 SOA Concept Model (Architecture)

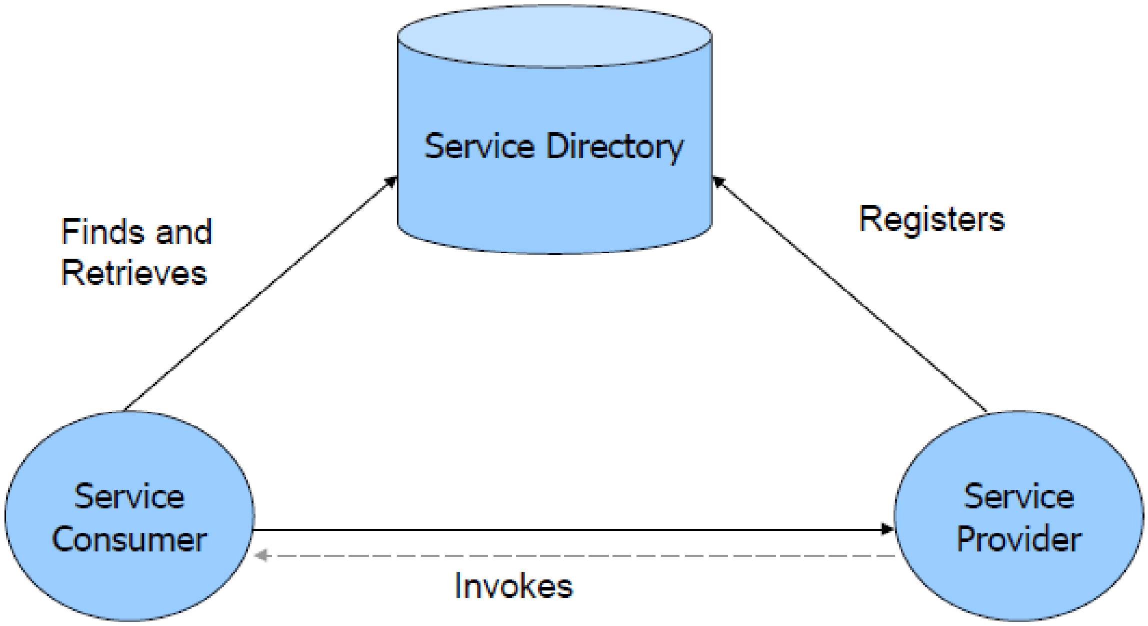



*Figure 9: SOA Concept model*

In a Service Oriented Architecture, the business functions are packaged into services which are consumed by client systems as Webservices. The service provider must first register the service in a service directory. The service consumer will search for the business service in a service directory, bind and then invokes the web service provider's endpoint address.

SOA consists of below primary components:

a) Service Provider

   The service provider is a service that handles a service consumer's request. When invoked, it executes the client requests and provides a result. Service provider must be published to be discoverable to service consumers

b) Service Consumer

   The service consumer is a client application that requires a service. It has to first locate the service provider by searching the service directory, bind to the service endpoint and send a request to the service provider in the format specified in the contract. The consumer can use the uniform resource identifier (URI) for the service description directly as a RESTful service call.

c) Service Directory

Service directory is a registry located within the network that contains the services. Service providers publish (register) services to the service directory, so that is easily discoverable (find and retrieve) by the service consumers.

d) Service Contract

A service contract is a specification of the way a service consumer of a service will interact with a service provider by specifying the format of a request and response.

e) Service Stub

A service stub serialises the operation and parameter into the body of a SOAP web service request to the service provider and deserializes the response from the service provider.

In the below diagram, it shows how the various SOA components interact with each other while a service request is being executed:

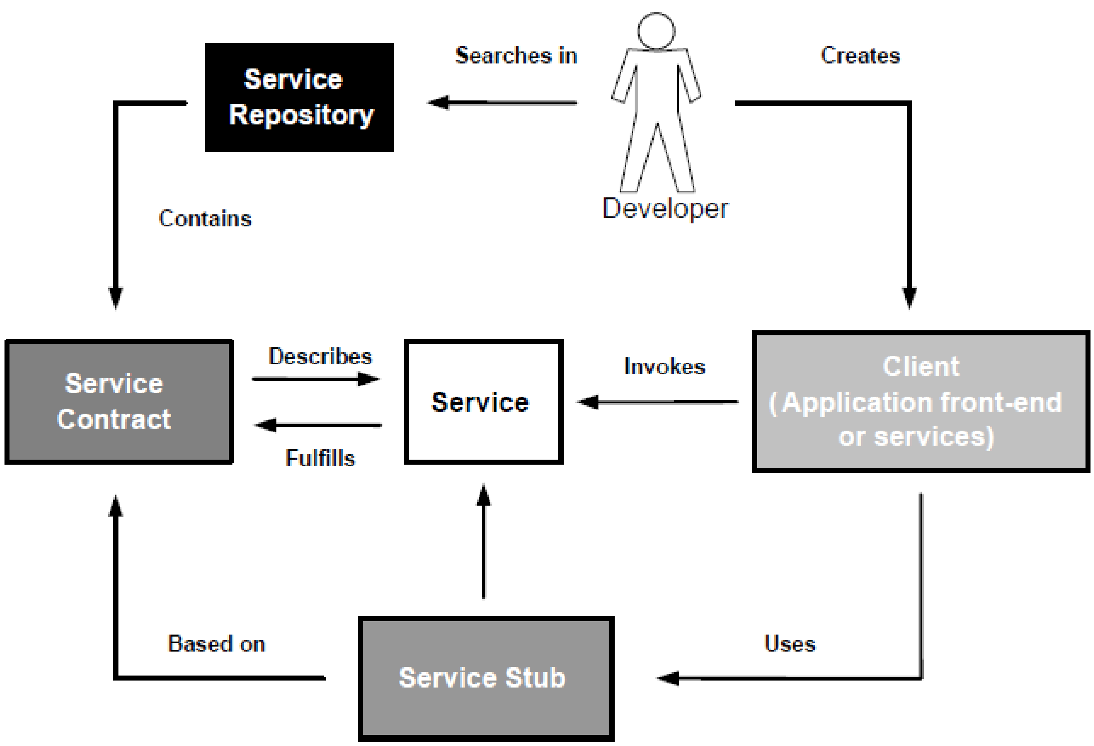



*Figure 10: SOA Components*

### 2.17.2 SOA Methodologies

There are several SOA methodologies currently available. In this research study, we are going to review the below three popular methodologies and choose the most appropriate methodology for implementing the centralised patient registry:

i) Michael Rosen et al. SOA implementation methodology.
ii) Thomas Erl's Evaluation Mainstream Service Oriented Methodology (MSOAM).
iii) IBM's Service Oriented Modelling and Architecture (SOMA).

#### *2.17.2.1 Michael Rosen et al. SOA implementation methodology.*

This SOA methodology as designed by (Rosen, Lublinsky, Smith, & Balcer, 2008) has below activities in the implementation of SOA:

i) SOA reference architecture

   It is the first step in defining SOA reference architecture aspects which include: -

   - Service name
   - Service types
   - Service relationships
   - Service processes

ii) Business architecture definition

   This step involves the definition of the enterprise business architecture for the business.

iii) Service identification

   Involves listing of all services (service inventory) that will support the enterprise.

iv) Semantic information model definition

   Shared semantics between interoperating systems are modelled in this step.

v) Service specification

   Service interface and contracts are modelled at this stage.

vi) Service realization

   Involves actual design and implementation of the services.

vii) Implementation of the SOA

   High-level business architecture and specific services are built first then the implementation of generic services follow later.

#### *2.17.2.2 Thomas Erl's Mainstream Service Oriented Methodology (MSOAM).*

According to (Erl, 2005) the MSOAM methodology is focused on definition and discovery of service collections (service inventories), and definition and delivery of individual services through the below lifecycle:

(i) Business Modelling
(ii) Service Oriented Analysis
(iii) Service Contract Design
(iv) Service Logic Design
(v) Service Development
(vi) Service Testing
(vii) Service Deployment
(viii) Service Governance

The limitation of the MSOAM is that it expects business modelling tasks to be completed before developing specific services. The documentation of this methodology is not openly available hence difficult when used for analysis. The application of this methodology in the industry is not yet been accepted nor popular, unlike other methodologies.

#### *2.17.2.3 IBM's Service Oriented Modelling and Architecture (SOMA).*

Service-oriented modelling is a phase-oriented process for modelling, analysing, designing, and producing a SOA that aligns with business processes and goals (Arsanjani, 2004). SOMA was developed by IBM to guide the design and building of SOA-based application. It consists of seven phases which include:

i) Business modelling and transformation
ii) Solution Management
iii) Identification,
iv) Service Specification,
v) Realization,
vi) Implementation
vii) Deployment, monitoring and management.

The SOMA phases are described in detail as below:

**Phase 1: Business modelling and transformation**

This stage identifies the tasks (e.g. introduction of a new system) and parties (owners and users) within a business workflow.

**Phase 2: Solution management**

SOMA has solution templates that consist of a set of tasks, roles and guidance which vary from situation to situation.

**Phase 3: Identification**

In this phase, services, components and flows are identified using techniques like Goal services modelling, Domain decomposition and Asset analysis.

**Phase 4: Service specification**

The detailed specification of the services (messages, service operations, service input and output) is provided in this phase. For each service and component, the design is described and contains information about the messages, the service operations, the service input and output. These are usually gathered in use-case, services-case and component diagrams. Moreover, a service context diagram is created containing details about the interaction between services, the providers, the consumers and the back-end system supporting the services.

**Phase 5: Realization**

Technical feasibility exploration and a more detailed description of SOA layers are performed in this phase. Arsanjani et al (2008) defines the technical feasibility exploration as “a way of assessing, planning, and implementing key prototypes that exercise the architectural constructs outlined in the realisation decisions and that have the highest potential of impact and risk to the nonfunctional (operational) requirements of the SOA-based solution”.

**Phase 6: Implementation**

Implementation depends on the chosen solution template. This phase is ended with various types of tests such as unit testing or integration testing.

**Phase 7: Deployment, monitoring and management**

The last phase consists in the deployment of the services in the production environment. As soon as this takes place, another set of tests mostly concerning user acceptance are conducted. The management and performance monitoring of services are on-going processes.

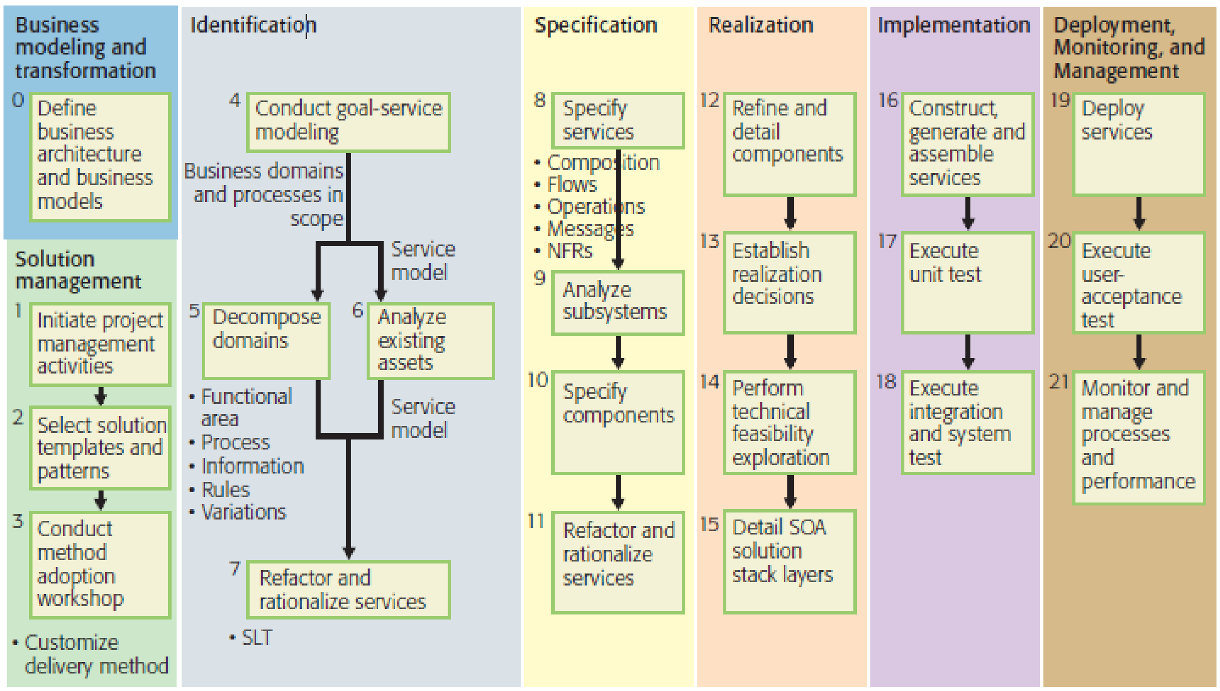



*Figure 11: A method for developing service-oriented solutions (Arsanjani et al, 2008, SOMA*

The researcher chose Service Oriented Modelling and Architecture (SOMA) to model the business services in the implementation of the Omnichannel Personal Health Record System as a guiding methodology due to its immense benefits over other reviewed methodologies below:-

i) Meet-in-the-middle delivery strategy

   Allows incorporating SOA design principles into business analysis before integrating Web Services technologies into technical environments

ii) Supports full SOA lifecycle

   Including planning, analysis and design, construction, testing, deployment, and governance.

iii) Granularity of services

Using techniques such as goal-service modelling, service model creation, and service litmus.

iv) Documentation

The SOMA documentation is easily available to the public.

v) Agile/Flexible

SOMA encourages agile approach to SOA services development hence flexible.

vi) Reusability

SOMA encourages using existing proven processes in SOA implementation through templates.

iv) Popular

SOMA has been used widely as a SOA methodology by large sectors such as finance, healthcare and telecommunication.

Whereas SOMA has been successfully used in several projects and is based on a well-known process, it is a complex methodology which requires producing a large volume of documentation and using many tools. For this project, the advantages are more than the limitations and so its is adopted as preferred methodlogy.

# 3 RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter describes a step by step process of implementing the Omnichannel Personal Health Record System based on SOA architectural style. Information technology product design and development research strategy was employed whereas Service Oriented Modelling and Architecture (SOMA) phases were used to model, identify, select, implement, deploy and monitor the services in the

Omnichannel PHR solution.

## 3.2 Research strategy

Information technology product design and development research strategy were used. At the end of this research study, a working software prototype (artifact) was developed which is the Omnichannel PHR system based on SOA.

## 3.3 Research design

Methodology describes the outline of solving a problem using specific components which include phases, tasks, methods, techniques, and tools to be used. In order to develop and implement the services for the Omnichannel PHR solution, IBM's Service Oriented Modeling and Architecture (SOMA) phases were followed. The SOMA phases described in the literature review section are listed below in the context of implementing the Omnichannel PHR solution: -

- i) Business modeling and transformation
- ii) Solution management
- iii) Service identification
- iv) Service specification
- v) Service realisation
- vi) Service implementation
- vii) Service deployment, monitoring, and management

First, a business model was defined, along with a set of templates for each of the possible integration solutions. There after, the Omnichannel PHR services were identified and included in the solution architecture as required. The services were refactored, rationalised and specified as part of a SOA architecture while others were deferred for later implementation (out of scope of this research project). Finally, the critical services were selected as per need and priority, implemented, deployed and monitored. As soon as the web services were designed and developed, the database was designed, and the channels were developed (mobile application, web portal and temperature monitoring device), and they consumed the deployed web services.

### 3.4 Study area and Sample design

The research focused on solving interoperability of patient data across healthcare facilities by rolling out an Omnichannel PHR which will validate patient demographic information against IPRS system, store and generate a National Patient Master Index (NMPI) alongside patient EMR data. It was piloted at the Kenyatta National Hospital which is located in Nairobi County. Nairobi County was chosen due to the high population density hence the number of patients is higher.

Purposeful sampling was used to select patients or individuals for study. This method is suitable in that participants will be chosen according to the need of the study.

The respondents were requested if they are willing to partake in the research exercise. If so, the questionnaires were shared with them electronically.

Healthcare professionals were also given the questionnaires. In addition to questionnaires, some of the healthcare personnel were nominated for an oral interview as follows:

| **Department** | **Target Population** |
| --- | --- |
| ICT | 1 |
| Reception/records office | 1 |
| Physicians | 1 |
| Emergency | 1 |
| **Total** | **4** |

*Table 1: Interview sample space*

The participants were asked to determine if they are familiar or used a PHR was useful to them, and if so, they were also asked about the aspects of a PHR that could be important in patient centric care. The sampling frame for the health providers included one healthcare provider in Nairobi. It also included all patients and identified caregivers from hospitals and clinics. A total of 120 electronic questionnaires were shared with patients, individuals and healthcare professionals via email and social media channels (WhatsApp) link.

The features that were identified in the survey were used to develop the PHR that best fit the needs of these stakeholders. The services were modeled to support the PHR services. The purpose of the questionnaire was described in the introduction section (and email), which also requested the respondents to complete the survey and to answer questions about their current challenges pertaining data sharing across facilities, the perception of the potential use of PHR solution and probable features.

## 3.5 Data Collection Tools

The research study used both qualitative and quantitative methods discussed below. The consent of respondents was sought in advance before collecting data from them by briefing them of the objectives and their respective roles in this research. Formal approval was sought from the university and health facility professionals.

**i) Secondary Data (Document review)**

The literature informed on the choice and use of the research model, that is SOA architectural design and SOMA methodology.

**ii) Interviews**

The physicians and technical healthcare workforce and technology experts were interviewed on the challenges of patient identification, interrogating or searching for patient medical history. The respondents were also asked about the current mitigation strategies and their drawbacks as well as far as their opinion on adoption of the master patient index as universal patient identification and a personal health record for sharing data between patients and healthcare personnel. The structured interviews were preferred since it saves time as instant feedback is received and any ambiguity was to be resolved or questions clarified immediately. The limitation is that it may be costly. However, few key participations were chosen for the interview.

**iii) Questionnaires**

Patients, physicians and technical experts were given structured questionnaires since it is the most used data collection tool, cheap to administer, also timesaving. The self-administered questionnaire was shared with the respondents to understand their perceptions of the use of PHR for patient care and the importance of National Master Patient Index in health care. Prior administration of questionnaires, it was piloted by experienced researchers and a small set of other respondents in health facilities, medical insurance organisations, and the public. The questionnaires were administered online using Google Forms for ease of distribution and also aid in the analysis as the responses were stored in electronic format.

## 3.6 Data processing and analysis

The data from the questionnaires were first cleaned by proofreading. The responses were exported into a spreadsheet (Google Forms). The data collected was secured in that no one can access the responses as long as they do not have credentials to the Google drive. The data were analysed as text using Statistical Package for Social Science (SPSS). Qualitative data from questionnaires and oral interviews were coded and entered into SPSS, which has extensive data handling capabilities. Mean, mode, median, percentages and variance shall be calculated using excel.

## 3.7 Data Presentation

The analysed data were presented using descriptive statistics such as percentages, frequency tables, graphs and pie charts.

## 3.8 Proposed prototype

In the reviewed architecture, it was proposed that a universal patient identification is crucial in the continuity of patient care by aiding the physicians through the use of patient medical history. Since the centralised patient registry will be accessed by a multitude of healthcare and medical insurance providers in disparate locations, SOA architectural design pattern is preferred to address the scalability, loose coupling, and platform independence and location transparency. Use case diagrams will be used to design the prototype to model the interacting systems in a seamless integration end-to-end.

The prototype was designed using open source technologies such as: -

i. Java Enterprise Edition (Java EE) programming language,
ii. HTML5 and JavaScript technologies for user interface design,
iii. Tomcat Enterprise Edition (TomEE) application server,
iv. MySQL community edition database,
v. Jasper reporting tools,
vi. Linux Operating System (Ubuntu),

vii. Netbeans Integrated Development Environment (IDE)
viii. Cross-platform Mobile Applications
ix. Arduino Mega 2560 Board, Ethernet LAN Network and LM35 Temperature Sensor

The Omnichannel PHR was integrated with existing Integrated Population Registration System (IPRS) as an extra layer of patient validation to prevent identity theft and also ensuring there are no duplicates in the registry. The individual hospitals and other healthcare providers shall integrate to the centralised patient registry to look up NMPI if existing or generate it if it is a new patient. The patients themselves could sign up using the mobile application, USSD or Web portal. The solution allows update of patient demographic information, e.g. new hospital visits, biometric information (if not captured previously) by healthcare staff and patients themselves. All system interactions were timestamped and logged for use by the system owners and patients.

## 3.9 Evaluation

After the prototype was been developed, it was tested on the system goals such as performance, scalability, high availability as well as evaluating whether it met the functional requirements.

## 3.10 Summary of methodologies used

| **Objective** | **Methodology** |
|---|---|
| To understand people's perception of personal health record system in mitigating current healthcare data sharing (interoperability) between different healthcare facilities. | Questionnaires, interviews |
| To identify the current mechanisms of identifying patients in health facilities and alternatives for universal patient identification. | Questionnaires, interviews, document review |
| To develop SOA architectural model and prototype for the proposed Omnichannel PHR System. | Service Oriented Architecture and Modelling to come up with the proposed architecture and list services.<br>Agile Software Development to develop patient/physician portal, patient mobile application and backend services to support the application requests |
| To test the developed Omnichannel Personal Health Record | Share prototype system and administer survey with selected experts, patients and health care personnel. |

*Table 2: Summary of Methodologies*

# 4 SYSTEM ANALYSIS, DESIGN, IMPLEMENTATION AND TESTING

## 4.1 Introduction

This section presents the proposed prototype of the Omnichannel PHR system for maintaining patient demographic and electronic medical record information. The patient was uniquely identified by a National Master Patient Index (NMPI). The system's overall goal is to allow patients to opt in/out voluntarily (register or deregister), store medical records centrally and control who, how and when an interested party accesses their information through a mHealth mobile app or a web portal.

The Omnichannel PHR web services was designed and implemented using the Service Oriented Architecture and Modelling Methodology phases described in the literature review and methodology section.

## 4.2 Overview

This represents the actual input and output processes of the system. The Omnichannel PHR was implemented based on Service Oriented Architecture (SOA). The registration, lookup services, amongst others were exposed and or integrated to external systems via RESTful Web Services depending on the peripheral client system. End users (patients) will access the system via both the mobile application and web portal whereas the system administrators and physicians (healthcare personnel will access the PHR system through a web portal.

## 4.3 System Analysis, Design, Implementation and Testing

The database and third-party integrations functionalities were exposed via REST APIs to end-user applications and web interface. These services were hosted on Tomcat Enterprise application server. Representation State Transfer (REST) APIs were chosen for this project over Simple Object Access Protocol (SOAP) as was lightweight, produces human readable results and easy to build as no toolkits required. The message formats were in JavaScript Object Notation (JSON). However, the backend applications were able to support the various client protocols and message standards which can be continuously added or removed over time. Thanks to Service Oriented Architecture and Modelling (SOMA) and agile software development methodology.

Below is a high-level representation of the solution:

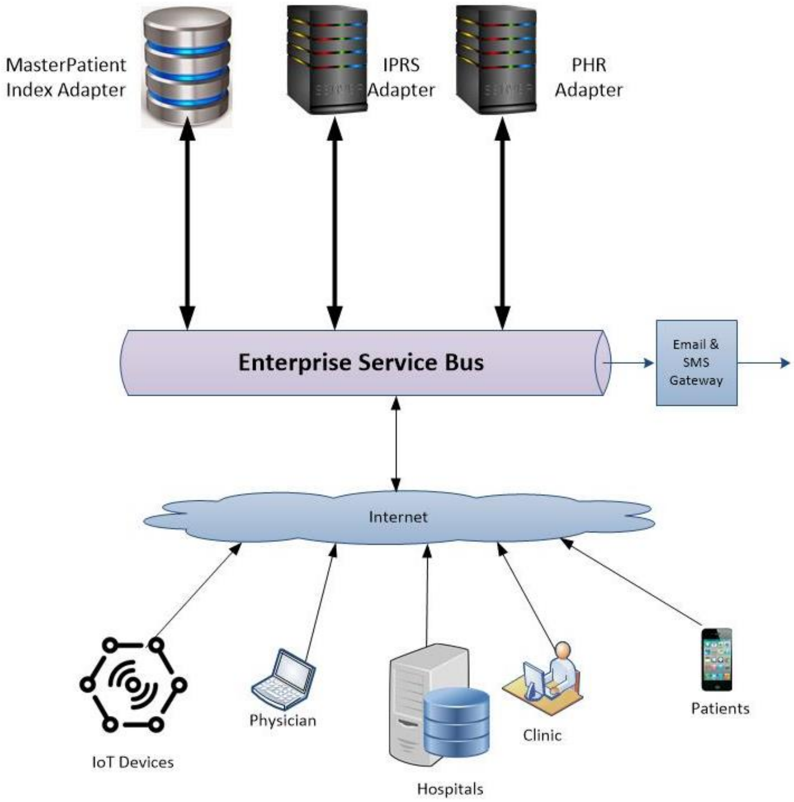



*Figure 12:High-level representation of the solution*

Below are the steps for modelling the services using SOMA phases:

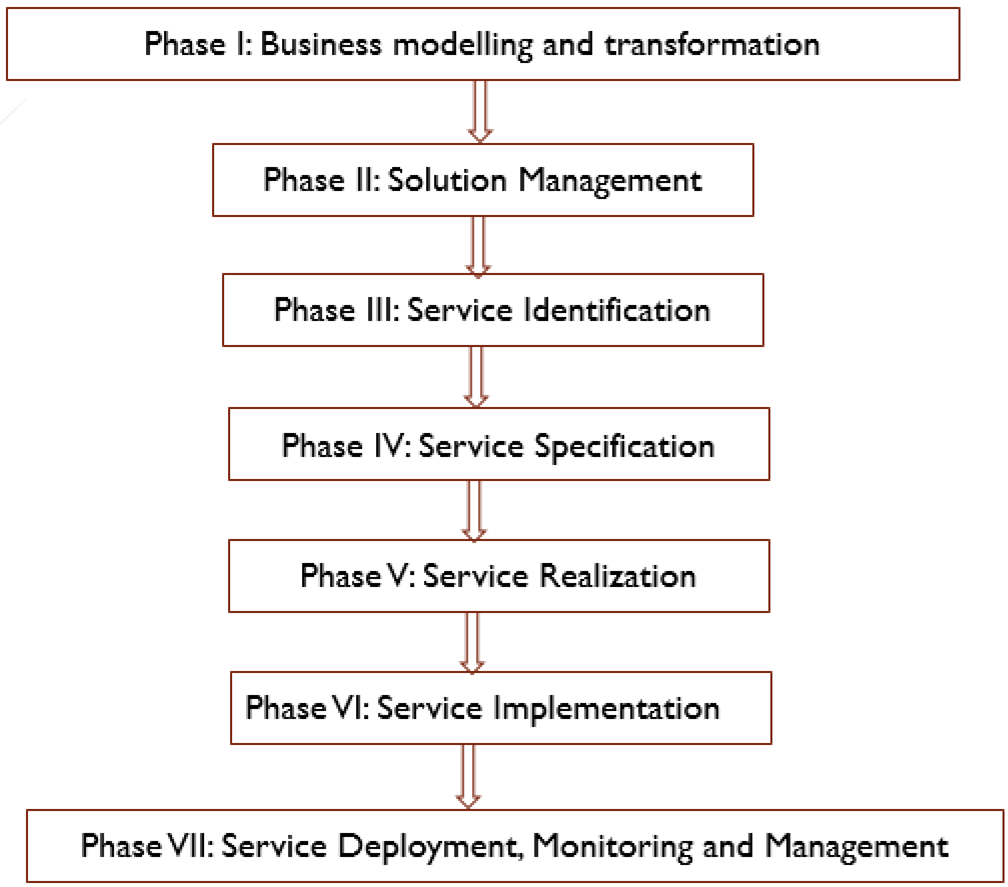



*Figure 13: Service Oriented Modelling and Architecture*

### 4.3.1 Phase 1: Business modeling and transformation

This stage identifies the tasks and parties (owners and users) within a business workflow. The business is modeled, simulated and optimise whilst a focal area is transformed. The main tasks were the system functional requirements. As part of the system analysis, the researcher administered questionnaires to patients (individuals), health professionals and technology experts. The researcher went ahead to interview some of the healthcare personnel at various levels in one of the hospitals in Nairobi. Based on the feedback received from the study respondents, it was evident that there are challenges in the universal patient identification, limited patient data sharing and interoperability bottlenecks. Although patients own mobile devices, most of them do not use them for managing medical related information, many are willing to use PHR on several channels like web browser, mobile phone app, as well as direct EMR system implementation.

As a result, Service Oriented Architecture was chosen for integration all the channels in exposing the required services to be accessed by patient and healthcare personnel. This greatly reduces the reliance on paperwork which are not presented to patients after treatment or are not readily portable for the client whenever they seek medical attention.

### 4.3.2 Phase 2: Solution management

SOMA has solution templates that consist of a set of tasks, roles and guidance which vary from situation to situation.

#### *4.3.2.1 Solution scope*

The scope of the solution was the implementation of backend web services, development of a web portal and a cross-platform mobile app.

#### *4.3.2.2 Solution features*

**Implementation goals**

The service-oriented architecture was chosen for implementation of the Omnichannel Patient Health Record system. The following goals were expected at the end of this study:

i. Interoperability
ii. Reuse of services
iii. Ease of use, simplicity and navigation (usability)
iv. Security and privacy
v. Omnichannel (Mobile and Web)
vi. Audit trail and logging
vii. Anonymized data, high quality
viii. User-generated data – Self-service data entry
ix. Compliance with legal mandates – HIPAA, ERC, ICT Act

**Functional specs and functional requirements**

i. Ability to register patient in the Omnichannel PHR using the popular channels (Web, mobile) by patients themselves, by healthcare personnel on Web portal or automatically using IoT equipment.
ii. Ability to add or update medical data by patients or healthcare personnel.

iii. Ability to provide reliable access to the medical data based on preset permissions by patients.
iv. Ability to ensure utmost security, privacy and confidentiality of the patient data.
v. Ability to ensure high availability and performance of the solution even in extreme conditions like network coverage or partial system downtime.
vi. Ability to offer additional benefits and added value to effectively compete with existing mHealth, EMR, NMPI and other systems.

#### *4.3.2.3 Solution components*

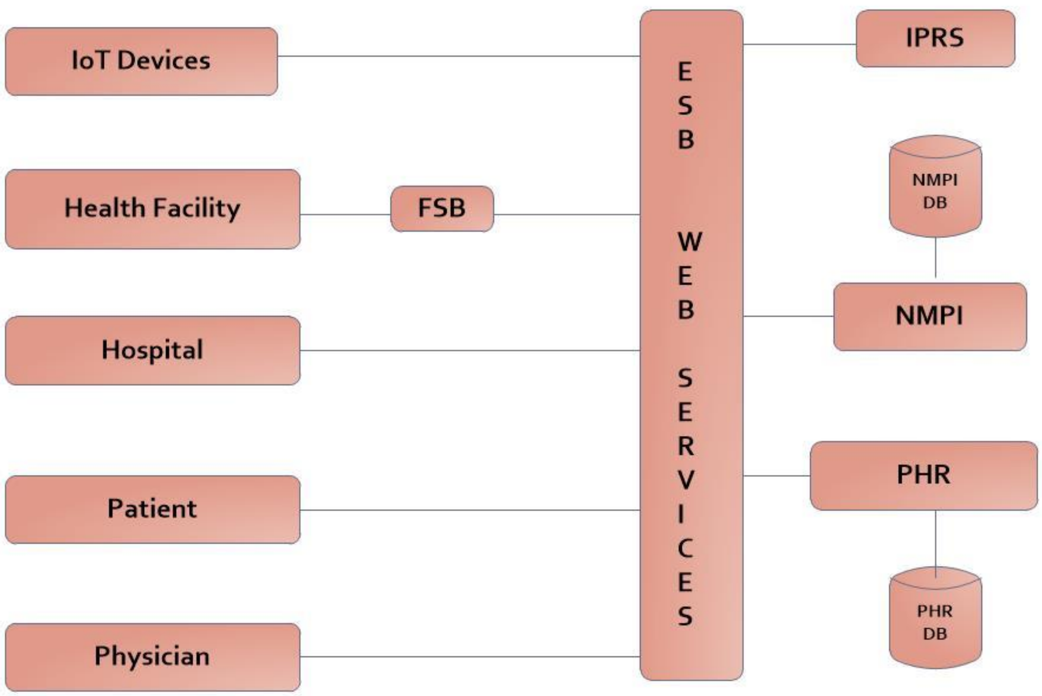



*Figure 14: PHR Solution Components*

**Enterprise Service Bus**

The ESB acts as the routing engine that dispatches requests to their destination, that is, the appropriate service or application running such as Master Patient Index Adapter, CDS, IPRS Adapter, Notification Adapter, etc. It allows peripheral systems such as the mHealth apps, Web Portal and healthcare systems access services and other systems. The SOA allows the interfacing of such systems without having to connect directly to each other. It was deployed as a central dispatching system whereby all the other end systems only need to exchange messages with the ESB, and the ESB knows where to route the messages to the other systems. The ESB exposes various services are rest endpoints. Data exchange is via JavaScript Object Notation (JSON) messaging format.

**EMR Data Store**

The EMR Data store stores clinical documents and makes them available on request. It uses a MySQL database that consists of several tables. The data to be stored include:

i) Allergies
ii) Immunizations
iii) Known Illnesses
iv) Family medical history
v) Disorders
vi) Prescriptions
vii) Radiology images
viii) Lab tests and results

**National Master Patient Index Registry**

The National Master Person Index (NMPI) Registry maintains a database of person identities and allows operations on the person index using. It uses a MySQL database that contains person entries with demographics and multiple identifiers for a person, such as names, date of birth, fingerprints, race, etc.

**IPRS Adapter**

The Integrated Population Registration System (IPRS) was used to validate the demographic information of all the registered residents in Kenya. IPRS integrator is the web service client that will consume the IPRS system API.

**Notifications Adapter**

The notifications adapter is responsible for sending alerts to system users. There are two types of alerts: short message service (SMS) and electronic mail (email). Patients, physicians and administrators will receive below types of notifications

i) Registration success

ii) One time password verification code

iii) Profile Access hits

iv) Password reset notification

### 4.3.3 Phase 3: Service Identification

In this phase, the services, components and flows will be identified using goal service modeling technique.

| Goals | KPIs | Metrics | Services |
|---|---|---|---|
| Enable universal registration of patients | Percentage of patients registered against target patient population | Number of patients registered in the OmniChannel PHR solution | Signup service |
| Enable patients update their profile | Percentage of patients with up to date profile | Number of patient profile updates in the OmniChannel PHR Solution | Profile management service |
| Enable accurate identification of patients | Percentage of patients accurately identified against the total number of patients served | Number of patients accurately identified using the OmniChannel PHR solution | Search Patient service |
| Enable patients to share their information with physicians | Increase patient confidence in sharing their profile information to specific healthcare personnel | Number of patients who have shared their profile with physicians | Profile sharing service |
| Enable complete view patient profile, past illness, past medical history by physician with patient consent | Increased usage of PHR system for medication by physicians | Number of patients who have been successfully treated based on their medical history | View Permissible records |
| Enable patients record their generic medical characteristics | Percentage of patients with up to date medical information against the total registered patients | Number of patients with up to date general medical records | Generic data management service |
| Enable physicians record patient | Number of patients who have recorded their medical tests | Number of patients with medical treatment records | Diagnosis management service |

| | | | |
|---|---|---|---|
| diagnosis, xray, prescriptions, etc | and treatment in the system against all active patients in PHR system | | |
| Enable authentication of patients and physicians accessing the PHR system irrespective of channel | Percentage of authenticated users against all login attempts | Number of authenticated users in the System | Login Service |
| Enable patients opt out of the PHR system | Number of patients who have deactivated their accounts against the total number of Registered patients | Percentage of patients who have opt out of the PHR system | Account deactivation Service |
| Enable onboarding of health facilities, physicians, administrators and other systems | Percentage of registered health facilities in the PHR System against a the | Increased number of participating entities in the PHR system | User/system management service |
| Enable system parameter configurations | Number of configurable parameters in the PHR System | Increased system scalability | Parameter setup service |

*Table 3: Service identification using goal-service modeling technique.*

### 4.3.4 Phase 4: Service specification

The detailed specification of the services (messages, service operations, service input and output) were provided in this phase. For each service and component, the design is described and contains information about the messages, the service operations, the service input and output. These were gathered in use-case and component diagrams. Moreover, a service context diagram was created containing details about the interaction between services, the providers, the consumers and the back-end system supporting the services.

| **Name of Service** | **Description** | **Required interfaces** | **Dependency** |
|---|---|---|---|
| Patient Signup | This web service is used solely for registering new patient details. The request will be received by health facilities' consumer web service and various validations will be applied according to the business logic. | Integrated Population and Registration Service (IPRS) | Verification of ID details will depend on IPRS |

| | | | |
|---|---|---|---|
| Children Signup | Parents can sign up their children who are under age of eighteen. | | |
| Search patient | Patient information can be looked up using the NMPI besides the demographic information using this service | | |
| Update patient | Health facilities can populate additional information of patient not captured previously, for example biometric information using this webservice | | |
| View Permissible records | Physicians can view the authorized medical information for a particular patient. | SMS or Email Gateway service for delivery of authorization token if fingerprint capture is absent | SMS or Email Gateway |
| Diagnosis | Physicians and/or Patients can upload medical diagnosis information into the personal health record. | | Patients must give write access to physicians |
| Login Service | All system users (patients, physicians and system administrators) must be fully verified before accessing any service. | | Participants must be enrolled to the system to login. Patients can sign up themselves and/or their children |
| Consent management service | The consent management service gives patients the mechanism to share their specific medical information to a particular physician within a certain period. | | The patient must have signup with at least one medical record information |
| Deactivate profile | This service allows the patient to delete their profile and corresponding data. The patient may decide not to erase the non-personally identifiable information for the purpose of future use by researchers and other interested parties like Ministry of Health. | No interfaces required. | Patient must have signup for the PHR service |

*Table 4: Service specification listing*

### 4.3.5 Phase 5: Realization

Technical feasibility exploration and a more detailed description of SOA layers were performed in this phase. A SOA reference architecture was drawn. The layers were then instantiated alongside the SOMA phases of service identification, specification and up to service realisation. It provided a dashboard view of the artifacts that were produced. It covered all aspects of SOA development including the governance. Figure 15 shows the instantiation of the SOA reference architecture for the Omnichannel PHR Solution.

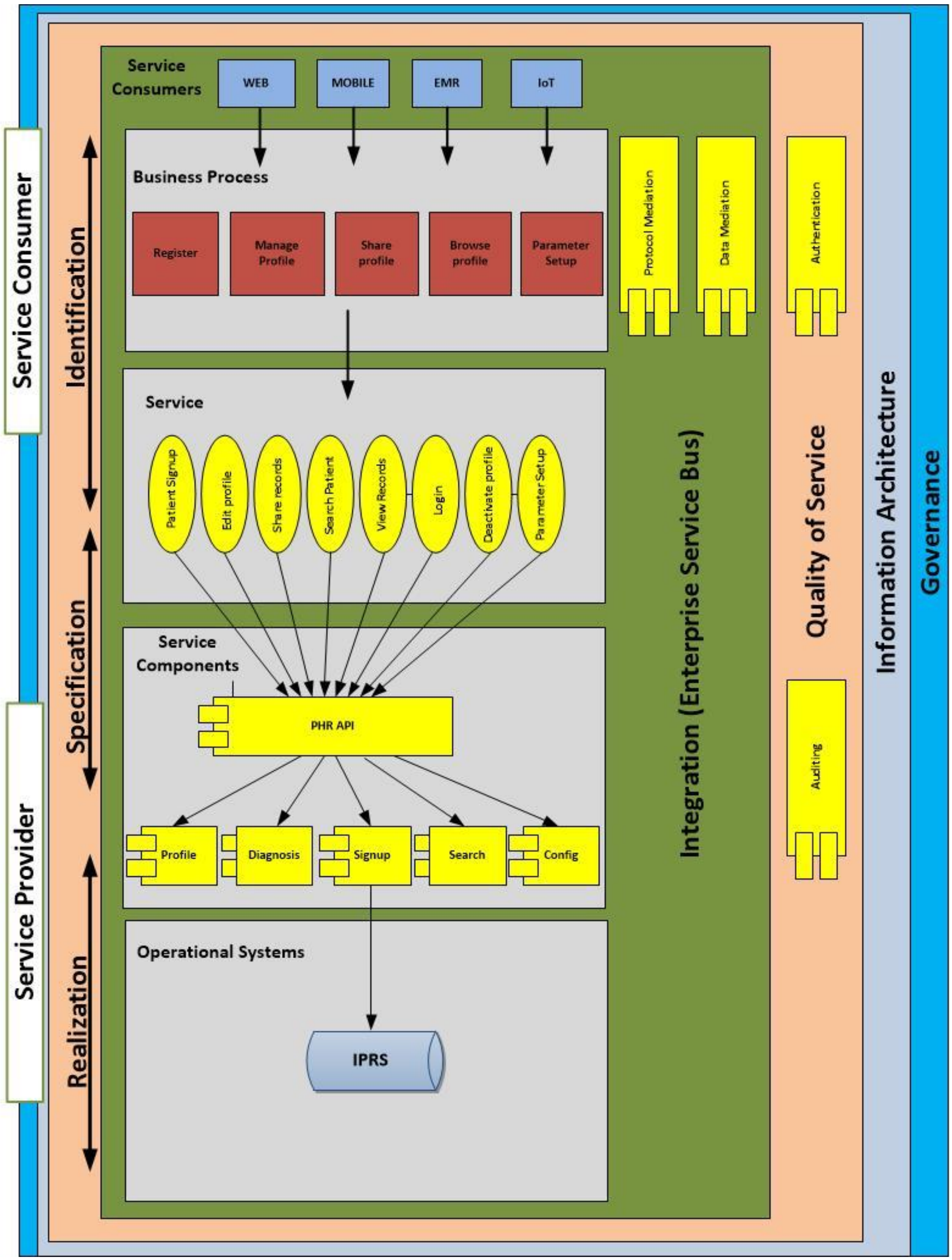



*Figure 15: Instantiation of the SOA reference architecture for Omnichannel PHR Solution*

##### 4.3.5.1.1 Operation Layer

The operational layer consists of existing systems. The Omnichannel PHR system shall integrate to Integrated Population Registration System (IPRS) for validating the identification documents

##### 4.3.5.1.2 Component Layer

The component layer consists of software components that will provide implementation of services.

##### 4.3.5.1.3 Service Layer

The Service layer consists of all the services identified in the service identification phase.

##### 4.3.5.1.4 Business Process Layer

Business process Layer dictates the flow of information based on business rules and policies.

##### 4.3.5.1.5 Consumer Layer

The consumer layer is the presentation layer where the end user can interact with the PHR system via different interfaces which include mobile applications, web applications or Electronic Medical Record (EMR) system.

##### 4.3.5.1.6 Integration Layer

The integration layer is the key aspect of the Enterprise Service Bus. It facilitates the mediation, routing and transport of service requests from various channels (app, portal, other systems) to correct services like NMPI database, PHR database, IPRS system, SMS gateway and Email Gateway.

##### 4.3.5.1.7 Governance Layer

The governance layer dictates the applicable business rules to guide the implementation of business logic, validation rules as well as input/output transformations.

### 4.3.6 Phase 6: Implementation and testing

Implementation depends on the chosen solution template. This phase ended with various types of tests such as unit testing or integration testing. At this phase, services, functional and technical components, process flows, user interfaces are designed, developed and tested.

#### *4.3.6.1 Tools and Technologies*

The following open source technologies were used to implement the omnichannel Patient Health Record system: -

i) Java Enterprise Edition (Java EE) programming language,
ii) HTML5 and JavaScript technologies for user interface design,
iii) Apache Tomcat Enterprise Edition application server,
iv) MySQL community edition database server,
v) Jasper reporting tools,
vi) Linux Operating System.
vii) Arduino Mega 2560 Board, Ethernet LAN Network and LM35 Temperature Sensor

The open source technologies were used due to the massive software support by the community at no additional licensing costs. The community can then support the opensource Omnichannel PHR software as part of the continuous enhancements.

#### *4.3.6.2 Database Design*

All the data was stored in the databases as well as log files and configurations in the file system. Database interaction will be via Java Database Connectivity (JDBC). The operations include: Select, Insert, Update and Delete. MySQL Community Server was used as the database for the Omnichannel PHR backend and Master Patient Index registry whereas SQL Lite is chosen for storage for the mobile applications. Patients can download and store a copy of their data in local storage. They can synchronise with the central database whenever they are online. This ensures that patients can access their data in remote areas where internet access is unavailable or unreliable. The database design was modeled using the Entity Relationship Diagram. The ERD is designed to capture the entities that are used in the database to capture, save and retrieve data to be accessed via the various end-user interfaces (Web, USSD, Mobile). It sought to show the specific tables and the resultant relationships. We have two databases named LambaPHR and PatientMasterDB. The separation is necessitated by having the PatientMasterDB to hold the patient identifiable information like names, identification numbers, next of kin, e.t.c. and LambaPHR to store non-patient identifiable information such as age, medical history, allergies, etc. The separation ensures that in the event that one of the databases is compromised, the attacker is not able to match the medical records with a real patient. The data at rest need were encrypted, not only the data in transit.

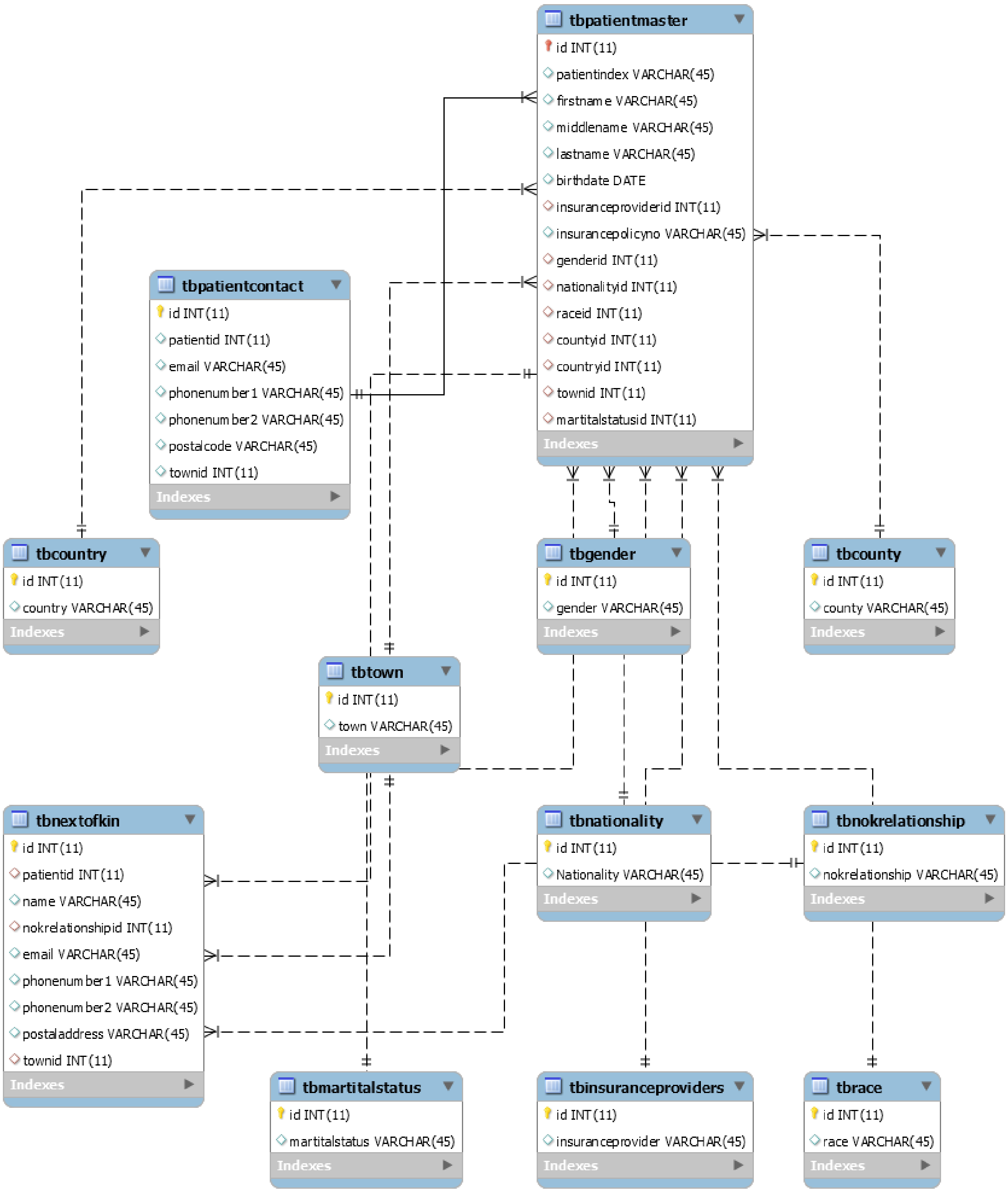



*Figure 16: PatientMaster Database ERD*

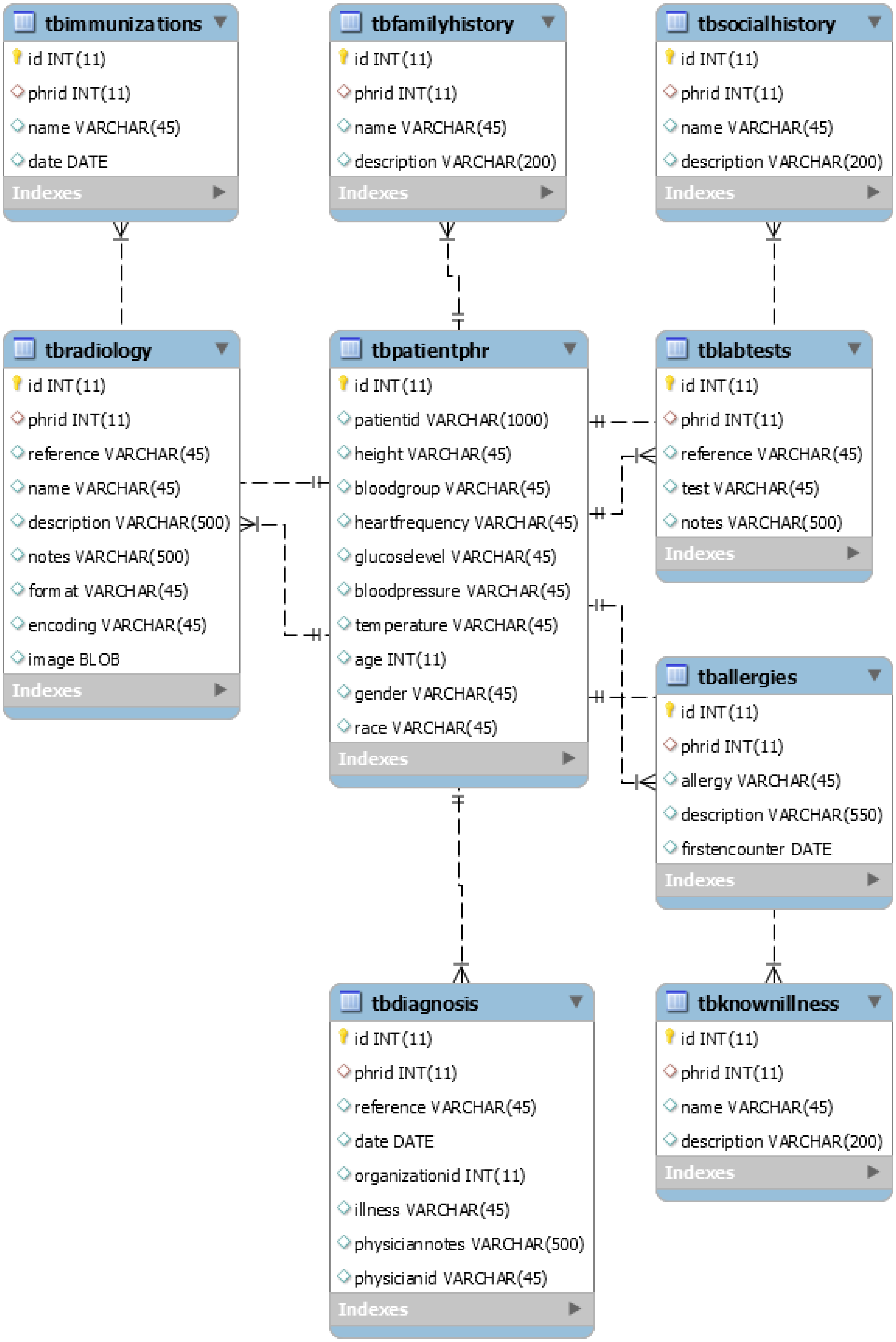

tbimmunizations
id INT(11)
phrid INT(11)
name VARCHAR(45)
date DATE
Indexes
tbfamilyhistory
id INT(11)
phrid INT(11)
name VARCHAR(45)
description VARCHAR(200)
Indexes
tbsocialhistory
id INT(11)
phrid INT(11)
name VARCHAR(45)
description VARCHAR(200)
Indexes
tbradiology
id INT(11)
phrid INT(11)
reference VARCHAR(45)
name VARCHAR(45)
description VARCHAR(500)
notes VARCHAR(500)
format VARCHAR(45)
encoding VARCHAR(45)
image BLOB
Indexes
tbpatientphr
id INT(11)
patientid VARCHAR(1000)
height VARCHAR(45)
bloodgroup VARCHAR(45)
heartfrequency VARCHAR(45)
glucoselevel VARCHAR(45)
bloodpressure VARCHAR(45)
temperature VARCHAR(45)
age INT(11)
gender VARCHAR(45)
race VARCHAR(45)
Indexes
tblabtests
id INT(11)
phrid INT(11)
reference VARCHAR(45)
test VARCHAR(45)
notes VARCHAR(500)
Indexes
tballergies
id INT(11)
phrid INT(11)
allergy VARCHAR(45)
description VARCHAR(550)
firstencounter DATE
Indexes
tbdiagnosis
id INT(11)
phrid INT(11)
reference VARCHAR(45)
date DATE
organizationid INT(11)
illness VARCHAR(45)
physiciannotes VARCHAR(500)
physicianid VARCHAR(45)
Indexes
tbknownillness
id INT(11)
phrid INT(11)
name VARCHAR(45)
description VARCHAR(200)
Indexes

*Figure 17: Patient PHR  Database ERD*

#### *4.3.6.3 End User Applications*

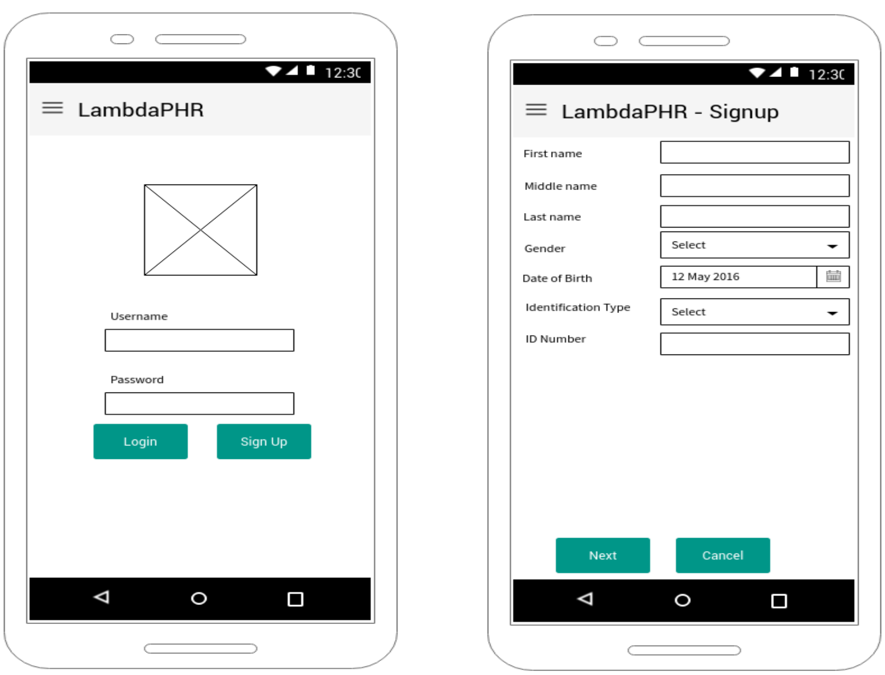
The end user applications are a collection of mobile applications (Android, iOS, Windows Mobile), USSD, IoT devices web portal to be used by the patients and healthcare personnel to:

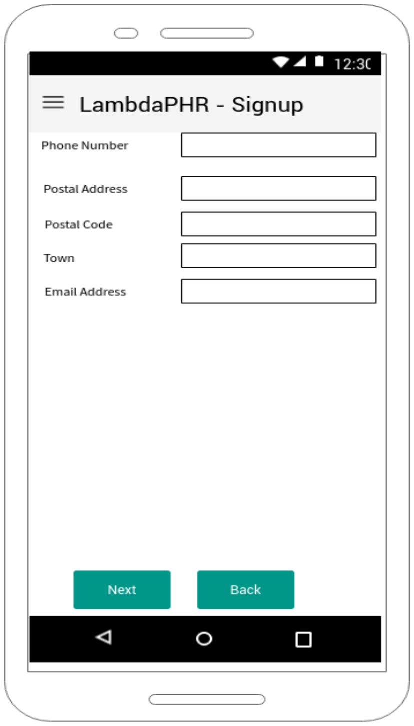
i. Sign up patients
ii. Upload patient records
iii. access patient records,
iv. grant/revoke permissions to healthcare personnel,
v. update profiles
vi. update medical information
vii. read notifications,

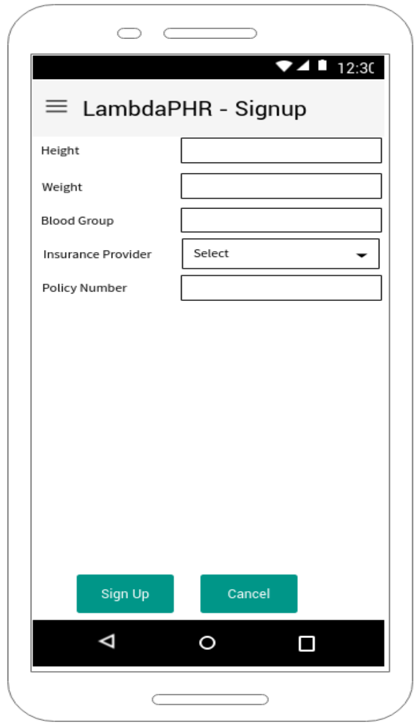
##### 4.3.6.3.1 Mobile Apps

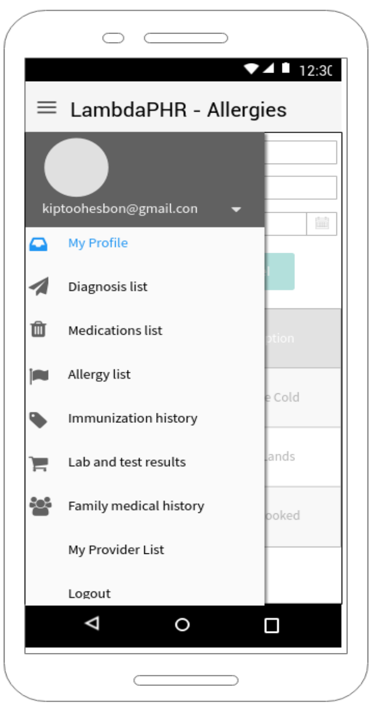
The cross-platform mobile application was designed and developed using the Ionic Framework. Patients can download the application from the favorite app stores, register themselves and perform a set of actions and configurations.

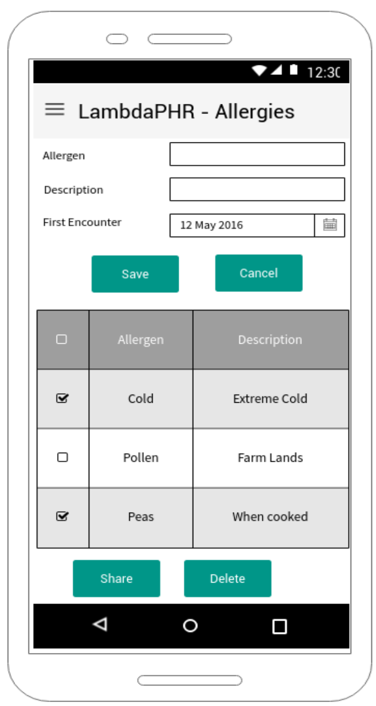
**Wireframes**

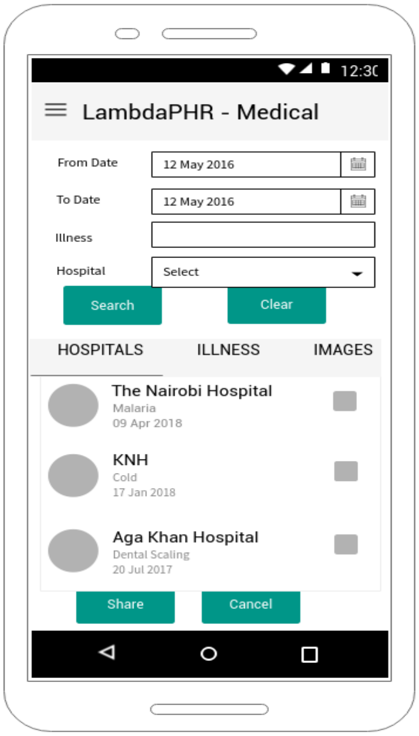


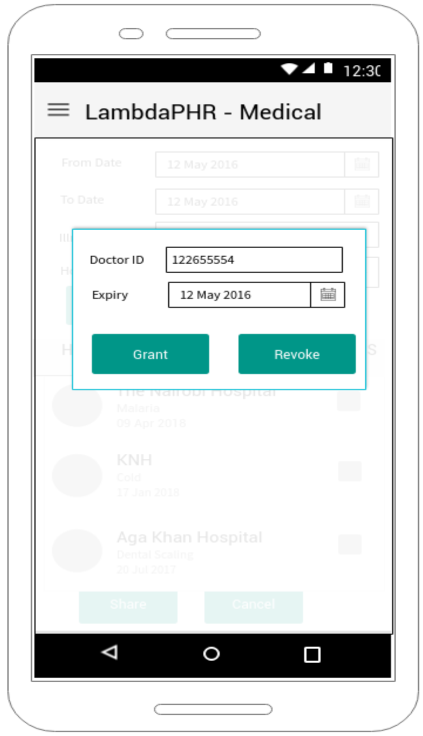

12:30
LambdaPHR - Signup
Phone Number
Postal Address
Postal Code
Town
Email Address
Next
Back

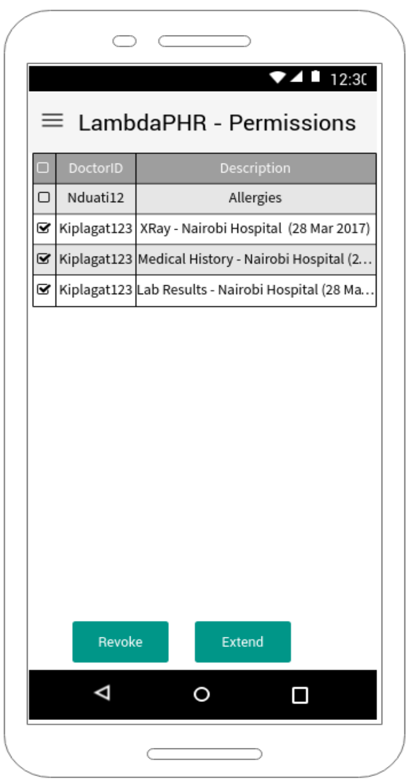

12:30
LambdaPHR - Signup
Height
Weight
Blood Group
Insurance Provider
Select
Policy Number
Sign Up
Cancel

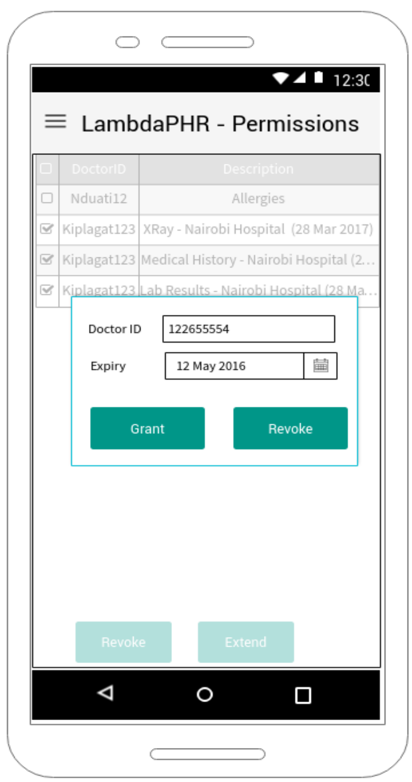

12:30
LambdaPHR - Allergies
kiptoohesbon@gmail.con
My Profile
Diagnosis list
Medications list
Allergy list
Immunization history
Lab and test results
Family medical history
My Provider List
Logout


12:30
LambdaPHR - Allergies
Allergen
Description
First Encounter
12 May 2016
Save
Cancel
Allergen
Description
Cold
Extreme Cold
Pollen
Farm Lands
Peas
When cooked
Share
Delete


12:30
LambdaPHR - Medical
From Date
12 May 2016
To Date
12 May 2016
Illness
Hospital
Select
Search
Clear
HOSPITALS
ILLNESS
IMAGES
The Nairobi Hospital
Malaria
09 Apr 2018
KNH
Cold
17 Jan 2018
Aga Khan Hospital
Dental Scaling
20 Jul 2017
Share
Cancel


12:30
LambdaPHR - Medical
Doctor ID
122655554
Expiry
12 May 2016
Grant
Revoke


12:30
LambdaPHR - Permissions
DoctorID
Description
Nduati12
Allergies
Kiplagat123
XRay - Nairobi Hospital (28 Mar 2017)
Kiplagat123
Medical History - Nairobi Hospital (2...
Kiplagat123
Lab Results - Nairobi Hospital (28 Ma...
Revoke
Extend


12:30
LambdaPHR - Permissions
Doctor ID
122655554
Expiry
12 May 2016
Grant
Revoke

#### 4.3.6.3.2 Web Portal

The web portal would be accessed by system administrators, patients and healthcare personnel. It is role-based supporting three profiles: patient, physician, system administrator. The Web Portal is the user interface that is accessed by both healthcare personnel as well as patients. The prototype was be based on Model View Controller (MVC) which separates concerns in the application interface for input, processing and output respectively as below:

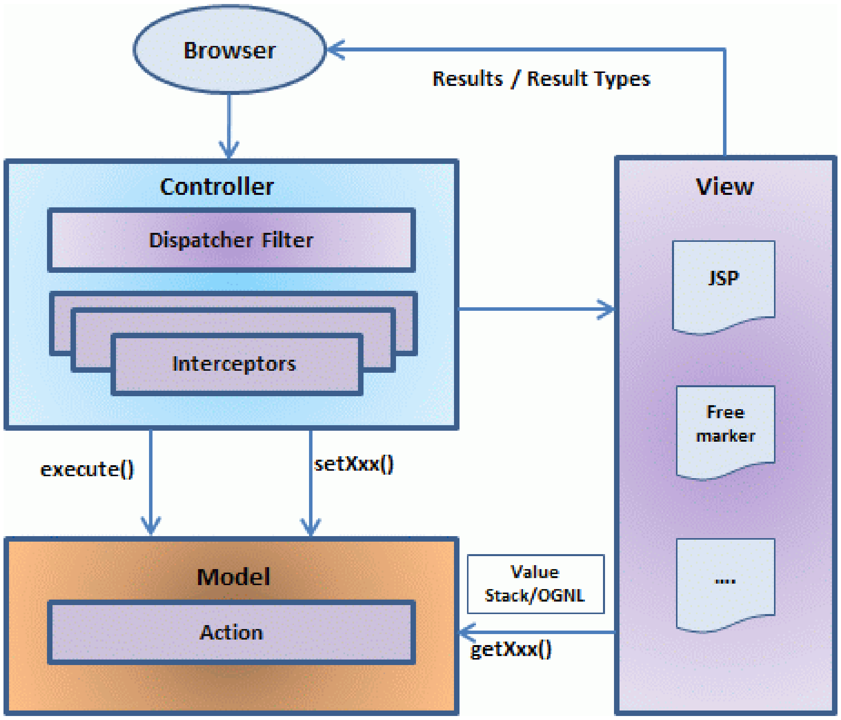



*Figure 18: A representation of Struts2 Architecture.*

Security was guaranteed in that the user has to provide username and password plus other two-factor verification like OTP in order to log in to the PHR. It was important that any person seen at any clinic or registered in the PHR system is positively identified, whether new or returning patients. The patients verified by entering patient National Master Patient Index, fingerprints (if fingerprints are available) and other demographic data (e.g., name, gender, date of birth or medical insurance number). If the patient is not registered, the healthcare personnel can ask the patient to register themselves, or the physician can register them on their behalf.

Below menus or modules will be available in the web portal

| Menu | Sub Menu | Description |
|---|---|---|

| | | |
|---|---|---|
| User management | Add User | The module was charged will authenticating users before accessing the systems |
| | Manage User | |
| Parameters | Health Facilities | System configurations are setup using this module. |
| Reports | Registered users,<br>System audit trail,<br>User audit trail | The reports module will provide printable reports in various formats (PDF, Word, CSV). |
| Dashboard | | Vital statistics like hospital visits, key diseases, active patients, registered entities, etc. |
| Signup | Signup Patient | Patient has to sign up themselves by presenting their statutory document details |
| | Signup child | Children can only be signed up by their parents. Parents will use their PHR details (Patient Index) alongside their statutory documents (parent ID, child birth certificate no) |
| My Profile | Basic information | Basic information about the patient |
| | Next of Kin | Patient next of kin |
| | Diagnosis List | List of diagnosis for patient which include hospital visits, diseases diagnosed |
| | Allergies | List of allergic reactions experienced by the patient. |
| | Immunization | Shows immunization history of the patient |
| | Lab Test/Results | Lab tests performed by physicians |
| | Radiology | Xray and other scans performed by physician |
| | Family History | Family medical and/or disease history of patient |
| Institution Management | Institution Bio Data | Information about the healthcare facilities |
| | Ownership details | Ownership doc, institution cert, incorporation doc |
| | Physicians | List of healthcare workforce that will access the system. |
| Search patient profile | Search by Master Patient Index | Query patient using National Master Patient Index (NMPI). By using an NMPI, a patent has to authorise it by presenting a one time password (OTP) for varication. |
| | Search by Fingerprint | Enables authentication of patient using biometric information (Fingerprint) |
| | Basic information | |

| | | |
|---|---|---|
| View Patient Profile | Generic medical information | Once patient is authenticated, physician can view the permissioned records either read/write or both |
| | Other medical information | |
| | Treatment history | |
| | Record patient treatment history | |
| System configuration | Manage users | Add/Update/Delete administrators, physicians, patients |
| | Manage Institutions | Add/Update/Delete hospitals, insurances, etc |
| | Manage system parameters | System parameters like identification types, next of kin relationships, user types, etc |

*Table 5: Listing of web portal menus and functionality*

**IoT equipment**

Microcontroller and Microprocessor Gateway


*Figure 19: Arduino Mega 2560 Microcontroller and Microprocessor*

Ethernet Network Gateway

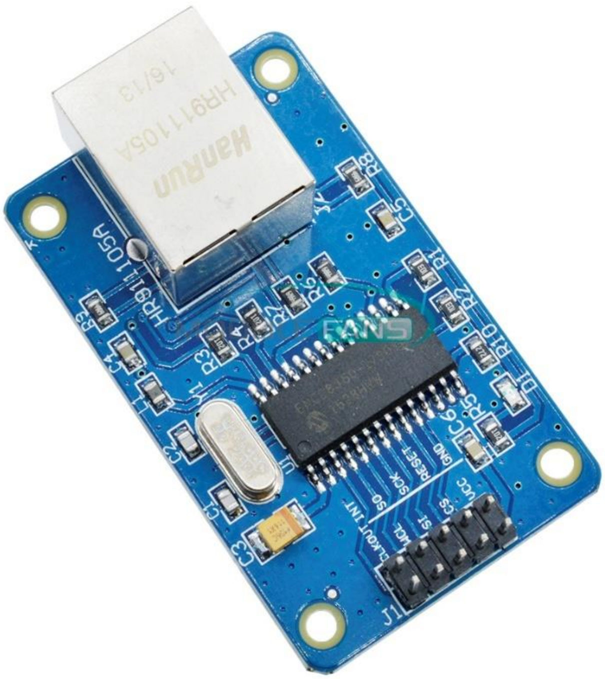



*Figure 20: Ethernet LAN Network Module ENC28*

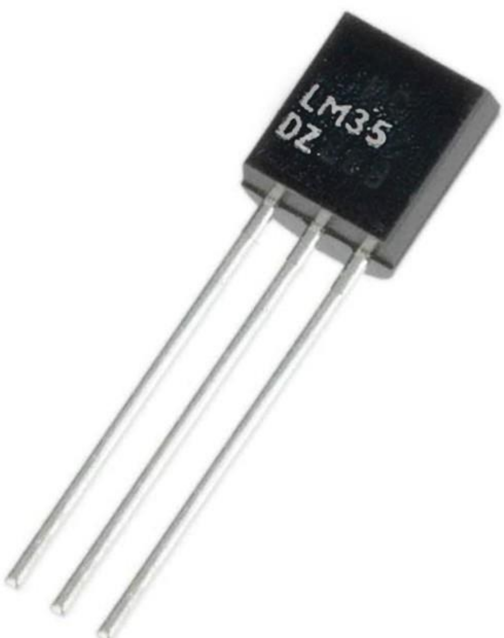



*Figure 21: LM35 Temperature Sensor*

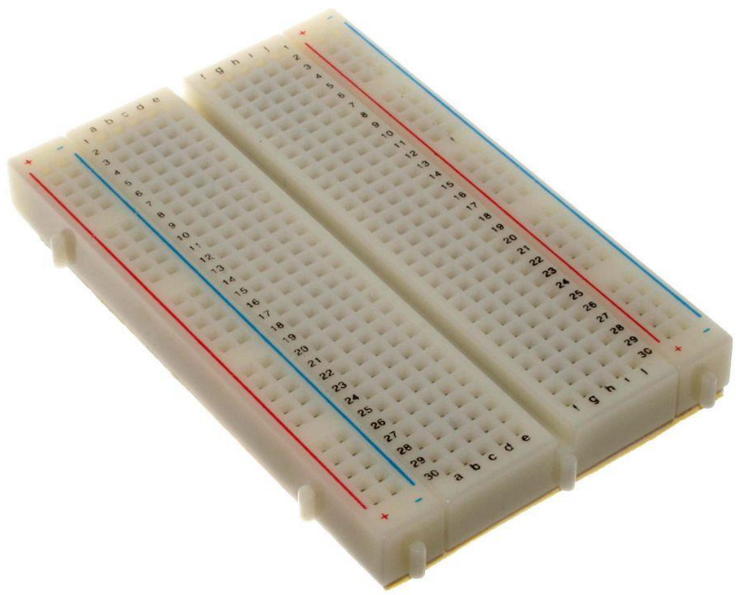


*Figure 22: Breadboard*

#### *4.3.6.4 Security Considerations*

The Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule dictates that all individually identifiable information stored or transmitted must be protected. These include name, address, birth date, national identification number, biometric information, device serial numbers, mobile numbers, The Personal Health Information (PHI) must be de-identified to mitigate the privacy risks to patients. The de-identified information can then be used for research and policy assessment. For this research, HIPAA's Safe Harbor De-Identification method was used. This involved the removal of PHI information by assigning a unique code to every patient called National Master Patient Index (NMPI) to the data. In addition, the solution has two databases, one containing PHI which is locked and another containing medical information which were not personally identifiable. The patient data were re-identified using the NMPI. This NMPI must not be disclosed to anyone other than the health facility. If the NMPI ends up in the wrong hands, the unauthorised holder will not be able to identify the patient PHI due to the mechanisms that have been put in the development of the Personal Health Record (PHR) system.

All the users of participating health facilities were first registered to access PHR system and provided with an account and login credentials. Each Patient had a list of records and participant identifiers that have read and/or write access to their medical records. The records were anonymised (de-identified) in that the protected health information were stored in a separate database. However, the records were re-identified by linking the data in the two databases. The data in both databases were encrypted to maintain patient privacy and the safety of patient records.

#### *4.3.6.5 Process Flows*

**a) Patient Signup**

The patient can sign up themselves or be assisted by the physicians (or other healthcare personnel). The patient has to provide their demographic information including the personal information (identification documents, full name, age, marital status, insurance type, phone number, email, address) as well optionally provide physical body quantitative data (height, weight, temperature, heart frequency, glucose, blood pressure)

**b) Patient profile update**

Healthcare providers and patients themselves can upload the EMR data for a particular patient. Data originated from healthcare personnel were deemed to be reliable and hence those submitted by patients may not be used for healthcare services but is up to the discretion of the physicians to use or discard them. As mentioned previously, data upload to the PHR is voluntary; patients can ask the healthcare providers to upload their medical history to the PHR via API integration or manual key entry or upload via web portal. In future, legacy support will be provided to facilitate patient data upload in a a standardised format (HL7, FHIR, etc). All the data uploads (write) permissions have to be granted by the patient, same case as read and delete. Data uploaded include illness history, family illness history, blood group, medication list, allergies, surgical procedures, social history (alcoholism, drug addiction), immunisations, psychological disorders, emotional disorders, etc.

1. Validate MPI – if not, ask patient to register
2. Validate write permission – if not, send notification patient to accept or reject. The temporarily stored info is saved or deleted
3. Get patient public key
4. Create new document key
5. Encrypt document key

6. Encrypt medical record
7. Save record to storage
8. Notify patient

### c) Patient Profile Access

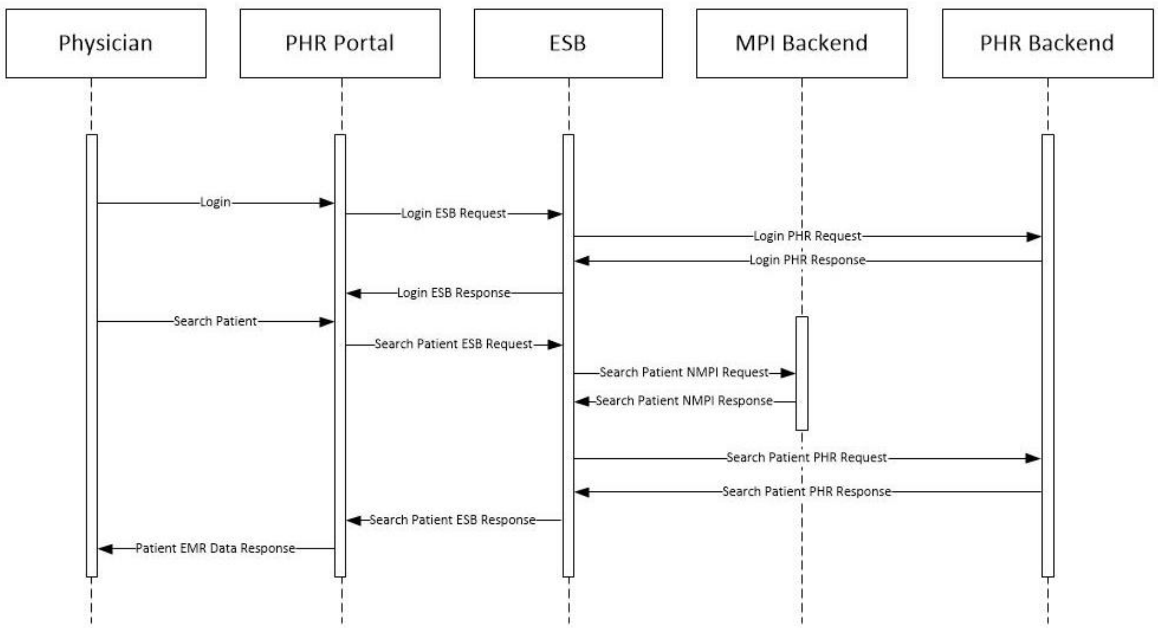



*Figure 23: Patient profile access sequence diagram*

Detailed Process for querying patient medical data in the PHR is as follows:

| Process Name | Patient Profile Access |
|---|---|
| Actor | PHR Web Portal |
| Pre-condition | The Physician must be registered in the PHR database |
| Basic Flow | 1. Physician opens the PHR URL. |

| | |
|---|---|
| | 2. Physician is presented with a screen to enter their credentials<br>3. Physician enters their credentials and submits the login request to ESB<br>4. The ESB validates the message and dispatches it to PHR Adapter<br>5. The PHR Adapter validates the physician credentials and returns a response including the physician profile.<br>6. The physician is presented with a dashboard of action to perform: (Signup patient, Query patient data, Upload patient data, Update patient data).<br>7. Physician selects Query Patient data<br>8. Physician will be presented with a screen to enter patient NMPI code or capture fingerprint<br>9. Physician enters the patient NMPI and submits the request to ESB<br>10. The ESB validates the message and routes it to NMPI Adapter.<br>11. The NMPI adapter queries the database. The NMPI adapter generates an OTP code which is send to the patient. The patient presents the OTP to the physician.<br>12. The physician enters the OTP on the Web portal and submits to ESB.<br>13. ESB dispatches the request to NMPI Adapter.<br>14. The NMPI adapter validates the session information including the OTP and returns encrypted basic demographic data of the patient.<br>15. The ESB then dispatches the message to the PHR Adapter<br>16. The PHR Adapter queries the permissible records of the patient shared with the physician and returns the encrypted data to the ESB<br>17. The ESB returns the data to the web portal<br>18. The data is decrypted and displayed to the physician on the browser |
| Post Condition | The patient data is returned (Encrypted JSON file) and displayed to the physician on the PHR portal |

*Figure 24: Detailed Process for querying patient medical data in the PHR*

#### *4.3.6.6 System Testing*

Agile testing methodology was adopted to allow the researcher fail early. The process was iterative in the sense that a specified user group (colleagues and friends of the researcher) were given the prototype to test specific services. It started with high fidelity wireframes for the mobile app. Amendments were made to the wireframes and the mobile application until the final system was implemented.

System testing was inevitable as it evaluates the system's ability to fulfill the requirements it was intended to. Below scenarios were tested:

**Unit testing**

Each module was tested iteratively as it was being developed. Individual modules were independently tested manually as the researcher was building the modules. This allowed the researcher to modify the source code accordingly without worrying about the regression effects on other modules. This was done continually until all the modules were completed. Automated testing was done using programmed scripts.

**Integration Testing**

Integration testing was done before integrating all the modules. This was achieved using simulated tools like Soap UI to test the ESB Web services to test the correct working of the APIs as well as the load tests. After that, the end user systems were integrated and end to end system testing was done.

**Acceptance testing (Beta Testing)**

Having completed the development of the system, users were sampled to test the system. A set of users disguised as patients while a few practicing health care professionals (physicians) attended to the patients. The main objective is to uncover bugs and gaps in the solution. At the end of testing, users provided a feedback on product features and usability that would help in refining the product.

**Test plan**

| **Item** | **Description** |
|---|---|
| Objective | The main objective of this user acceptance testing is test the prototype and get feedback from the sampled users. |
| Scope | Areas to be tested:<br>• Sign up<br>• Login<br>• Manage profile<br>• Upload data |

| | |
|---|---|
| | • Share data<br>• Deactivate account |
| | Areas not to be tested:<br>• Integration to EMR systems |
| | Specific data to be used for a particular feature:<br>Sign up:<br>• Use national ID only<br>Profile Sharing:<br>• Doctor id: rotich<br>• Hospital: KNH, MTRH |
| Test Approach | What to focus on:<br>• Functionality,<br>• Features<br>• Response time<br>• Security |
| | Procedure to log feedback and bugs:<br>• Fill questionnaire<br>• Share screenshots to researcher WhatsApp number or email address |
| Schedule | Start date: 15th July 2018 |
| | End date: 24th July 2018 |
| | Duration per cycle: 20 mins |
| Tools | Smart Phone, Personal computers, IoT Devices |
| Budget | No incentives |
| Feedback | Fill questionnaire provided in the link below: https://goo.gl/forms/uv1x6o5t9v6SEF9n2 |

*Table 6:User Acceptance Testing Test Plan*

**Participant recruitment**

| User type | Number of Users | Description of users |
|---|---|---|
| Individual/Patient | 16 | Patients/individuals |
| Physician/Healthcare personnel | 2 | Radiology specialist, KNH<br>Clinical Officer, Chepkanga Health Center |
| Professional Experts (IT professionals, security experts) | 2 | Software Engineer, NMB Bank TZ<br>ICT Support |

*Table 7: User Acceptance Testing User Listing*

**Product Launch**

Links were shared containing the links from where the users can download and Install or access the applications. In situations where this was not possible to test the system remotely, for example the special IoT device, the researcher had to showcase the sample in front on the users and get their feedback immediately

| **Terminal** | **Link or description** |
|---|---|
| Mobile App | Download from link:<br>https://159.89.139.220:9443/apk/lambdaphr.apk |
| Web Portal | Visit link: https://159.89.139.220:9443/LambdaPHRPortal/ |
| IoT device | Researcher to showcase the device in the presence of the users |

*Table 8: Product Launch mechanism*

**User Manuals**

Manuals were created to help guide users in testing the solution. The manuals are available in Appendix I which include manuals for Mobile App, Web Portal and IoT device.

**Feedback collection and Evaluation criteria**

Having tested the solution, the users were expected to provide feedback to the researcher in the form of a questionnaire (for remote testing) or face to face instant feedback (for IoT device showcased by the researcher). The feedback includes bugs and suggestions based on experience with the solution. See Appendix V for a sample post-implementation survey. The feedback was to be used to improve the product in its next versions

**System Testing Results**

i) Webservices - simulations, stress tests, logs, graphs

ii) Web portal

- Registered physicians
- Registered patients
- Registered administrators
- Patients treated
- Validated patients
-

iii) Mobile Apps

- Registered patients

- Registered children
- Records in database
- Shared records

### 4.3.7 Phase 7: Deployment, monitoring and management

The last phase consists in the deployment of the services in the production environment. As soon as this takes place, another set of tests mostly concerning user acceptance were conducted. The management and performance monitoring of services were on-going processes.

#### *4.3.7.1 Deployment environment*

The Omnichannel PHR solution was hosted in a cloud environment consisting of the following tools: Mention environment

i) Linux Operating System (Ubuntu OS, 2GB RAM, 50 GB Solid state disk).
ii) MySQL Community Server (MySQL 8.0).
iii) Apache Tomcat Enterprise Edition Application Server (TomEE 7.0.2).

The modules were deployed in a cloud environment where it was accessible to patients and doctors/physicians over the secure internet. The data in transit and rest were encrypted using asymmetric key encryption (AES) as well as a secure protocol (TLS) was used to encrypt the data as they were being transferred over the public internet. The sampled patients and/or individuals downloaded the mobile app from the same cloud and installed on their phones.

The different modules hosted are explained below:

##### 4.3.7.1.1 LambdaPHR Portal

The Lambda PHR Portal was accessible to patients, physicians and system administrators. The patients can register or deregister themselves, update their personal and medical profile as well as sharing or revoking access permissions. The physicians, on the other hand, are the health care professionals who offer medical services to the patients can access the web portal and browse the patient profile. The patients can give the either read, write or both read and write access to their profile for a specified period. Apart from viewing the profile, physicians can update profile of the patient by key entry, system integration or batch upload. The system administrators manage the system by performing duties like health facilities creation, registering physicians, etc besides providing patients and physicians system technical support.

##### 4.3.7.1.2 LambdaPHR Mobile App

The LambdaPHR Mobile App is accessible to patients or individuals only. It provided the patients all the services provided by LambdaPHR portal plus more features such as the ability to capture photos from diagnosis or prescriptions.

##### 4.3.7.1.3 LambdaPHR Enterprise Service Bus

LambdaPHR Web Services are the Application Programming Interfaces that allow the LambdaPHR Mobile App and Web Portal to access data and external services like integration to IPRS, SMS and Email Gateways. All the services were enabled through the Lambda ESB which includes Registration, Profile management, Rights management, Permission management, etc.

#### *4.3.7.2 Monitoring and Management*

The modules mentioned above were monitored in the environment they were being deployed. Tomcat application server that hosted the web portal and web services provided a means of checking the service status as either running or stopped. The applications can be stopped, started, reloaded or undeployed as shown in figure 25.

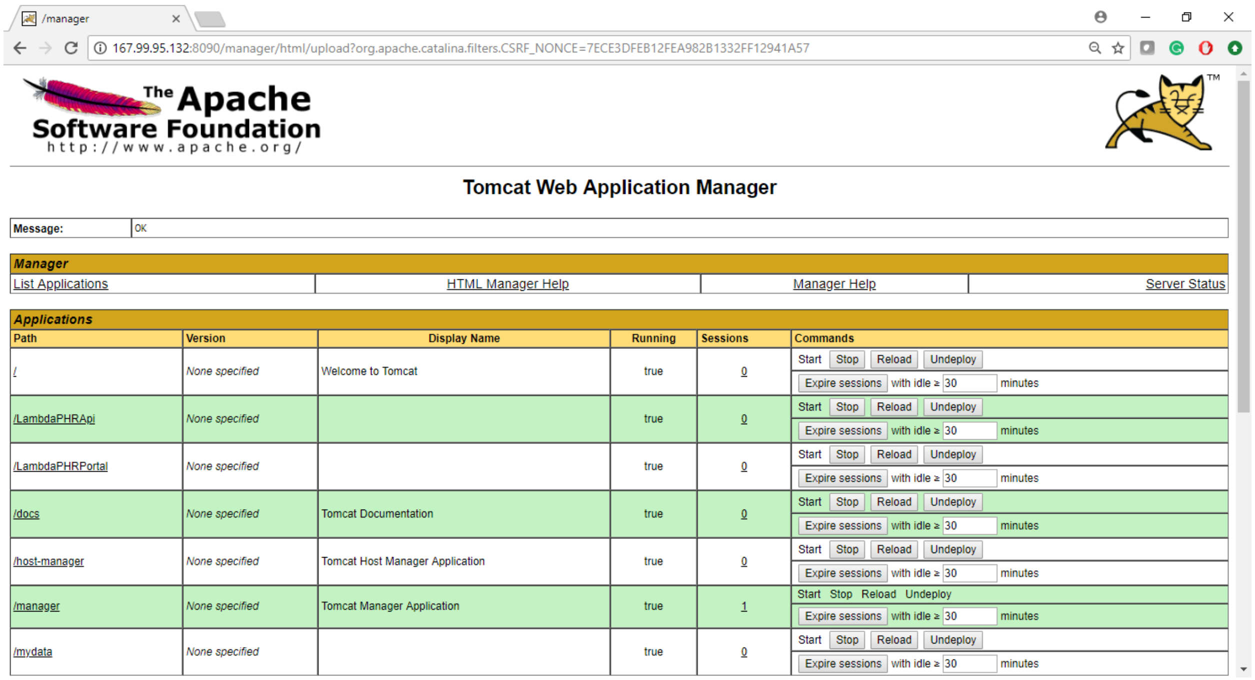



*Figure 25: Tomcat Web Application Server dashboard*

We used MySQL Workbench to access the MySQL Server Community Edition to access the database objects. Through the MYSQL workbench, we can query data, create, update, delete tables and corresponding data. Vital statistics were also obtained about the health of the database like server state, threads, open connections, data traffic, etc as shown in the figures below:

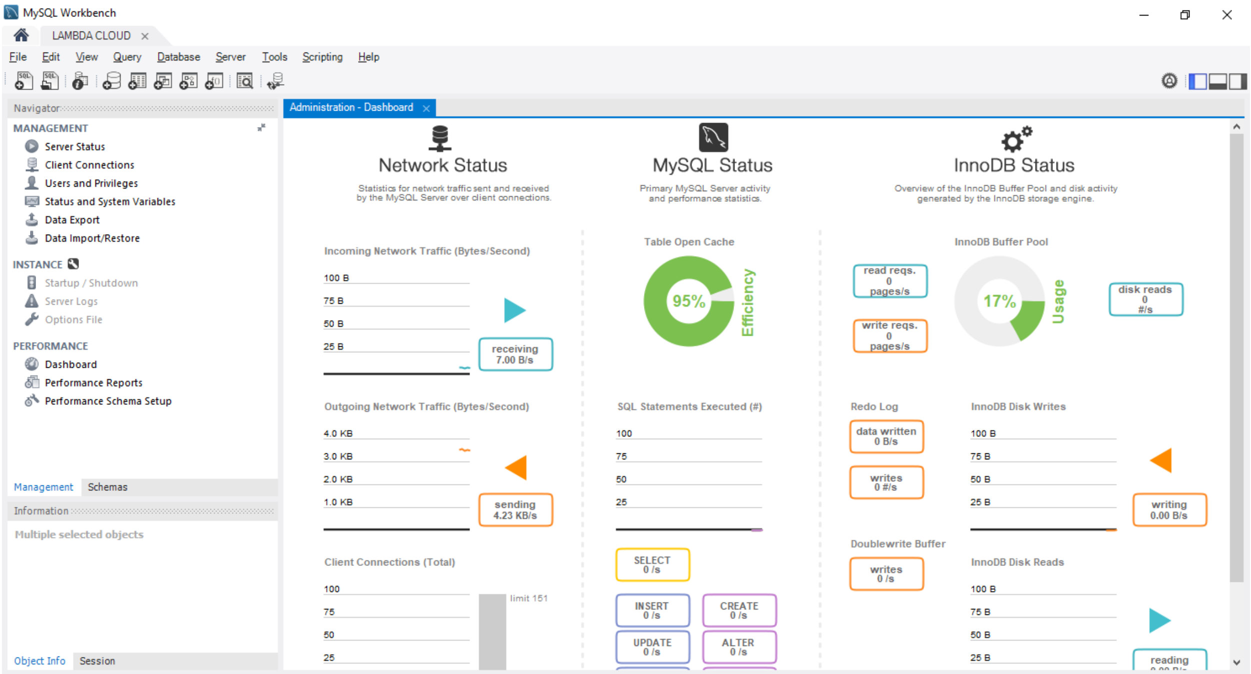



*Figure 26:MySQL Workbench InnoDB Status Dashboard*

# 5 RESULTS ANALYSIS, PRESENTATION AND DISCUSSION

## 5.1 Introduction

In this chapter, the results of data collected during pre-study and system testing were analyzed. The findings were further discussed and presented. Questionnaires were administered to patients, medical personnel and technology experts. Selected medical personnel were identified and interviewed in specific health facilities. Descriptive statistics such as frequency and percentages were extensively used in the analysis.

## 5.2 Preliminary study results and findings

A sample was randomly selected and a total of 120 respondents were selected. Only 83 respondents responded to the questionnaire. Physicians and technology experts were also interviewed to get in-depth information regarding the patient identification and use medical as history as well as current health care systems architecture respectively. The questionnaires were distributed electronically to selected sample of respondents.

| Variable | Attribute | Total Respondents | % of Respondents |
|---|---|---|---|
| Age | 20 - 30 years | 71 | 85.54 |
| | 31 - 40 years | 11 | 13.25 |
| | 40 - 50 years | 1 | 1.20 |
| | Over 50 years | 0 | 0.00 |
| User group | Patient (Individual) | 74 | 89.16 |
| | Doctor/Physician | 9 | 10.84 |
| Own Smartphone | Yes | 82 | 98.80 |
| | No | 1 | 1.20 |
| Using Smartphone for medical reasons | Yes | 46 | 55.42 |
| | No | 37 | 44.58 |

*Table 9: Demographic characteristics of respondents*

Nearly all the respondents owned a smartphone (98%). However, only 55% have used smartphones to obtain health-related information. In this case, there is an opportunity to sensitise individuals to take advance of internet technologies in improving their health. Only 11.7% of the respondents have used Personal Health record system despite all having a smartphone.

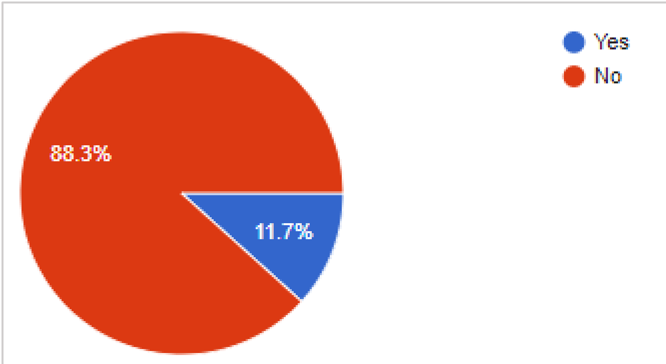



*Figure 27: Personal Health Record usage*

### 5.2.1 Objective 1:

**To understand people's perception of personal health record system in mitigating current healthcare data sharing (interoperability) between different healthcare facilities.**

Several respondents gave reasons for not using PHR which include:

| Reason | Total | % |
|---|---|---|
| I have never heard of a PHR. | 31 | 39.24 |
| I would if my physician or other healthcare professional recommended it to me. | 27 | 34.18 |
| I do not seek much care and don't see the value. | 6 | 7.59 |
| I do not trust the security of the currently available Internet-based sites. | 6 | 7.59 |
| I do not want a written record of sensitive personal health information. | 5 | 6.33 |
| I do not want to spend the time to initially input and update the information. | 2 | 2.53 |
| Too complicated | 1 | 1.27 |
| It would be easier to have one if we had digital ones. | 1 | 1.27 |

*Table 10: Reasons for not using PHR systems*

39.24% have never had of a PHR and 34.18% of the respondents are willing to use it if they were recommended by their physicians. This means that we can achieve more than 75% of the population using PHR system of they are sensitised on the availability of local PHR solutions and their importance in medical care. Incentives can be given to patients to encourage them to use the PHR solutions in various ways.

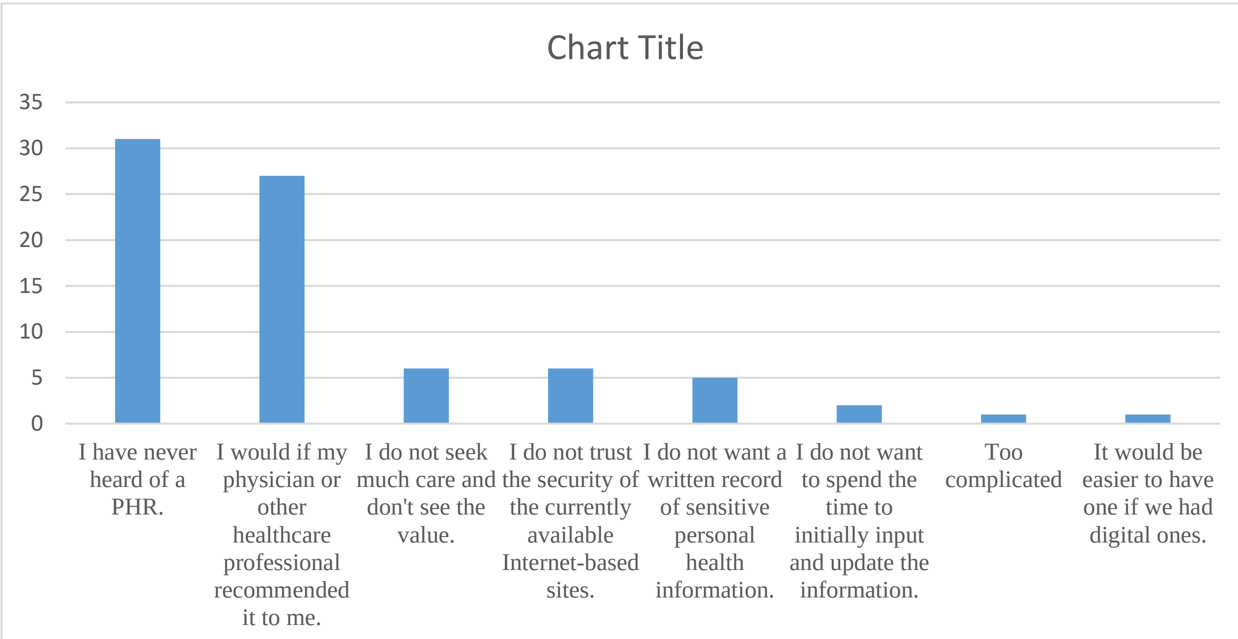



*Figure 28: Reasons for not using PHR systems*

Respondents expressed their challenges when they attend different healthcare facilities, either transfer or first-time visits to new health facilities. The majority of the respondents (64.2%) indicated that they are cost and time conscious in that they have to redo the tests again amounting to additional costs and time wastage, especially during critical conditions. About 58% said that they do not know their medical history as they do not always memorise or carry their past medical records (paper records) when they seek medical care in other hospitals. Few indicated that they may be unconscious and are afraid of being misdiagnosed more so when next of kins cannot could not contacted which has led to a large number of deaths in health facilities

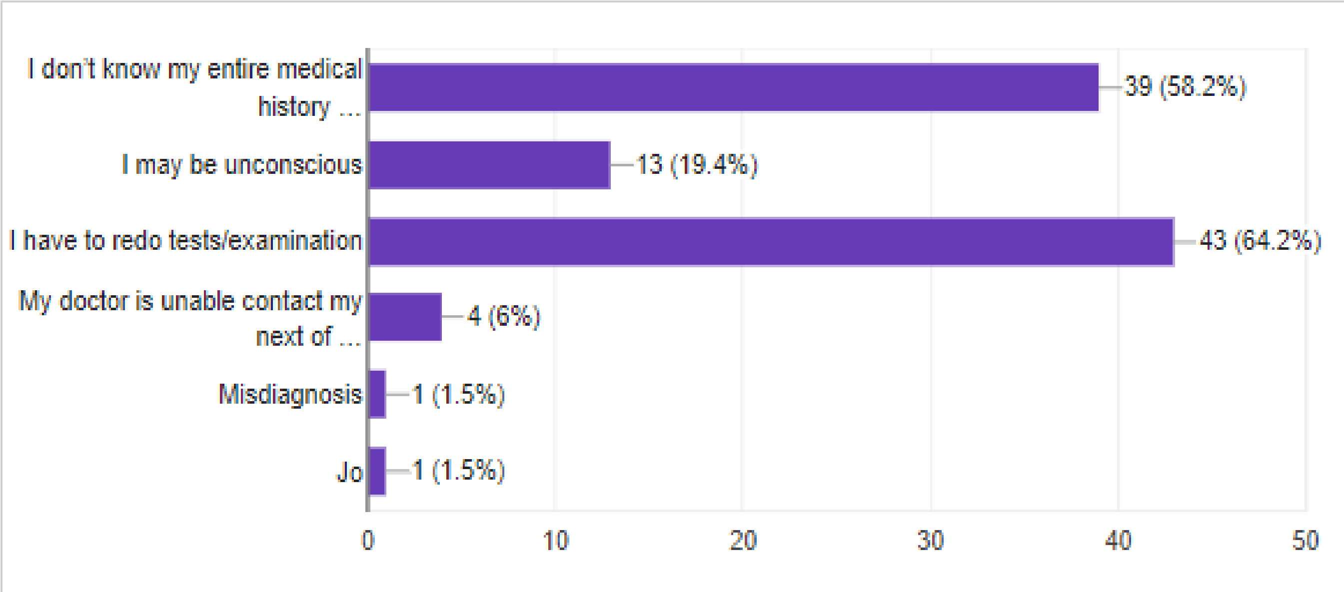



*Figure 29: Challenges when being transferred from one health facility to another*

It is due to the above plethora of challenges that have made 84.2 % respondents willing to use a PHR system that can store their medical history as long as certain set of conditions are fulfilled which include privacy, safety, security and confidentiality of records maintained as expressed by most of the respondents. Some have indicated that if confidentiality is not maintained, the exposed data may be used to stigmatize which may be disastrous hence may opt not to use PHR solutions. It is in this case that majority (84.4%) will agree to share their records only with their consent to specific health care professionals

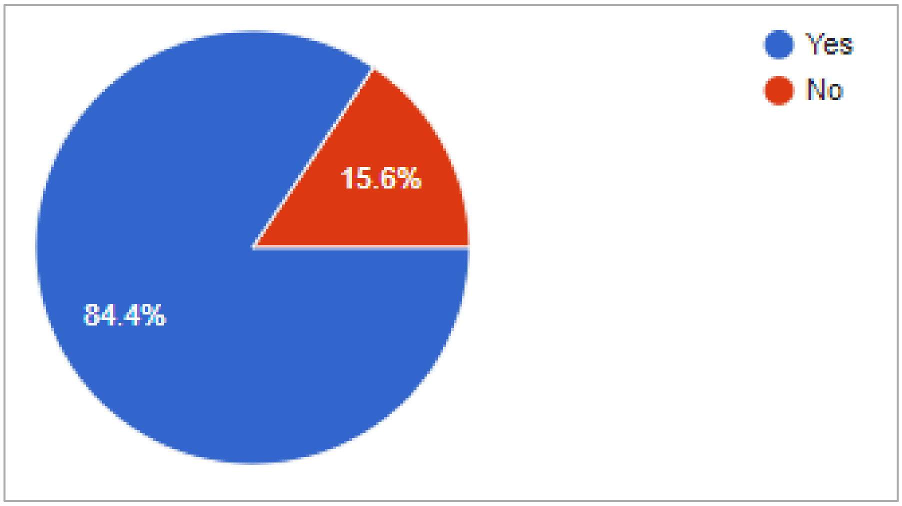



*Figure 30: Percentage of patients/individuals willing to share their medical records in a PHR solution*

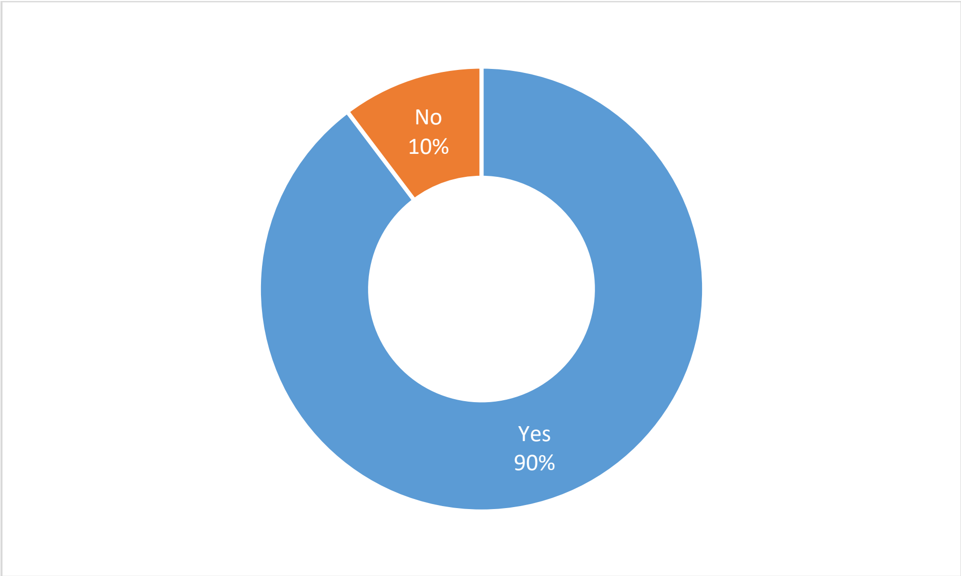



*Figure 31: Percentage of patients willing to share records with specific health care professions (patient consent)*

In as much as the respondents were willing to share their data, not everyone can have access, even if they were to be paid to have their data used for research. 57.9% of respondents said that they will not accept rewards exchange for their medical data.

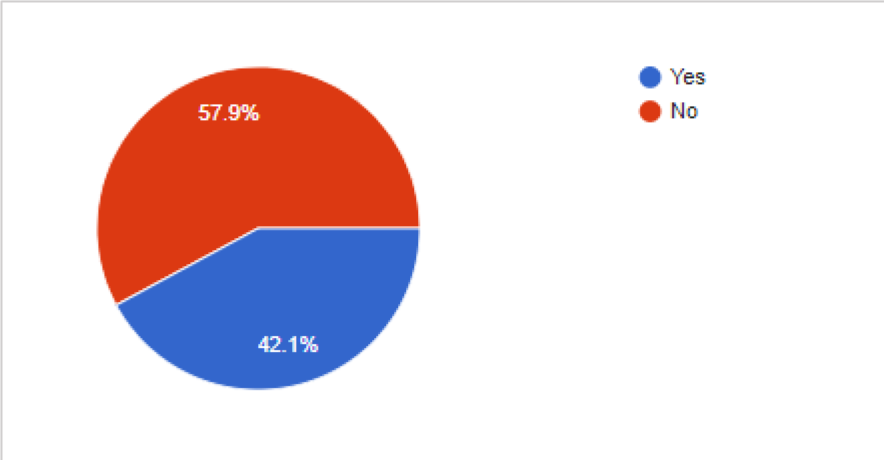



*Figure 32: Percentage of patient willing to accept payment for sharing anonymous data for research (survey)*

It was also evident they were willing to share their medical records with specialists (73.3%) as opposed hospitals (25.3%) followed by the emergency team (56%), next of kin (52%), health insurance (20%), medical researchers (14.7%) and lastly their employer. It is on this consideration that the above parties need to be involved in order of priority.

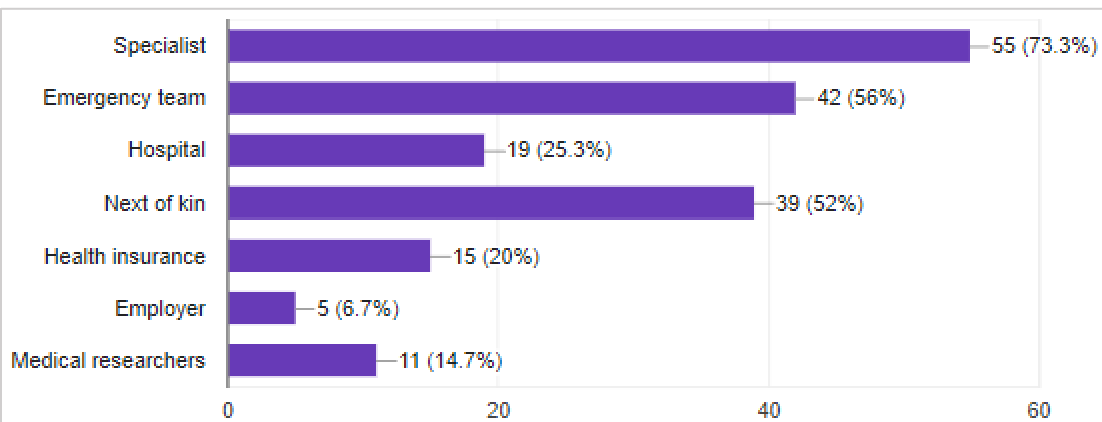



*Figure 33: Percentage of patients willing to share medical data with other parties other than primary doctors*

The willingness to share medical information are attributed to below reasons below:

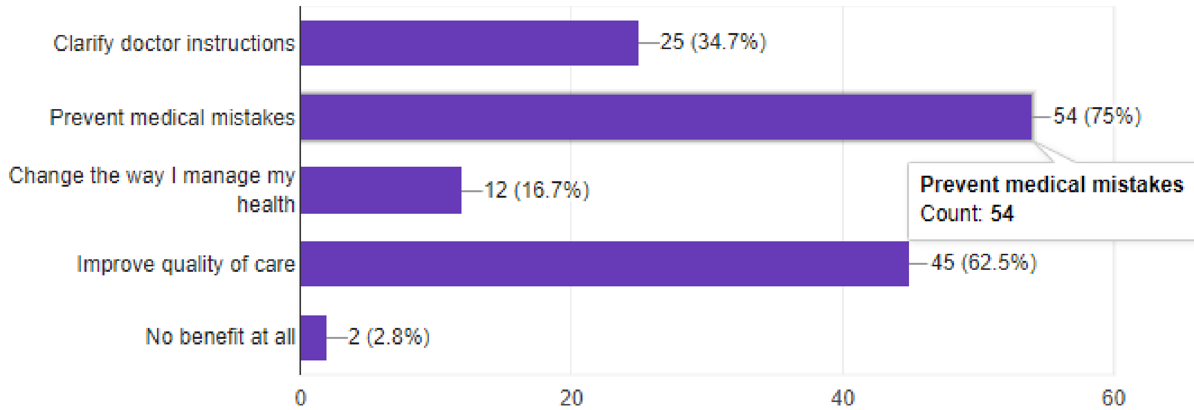



*Figure 34: Benefits comparison of sharing medical information in a PHR system*

63.8% of the patients/individuals stro ngly believe that PHR solutions would most suit for storing allergies and adverse drug reactions whereas payment services e.g. medical bills was least suitable for a PHR solution.

| **Recommended PHR Features** | **no extend at all (%)** | **small extend (%)** | **moderate extend (%)** | **large extend (%)** | **very large extend (%)** |
|---|---|---|---|---|---|
| Storing illnesses and hospitalizations | 7.04 | 9.86 | 18.31 | 19.72 | 45.07 |
| Doctor-finder with contact information and background | 7.04 | 11.27 | 14.08 | 18.31 | 49.30 |
| Schedule doctor/specialist appointment | 9.86 | 8.45 | 14.08 | 21.13 | 46.48 |
| Storing allergies and adverse drug reactions | 4.35 | 11.59 | 10.14 | 10.14 | 63.77 |
| Storing medical Prescription record | 7.35 | 10.29 | 11.76 | 17.65 | 52.94 |
| Laboratory test results and image reports | 12.86 | 11.43 | 14.29 | 20.00 | 41.43 |
| Transfer medical information to doctors and specialists | 5.71 | 8.57 | 17.14 | 21.43 | 47.14 |
| Payment services e.g. pay medical bills from a PHR app | 10.14 | 13.04 | 20.29 | 20.29 | 36.23 |

*Table 11: Percentage of extend of recommended PHR features*

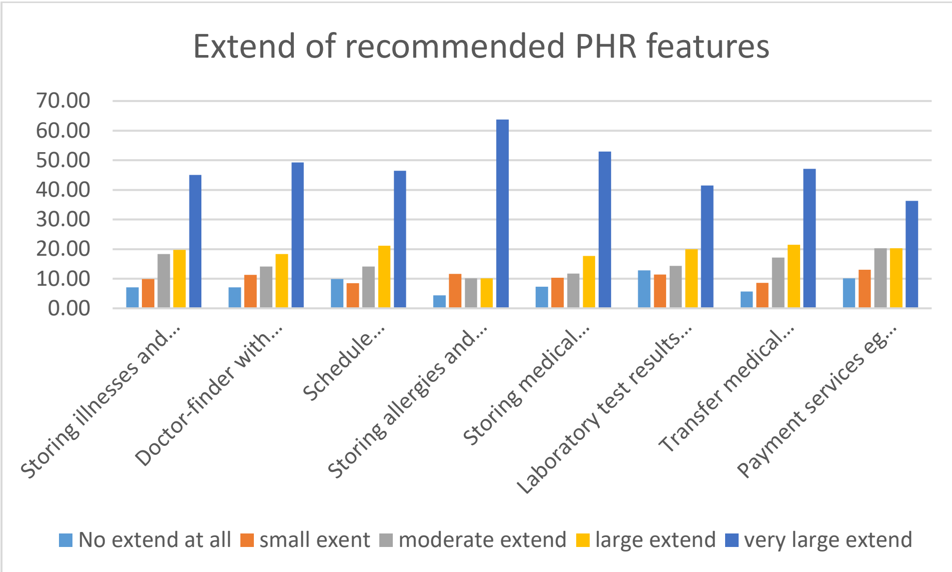



*Figure 35: Percentage of extend of recommended PHR features*

### 5.2.2 Objective 2

**To identify the current mechanisms of identifying patients in health facilities and alternatives for universal patient identification.**

More than half the health facilities in Kenya have unique patient identification scheme. However, this identification scheme (unique patient identifier) is only know to a particular health facility. The patients were not able to memorize this numbers as they vary from one health facility to another and that explains why 73.5% of respondents do not know their medical reference number when they were asked during the survey. It calls for patient data interoperability which starts with universal patient identification across health care facilities.

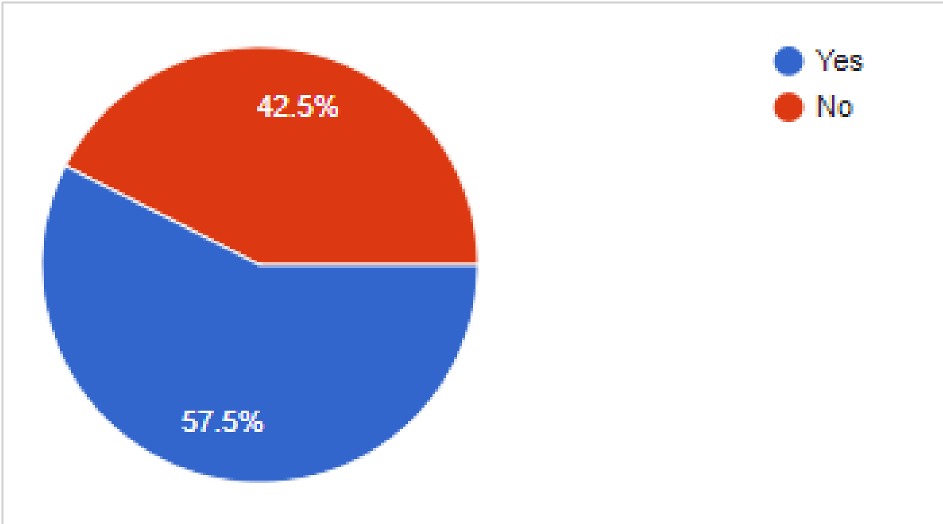



*Figure 36: Percentage of health Facilities with unique patient identification scheme*

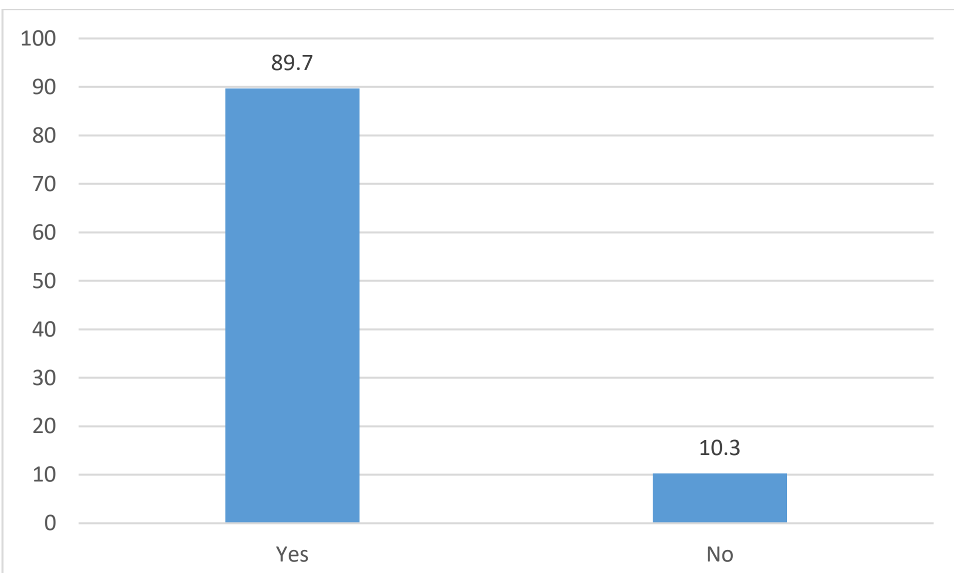



*Figure 37: Percentage of patients who know their medical reference numbers*

The rest of the hospitals that do not have unique patient identification scheme resort to use other alternatives, which may also be captured prior issuing a unique patient identifier. Majority of the respondents mentioned that personal information was most popularly used followed by statutory documents and biometric information and lastly other documents like insurance member number. The use of personal information for identification is popular in health facilities since the patients especially those under the age of eighteen. Physicians or healthcare personnel do not usually ask for statutory documents like national identity card. Biometric information verification like fingerprint are gaining popularity in Kenya championed by medical health insurance providers.

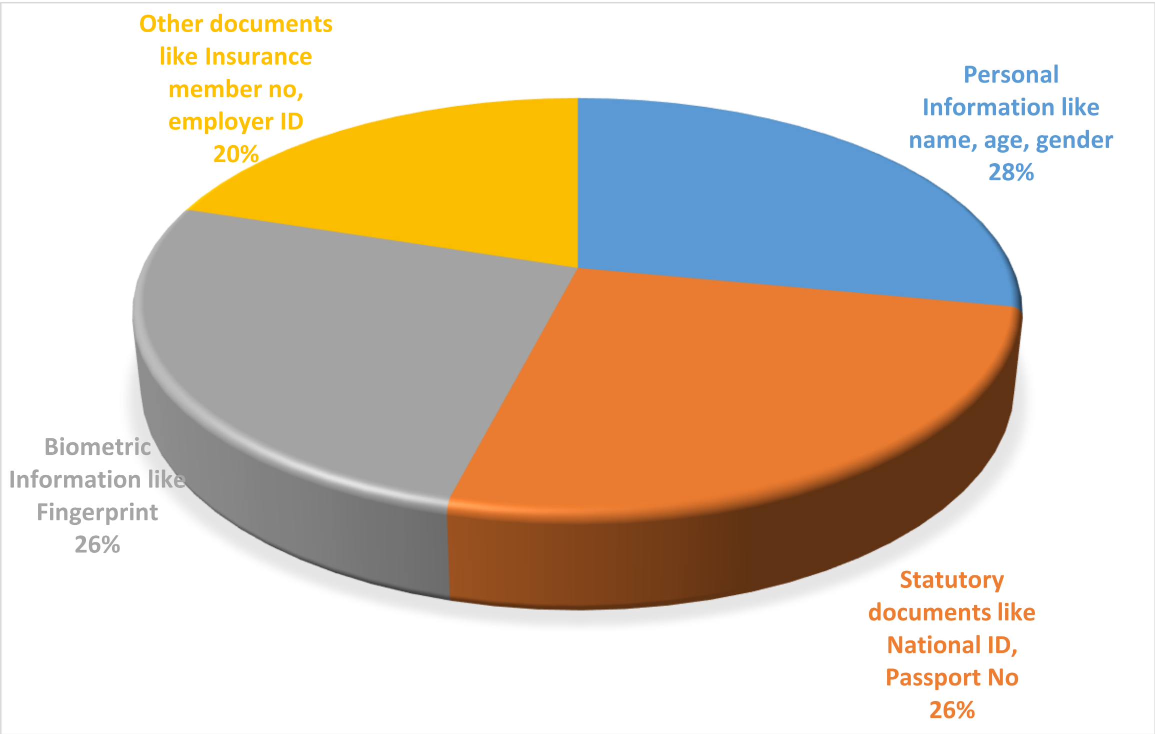



*Figure 38: Unique patient Identification alternatives comparisons*

Besides patient identification, health care personnel usually interview patients on information they know. Some may request documents from previous health facilities in case of referral. During interview at Kenyatta National Hospital, patients seeking specialized treatments like xray scanning must provide referral letters otherwise they will be subject to fresh consultation and tests by physicians. Based on the respondent feedback, patient identification by inquiring about personal information is most common (65%) followed by health information at 51.9%, physical body characteristics and drug prescription history follow at percentage of 40.7% and 37% respectively as shown below:

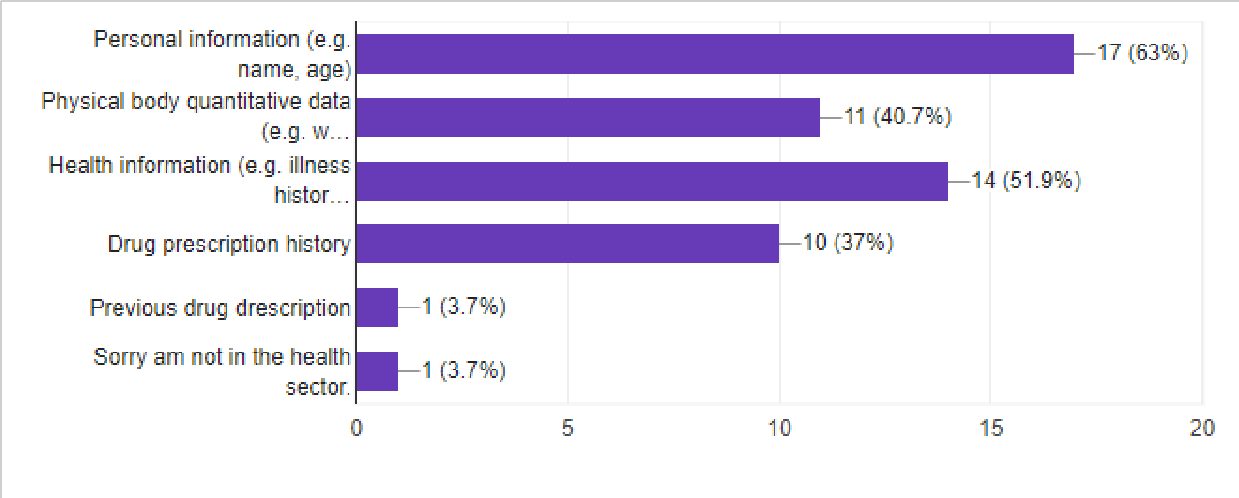



*Figure 39:Comparisons  information do you receive about a patient when they are transferred to your health facility from another health facility*

Many times, it may not be possible to ask information from a patient when they are critically ill or unconscious such that they cannot speak. 60% of the healthcare personnel would back on contacting or asking their next of kin, 15% resort to checking their existing records using any available identification like national identity card number, while 10% would offer first aid and rest 10% medical diagnosis. Only 5% would give patient prescriptions which is very risky as the patient may be misdiagnosed or may be allergic to drugs administered to them. Although most of the healthcare personnel (physicians) opt for consulting the patient's next of kin, most of the medical information may not be known to them, either because they have not been together in their entire lifetime or patient has failed to share their medical history with their next of kin. They say "computers never argue, they remember everything". A Personal Health Record system is most suitable for storing, sharing and retrieving medical history of a patient.

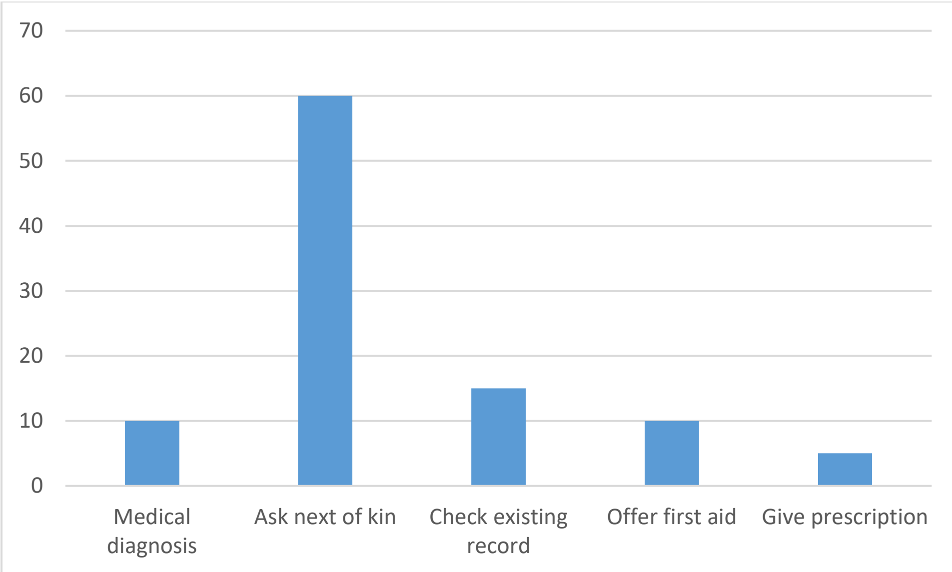



*Figure 40: What to do you if the patient is unable to remember their medication history due to their medical condition*

### 5.2.3 Objective 3

**To develop SOA architectural model and prototype for the proposed Omnichannel PHR System.**

Data interoperability among system in various sectors is still a challenge. 39% of the respondents believe that interoperability of medical information between different health facilities as very low, 22% and 17% believe that it is average and low respectively. 6% respondents indicate that it is medium while the rest 5% believe that is high.

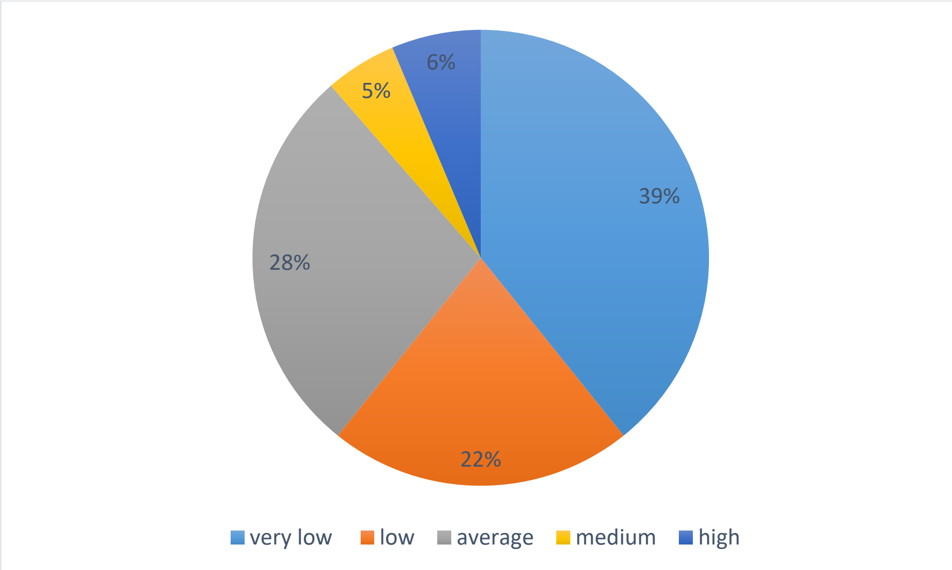



*Figure 41: Level of Interoperability between healthcare facilities in Kenya*

The low level of interoperability can be attributed to factors like lack of universal patient identification at 46% as the highest, 39% attributed to multiple standards while 38% is due to reluctance by health care facilities to share data with others. Other factors include partner focused solutions in place, poor ways of keeping patient records especially filing, fear of losing competitive edge, lack of proper legislation, regulation and oversight which contributes 1% each.

| **Barrier** | **Total Respondents** | **%** |
| --- | --- | --- |
| Lack of universal patient identification | 46 | 57.5 |
| Multiple standards that are not uniform | 39 | 48.8 |
| Reluctance by health facilities to share data | 38 | 47.5 |
| Partner-focused solutions in place | 1 | 1.3 |
| Poor ways of keeping patient records especially filing | 1 | 1.3 |
| Fear of losing competitive edge | 1 | 1.3 |
| Lack of proper legislation, regulation and oversight | 1 | 1.3 |

*Table 12: Barriers to medical data interoperability in Kenyan health facilities*

A Majority of the respondents (37%) didn't know the current architecture employed by healthcare facilities. The researcher went on to interview the technical health care workforce and technology experts about the architecture. 19.2% indicated that the architecture is two-tier client-server architecture, 16.4% say it is distributed component (service oriented architecture) and 13.7% peer-to-peer architecture. 12.3% mentioned that it is master-slave architecture while 8.2% a multi-tier client-server architecture. This study proposes adoption of service oriented architecture based on the literature review as it is being adopted by leading industries in finance, manufacturing and healthcare as well. Also, the researcher has a vast professional experience in implementing systems based on SOA.

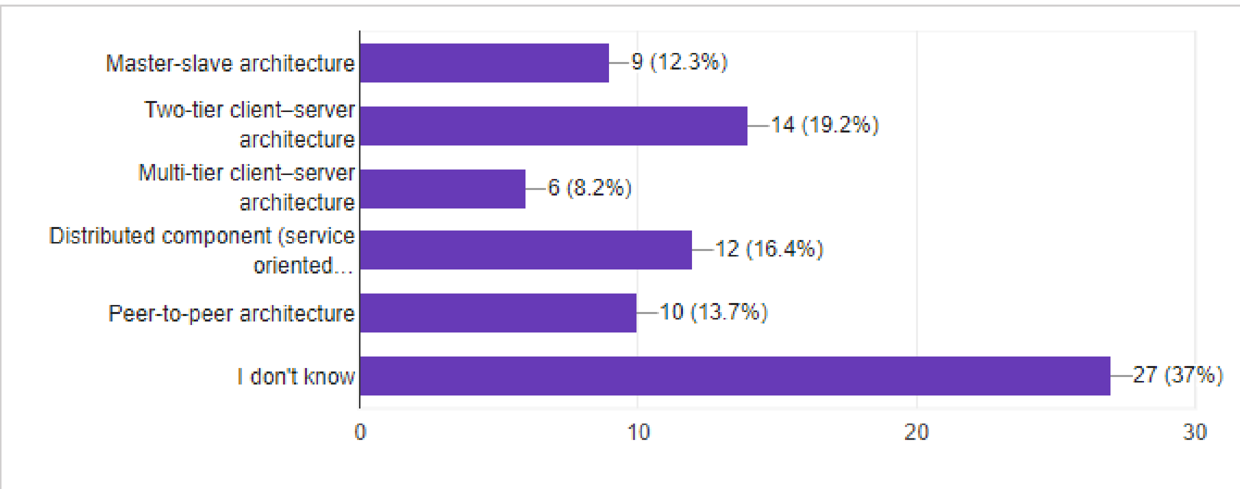



*Figure 42:Current architectures used in developing your distributed healthcare systems*

Respondents were asked to choose the most appropriate channel for accessing the proposed Personal Health Record System. 67.1% indicated that mobile is most suitable followed by web at 49.4%. Desktop and USSD were ranked the least at 22.8% and 21.5% respectively. Although the Omnichannel Personal Health Record system intended to encompass all the channels, only web and mobile were implemented since they are most popular. Time was limited to implement all the other channels which include other systems, Internet of Things like wearable sensors were out of scope of this research but can be readily accommodate in the service oriented architecture.

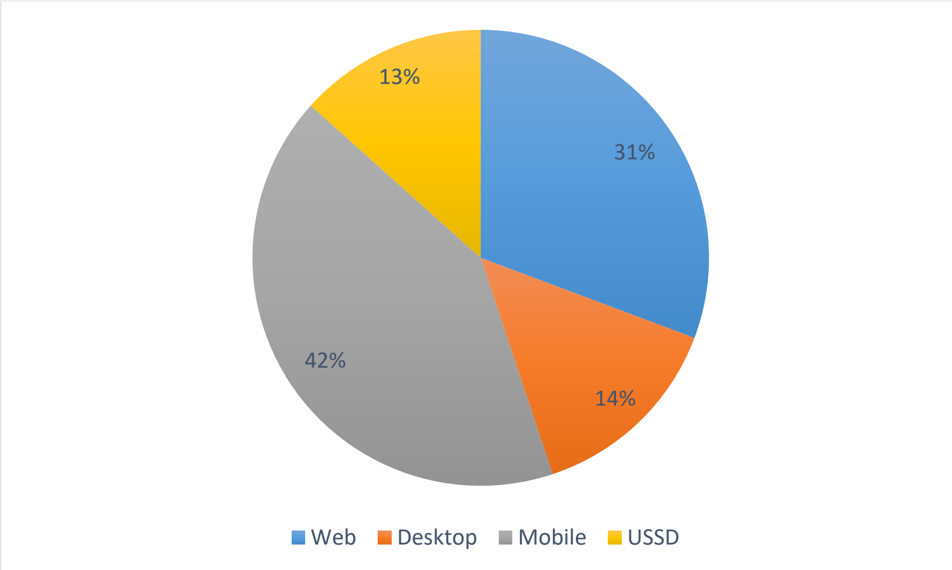



*Figure 43: Preferred channels for accessing a PHR system*

## 5.3 System testing results and findings

### 5.3.1 Objective 4

**To test the Omnichannel PHR system developed.**

#### *5.3.1.1 API Testing Results*

The Omnichannel PHR Webservices were tested independently. As part of unit and system integration testing, Application Programming Interface testing was performed directly to determine if they meet expectations for functionality, reliability, performance, and security.

API testing was achieved by executing pre-scripted sample request messages. Both negative and positive tests were carried out. Response times were recorded and tabulated to test whether the system can withstand high volume requests. An estimated 1000 requests were made to the API per service.

| **Service Name** | **Test type** | **Request** | **Response** | **Status** |
|---|---|---|---|---|
| Signup | Wrong identification | {"firstname":"Victor","birthdate":"2017-05-01","identificationtypeid":"1","phonenumber1":"254321874258","auth":"949085","middlename":"C","emailaddress" | {"firstname":"Victor","birthdate":"2017-05-01","identificationtypeid":"1","phonenumber1":"254321874258","auth":"949085","middlename":"C","emailaddress":"jumo@gmail.com**","error":"Wrong first** | FAIL |

| | | | | |
|---|---|---|---|---|
| | documents | :"jumo@gmail.com","identificationnumber":"60527838","lastname":"Jumo"} | **name"**,"message":"Failed to register","lastname":"Jumo**","statuscode":"57"**,"identificationnumber":"60527838"} | |
| | Existing record | {"firstname":"Hesbon","birthdate":"1987-10-02","identificationtypeid":"1","phonenumber1":"254724835188","auth":"4541545","middlename":"K","emailaddress":"kiptoohesbon@gmai.com","identificationnumber":"27320837","lastname":"Kiptoo"} | {**"statuscode":"57"**,"firstname":"Hesbon","birthdate":"1987-10-02","identificationtypeid":"1","phonenumber1":"254724835188","auth":"4541545","middlename":"K","emailaddress":"kiptoohesbon@gmai.com","message":"Failed to register","error":"**Already Registered**","identificationnumber":"27320837","lastname":"Kiptoo"} | FAIL |
| | Valid input data | {"firstname":"Victor","birthdate":"2017-05-01","identificationtypeid":"1","phonenumber1":"254721874258","auth":"9857085","middlename":"C","emailaddress":"jumo@gmail.com","identificationnumber":"8034533","lastname":"Jumo"} | {"firstname":"Victor","birthdate":"2017-05-01","identificationtypeid":"1","phonenumber1":"254721874258","auth":"9857085","patientindex":"902183935913","middlename":"C","emailaddress":"jumo@gmail.com","message":"**Successfully registered**","lastname":"Jumo**","statuscode":"00"**,"identificationnumber":"8034533"} | |
| Login | Missing session token | {"password":"186e8185b9804bfd8dda28b1d25fcdeb2a9295a47d4fef2287de1f7ace54955e",,"usertype":"2","username":"hesbon"} | {**"statuscode":"57"**,"usertype":"1","message":"Failed to login","error":"**Could not validate session token**","username":"hesbon"} | FAIL |
| | Invalid Credentials | {"password":"dfgfdgfdda28b1d25fcdeb2a9295a47ddfgret7de1f7ace54955e","auth":"94904545","usertype":"2","username":" hesbontoo "} | {**"statuscode":"57"**,"auth":"949085","usertype":"1","message":"Failed to login","error":"**Username or password invalid**","username":"rotich"} | FAIL |
| | Correct credentials | {"password":"186e8185b9804bfd8dda28b1d25fcdeb2a9295a47d4fef2287de1f7ace54955e","auth":"9490485","usertype":"2","username":"hesbon"} | {"firstname":"HESBON2","birthdate":"1987-10-02","phonenumber1":"","birthcertnumber":"","auth":"949085","patientindex":"548454","profile":"Patient","usertype":"1","middlename":"KIPCHIRCHIR2","emailaddress":"",**"message":"Login Success**",**"statuscode":"00"**,"username":"hesbon"} | PASS |
| Profile View | Unauthorized patient record view | {“doctorID”:5,”patiendindex”:” 282582378807”,”otpcode”:”5400311372”} | {"statuscode":"57","message":"Invalid OTP Code for patient index 282582378807"} | FAIL |

| | | | | |
|---|---|---|---|---|
| | Authorized patient record view | | {"phi":{"firstname":"Bernard","birthdate":"1989-07-21","identificationtypeid":"1","patientindex":"635355411858","nhifno":"","nationalityid":"","genderid":"","registrationdate":"2018-06-24 17:41:51","fingerprintdata":"","parentid":"","createdby":"","postalcode":"","maritalstatusid":"","id":"36","insuranceproviderid":"","raceid":"","identificationDocuments":[],"phonenumber2":"","passportphoto":"","phonenumber1":"0721411331","birthcertnumber":"","nextOfKin":[],"emergencyContact":[],"isparent":"1","postaladdress":"","middlename":"M","emailaddress":"bettbernard@gmail.com","townid":"","countryid":"","lastname":"Cheress","countyid":"","insurancepolicyno":"","isphysician":"0","identificationnumber":"27087974"},"statuscode":"00","patient":{"allergies":[{"firstencounter":"2018-06-26","createdby":"bettbernard@gmail.com","allergy":"Skin","description":"Something to describe","id":"17","datecreated":"2018-06-26 18:55:33","phrid":"25"}],"familyhistory":[{"createdby":"bettbernard@gmail.com","name":"Skin allergy","description":"This type of allergy is so irritating","id":"3","datecreated":"2018-06-26 19:05:12","phrid":"25"}],"emotionaldisorders":"0","gender":"","race":"","patientindex":"635355411858","socialhistory":[],"asthma":"0","datecreated":"2018-06-24 17:41:51","glucoselevel":"","knownillness":[{"image":"","createdby":"bettbernard@gmail.com","name":"STI","description":"Sexually transmitted deasese","id":"2","datecreated":"2018-06-26 20:49:32","phrid":"25"}],"bloodgroup":"","immunizations":[{"date":"2018-06-26","image":"","createdby":"bettbernard@gmail.com","name":"Polio","description":"Chanjo ya polio","id":"6","datecreated":"2018-06-26 19:49:41","phrid":"25"}],"temperature":"","bloodpressure":"","psychologicaldisorders":"0","id":"25","heartfrequency":"","diabetes":"0","age":"","height":""},"diagnosis":{"radiology":[],"hospitalVisits":[{"reference":"TRYRYTSGSH","date":"","organizationid":"74747474","image":"","notes":"hsjsjsjsj","createdby":"bettbernard@gmail.com","id":"2","datecreated":"2018-06-26 | PASS |

| | | | | |
|---|---|---|---|---|
| | | | 20:09:13","isphysician":"0","phrid":"25","illness":"Malaria"}],"labtests":[],"prescriptions":[{"reference":"GSHSH","organizationid":"34567","dosage":"1 pair per day","image":"","quantity":"100","createdby":"bettbernard@gmail.com","description":"","id":"2","datecreated":"2018-06-26 21:13:54","isphysician":"0","phrid":"25","drug":"Panadol"}]},"message":"Data retrieved successfully"} | |

*Table 13: API testing results*

The average response time for servicing requests at Webservice API are tabulated below:

| **Service Name** | **Number of requests** | **Sent time** | **Receive time** |
|---|---|---|---|
| Signup | 1,000 | 2018-06-21 18:49:50 | 2018-06-21 18:53:36 |
| Login | 1,000 | 2018-06-21 19:10:23 | 2018-06-21 19:12:03 |
| Update profile | 1,000 | 2018-06-21 19:03:41 | 2018-06-21 19:06:49 |
| View profile | 1,000 | 2018-06-21 19:52:20 | 2018-06-21 19:53:28 |
| Share profile | 1,000 | 2018-06-21 20:01:49 | 2018-06-21 20:04:18 |

*Table 14: API stress test results*

#### *5.3.1.2 User Acceptance Testing Results*

A post-implementation survey was conducted to test the Omnichannel PHR solution. Respondents were given instructions on how to access the prototype. A total of 17 respondents participated in the post-implementation survey. The respondents either downloaded a cross-platform mobile application or accessed via a web interface although they were encouraged to try both channels and give their experience on both. Healthcare professionals were first registered on the web portal by the register once they accepted to participate in the post-implementation survey. Both categories of users were to use the system disguised as patients and practising doctors and later they filled questionnaires to determine if intended functional requirements were met through the use of this prototype system. Respondents were also asked to indicate what features could be added to the PHR system and how the existing features can be improved to meet their needs.

- Ability to register patient in the Omnichannel PHR using the popular channels (Web portal, Mobile Application) by patients themselves or by healthcare personnel on the Web portal.
- Ability to add or update medical data by patients or healthcare personnel.
- Ability to provide reliable access to the medical data based on preset permissions by patients.
- Ability to ensure a high level of security, privacy and confidentiality of the patient data.
- Ability to ensure high availability and performance of the solution even in extreme conditions like network coverage or partial system downtime.
- Ability to offer additional benefits and added value to effectively compete with existing mHealth, EMR, NMPI and other systems.

82.67% of the respondents accessed the PHR solution by downloading the mobile app while 17.33% used both web application and mobile application. The mobile applications are gaining popularity of personal computers. Mobiles are becoming part of their livelihood.

All the respondents were able to use the PHR system without being helped

| **Assisted by** | **Total Respondents** | **%** |
|---|---|---|
| My Doctor | 0 | 0 |
| A friend | 0 | 0 |
| I was not assisted, did it by myself | 17 | 100 |

*Table 15: Number of patients assisted in using PHR system*

On Average, more than 78% of the respondents agree that the PHR features listed have met their objectives to a large and very large extend cumulatively.

| **PHR features** | ***no extent at all*** | ***small extent*** | ***moderate extent*** | ***large extent*** | ***very large extent*** |
|---|---|---|---|---|---|
| Storing illnesses and hospitalizations | 0.00 | 0.00 | 11.76 | 29.41 | 58.82 |
| Storing allergies and adverse drug reactions | 0.00 | 0.00 | 0.00 | 23.53 | 76.47 |

| | | | | | |
|---|---|---|---|---|---|
| Storing medical Prescription record | 0.00 | 0.00 | 0.00 | 17.65 | 82.35 |
| Laboratory test results and image reports | 0.00 | 0.00 | 5.88 | 29.41 | 64.71 |
| Transfer medical information to doctors and specialists | 0.00 | 0.00 | 17.65 | 76.47 | 11.76 |

*Table 16: Extend of satisfaction on the features in the PHR system*

Respondents were asked to mention other tasks that think if incorporate would help them perform specific duties like reminders to take medication, find nearby health facilities, pay for medical services via the app, schedule doctor appointment.

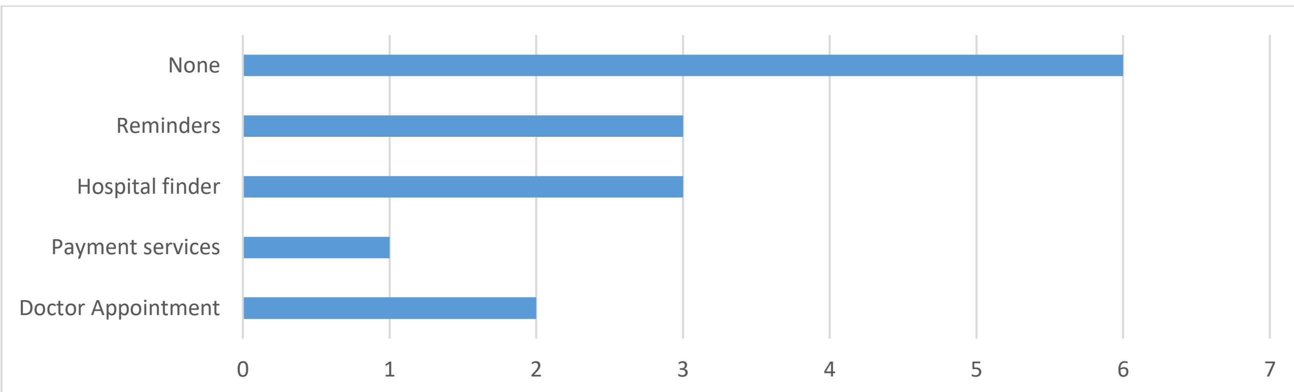



*Figure 44: Additional features to be added to PHR system*

23% of the respondents strongly believe that security is paramount for success of adoption of the PHR system. Others have suggested the use of certain technologies like wearables and blockchain that if leverages, the system can be improved to a great extent.

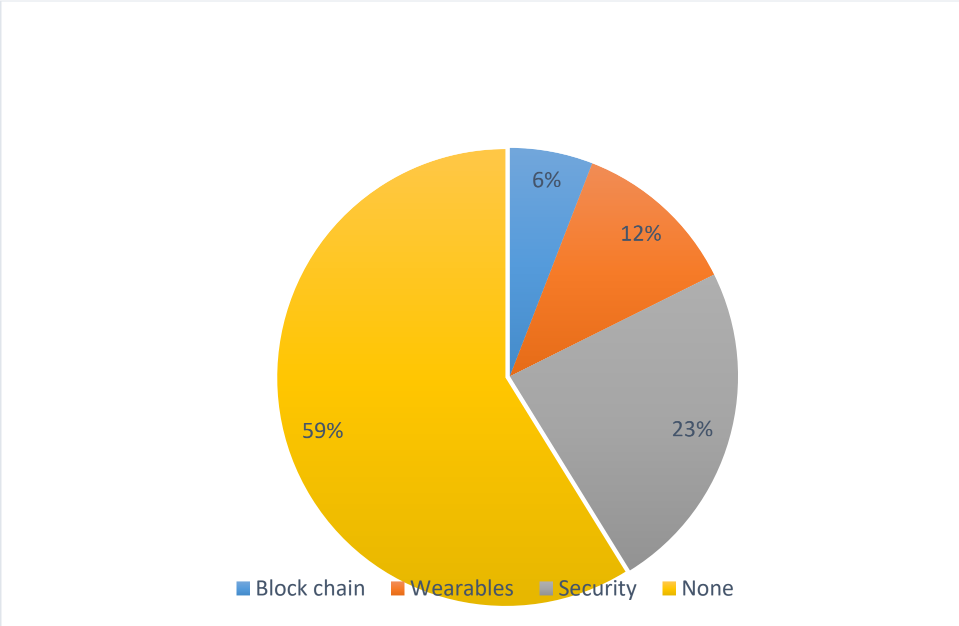



*Figure 45: Proposed improvements to the PHR system*

The respondents are happy with the security considerations of the app. The ability to share records and two-factor authentications (SMS OTP) when requesting access to profile information and verification of documents when onboarding.

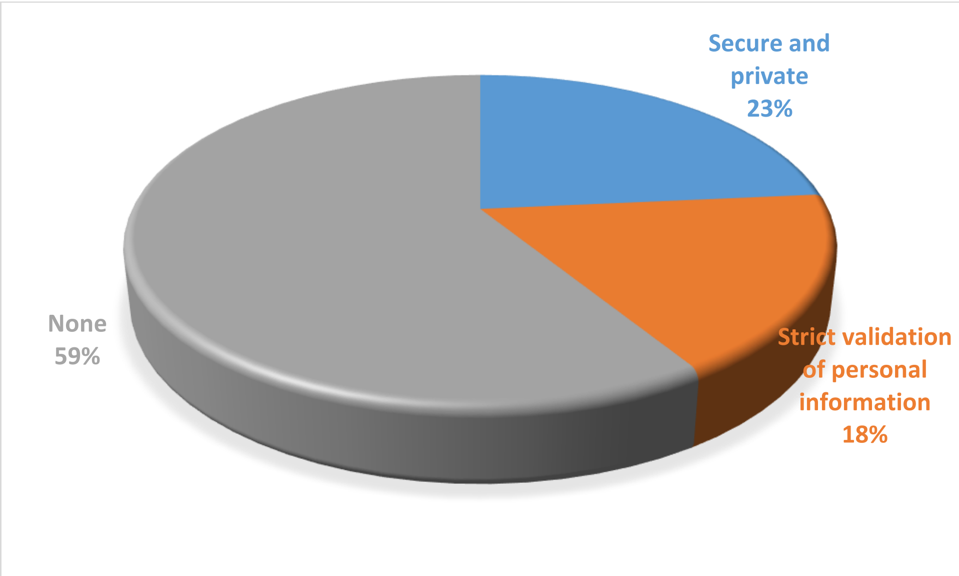



*Figure 46: Features they like about the app*

88.2% percent recommend the system for use by family and friends as they are happy and confident with use of the app.

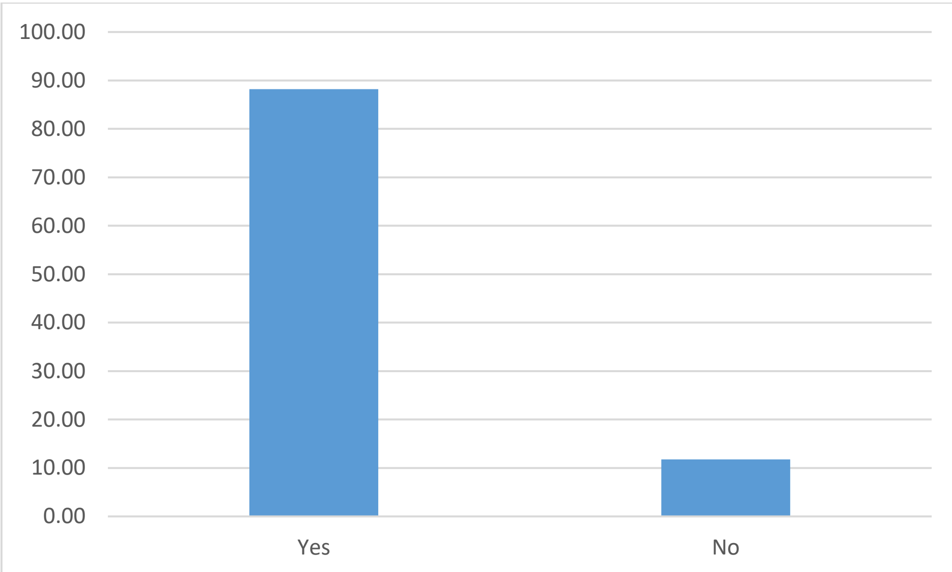



*Figure 47: Percentage of respondents willing to recommend PHR system to family and friends*

# 6 CONCLUSION AND RECOMMENDATIONS

## 6.1 Introduction

This chapter presents limitations, conclusion and recommendations for future research.

## 6.2 Summary

The main objective of the research was to implement an Omnichannel Personal Health Record System based on Service Oriented Architecture (SOA) framework to facilitate patient-centred self-care and collaboration with caregivers. The prototype aimed at demonstrating universal patient identification and data sharing by patients with health care providers.

## 6.3 Limitations of the research

The proposed Omnichannel Personal Health Record system intended to allow patients to access the system through various interfaces (channels). However, only two channels were implemented, web portal and mobile application, based on the pre-study carried out where respondents indicated that they were more likely to use the web and mobile application than the other channels like USSD. Internet of things (IoT), Electronic Medical Record (EMR) system integrations were not part of the scope due to the limited time and budget. Patients and healthcare personnel had to perform manual entries to the PHR system. This may introduce potential errors in data and chances of having duplicate entries into the system. This was mitigated by allowing patients and physicians to upload images of various reports like lab tests, doctor summary, prescription notes, etc. Patient verification using IPRS database ensured no duplicates prior registering the patient in the system. Only parents were allowed to sign up their children.

Furthermore, not all aspects of PHR were implemented like reminders, medical device integrations, health insurance, wellness information. Only the generic functional requirements of a Omnichannel PHR System. The healthcare and dentistry board have to determine the suitability of this project before the actual implementation of the project.

## 6.4 Conclusion

The overall objective of this research project was to implement an Omnichannel Personal Health Record System based on Service Oriented Architecture (SOA) framework to facilitate patient-centered self-care and collaboration with healthcare providers. The prototype system offered patients/individuals ability to manage their medical history, chose whom to share with within a particular period of time. The physicians can use the patient’s medical history irrespective of their previous health facility visited. Although a greater percentage of respondents have never had of a PHR most of them were willing to use it if their physicians recommend them. The respondents recommended to a very large extent the PHR features suggested.

Interoperability of medical data between different healthcare facilities is still very low which is attributed mostly to lack of a nationwide universal patient identification followed by multiplicity of message standards as well as reluctance by health facilities to share data. Biometric verification is gaining popularity as it is heavily used by medical insurance facilities in identifying their members. It can be harnessed in positively identifying in cases of emergency especially where patients are not able to speak with the health care provider. They mostly resort to asking their next of kin. This method of verification is provided in the PHR system.

A mix of architectures exists in the healthcare. The researcher proposed the adoption of Service Oriented Architecture because of leading success stories industries in finance, manufacturing and healthcare as well as the researcher has a vast professional experience in implementing systems based on SOA.

The findings of this research study and evaluation of the prototype demonstrated interoperability could be easily achieved by giving the patients the ability to record their own medical information using different platforms (web and mobile) without having to carry papers whenever they seek medication. Healthcare professionals can assist the patients in updating their profiles whenever they seek medical treatment. Patients are very cautious about the privacy of their data and were comfortable by having control who can read or write their records.

Finally, the Service Oriented Architecture provided an integration layer that will facilitate the interoperability of different channels, devices and third-party systems or applications. As such PHR data will to available anytime, anywhere, any terminal over cloud technologies.

## 6.5 Recommendation for future work

The Service Oriented Architecture (SOA) has demonstrated to a great extent the potential to improving patient data interoperability by allowing patients to manage their data and sharing with their physicians. Having a central database of patient information ensures universal patient identification and availability of specific patient medical data on demand which improves patient care.

Due to the limited research time and resources, the researcher could not implement the feedback from the respondents who participated in the post-implementation survey to test the system which proposed modifications to the system like Mobile Wallets. Patients can optionally create a mobile wallet. The wallet can be funded through other payment providers like Mobile Money or Bank Transfer. Patients in the ecosystem can also send each other e-value. The e-Value can be used to pay for treatment, purchase medicine as well as settling other bills. Patients will earn loyalty points when making payments to encourage them to use the platform. The patients can also earn points when they participate in surveys or by selling their anonymous data for research purposes. The loyalty points can be used to make payments.

Future researchers are also encouraged to implement linkage of existing patient data with PHR systems and also adopt distributed ledger technologies to improve security and usability of the PHR system. Although Distributed Ledger Technology (DLT) is still in its infancy, Blockchain has great potential in solving most of the healthcare issues especially on data sharing, security and speed of transactions. Private permissioned blockchain is recommended like IBM Hyper Ledger Fabric.

**BIBLIOGRAPHY**

AHIMA, M. T. (2011). Managing the Master Patient Index in an Integrated Delivery System. *Journal of AHIMA 69, no. 1 (1998)*.

Arabinda, R. (2007). Introduction to SOA. *HynesConvention Center*. Boston: SD Best Practices Confererence Expo 2007. Retrieved Apr 12, 2018, from https://www.slideshare.net/datainc/introduction-to-service-oriented-architecture

Arsanjani, A. (2004). Service-oriented modeling and architecture, How to identify, specify, and realize services for your SOA. *IBM Developer Works*.

Arzt, N. H. (2017). Is There a National Strategy Emerging for Patient Matching in the US? *KEI Journals*.

Bell, G., & Sethi, A. (2001). Matching records in a national medical patient index. *Communications of ACM*.

CAK. (2017, Dec). *Internet Penetration hits 112 per cent, Latest Report Shows*. Retrieved May 17, 2018, from Communications Authorithy of Kenya: http://ca.go.ke/images/downloads/STATISTICS/Sector%20Statistics%20Report%20Q1%20%202017-18.pdf

Chapman, S. (2014, May). *Patient Identification in an HIE Environment*. Retrieved 04 12, 2018, from For The Record: http://www.fortherecordmag.com/archives/0514p10.shtml

*E-Estonia*. (n.d.). Retrieved Apr 12, 2018, from E-Estonia Health Care: https://e-estonia.com/solutions/healthcare/e-health-record/

e-estonia. (n.d.). *e-estonia Healthcare*. Retrieved May 06, 2018, from e-estonia: https://e-estonia.com/solutions/healthcare/

Erl, T. (2005). *Service-Oriented Architecture: Concepts, Technology, and Design.* Upper Saddle River, NJ: Prentice Hall.

Ge, Y., Ahn, D. K., Gage, D. H., & Carr, J. J. (2013). Patient-controlled sharing of medical imaging data across unaffiliated healthcare organizations. *Journal of the American Medical Informatics Association*, 57 - 163.

Genevieve Morris, Greg Farnum, Scott Afzal, Carol Robinson, Jan Greene, & Chris Coughlin. (2014). *Patient Identification and Matching Final Report.* Baltimore: Audacious Inquiry, LLC.

*Good Practices for the Implementation and Management of a National Master Patient Index*. (2015, Sept 01). Retrieved May 14, 2017, from MEASURE Evaluation: https://www.measureevaluation.org/resources/publications/fs-15-147/at_download/document

GSMA. (2011). *A High Level Reference Architecture.* New Fetter Lane, London EC4A 3BF UK: GSMA Mobile Health.

Hasan, H. (2003). Information systems development as a research method. *Australasian Journal of Information Systems*.

HealthLeaders Media Magazine. (2015). *A Framework for Cross- Organizational Patient Identity Management.* Health Leaders Media Magazine.

Heerden, A. v., Tomlinson, M., & Swartz, L. (2012). Point of care in your pocket: a research agenda for the field of m-health. *Bulletin of the World Health Organization*.

InApp. (n.d.). *Service Oriented Architecture*. Retrieved Oct 9, 2017, from InApp: https://inapp.com/service-oriented-architecture/

ITU. (2012). *E-health Standards and Interoperability ITU-T Technology Watch Report April 2012.* International Telecommunication Union, (cited 19 February 2017); http://goo.gl/VTjdo 2012.

Jamie, T. (2015, Jun 15). *Client Registry Resource Library*. Retrieved Oct 09, 2017, from Jembi: https://jembiprojects.jira.com/wiki/spaces/RHEAPILOT/pages/9437901/Client+Registry+Resource+Library

Jingquan, L. (2017). A Service-Oriented Approach to Interoperable and Secure Personal Health Record Systems. *EEE Symposium on Service-Oriented System Engineering (SOSE)*.

Karimi, O., & Modiri, N. (2011). Enterprise Integration using Service Oriented Architecture. *Advanced Computing: An International Journal (ACIJ)*.

Kenya National e-Health Ploicy 2016-2030. (2016). *Kenya National e-Health Ploicy 2016-2030.* Ministry of Heakth. Retrieved Oct 05, 2017, from https://www.medbox.org/kenya-nation-e-health-policy-2016-2030/download.pdf

Kenya National e-Health Strategy (2011-2017). (2011). *Kenya National e-Health Strategy (2011-2017).* Ministry of Medical Services and Ministry of Public Health and Sanitation. Retrieved Oct 5, 2017, from https://www.isfteh.org/files/media/kenya_national_ehealth_strategy_2011-2017.pdf

Keyur, P. K., & Sunil, P. M. (2016). Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*.

Kolly, V., Cleaphas, A., Bovier, P. A., Ganerin, P., & Perneger, T. V. (2004). Acceptability of identification bracelets for hospital inpatients. *Quality and Safety in Health Care*.

Lake, D., Rayes, A., & Morrow, M. (2018, July 8). *The Internet of Things - The Internet Protocol Journal,*. Retrieved from Cisco Systems: https://www.cisco.com/c/en/us/about/press/internet-protocol-journal/back-issues/table-contents-57/153-internet.html

Lenson, C., RHIA, & M, L. (1995). Preparing the Master Patient Index For an Integrated Delivery System. *Journal of AHIMA*, 56-60.

Li, J. (n.d.). A Service-Oriented Approach to Interoperable and Secure Personal Health Record Systems.

Masava, V. L. (2013). *An Electronic Government Integrated System using Service Oriented Architecture (SOA).* Nairobi: University of Nairobi.

Ministry of Health Rwanda. (2011, Aug 11). *Rwanda Client Registry*. Retrieved Apr 12, 2018, from Colleaga: https://www.colleaga.org/sites/default/files/RwandaClientRegistryMoH.pdf

Nadhan, E. G. (2004). Service-Oriented Architecture: Implementation Challenges. *Microsoft Architect Journal*.

NEMIS. (n.d.). *NEMIS User Manual*. Retrieved May 29, 2018, from Ministry of Education.

OpenHIE. (n.d.). *Client Registry*. Retrieved May 14, 2017, from OpenHIE: https://ohie.org/client-registry/

Papazoglou, M., & Heuvel, W.-J. (2007). Service oriented architectures. *Very Large Database Journal*.

PharmD, J. Z. (2016, Nov 8). *Benefits, Risks, and Drawbacks of an Electronic Personal Health Record*. Retrieved Sept 12, 2017, from Centerpoint Clinical Services: https://www.centerpointclinicalservices.com/blog-posts/benefits-risks-and-drawbacks-of-an-electronic-personal-health-record/#ref5

Phil Bianco;Rick Kotermanski;Paulo Merson. (2007). *Evaluating a Service-Oriented.* Hanscom AFB: Software Architecture Technology Initiative.

Pulier, E., & Taylor, H. (2006). *Understanding Enterprise SOA.* USA: Manning Publication.

Purkis, B., Morris, G., Afzal, S., Bhasker, M., & Finney, D. (2012). *MASTER DATA MANAGEMENT WITHIN HIE INFRASTRUCTURES: A FOCUS ON MASTER PATIENT INDEXING APPROACHES.* Office of the National Coordinator for Health Information Technology.

PWC. (2014). *Emerging mHealth: Paths for growth.* PWC.

Qiang, C. Z., Yamamichi, M., Hausman, V., Miller, R., & Altman, D. (2012). *Mobile Applications for the Health Sector.* Washington DC: ICT Sector Unit World Bank.

Rosen, M., Lublinsky, B., Smith, K. T., & Balcer, M. J. (2008). *Applied SOA: Service-Oriented Architecture and Design Strategies.* Wiley Publishing, Inc.

Rouse, M. (2017, Aug 01). *Enterprise Master Patient index (EMPI)*. (WhatIs.com) Retrieved Nov 09, 2017, from TechTarget: http://searchhealthit.techtarget.com/definition/master-patient-index-MPI

S, P. C., L, L. S., & H, G. R. (n.d.). Barriers to the Adoption and Use of Personal Health Record Systems. *ProciConference*.

Scott , S. (2010, Sept 30). *Approaches to statewide patient identification: pros and cons*. Retrieved May 7, 2017, from Healthcare IT News: https://www.healthcareitnews.com/blog/approaches-statewide-patient-identification-pros-and-cons

Sonic Software Corporation, A. I. (2005). *A NEW SERVICE-ORIENTED ARCHITECTURE (SOA) MATURITY MODEL.* Retrieved from http://www.omg.org/soa/Uploaded%20Docs/SOA/SOA_Maturity.pdf

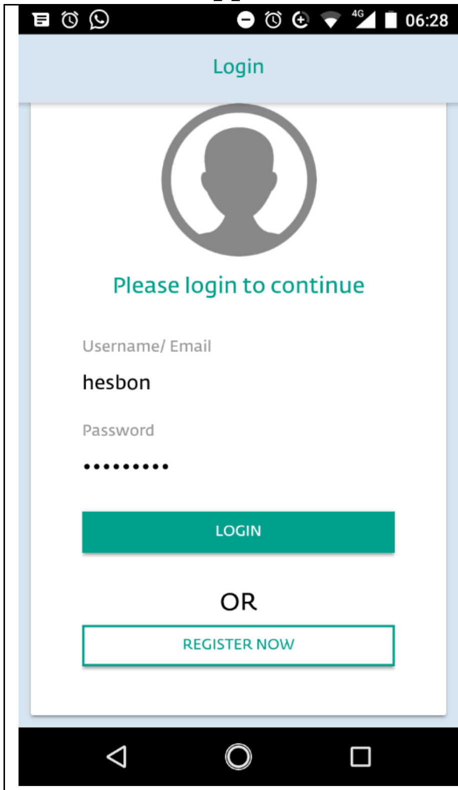
*Summary of the HIPAA Security Rule*. (n.d.). Retrieved Apr 12, 2018, from HHS Gov Health Information Privacy: https://www.hhs.gov/hipaa/for-professionals/security/laws-regulations/index.html

Terry, K. (2015, Aug 18). *National patient identifier struggles for life*. Retrieved May 7, 2017, from CIO: https://www.cio.com/article/2972266/healthcare/national-patient-identifier-struggles-for-life.html

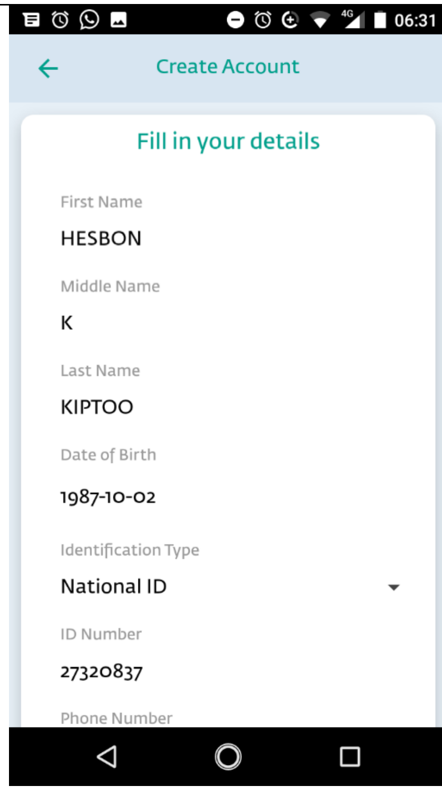
# APPENDIX

## Appendix I: Sample Screen shots

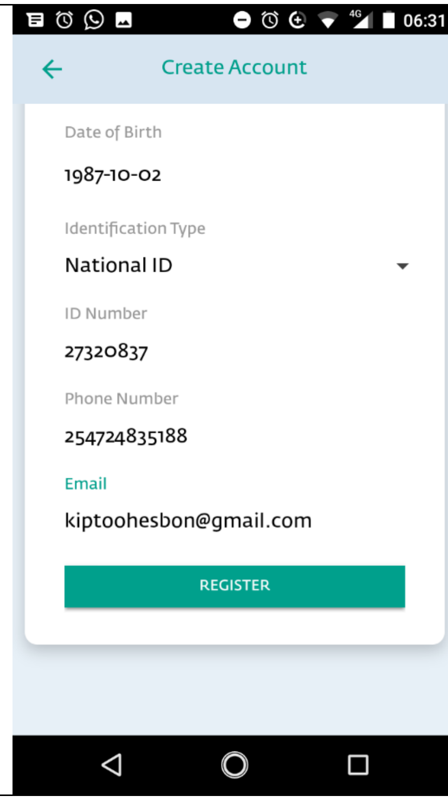
### Mobile App



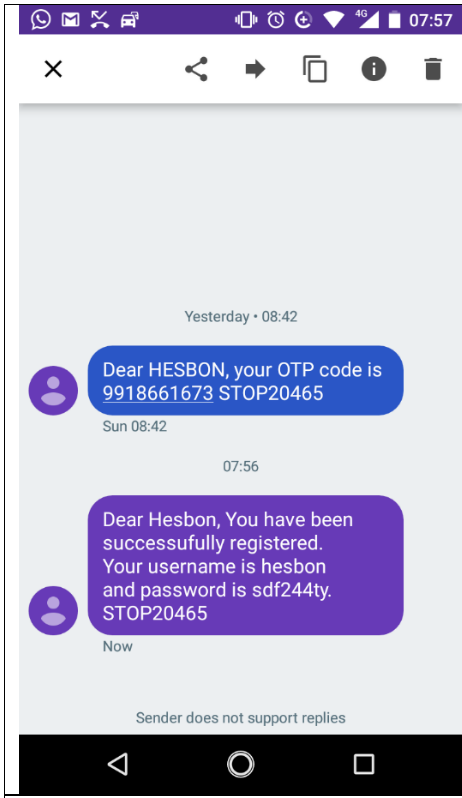
Login Page



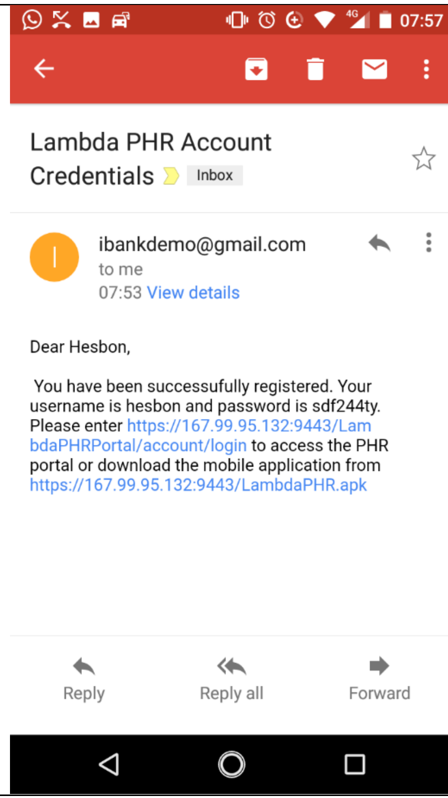
Signup (1)



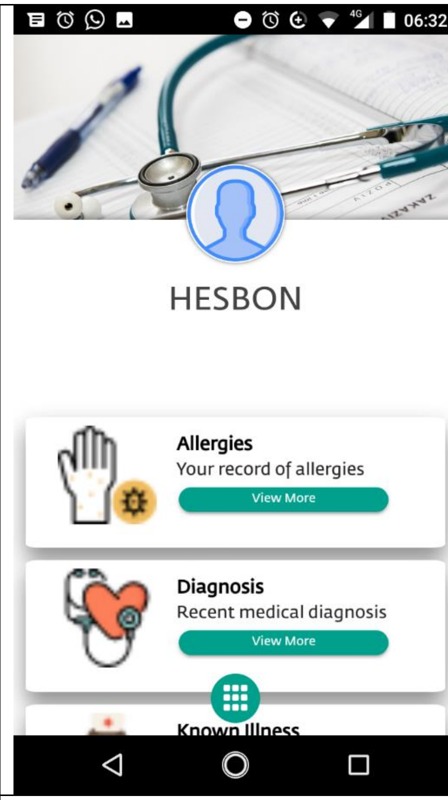
Signup(2)



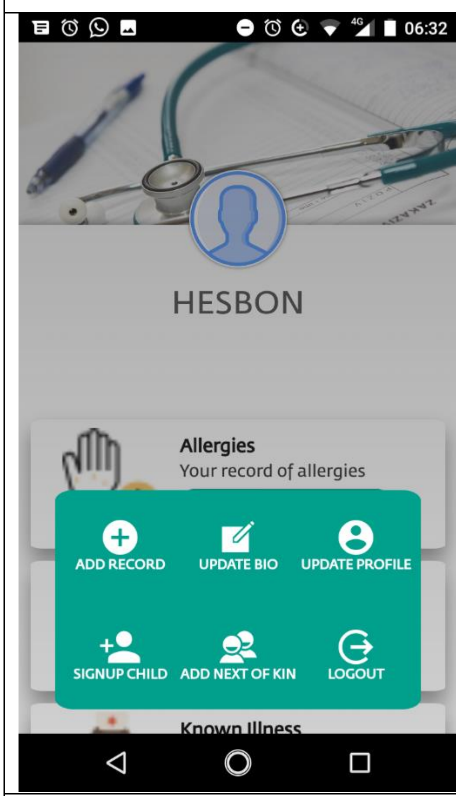

Signup SMS Notification



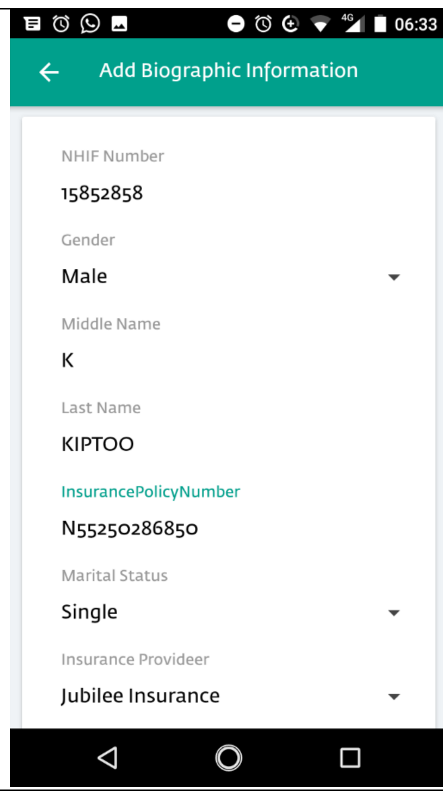

Email SMS Notification



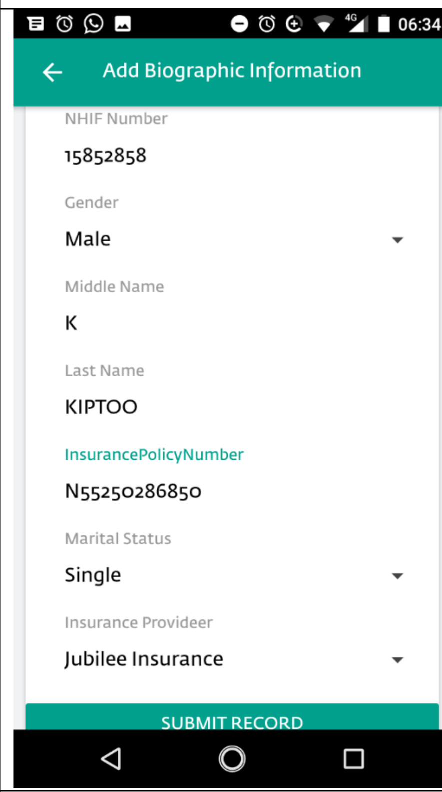

Landing Page



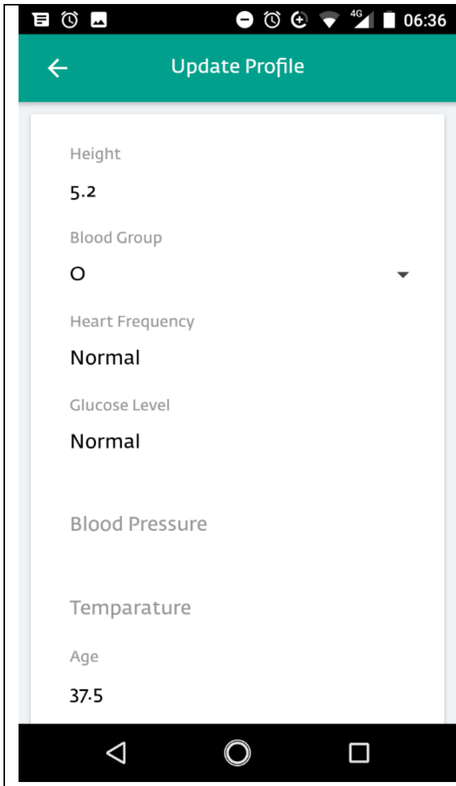

Main Menu



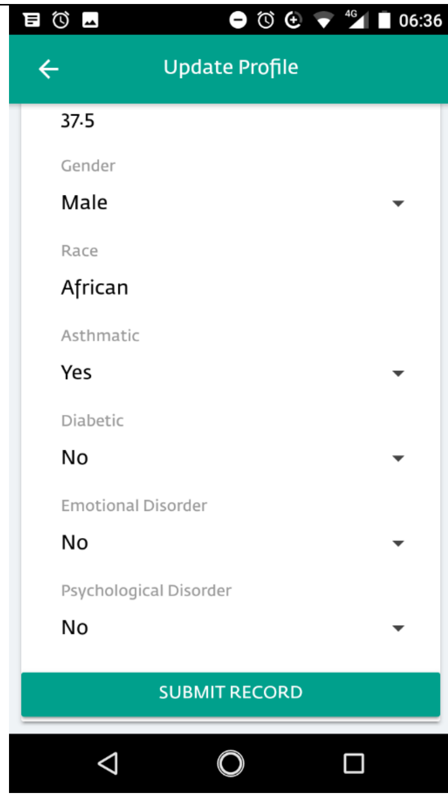

Manage Basic Information (1)



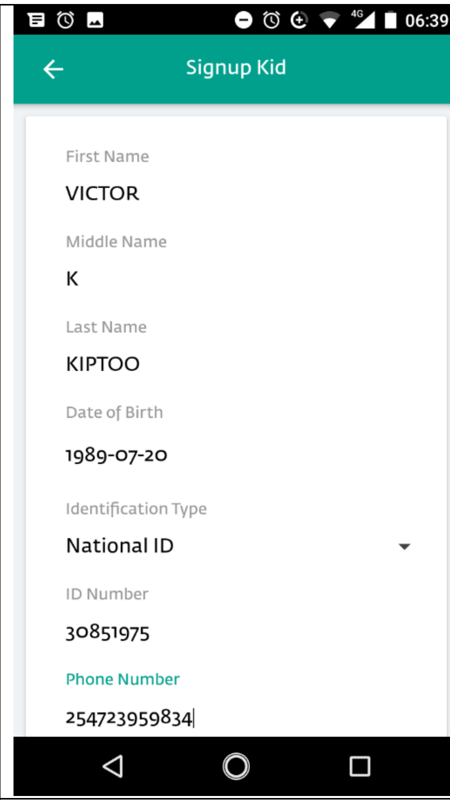

Manage Basic Information (2)



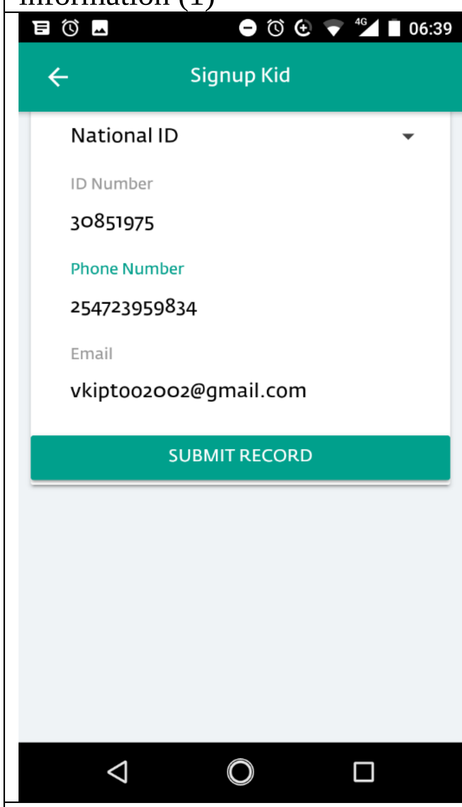

Manage Manage Generic Medical information (1)



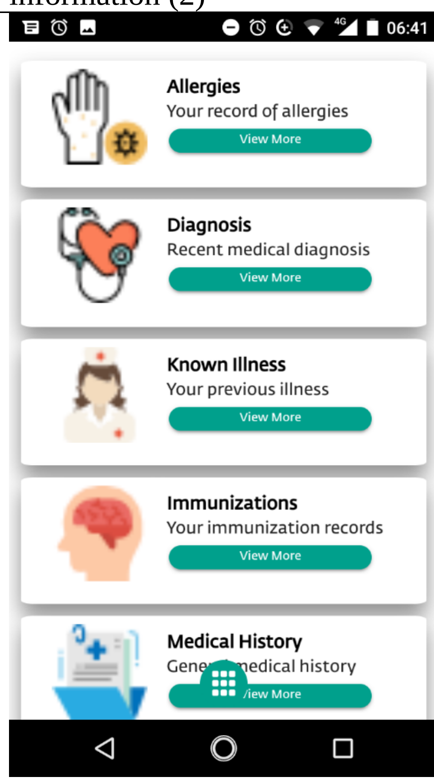

Manage Manage Generic Medical information (2)



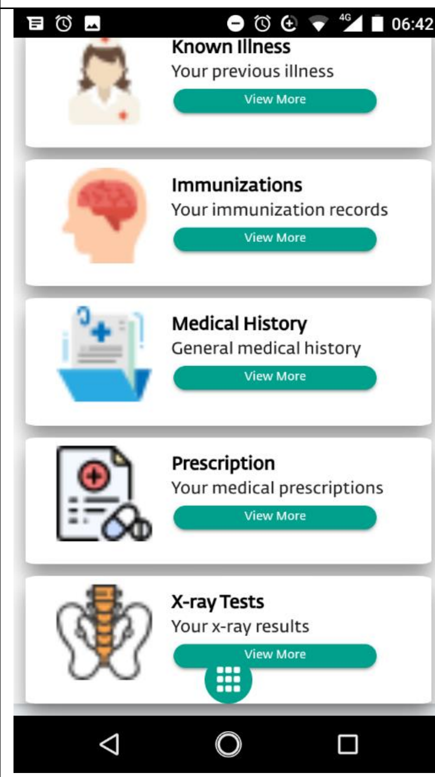

Sign up child (1)



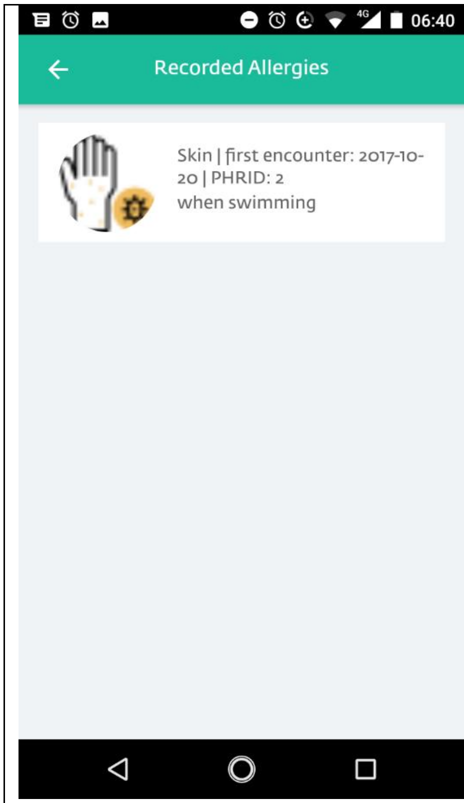

Sign up child (2)



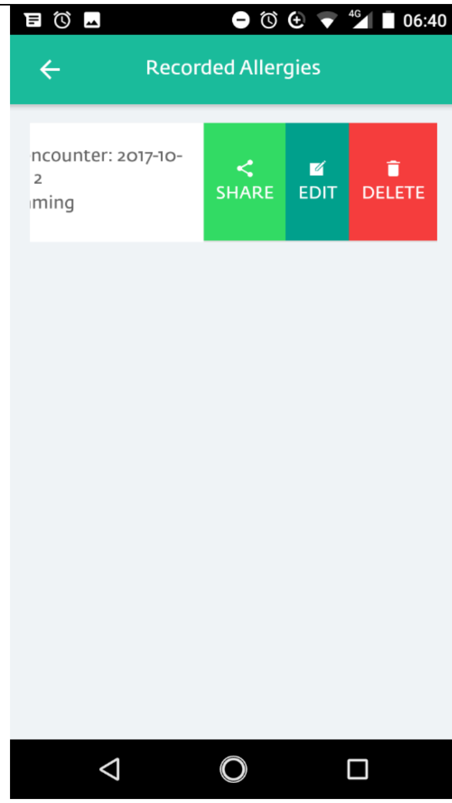

Home page (1)



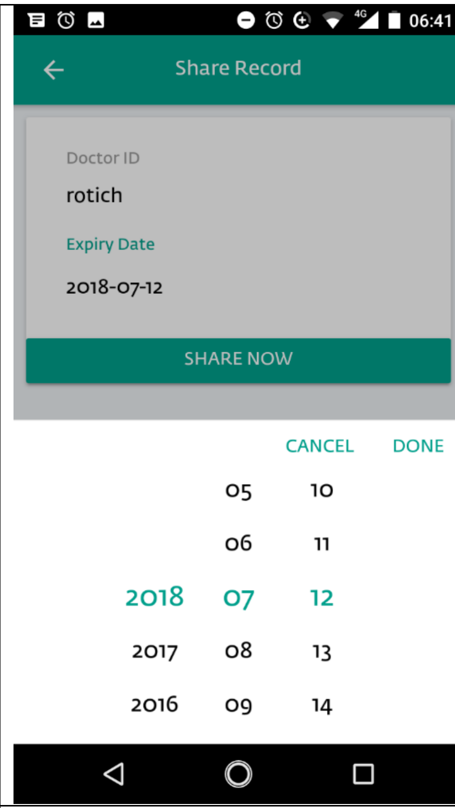

Home Page (2)




View alergies

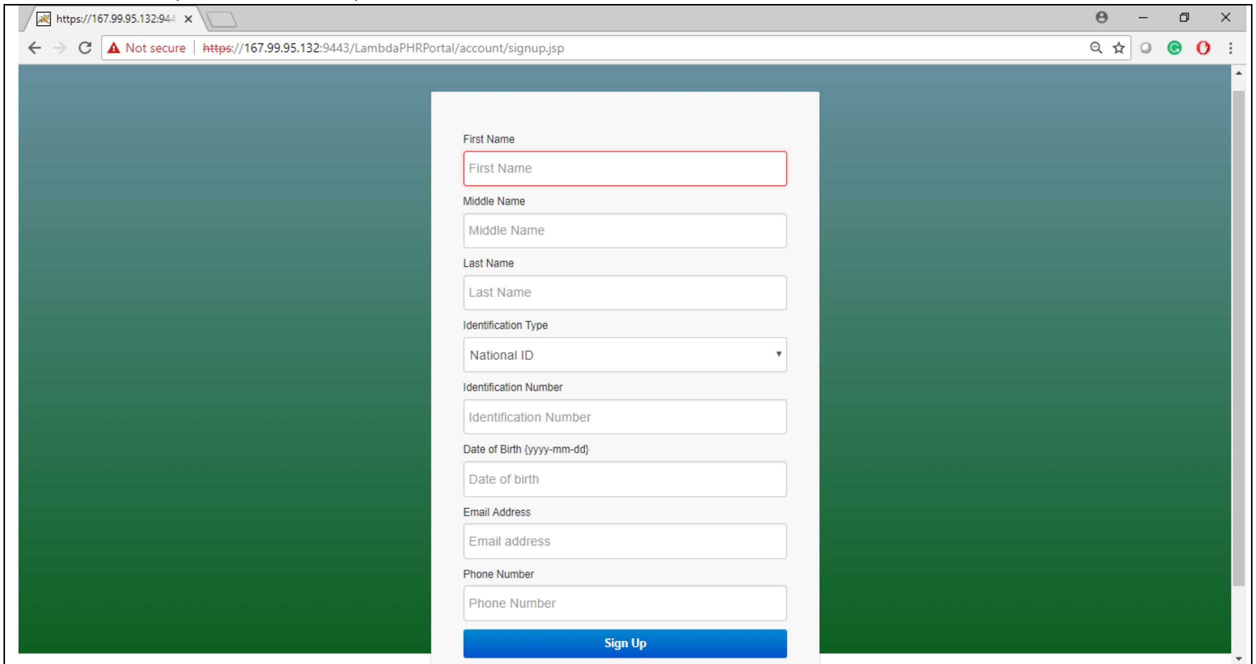



Manage Allergies

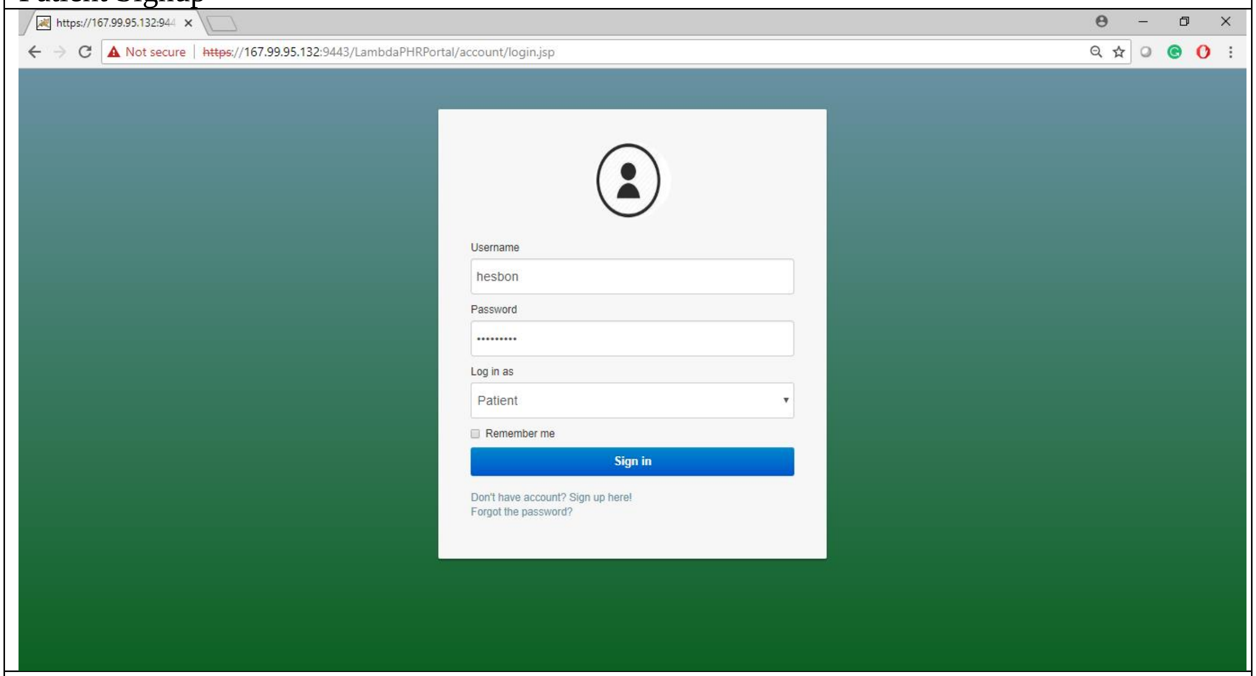



Share Allergies

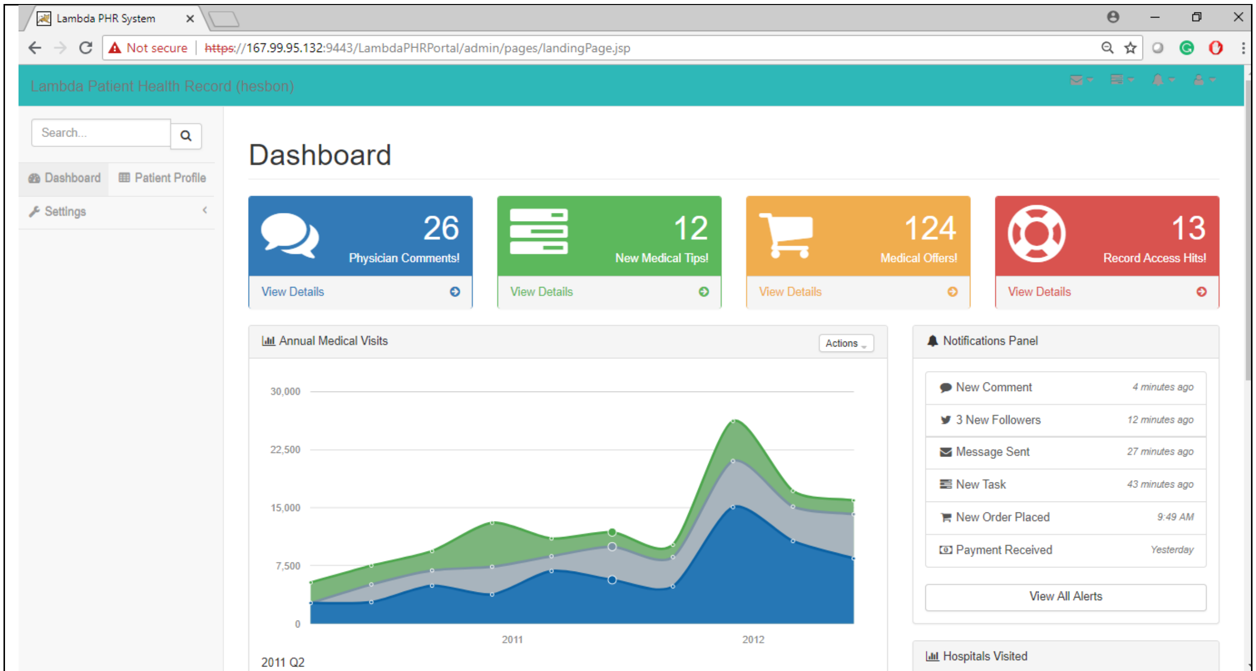
## Web Portal (Patient View)



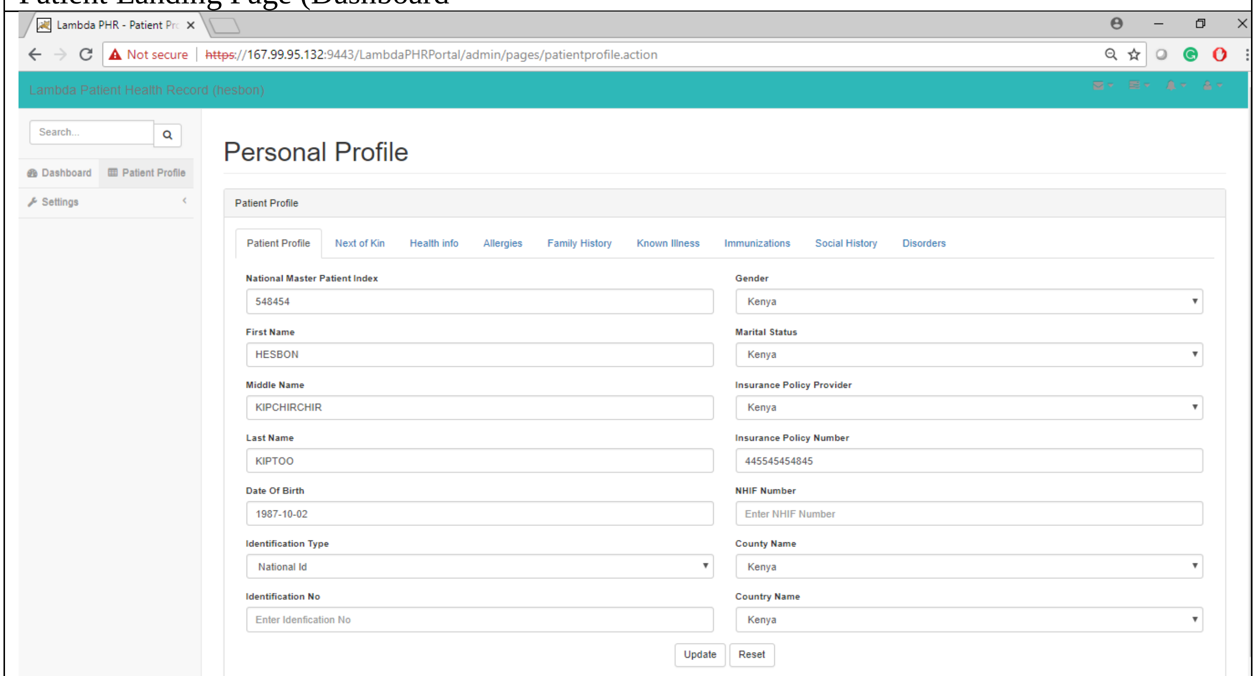

Patient Signup



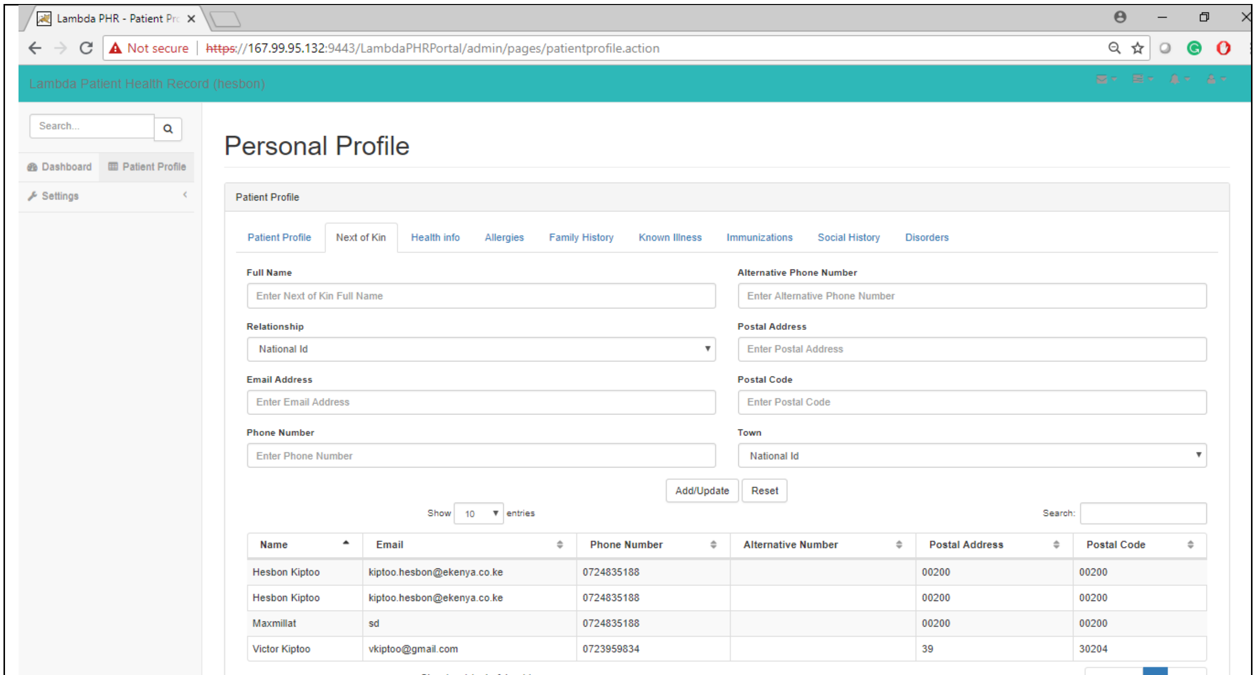

Patient Login



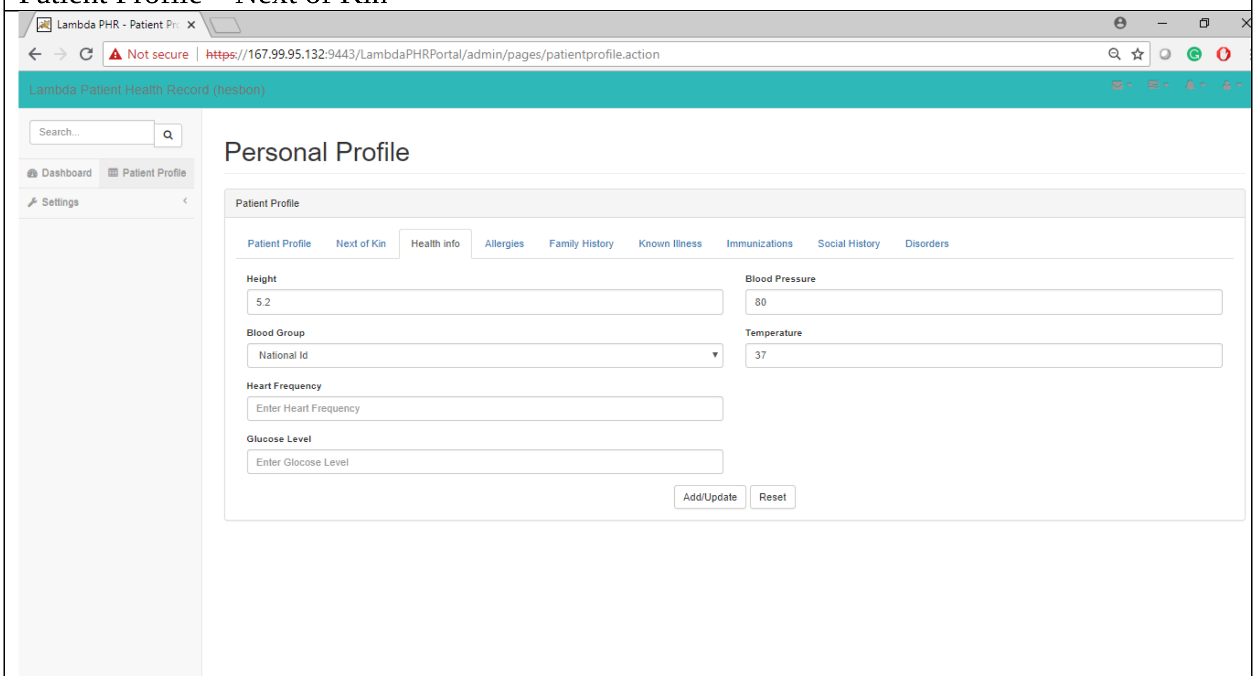
Patient Landing Page (Dashboard



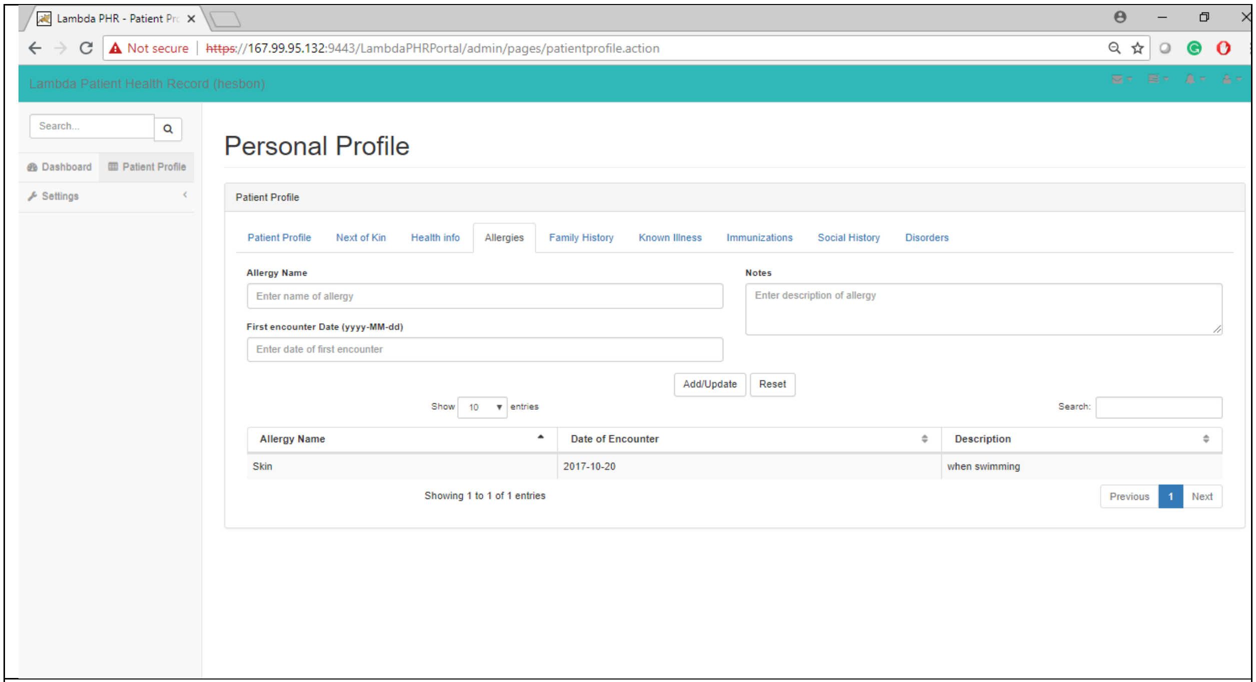
Patient Profile – Basic Information




Patient Profile – Next of Kin

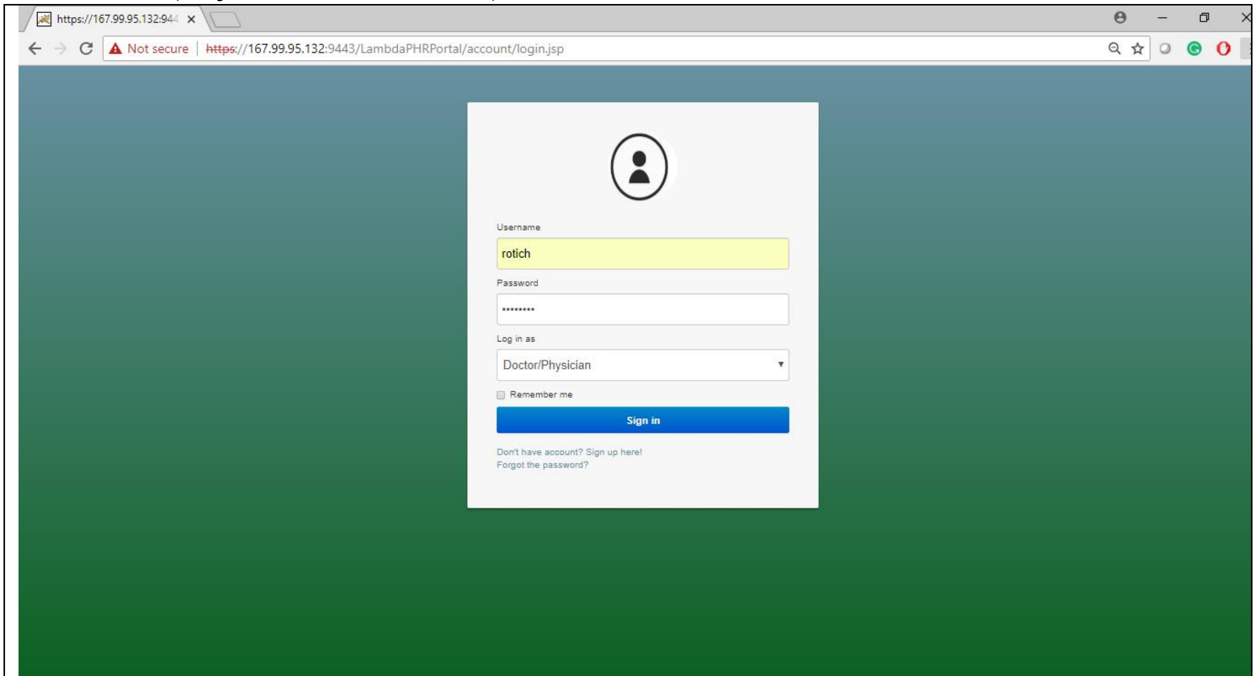



Patient Profile – Generic Medical Information

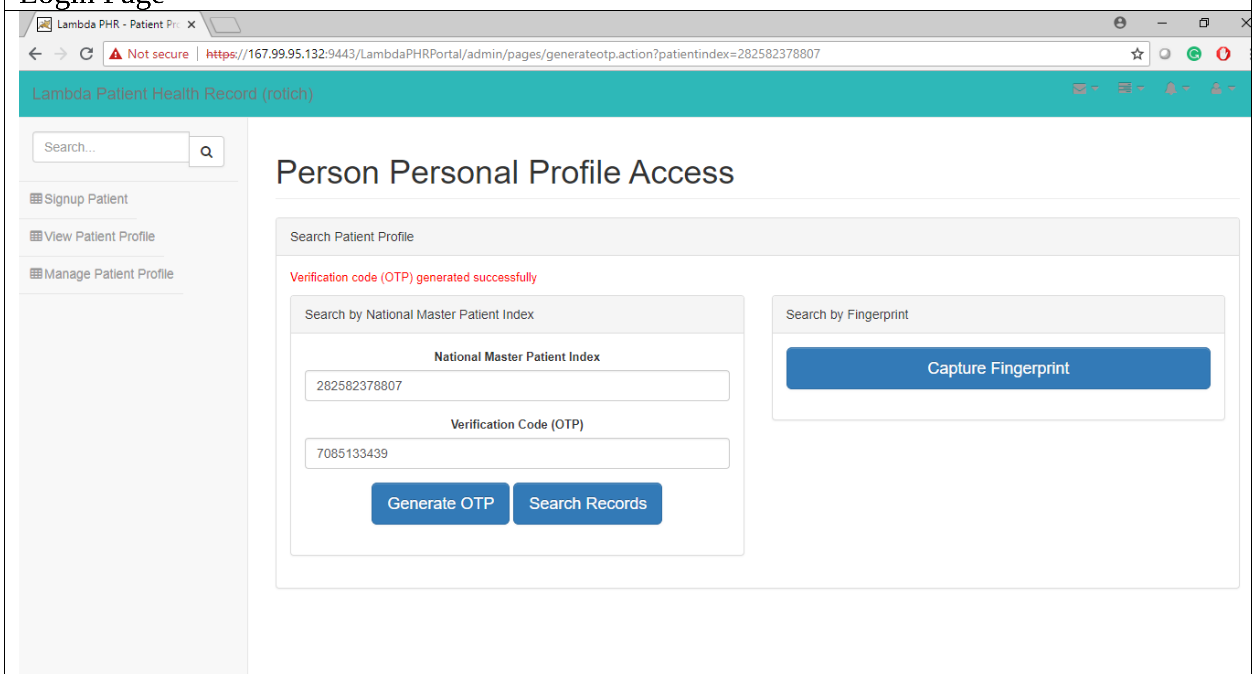



Patient Profile –Allergies

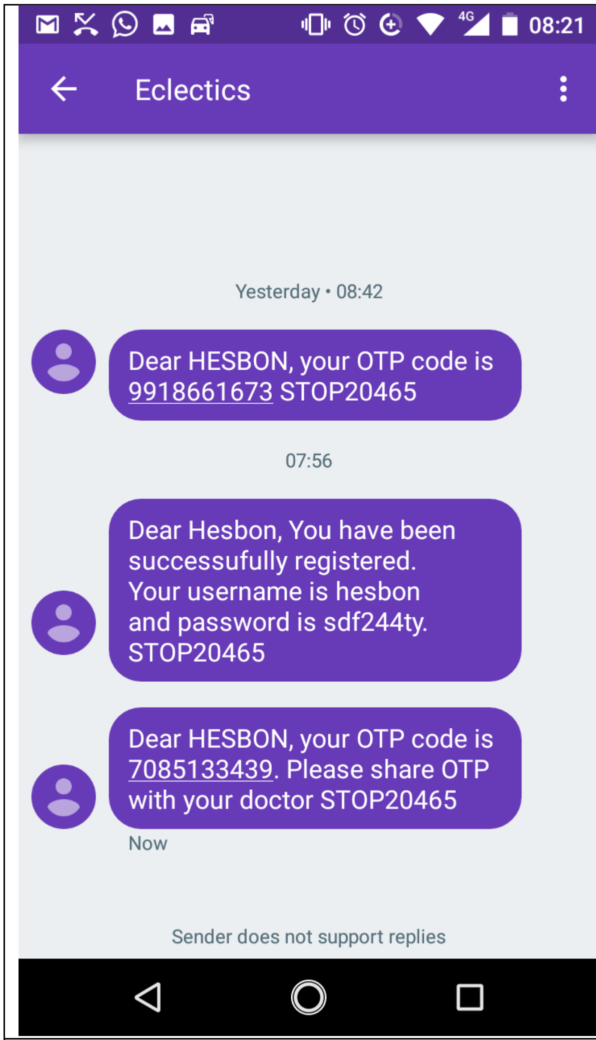
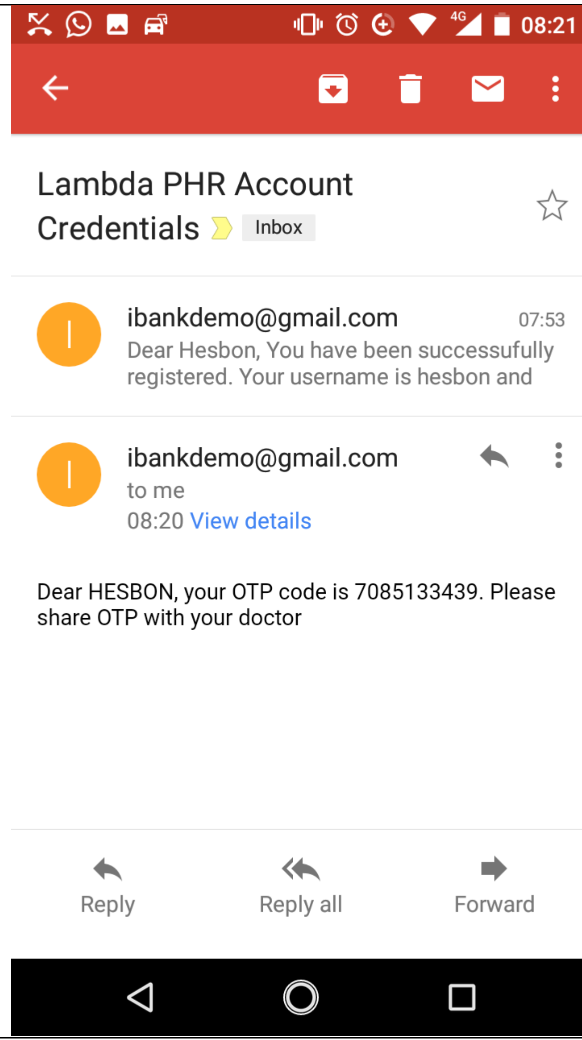
**Web Portal (Physician/Doctor View)**

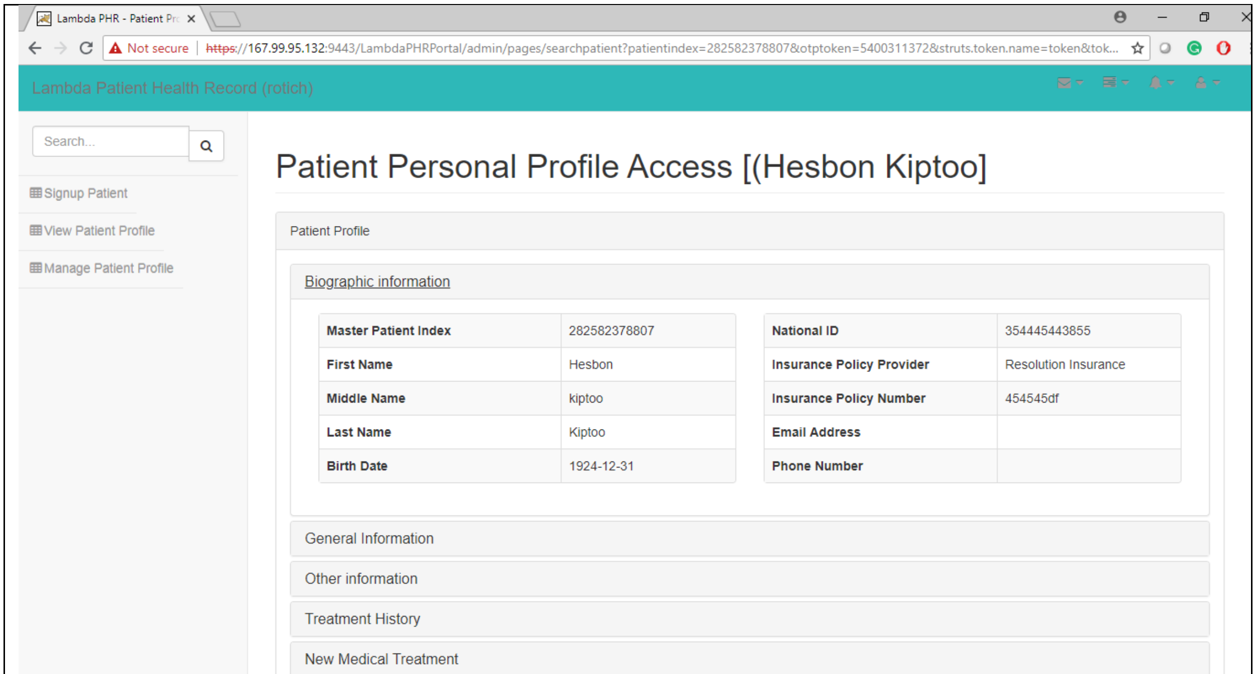



Login Page

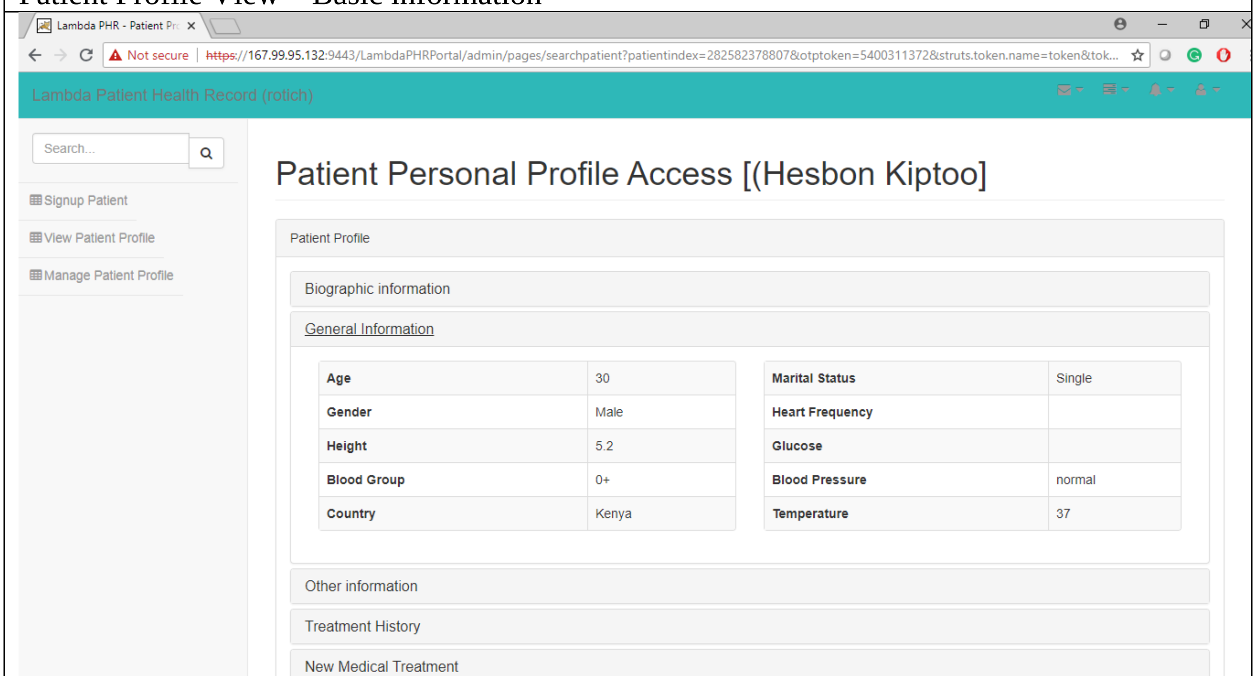



Landing page (Search a patient with verification code)

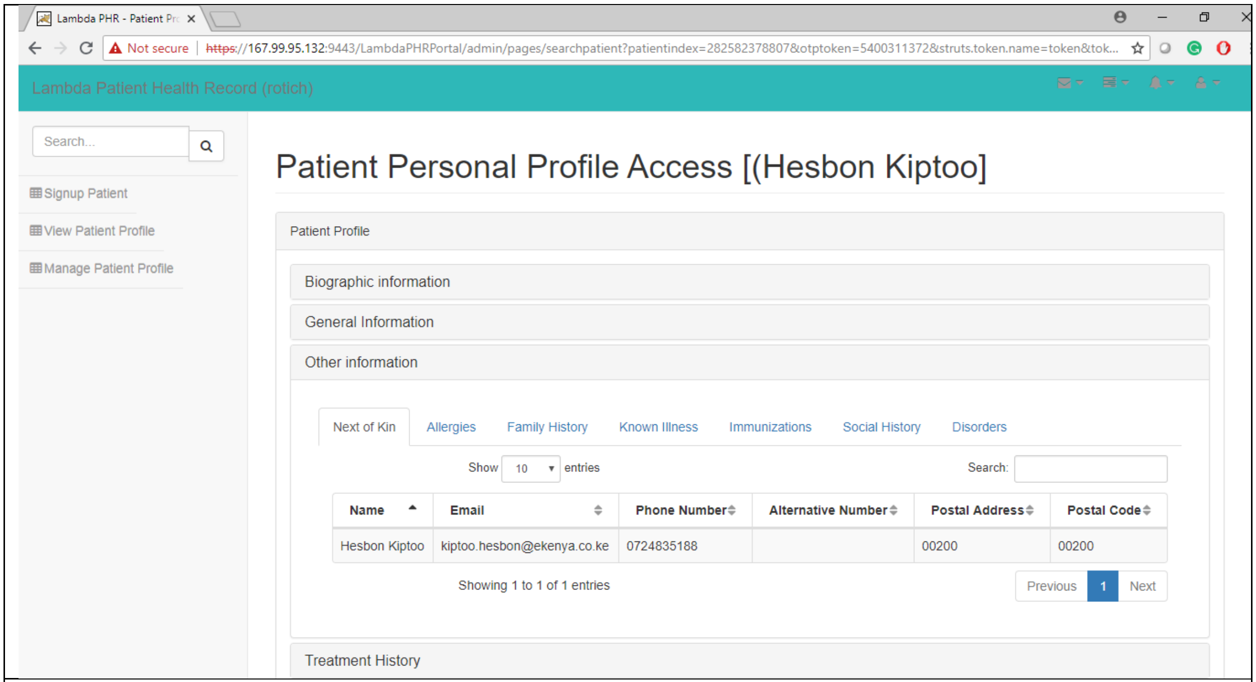
| | |
|---|---|
|  |  |
| OTP verification code sent via SMS | OTP verification code sent via Email |



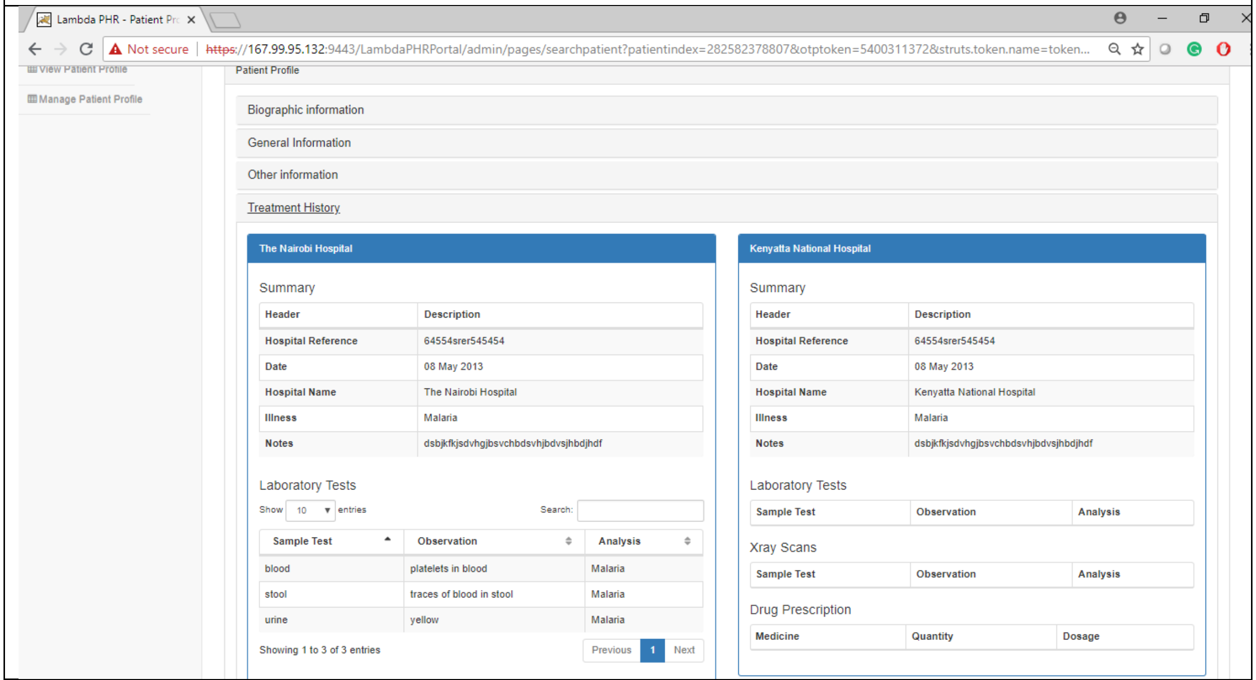
Patient Profile View – Basic information



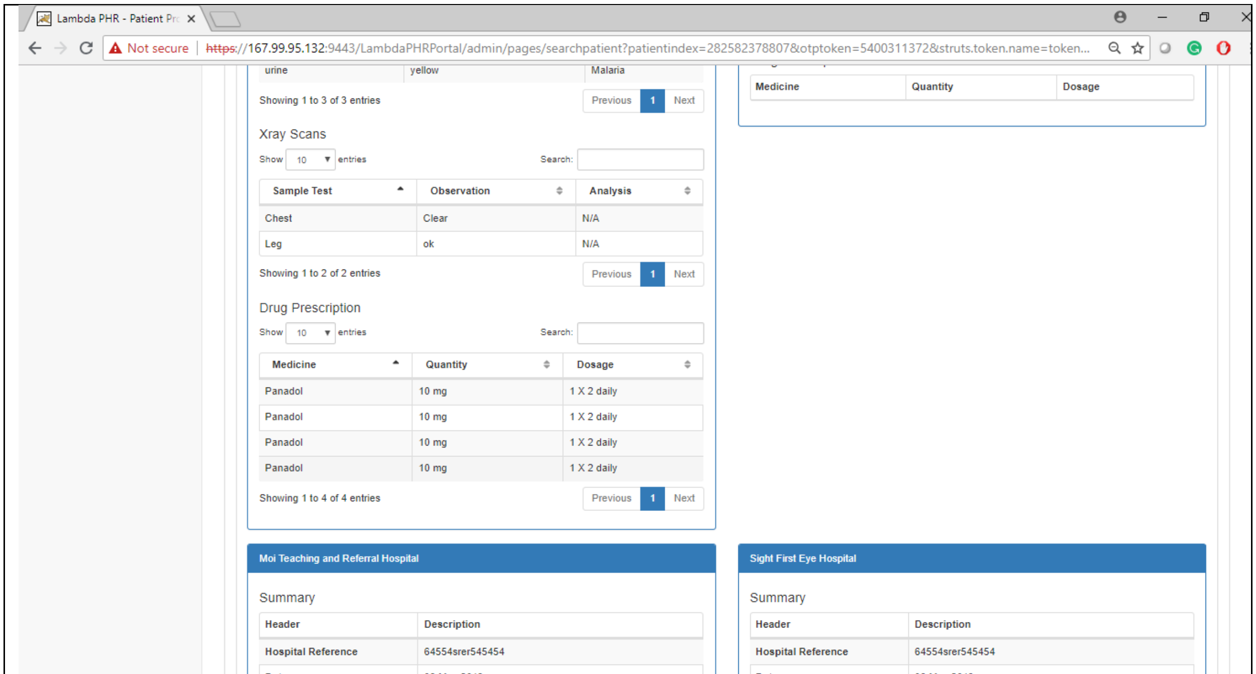
Patient Profile View – General medical information




Patient Profile View – Other information

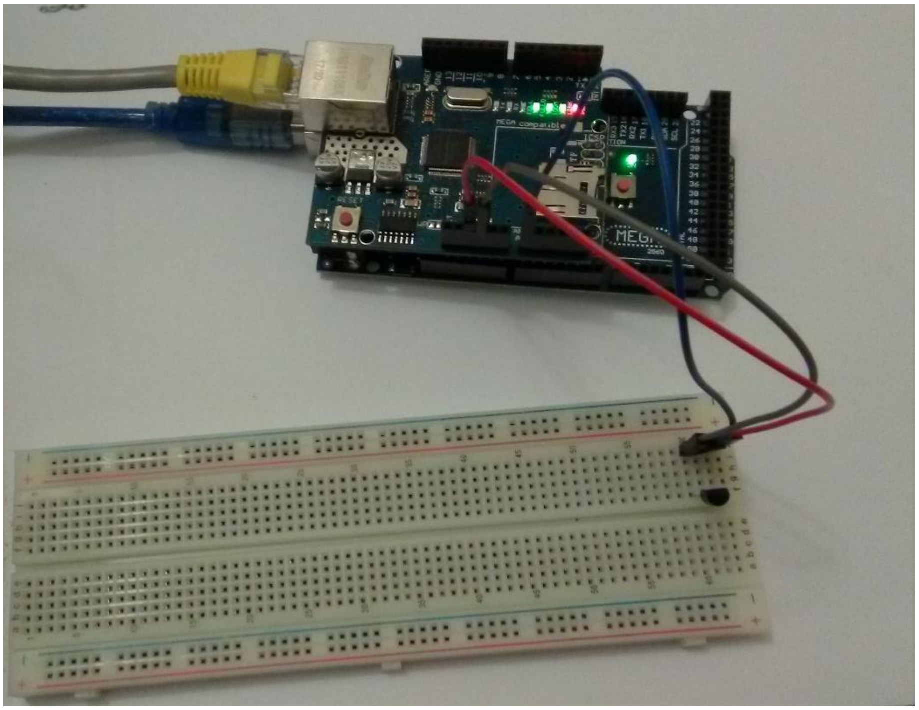



Patient Profile View – Treatment History (1)




Patient Profile View – Treatment history (2)

**Arduino Sketch for Temperature Sensor**



## Appendix II: Sample Source Code

## API WebService Server

**Login Attempt**

```
@POST
   @Path("login")
   @Consumes(MediaType.APPLICATION_JSON)
   @Produces(MediaType.APPLICATION_JSON)
   public String login(@Context HttpHeaders headers, String data) {

      LogHandler logh = new LogHandler("DATAIN", "login->" + data);
      logh.log();
      String jsonData = encryptUtil.decrypt(data);

      if (validateToken(headers, jsonData)) {

         UserLogin logon = new UserLogin(jsonData);
         data = logon.process(headers);
      } else {
         data = invalidToken;
      }

    (new AuditTrailManagement()).recordAuditTrail(headers, patientindex, "loginattempt", "login attempt for user "
+ data, "", true);

      String encData = encryptUtil.encrypt(data);
      logh = new LogHandler("DATAOUT", encData);
      logh.log();
      return encData;
   }
```

## IOT update metric

```
@POST
   @Path("iotupdateprofile/{patientindex}/{metrictype}/{value}")
   @Consumes(MediaType.APPLICATION_JSON)
   @Produces(MediaType.APPLICATION_JSON)
   public String iotUpdateProfilePost(@Context HttpHeaders headers, @PathParam("patientindex") String
patientindex,@PathParam("metrictype") String metrictype,@PathParam("value") String value) {
       System.out.println("iotUpdateProfile" + " has recieved patientindex=" + patientindex);
       LogHandler logh = new LogHandler("DATAIN_PLAIN", "iotUpdateProfile ==> patientindex= " +
patientindex + " metrictype = "+ metrictype + " metricvalue=" + value );
       logh.log();
       String result = "";
       (new AuditTrailManagement()).recordAuditTrail(headers, patientindex, "iotUpdateProfile", "iotUpdateProfile
for patient index " + patientindex, patientindex, true);
       if (validateToken(headers, "")) {
           String data = "{\"" + metrictype + "\":\"" + value +"\"}";
           ManagePatientProfile pfl = new ManagePatientProfile(data);
           result = pfl.updateProfileInfo("lambdaphr","tbpatientphr","patientindex",patientindex);
       } else {
           result = invalidToken;
       }
       logh = new LogHandler("DATAOUT_PLAIN", result);
       logh.log();
       String encData = encryptUtil.encrypt(result);
       logh = new LogHandler("DATAOUT", encData);
       logh.log();
       return result;
   }
```

## API WebService Client Request (Mobile App)

```
api(body, auth, endPoint?): Promise<any> {
   const url = "https://159.89.139.220:9443/LambdaPHRApi/"+endPoint;
   let headers = new Headers({
     "Content-Type": "application/json",
     token: auth,
   });
   let options = new RequestOptions({ headers: headers });
   return new Promise(resolve => {
     this.http
       .post(url, body, options)
       .timeout(40000)
       .map(res => res.text())
       .subscribe(
         data => {
           this.data = data;
           resolve({ data: this.data, error: "" });
         },
         err => {
           if (err != "Request timed out kindly try again later") {
             err = err;
           }
           resolve({
             data: "",
```

```
        error: "Something went wrong. Please try again later."
      });
    }
  );
 });
}
```

## API WebService Client Request (Web Portal)

```
public JSONObject postDataSecure() {

    try {
        String StrUrl = "https://localhost:9443/LambdaPHRApi/" + path;
        URL url = new URL(StrUrl);
        System.setProperty("javax.net.ssl.trustStore", "/usr/lib/jvm/java-1.7.0-openjdk-1.7.0.51-
2.4.5.5.el7.x86_64/jre/lib/security/cacerts");
        System.setProperty("javax.net.ssl.keyStorePassword", "changeit");

        HttpsURLConnection conn = (HttpsURLConnection) url.openConnection();
        conn.setHostnameVerifier(new HostnameVerifier() {
            @Override
            public boolean verify(String hostname, SSLSession session) {
                return true;
            }
        });
        conn.setDoOutput(true);
        String authHeader = "username:password";
        conn.setRequestProperty("Authorization", authHeader);
        String token = getTokenID();
        conn.setRequestProperty("token", token);
        data.put("auth", token);
        conn.setRequestProperty("Connection", "close");
        conn.setRequestProperty("Content-Type", "application/json");
        conn.setRequestProperty("Authorization", authHeader);
        conn.setRequestProperty("Content-Length", String.valueOf(data.toString().getBytes("UTF-8").length));
        conn.setConnectTimeout(15000);
        conn.setReadTimeout(45000);
        try (OutputStreamWriter writer = new OutputStreamWriter(conn.getOutputStream())) {
            //System.out.println("\n\ndata=" + xmlMessage);
            String encData = encryptUtil.encrypt(data.toString());
            writer.write(encData);
            writer.flush();

            LogHandler logh = new LogHandler("API_DATAOUT", path + "->" + encData);
            logh.log();
            String result = getStringFromInputStream(conn.getInputStream());
            String decryptResult = encryptUtil.decrypt(result);
            logh = new LogHandler("API_DATAIN", result);
            logh.log();

            data = new JSONObject(decryptResult);

        } catch (Exception ex) {
            ex.printStackTrace();
            data.put("statuscode", "57");
            data.put("message", "Cannot connect to server");
            data.put("error", ex.getMessage());
```

```
        }

      } catch (Exception ex) {
        ex.printStackTrace();
        LogHandler logh = new LogHandler(ex, path + "->" + data);
        logh.log();
      }

      return data;
    }
```

## API WebService Client Request (IoT Device)

```
#include <SPI.h>
#include <Ethernet.h>

int ledPin = 13;
float temp;

// Enter a MAC address for your controller below.
byte mac[] = { 0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0xED };
// use the numeric IP instead of the name for the server:
char server[] = "167.99.95.132";    // numeric IP for API (no DNS)

// Set the static IP address to use if the DHCP fails to assign
IPAddress ip(192, 168, 0, 177);

// Initialize the Ethernet client library
EthernetClient client;

void setup() {
  // put your setup code here, to run once:

  //initialize pins as outputs
  pinMode(ledPin, OUTPUT);

  // Open serial communications and wait for port to open:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port only
  }

  // start the Ethernet connection:
  if (Ethernet.begin(mac) == 0) {
    Serial.println("Failed to configure Ethernet using DHCP");
    // try to congifure using IP address instead of DHCP:
    Ethernet.begin(mac, ip);
  }
  // give the Ethernet shield a second to initialize:
  delay(1000);

  if (client.connect(server, 8090)) {
    Serial.println("connected");

  } else {
    // if you didn't get a connection to the server:
    Serial.println("connection failed");
```

```
  }

}
void loop() {
  // put your main code here, to run repeatedly:

  delay(300);

  temp = analogRead(A0);
  temp = temp * 0.48828125; //5/1024/10
  Serial.print("TEMPERATURE: ");
  Serial.print(temp);
  Serial.print("*C");
  Serial.println("");

  digitalWrite(ledPin, HIGH);

  // Make a HTTP request:
  String target = "POST /LambdaPHRApi/iotupdateprofile/282582378807/temperature/" + String(temp)+ "
HTTP/1.1";
   Serial.println(target);
  client.println(target);
  client.println("Host: 167.99.95.132");
  client.println("Connection: open");
  client.println("token: 1232323");
  client.println("Content-Type: application/json");
  client.println("user-agent: arduino mega 2560");

  digitalWrite(ledPin, LOW);

  // if there are incoming bytes available
  // from the server, read them and print them:

  if (client.available()) {
    char c = client.read();
    Serial.print(c);
  }


  // if the server's disconnected, reconnect the client:
  if (!client.connected()) {
    Serial.println();
    Serial.println("reconnecting.");
    //client.stop();
    client.connect(server, 8090);
  }
delay(5000);
}
```

## Appendix III: Questionnaire Letter of Introduction

**UNIVERSITY OF NAIROBI**
**COLLEGE OF BIOLOGICAL AND PHYSICAL SCIENCES**
**SCHOOL OF COMPUTING AND INFORMATICS**

Telephone: 4447870/4444919/4446544
Telegrams: "Varsity" Nairobi
Telefax: 254-2-4447870
Email: director-sci@uonbi.ac.ke

P.O. Box 30197
Nairobi
Kenya

Our Ref: UON/CBPS/SCI/MSC/AC/2016

21st May, 2018

Kenyatta National Hospital
P.O. Box 20723 00202
Nairobi, Kenya

Dear Sir/Madam

**RE: HESBON KIPCHIRCHIR KIPTOO: REG. NO. P51/85924/2016**

This is to confirm that the above named is a bona fide student of the University of Nairobi, School of Computing and Informatics.

He is pursuing M.Sc. in Applied Computing and would like to collect data for his project entitled: ***"A Service Oriented Architecture Approach to Implementing an Omnichannel Personal Health Record System"*** Under the supervision of Prof. Peter W. Waiganjo.

Any assistance accorded to him will be highly appreciated.

Yours faithfully

School of Computing & Informatics
University of NAIROBI
P. O. Box 30197
NAIROBI

**DR. AGNES N. WAUSI**
**DIRECTOR**
**SCHOOL OF COMPUTING & INFORMATICS**

## Appendix IV: Sample Pre-Study Questionnaire

Dear Respondent,
I am a Masters student in the School of Computing and Informatics, University of Nairobi, conducting a research entitled **A SERVICE ORIENTED ARCHITECTURE APPROACH TO IMPLEMENTING AN OMNICHANNEL PERSONAL HEALTH RECORD IN KENYA.**
As part of my research, you are hereby selected to aid in achieving the objectives of this study. I hereby request you to fill in the questionnaire below. Please do note that the information furnished here is purely for academic purposes and thus its confidentiality shall be safeguarded.

A Personal Health Record (PHR) is an electronic collection of health information of an individual. A PHR may include information about treatment by doctors, including test results and medications, as well as information entered by the individual. Some PHRs allow the individual full control of who has access to all or parts of the PHR and for how long this access lasts.

Kind Regards, Hesbon Kipchirchir Kiptoo.

### SECTION A: Respondent Details

1. Choose your age group:
   - ☐ 20 - 30 years
   - ☐ 31 - 40 years
   - ☐ 40 - 50 years
   - ☐ Over 50 years

2. What is your profession? ________________________________________________

3. What is the name of your county government?
   ________________________________________________

4. Are you currently using a smartphone and/or tablet PC?
   - ☐ Yes
   - ☐ No

5. If yes, are you currently using your smartphone or tablet PC to obtain or manage health related information or specific information for your condition?
   - ☐ Yes
   - ☐ No

### SECTION B: Patient Identification (Healthcare personnel only)

1. In your health facility, do you have a unique patient identification scheme?
   - ☐ Yes
   - ☐ No
2. What other alternatives would you use to uniquely identify patient?
   - ☐ Personal Information like name, age, gender
   - ☐ Statutory documents like National ID, Passport No
   - ☐ Biometric Information like Fingerprint

- ☐ Other documents like Insurance member no, employer ID

3. What information do you receive about a patient when they are transferred to your health facility from another health facility?
   - ☐ Personal information (e.g. name, age, gender)
   - ☐ Physical body quantitative data (e.g. weight, blood pressure)
   - ☐ Health information (e.g. illness history)
   - ☐ Previous drug Prescription
   - ☐ Any other information? ______________________________________________

4. What do you do if the patient is unable to share their medication history due to his/her condition e.g. patient is unconscious or unable to speak?
   ________________________________________________________________________________
   ________________________________________________________________________________
   _________________________________________________________________

**SECTION C: Personal Health Record (Patients/Individuals only)**

1. Do you have or know your medical reference number?
   - ☐ Yes
   - ☐ No

2. Have you used any PHR before?
   - ☐ Yes
   - ☐ No

If Yes, what is(are) the name (s) of the PHR used?
____________________________________________________________________________________
____________________________________________________

If No, what is the primary reason you have never used a PHR?

- ☐ I have never heard of a PHR.
- ☐ I would if my physician or other healthcare professional recommended it to me.
- ☐ I do not seek much care and don't see the value.
- ☐ I do not trust the security of the currently available Internet-based sites.
- ☐ I do not want a written record of sensitive personal health information.
- ☐ I do not want to spend the time to initially input and update the information.
- ☐ Any other __________________________________________

3. What are the challenges experiences when being referred from one hospital to the next?
   - ☐ I don’t know my entire medical history off head
   - ☐ I may be unconscious
   - ☐ I have to redo tests/examination
   - ☐ My doctor is unable contact my next of kin
   - ☐ Any other __________________________________________

4. If a system for allowing medical information sharing online with healthcare personnel was developed, would you allow your health record to be stored?
   - ☐ Yes
   - ☐ No. If No, Why? ____________________________________________________________

If Yes, what information would you want to store yourself or doctors?
   - ☐ Personal information e.g. name, age
   - ☐ Physical body quantitative data e.g. weight, blood pressure
   - ☐ Health information e.g. illness history
   - ☐ Drug Prescription
   - ☐ Any other information? ____________________________________________

5. Would it be all right with you if your primary doctor were to use access your entire medical history from all the health care facilities you have ever attended with your explicit permission?
   - ☐ Yes
   - ☐ No

If Yes, who else would you permit to access your medical history?

   - ☐ Specialist
   - ☐ Emergency room
   - ☐ Hospital
   - ☐ Next of kin
   - ☐ Health insurance
   - ☐ Medical researchers

If No, what concerns do you have?

   a) ………………………………………
   b) ………………………………………
   c) ………………………………………
   d) ………………………………………

6. What are your perceived benefits of having your medical history online (PHR) for sharing with medical personnel?
   - ☐ Clarify doctor instructions
   - ☐ Prevent medical mistakes
   - ☐ Change the way I manage my health
   - ☐ Improve quality of care
   - ☐ No benefit at all

7. To what extend would you recommend the below PHR features? Indicate the extent with *1 = no extent* at all, *2 = small extent*, *3 = moderate extent*, *4 = large extent*, *5 = very large extent)*

| | PHR features | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 01 | Storing illnesses and hospitalizations | [ ] | [ ] | [ ] | [ ] | [ ] |
| 02 | Doctor-finder with contact information and background | [ ] | [ ] | [ ] | [ ] | [ ] |
| 03 | Schedule doctor/specialist appointment | [ ] | [ ] | [ ] | [ ] | [ ] |
| 04 | Storing allergies and adverse drug reactions | [ ] | [ ] | [ ] | [ ] | [ ] |
| 05 | Storing medical Prescription record | [ ] | [ ] | [ ] | [ ] | [ ] |
| 06 | Laboratory test results and image reports | [ ] | [ ] | [ ] | [ ] | [ ] |
| 07 | Transfer medical information to doctors and specialists | [ ] | [ ] | [ ] | [ ] | [ ] |
| 08 | Payment services eg pay medical bills from a PHR app | [ ] | [ ] | [ ] | [ ] | [ ] |

8. Will you accept to be paid for sharing your anonymous data for research purposes?
   - ☐ Yes
   - ☐ No

## SECTION D: PHR Architecture and Interoperability

1. On a scale of 1 – 5 (where 5 is the highest and 1 the least), how would you rate the level of standardization of the healthcare semantic standards? Indicate the extent with 1 = *very low*, 2 = *low*, 3 = *average*, 4 = *medium*, 5 = *high*)
   Your Answer ____________________________
2. What do you think are the barriers to medical data interoperability in Kenyan health facilities?
   - ☐ Multiple standards that are not uniform
   - ☐ Reluctance by health facilities to share data
   - ☐ Lack of universal patient identification
   - ☐ I don't know
   - ☐ Any other? ________________________________________________
3. What are the architectures used in developing your distributed healthcare systems? (Tick what is applicable).
   - ☐ Master-slave architecture
   - ☐ Two-tier client–server architecture
   - ☐ Multitier client–server architecture
   - ☐ Distributed component (service oriented) architecture
   - ☐ Peer-to-peer architecture

4. Which of the following channels would most patients, doctors or specialists use to access a PHR system? (Tick what is applicable).
   - ☐ Web
   - ☐ Desktop
   - ☐ Mobile
   - ☐ USSD

## Appendix V: Sample Post-Implementation Questionnaire

Dear Respondent,

I am a Masters student in the School of Computing and Informatics, University of Nairobi, conducting a research entitled "**A SERVICE ORIENTED ARCHITECTURE APPROACH TO IMPLEMENTING AN OMNICHANNEL PERSONAL HEALTH RECORD SYSTEM IN KENYA**".

As part of my research, you are hereby selected to aid in achieving the objectives of this study. I hereby request participate in testing the prototype as a ______________. Please do note that your feedback and suggestions are purely for academic purposes and thus its confidentiality shall be safeguarded.

A Personal Health Record (PHR) is an electronic collection of health information of an individual. A PHR may include information about treatment by doctors, including test results and medications, as well as information entered by the patient. Some PHRs allow the patient full control of who has access to all or parts of the PHR and for how long this access lasts.

Areas to be tested include ability to Sign up, Login, Manage profile, Upload data, Share data, Temperature Realtime Monitoring and Deactivate account. You are required focus on system Functionality, Features, Response time and Security.

To download the mobile application, visit the link https://159.89.139.220:9443/apk/lambdaphr.apk. You can access the web version of the system by clicking this link: https://159.89.139.220:9443/LambdaPHRPortal/

Kind Regards: Hesbon Kipchirchir Kiptoo.

1. What is your role? (Tick what is applicable).
   - ☐ Patient
   - ☐ Physician/Health care professional
   - ☐ ICT Expert

2. Which device did you use to access the Personal Health Record (PHR) System? (Tick what is applicable).
   - ☐ Web
   - ☐ Mobile
   - ☐ IoT device

3. Who assisted you assisted in using the PHR system? (Tick what is applicable)
   - ☐ A Doctor
   - ☐ A friend
   - ☐ I was not assisted, did it by myself.

4. To what extent did you find below PHR features useful? Indicate the extent with *1 = no extent* at all, *2 = small extent, 3 = moderate extent, 4 = large extent, 5 = very large extent)*

| | PHR features | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 01 | Storing illnesses and hospitalizations | [ ] | [ ] | [ ] | [ ] | [ ] |
| 02 | Storing allergies and adverse drug reactions | [ ] | [ ] | [ ] | [ ] | [ ] |
| 03 | Storing medical Prescription record | [ ] | [ ] | [ ] | [ ] | [ ] |
| 04 | Laboratory test results and image reports | [ ] | [ ] | [ ] | [ ] | [ ] |
| 05 | Transfer medical information to doctors and specialists | [ ] | [ ] | [ ] | [ ] | [ ] |

5. In your opinion, what other task do you think you would need the system help you perform?

______________________________________________________________________________

______________________________________________________________________________

6. Was the app useful?
   - ☐ Yes
   - ☐ No

7. What advantages have you seen with the PHR?

______________________________________________________________________________

______________________________________________________________________________

8. Which functions didn't work as expected?

______________________________________________________________________________

______________________________________________________________________________

9. How can system can be improved?

______________________________________________________________________________

______________________________________________________________________________

10. Would you recommend this PHR system to your friends or your family?
    - ☐ Yes
    - ☐ No